WATERSHED HYDROLOGICAL MODELLING CONSIDERING LANDUSE AND CLIMATE CHANGES

Ph.D. THESIS

by

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A THESIS

Submitted in partial fulfilment of the requirements for the award of the degree of

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CANDIDATE'S DECLARATION

I hereby certify that the work which is being presented in the thesis entitled **"WATERSHED HYDROLOGICAL MODELLING CONSIDERING LANDUSE AND CLIMATE CHANGES"** in partial fulfilment of the requirements for the award of the Degree of Doctor of Philosophy and submitted in the Department of Water Resources Development and Management of the Indian Institute of Technology Roorkee is an authentic record of my own work carried out during a period from July, 2014 to August, 2017 under the supervision of Dr. Deepak Khare, Professor, Department of Water Resources Development and Management, and Dr. S. K. Tripathi, Professor, Department of Water Resources Development and Management, Indian Institute of Technology Roorkee, Roorkee.

The matter presented in the thesis has not been submitted by me for the award of any other degree of this or any other institution.

Signature of the Candidate

This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

Dated: **Signature of the Supervisor**

ABSTRACT

Limited and deteriorated land resources coupled with the change and variability of climate, associated impact and vulnerabilities are the growing environmental issues of the world in the 21st century. It is accountable for numerous effects on overall hydrological cycle, which significantly influences the climatic parameters viz., rainfall and temperature, hence it hinders the overall environment in general and agricultural productivity in particular. Therefore, clearly knowing the climatic conditions and the overall hydrological behaviour of the watershed is quite important to plan, manage and use the available resources in a sustainable way without compromising the resultant ecosystems.

The present study is associated with investigating historical climatic data such as rainfall and temperature have been used for trend analysis and its associated effect to understand the long-term climatic situations of the Beressa watershed of Ethiopia. Land Use/Land Cover (LU/LC) change analysis and future prediction have been done in order to analyse the effects on runoff and sediment as well as on agricultural productivity. Soil and Water Assessment Tool (SWAT model) has been used to calibrate and validate runoff and sediment response to LU/LC change dynamics for Beressa watershed. Considering various scenarios viz., climatic trend and variability, LU/LC change dynamics, runoff and sediment process, sustainable integrated water resources planning and management and water harvesting has been suggested for the area.

The results of classified images shown that farmland and settlement areas have been expanded at the rate of 71.60 ha/year and 16.80 ha/year respectively. The share of forest cover decreased at the rate of 5 ha/year in the year between 1984 and 1999. While water bodies has decreased at the rate of 0.03 ha/year. However, in the second study period the year between 1999 to 2015 the share of forest cover has been regenerated by the rate of 15.60 ha/year. Likewise, water bodies has regenerated at the rate of 7.10 ha/year. The share of grazing land has been reduced to 10% in 1999. Similarly, barren land has been reduced to 10.10% in the year 1999, the share further discriminate to 6.10% of grazing land and 5.20% of barren land in 2015 compared to 12.40% of grazing and 13.10% of barren land in 1984. The probability of farmland and grazing land may decline in the future (2015-2030). Due to increase in settlement areas (35.14%) and barren land (36.11%), which facilitate the decline in farmland (6.73%) and grazing land (11.53%), even though forestland and water body slightly increase, it is insignificant. Therefore, the future dynamics of LU/LC classes may contribute to destruction of natural resources and hence severely affect the availability of food production.

Analysis of trend using MK test and Sen's slope as well as spatial distribution using IDW have done at local level for both annual and seasonal rainfall and mean, minimum and maximum temperature for 35 years (1980-2014). The rainfall trend of Beressa watershed shows both increasing and decreasing trends. Significantly decreasing trend of mean annual rainfall was observed in HG station (-8.62 mm/year and -27.88%), whereas, significantly increasing trend of mean annual rainfall was observed in the DB station with magnitude of 0.28 mm/year and 1.07% in DB station. During rainy season (*kiremit* season) significantly decreasing trend was recorded in the SD station with magnitude of (-0.90 mm/year and -16.20%) while significantly increasing trend was observed in DB station (1.62 mm/year). During small rainy season (*belg* season), significantly decreasing trend observed in the GIN station with the magnitude of -0.12 mm/year whereas significantly increasing trend was observed in the DB station (0.40 mm/year). A decreasing trend of *bega* season rainfall were observed in all stations varied from -0.06 mm/year in GIN station to -0.19 mm/year and -56.40% in DB station. Rainfall during *kiremit* and *belg* seasons shows slightly moderate distribution as compared to annual and *belg* rainfall in which high concentration of rainfall distribution emerged. From this observation, rainfall distribution is classified as irregular to erratic distribution hence significant effects on overall crop production. The trend of mean, minimum and maximum temperature have been increased in all stations with magnitude of 0.95^{o}C/35 year, 0.7^{o}C/35 year and 1.1^{o}C/35 year respectively.

Physical based hydrological model known as Soil and Water Assessment Tool (SWAT) has been used in order to understand the hydrological behaviour of Beressa watershed. Based on the results obtained, the model has been successfully calibrated (1980-1999) and validated (2000-2014) using the observed weather, runoff and sediment input data. In order to calibrate the model, thirteen (six for surface runoff and seven for sediment yield generation) most sensitive parameters were adjusted within the ranges until acceptable agreement between observed and simulated values were obtained. The objective function for the model evaluation statistics observed that 0.72, 0.62, 0.52 and 3.90% for R^2, NSE, RSR and PBIAS respectively during calibration period for runoff process whereas corresponding values during validation periods were 0.68, 0.64, 0.56 and 7.60% respectively. The model evaluation statistics during the calibration period showed 0.68, 0.71, 0.58 and 4.20% respectively for sediment yield whereas the corresponding values during validation period were 0.65, 0.67, 0.62 and 8.30 respectively. The value of calibration and validation results proved SWAT model is applicable to small watershed like Beressa watershed. Therefore, based on the calibration and validation parameters the model of runoff and sediment yield simulation provides assurance for further application of the model in order to assess the influence of LU/LC change dynamics on surface runoff process and sediment yield generation.

The alteration of LU/LC classes during the year between 1984 and 1999 from forestland, barren land and grazing land into farmland and settlement areas have significantly contributed for the increases of surface runoff and sediment yield for 1984 land cover by 4% and 6.03% respectively. The change of LU/LC types between 1984 and 1999 from forestland, barren and grazing land into farmland and settlement areas significantly contributed for increases of surface runoff and sediment yield by 4% and 6.03% respectively for 1984 and during simulation results using 1999 land cover runoff and sediment further increased by about 6.50% and 8.20% respectively. During the study periods, increase of farmland and settlement areas by about 18.20% and 59.70% respectively, consequently runoff process and sediment yield by about 158.10 mm/year and 4332 t/year respectively. Generally, LU/LC change dynamics significantly affect runoff and sediment yield of Beressa watershed.

Consequently, an option for hydro-climatological scenarios consideration was developed in order to allocate and sustainable uses of limited natural resources viz., land resources, water resources, and other resources. CROPWAT 8.0 model and Rainfall Contribution Index (RCI) have been used to describe the adverse effects of climatic variability. The analysis showed that crops growing during small and dry rainy season (February to June) have high water requirement, even during rainy season due to high rainfall concentration, the available rainfall is not sufficient for the whole growing periods hence less productivity. It is noted that, in the face of high competition among natural resource users where there is significant climatic variability, rainfall shortage, water scarcity, and other resources shortage in the watershed, supplemental irrigation, water harvesting and integrated water resources management, and equitable, sustainable and efficient resources utilization have always persisted a social and economic goals. Despite some common limitations, this research is important to support the planning and development of water harvesting, adaptation of climatic variabilities and integrated water resources management for the Beressa watershed.

Keywords: Climate change; climatic variability; Mann-Kendall; IDW; LU/LC; Supervised classification; Markov Chain Mode; SWAT model; CROPWAT 8.0; RCI; IWRM.

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(Tesfa Worku)

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ABBREVIATIONS

S.No.	Abbreviation	Full Name
1	ALPHA_BF	Bases flow Alfa factor
2	C-CH	Channel Erodibility Factor
3	CH_N	Channel Manning Factor
4	CN2	Curve Number
5	CROPWAT8.0	Crop Water Requirement
6	CV	Coefficient of Variation
7	DEM	Digital Elevation Model
8	FAO	Food and Agriculture Organization
9	GIS	Geographic Information system
10	GW_DELAY	Groundwater Delay Time
11	GwQMN	Threshold Depth of Water in the Shallow Aquifer for return flow to occur
12	Ha	Hectare
13	HRU	Hydrologic Response Unit
14	HRU_SLP	Average slope steepness
15	IDW	Inverse Distance Weighted Interpolation Method
16	ITCZ	Inter Tropical Convergence Zone
17	IWRM	Integrated Water Resources Management
18	Kc	Crop coefficient
19	Km	Kilometre
20	LSD	Least Significance Difference
21	LULC	Land Use and Land Cover Change
22	m	Meter
23	m^3/s	cube meter per second
24	MCM	Markov Chain Model
25	Mm	Millimetre
26	MoWIE	Ministry of Water, Irrigation and Electric Ethiopia
27	NMSA	National Meteorological Service Agency
28	NSE	Nash Sutcliffe Efficiency

29	PBIAS	Percentage Bias
30	PCI	Precipitation Concentration Index
31	R^2	Coefficient of Determination
32	RCHRG_DP	Deep Aquifer Percolation
33	RCI	Rainfall Contribution Index
34	RMSE	Root Mean Square Error
35	RS	Remote Sensing
36	RSR	Observation Standard Deviation Ratio
37	s	Second
38	SCS-CN	Soil Conservation Service-Curve Number
39	SPAW	Soil-Plant-Air-and Water Model
40	SPCON	Linear re-entrainment parameter for channel sediment
41	SUFI2	Sequential Uncertainty Fitting 2
42	SUR-LAG	Surface Runoff Lag Coefficient
43	SWAT	Soil and Water Assessment Tool
44	SWIO	South West Indian Ocean
45	t/year	Tone per year
46	UNESCO	United Nation Educational, Scientific and Cultural Organization under world cultural heritages
47	USLE	Universal Soil Loss Equation
48	USLE_C	Minimum value of USLE_C factor applicable to the land cover/plant
49	USLE_K	USLE soil Erodibility Factor_K
50	ULSE_P	USLE support practice factor
51	USDARS	United States Department of Agriculture Research Services
52	UTM	Universal Transfer Mercator
53	@	at
54	x^2	Chi-square
55	γ	Gamma
56	λ	Lambda
57	β	Beta
58	Δ	Delta

CHAPTER 1
INTRODUCTION

1.1 GENERAL

Availability of freshwater is indispensable in the socio-economic development and preservation of healthy environment. Impossible to imagine of the development of any country without access to adequate water for various purposes (viz., drinking, irrigation, environment and ecosystems) (Flint, 2004; Vallam and Qin, 2017). The availability of water resources are endanger at regional and global scale. Its availability is variable in time and space. In reverse, with alarming rate of population growth similarly increasing demand for it. This create severe pressure on the overall farming system and causes for a great obstacle to water resources planners and managers.

Taking into consideration water resources necessity, it become a core issue to look into global water resources pressures along with challenging threats, and formulate solutions. In the 20th century, population of the world has tripled and the demand for water has risen six folds. Billions of the world population remain in the water scarce regions, and even in the coming decades expected to increase (Falkenmark et al., 2009; Swain and Thomas, 2015). Scarcity of water inferred critically response for sustainable and integrated water resources planning and management to satisfy future water demand. Africa is endowed with numerous natural resources (water resources). However, due to natural and anthropogenic factors (climate change and variability, rainfall intensity and distribution, population growth) put significant pressures on sustainability issues of water resources. Consequently, the continent remain in worse condition due to water scarcity. The severity is prominent in sub-Saharan regions including Ethiopia.

Ethiopia is the oldest civilized, independent and land locked country in East Africa with diverse geographic diversity. The total area of the country is 1.1043 Million km^2 with an altitude ranged from 116 m below sea level to higher than 4000 m above sea level. Ethiopia is the second most populous country in Africa with total population around 92 Million. Even though it is one of the poorest and most food aid countries, with the per capital income of 454 USD per annum; recently the performance is amazingly 10.6% economic growth was registered averagely per a year from 2007 to 2012. Agriculture is the foundation of economic and social life of the whole population of the country. It contributes 40-45% of GDP, 80-85% of employment generation, 90% of export earning, and 90% of rural poor obtain their basic needs from this sector (Yami and Sileshi, 2001). Despite it is subsistence in nature, it has immense contribution to the national economy. Ethiopian's water demand is increasing at a faster rate and further increasing of agricultural sector coupled with climatic variability making the condition more severe. Even though Ethiopia is considered as the water tower of east Africa, the water resources development and management have took less emphasis even less than other Sub-Saharan African countries. In the last 20 years, the country continuously experienced recurrent drought and famines. Mismanagement, uneven distribution of water resources in space and time, climatic change and variability considerably contribute to the decline of water availability. The volume of surface water availability drying up and hence demand outstripping supply, therefore less water available for agriculture, domestic use and for the rest of the ecosystems. This study is undertaken in the Beressa watershed, in which one of the tributaries of upper Blue Nile basin in the area of intense natural resources completion. The detail discussion of the problems have been carried out under three subsections viz. the problem of natural resources degradation and its consequence, climatic change and variability and land use changes.

1.2 PROBLEM IDENTIFICATION

In Ethiopia, limited and deteriorated land resources coupled with rapid rate of population growth challenging the development of agriculture particularly in the highlands of the country in which majority of (85%) the population living. Increase in population caused for expansion of cultivation into forest areas, steep slopes and marginal land. Together with irregularity of rainfall, repercussion for agricultural production vulnerable to environmental shock (Diao et al., 2010). All the factors of land use changes and climatic variability may further intense the problems of land degradation, soil erosion, runoff processes and sediment deposition, hence it will hinder the agricultural productivity and the overall environmental systems. Therefore, it is necessary to explore and understand the impact of land use dynamics and its influence on runoff processes and sediment generation, climatic variability on the status of watershed condition, which will have paramount importance to improve the environmental and ecological condition, and overall livelihood condition of the community.

1.2.1 The problem of natural resources degradation and its consequence

Ethiopia experiences severe water, land and environmental degradation due to anthropogenic and natural causes. These make the country to repeated agricultural production failures and recurrent food shortages. Severe degradation together with temporal imbalance in the rainfall distribution and insignificant availability of water required at right time period are the major contributing factors for reduction of agricultural productivity. Hence, appropriate utilization of available resources (land, water, forest and soil resources) is vital to Ethiopia's subsistence agricultural development and realization of food shortage and food security. Improper natural resource use practices, poor resource management practices and lack of proper conservation measures, have substantial role for causing natural resources depletion problems in the country and dwindling the available farmland and limited availability of off-farm employment opportunities (Shiferaw and Holden, 1999; Bishaw, 2001; Tiwari et al., 2008). Majority of farm household owning less than 2 ha other 40% farming less than half hectares particularly the highlanders. Larger area of the highlands of Ethiopia- the home for more than 85% of the human population, 90% of cultivated area, and 75% of livestock population is suffering sever to moderate degradation (Hawando, 1997; Shiferaw and Holden, 1999; Bishaw, 2001; Feoli et al., 2002; Mekuria et al., 2007; Yayneshet et al., 2009; Zegeye et al., 2010). Consequently less fertile land into crop production, forced to cultivate sloping and marginal land without application of proper soil fertility management, inadequate attention to natural resources depletion and lack of sustainable conservation practices put forward problems related to land degradation, soil erosion and deforestation (Shiferaw and Holden, 1999; Mekuria et al., 2007; Zegeye et al., 2010). It is seriously devastating the economic and social development of the country as a whole (Hurni, 1993; Grepperud, 1996; Hawando, 1997; Tekle, 1999).

As reported by Hurni (1993) and CRSPT (2000), the average rate of soil loss from agricultural land has been estimated to be 42 tonnes $ha^{-1}yr^{-1}$. Likewise, from the individual field it may account to 300 tonnes $ha^{-1}yr^{-1}$. This is by far higher and incomparable with the rate of natural resource regeneration. According to FAO (1986) estimate, the highland is significantly eroded (50%), of which 4% with no return and other 25% is severely eroded. By far due to soil erosion by water, deforestation and land degradation, large number of Ethiopians particularly subsistence farmers have been seriously victims to the effect of drought and hence famine. During the period of 1972/73 and 1984/85 large part of Ethiopia was devastated by severe drought resulting in humiliated famines, which was ever widespread poverty of the population (Hawando, 1997; Shiferaw and Holden, 1999; Dubale, 2001; Nyssen et al., 2004). The Beressa watershed is one of the most affected areas by land degradation, sediment transport and severe soil erosion. The land, water and forest resources of the watershed are in danger due to the alarming rate of population growth, deforestation, intensive grazing, depletion of soil nutrients and increasing demand for fuelwood.

Despite the problems of erosion and degradation was consistently increasing, the issue of rehabilitating and conserving agricultural land and other natural resources were neglected until in the early 1970s (Shiferaw and Holden, 1998; Shiferaw and Holden, 1999). Following the devastating famine of 1972/73, then after awareness problem was incited (Bekele-Tesemma, 1997; Shiferaw and Holden, 1998; Shiferaw and Holden, 1999).

To grapple with the ongoing problems, massive efforts on soil and water conservation has been launched following land reform of 1975 which provide legal land use right particularly in most degraded and food deficit areas (Bekele-Tesemma, 1997; Tesfaye et al., 2014). More emphasis was given to rehabilitating the hillside using construction of physical and mechanical soil and water conservation, reforestation and afforestation activities, with no definite ownership rather on the common property. No matter about the quality of their activities, participation of farmers in the conservation activities was very impressive because of getting some edible oil and grain for the participation (Wood, 1990; Alemayehu, 1996; Bekele-Tesemma, 1997; Reij et al., 1998). However, farmers remained sceptical about the long-term benefit of the activities they were participating. The undefined ownership of hillsides, make community silent in opposing rehabilitation measure started. Limited critics, comments and involvements from local farmers, therefore conservation technology did not fit with local realities and insensitive to them (Bewket, 2003b). Therefore, the massive effort started was failed without achieving the intended objectives. Passive involvement of farmers in the implementation of conservation practices and lack of voluntary involvement of the community took a lion share for the failure (Admassie, 2000; Osman and Sauerborn, 2001; Addisu et al., 2013).

Given the diversity of socio-economic and severe resources degradation problems, the government embarked soil and water conservation work as a campaign work. Unlike the previous conservation practices, attempts to participate local farmers in the prioritization of watershed and sub-watershed has been considered (Teshome et al., 2016). As a strategy of sustaining food security while rehabilitating and conserving the environment using site specific and sustainable integrated water/shed management practices have developed. It is appropriate to identify the process, extent and rate of natural resources degradation and various socio-economic circumstance of farmers at local level (Rhoades, 1999; Simane, 2013).

The aim of integrated water/shed management practices is to achieve desired objectives with involvement of affected local farmers in all the phase of management practices in an integrated and holistic approach (Rhoades, 1998; Rhoades, 1999; Teshome et al., 2016). The interdependence of food insecurity, alarming rate of population growth, natural resources degradation and stagnation of agricultural productivity demand new management practices in reversing the problems (Dasgupta and Mäler, 1995; Reardon and Vosti, 1995). Integrated water/shed management practices take into consider interaction between agricultural practices with population growth, biophysical, ecological, upper and lower user groups as well as genuine involvement of local farmer at all level of management practices. In many part of the world (Asia and Africa), the assumption of integrated water/shed management practices being undertaken (Rhoades, 1998; Rhoades, 1999). Results obtained from different countries evidenced that integrated watershed management practices with the genuine involvement of stakeholders can create a sense of ownership and responsibility for farmers resulting in successfully reversing the trend of natural resources degradation and hence improved the livelihood condition of farmers (Hinchcliffe et al., 1999; Farrington et al., 1999; Kerr, 2002). Therefore, it is necessary to assess the hydrology, land degradation, erosion, deforestation and the overall watershed conditions, which will be important in the upper and lower stream of the watershed in the processes of planning, implementations and scale up of integrated conservation measures. Hence, play significant role in addressing short and long-term local problems.

1.2.2 The problems of climatic change and variability

According to report by IPCC (Pachauri et al., 2014), spatial, inter seasonal and annual rainfall variability was observed across the globe. It was found that variability in rainfall pattern has significant influence on the agricultural production in many parts of the Asia and Africa. This global warming (increase in surface temperature) may influence the long-term precipitation pattern, increased in frequency and intensity of weather shock has led to increase in sea level on the one hand and impacting on water availability (Barnett et al., 2005; Parida and Moalafhi, 2007; Kampata et al., 2008). Due to industrialization and anthropogenic emission of various poison gases caused the world surface temperature raised by about 1°C. In Ethiopia, over the past decades, minimum and maximum average temperature has been raised by about 0.25°C and 0.1°C respectively. Similarly, rainfall pattern has manifested by severely variable and volatile in the last 50 years (Wu et al., 2016). The fact of climatic change and variability in the past have rising trend and as suggested in various studies, it may further rise in the near future, urgently give attention about how the local community perceive the extent of climatic change pattern to design appropriate copping and adaptation strategies (Belay et al., 2005; Gan et al., 2016). According to results obtained from various model proposed that Ethiopia will see additional warming in all seasons between 0.7°C and 2.3°C by the 2020s and 1.4°C and 2.9°C by the 2050s and the concentration, duration and intensity of rainfall will vary over the entire parts of the country (Conway and Schipper, 2011; Simane et al., 2012). It has predicted that climate change decreases the GDP growth of the country between 0.5 and 2.5% in each year unless climatic shock and variability resilient mechanisms considered. Therefore, areas with low and variable rainfall and rise in temperature may lead to drought and famine conditions in the future. The variation of spatial and temporal distribution are wide throughout the country due to various atmospheric and other anthropogenic local influencing factors.

In order to understand change and variability of the climate, specific analysis at regional and local scale is required, similarly it is necessary to explore at various spatial scales (Sahoo and Smith, 2009). There are many researches on the intensity and climatic variability resulted for extreme change of hydrological parameters intern considerable impact on crop productivity, water resources and overall economy of the community. Therefore, clearly understanding of climatic variability has significant benefit in order to manage and improve the environment and climatic resilient rural community.

1.2.3 Land Use/Land Cover change

Land use dynamics is by and large influenced by the anthropogenic factors and should be monitored in order to explore and evaluate its implication to the environment (Reid et al., 2000). Dynamics in the LU/LC of an area are considered to be a major factor of significantly contributing to the alteration of the world environment (Turner et al., 1995; Minale, 2013). Spatiotemporal expansion of settlement areas are intensively dynamic. Alarming rate of population growth has led to rapid expansion of settlement areas and more demand for food crops (Liu et al., 2007). Expansion in settlement and agricultural areas by clearing of forests and vegetative covers are a cause for degradation, erosion and environmental change. Land Use/Land Cover change dynamics is tend to spread very quickly and considered to have huge impacts on ecological change to the globe (Lupo et al., 2001; Sahoo et al., 2006). Land use class of the globe such as forests, bush and grassland, vegetation and barren lands invasively converted into other LU/LC classes. Therefore, LU/LC change dynamics have considerable influence on the local as well as global environment.

Recently research on LU/LC change dynamics has drawn the attention of many scholars (Liang et al., 2002; Ayele et al., 2016). Land Use/Land Cover changes detection have studied by many researchers in different parts of Ethiopia. Decrease in forest covers has observed in last 50 years and cultivation of crops expanding into uncultivated land without appropriate management practices. Therefore, farm produce is still lagging behind by 2.67% population growth rate per annum (Asres et al., 2016), and most of the areas have significantly shown alteration of the vegetation cover into other classes with fast growing settlement areas. Likewise, prediction of future LU/LC change dynamics can considerably play important role for policy formulation as it gives awareness for future planning and development of the areas and its possible influences on the overall environment.

Geographic information system and remote sensing (GIS and RS) is considered as the influential tool in order to determine the dynamic nature of LU/LC change detection. To compare and explore change detection from various temporal images, information on a particular period possibly derived from satellite data. Regarding spatial distribution of different LU/LC class types and the trend of changes can be derived from temporal images of the area. The LU/LC change detection and future prediction play significant role in the design of various planning and management processes. Likewise, exploring LU/LC change dynamic is considerably important in order to recognize runoff process and sediment yield generation change dynamics (Azamathulla et al., 2012; Azamathulla et al., 2013; Azamathulla and Jarrett, 2013). The change of LU/LC classes from forestland, vegetation, bushes and grass and other land use areas into settlement areas and farmland may result in increased runoff processes, flood occurrences and sediment yield generation (Sahoo, 2008). Therefore, this will further accelerate the problem of farmland shortage, clearing of more forest, soil erosion and environmental degradation. This will significantly influence the availability of food in the long run.

1.2.4 Research gaps

1. Nevertheless, there have been many efforts elsewhere in watershed management practices analysis, less focus has been given for community based conservation techniques and awareness level related to resources degradation and benefit of integrated management practices, which would be important strategies for sustainable and effective management practices in the country in general and study area in particular.
2. Previous studies related to LU/LC changes encompasses only historical LU/LC changes and their impact analysis at a watershed and sub watershed level independently less attention was given to future land use changes and resultant consequences.
3. Most of the studies on climate change and variability and its implication on crop production have done on encompassing large areas of basin, regional, state and country level. Few studies have been undertaken at micro level encompassing small watershed.
4. Many researchers have done on hydrological model encompassing lager watershed. Few studies have been done on hydrological modelling of runoff-sediment response to LU/LC changes.

Therefore, this study will have paramount importance for policy planner and water resources managers with the objectives of allocating and using limited available water resources, land resources and other natural resources among upstream and downstream resource users- hence drought resilient communities. Particularly, countries like Ethiopia will have much utility from the output of the study.

1.3 THE OBJECTIVES OF THE RESEARCH

In view of the severity of the problems and research gaps of the study area discussed above, the following main objectives are outlined.

I) Examine the existing socio-economic conditions and management practices.

II) Analysis of the spatiotemporal LU/LC change dynamics and future prediction using satellite data.

III) Assess the spatiotemporal trend analysis of climatic variables and its implication on crop production.

IV) Calibrate and validate watershed model (SWAT model) based on observed dataset and identify runoff-sediment responses to LU/LC changes.

V) Recognize the requirements for the practical implementation of integrated water resources management in highlands of Ethiopia.

1.4 STRUCTURE OF THE THESIS

The thesis contain nine chapters. In **Chapter one** the overall general background, problems identification, research gaps and objectives of the study are presented.

In **Chapter two**, detail review of literature on the concepts of watershed management, the role of indigenous knowledge for watershed management, assessment of land use change and future prediction, historical trend of climatic variables (rainfall and temperature), hydrological modelling (SWAT model), land use change dynamics implication of surface runoff and sediment and concluding remarks are presented in this chapter.

Chapter three presents detail description about location of the study area along with topography, climate, farming system, land use system and soil types.

Chapter four, contains detail description about household perception about the devil of erosion and degradation problems, household level natural resources conservation practices and biofuel consumption.

In **Chapter five**, the spatiotemporal analysis of Land Use/Land Cover change detection and quantification for historical land use system and analysis of future prediction using Markov Chain model are explained.

In **Chapter six**, application of statistical parameter test is presented. Trend analysis using Mann-Kendal test, Sen's slope estimator, Precipitation Concentration Index, Moving average, percentage change and spatial distribution of rainfall and temperature, and its effect on crop production are presented.

In **Chapter seven**, the analysis of watershed hydrological behaviour using SWAT model is presented. Initially, hydrological model simulation capability is checked and summarised. The calibration and validation results are summarised. Finally, based on the performance of the model simulation, runoff-sediment response to LU/LC change dynamics are presented.

In **Chapter eight**, detail discussion about practical implementation of integrated water resources management and water harvesting in highlands of Ethiopia is summarised. Crop water requirement and rainfall contribution index is presented in this chapter.

In **Chapter Nine**, the overall summary and conclusions of the thesis are summarised. Study limitation, main research contribution, and some recommendation and future scope of the study are presented.

Note that even though overlapping of some sections in this thesis was unavoidable because of the results of one chapter is relied on the proceeding chapter; each of the chapter is thought to be independent.

CHAPTER 2
LITERATURE REVIEW

2.1 GENERAL

This section mainly focused on review of available literature related to the present study. Based on the proposed main objectives for this study, review of literature is addressed in the following sections. The **first section** presents review on general concepts of watershed management practices at global and Ethiopian perspectives, success and failure story of watershed management practices. **Section two** illustrates the various issues related to the assessment of LU/LC changes, the uses of Geographic Information System (GIS) and Remote Sensing (RS) for LU/LC changes using different methods and application of different methods and models for future LU/LC changes prediction. **Section three** presents review related to climatic variability and changes includes trend analysis of rainfall and temperature and different approaches used to manage climatic variability. **Section four** includes hydrological modelling approaches such as SWAT model, application of SWAT model and LU/LC change dynamics implication on surface runoff process and sediment yield. Finally, concluding remark from the reviewed literature have been discussed.

2.2 THE CONCEPT OF WATERSHED MANAGEMENT PRACTICES

In the rainfall dependent agrarian countries of the globe, productivity is insufficient, erosion and degradation of natural resources is intensive hence, the livelihoods condition of the people are worse. In the emerging depleting natural resources, the concept and idea of watershed management considered as a relief to rainfall dependent agriculture. Because watershed is a striking unit to manage soil, water and land resources for better production and sustainable natural resources conservation (Kerr, 2002). Afterward, concepts of community based participatory watershed management has emerged to watershed management programs more viable. The involvement of local peoples is a central point in addressing watershed and sub-watershed based resources conservation (Sharda et al., 2005), which is defined as the utilization and conservation of land, water and other natural resources at watershed and sub-watershed level to fulfil livelihoods to communities without compromising the resultant ecosystems. The ultimate objective therefore is stakeholders at the local level are the determinant factor of resources management. Similarly, community based watershed development and management recognize that indigenous farmers are best manager for their own resources because they realize dependence on natural resources for their survival is nearly absolute.

Community based watershed development and management is used to harmonize land, water, soil and biodiversity in a way that conserve natural resources while rising agricultural productivity through conserving soil moisture, and reducing soil removal by water and degradation of land resources as well (Bhattacharya, 2008). Therefore, watershed development and management particularly in erosion and degradation prone area as well as in rainfed area can have intense contribution for the survival of farm households. Many direct and indirect benefits can obtain from community based watershed management practices, for instance increase in soil fertility, productivity, reduce in soil erosion, and in deforestation, increase fodder production, enhance in fuelwood availability, hence off-farm employment opportunities, less in out migration and resilient for food insecurity shock.

Watershed management programs recently, sought to involve participatory resources planning and management started as a part of community involvement of watershed initiatives with explicitly wider social as well as political process. However, watershed in the catchment comprises a collection of inter-linked and interdependent activities. It forms dynamic and integrated socio-economic, biophysical, and environmental system specifically it contains communities, forestry, soil, water and river and agriculture. Watershed management practices is a complex and multifaceted phenomenon. Therefore, its management practices need diversified socioeconomic, physical policies and techniques, which assumed at curbing antagonistic consequences related to natural catastrophe, hence improvement and enhancement of the quality and wellbeing of the watershed community.

Additionally, the benefits of watershed management are to improve the natural capital, ground water recharge, value of land, availability of fodder and water for irrigation, bringing cultivable wasteland to cultivable land and become productive.

2.2.1 Why participatory watershed management?

Due to the complex nature of watershed management practices, multiple user uses different parts of the catchment for different purpose with conflict of interests. Therefore, any management interventions implemented may influence on others use, additionally; many different uses are mutually exclusive. For instance, the upper part of the catchments may have removed the forest cover, being communal land resources used for animal grazing as well as firewood collection by upper users. Therefore, natural resources management practices aimed in controlling soil erosion and land degradation, increase forest coverage, water harvesting and restriction to free grazing.

The negligence of constraint, needs and practice of local communities throughout many parts of the globe have not been considered in the management practices, resulted for the insignificant positive contribution of management practices. Stakeholders consists of all categories of which will influenced by, have different awareness in, and can affect the management involvement. They are not limited to specific groups; nevertheless, inclusive of all other groups. All stakeholders take part in all stages of watershed management practices. A report by Pretty and Ward (2001), stakeholder's participation referred to as performing in groups to formulate a certain criteria for a better natural resources conservation, pinpoint priorities, and evaluate appropriate solutions, identify constraints, and evaluate management impacts.

Deterioration of natural resources is not possibly reversed by top-down approach through food for work program rather the participation of concerned groups during planning and development of the project otherwise. The governmental and donor organization accepted that effective and sustainable watershed and sub-watershed level problem cannot be insured without genuine involvement of concerned watershed users (Pretty and Ward, 2001). Lesson obtained from the previous top-down watershed management project were the participation of local farmers was against their will. Therefore, constructed structures have been failed without attaining the intended objectives (Kerr et al., 1996; Rhoades, 1998). Therefore, contribution of people's involvement in any level of management process has to be recognized hence tackling severe natural resources degradation is successful and sustainable. Local farmers are very close to their real watershed problems than other experts and they demand conservation that is more practical and rehabilitation practices to obtain the long and short-term livelihoods problems. Additionally, the involvement of farmers in all aspects of watershed project considered very essential in increasing adoption and implementation of innovated watershed technology (Ashby, 1997).

According to Desta et al. (2005), in Ethiopia where the watershed project was centrally planned, conservation and rehabilitation project are endorsed with technically standard solution such as terrace construction, contour bund, soil and stone bunds, and conservation tillage. From this point of view conservation and rehabilitation measure are nationally the same application on the one hand and low level of farmer's awareness on erosion and degradation, and ignorant of the prevailing cause and consequent results. Such measures however, resulted for more resources degradation than even before where using their indigenous knowledge to conserve and rehabilitate, this is because of difficulty to adopt newly innovated conservation technology to the local conditions (Kerr et al., 1996; Kerr, 2002). In flexible and conventional types of conservation and rehabilitation approach where considering on rehabilitation of hillsides with various physical structures with limited consideration to ecological, economical, and social conditions, for example the Borkena dam in Southern Wollo, Ethiopia constructed in the 1980s, due to lack of ecological consideration therefore, the dam was silted (Desta et al., 2005). Community involvement in the watershed management project is not limited on individual land, rather it is inclusive of natural resources management of communal resources (i.e. gully rehabilitation, natural forest, water resources management, hillside rehabilitation and management etc.) and identifying the priority needs of local peoples based on real problems they face. Therefore, identifying the local knowledge and available local materials and integrating it with innovated watershed management technologies (Figure 2.1).

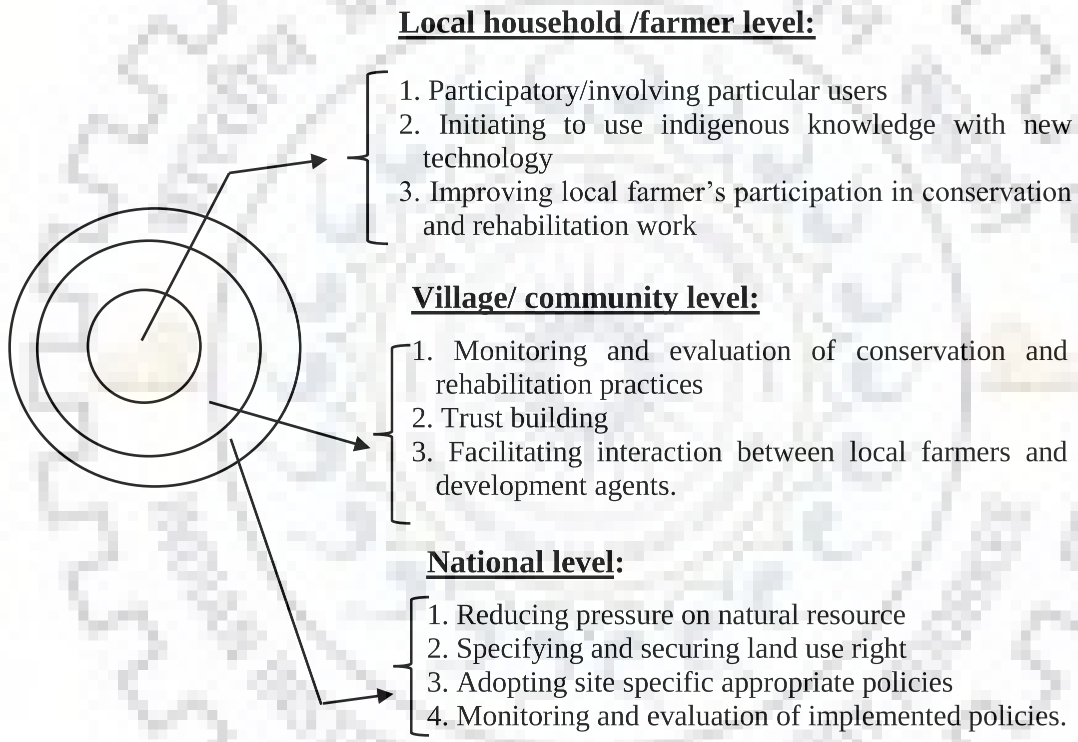


Figure 2.1 Framework of community based watershed management practices

According to Azene and Kimaru (2006), community based watershed management therefore, is involving concerned bodies at all levels of management process need prioritization, identifying their interest, adoption of technologies on the basis of local context, monitoring and evaluation of project impact in reversing erosion and degradation problems and hence the livelihoods conditions. Successful and sustainable watershed management project is possibly insured by the participation of concerned local farmers. Community based participatory approach giving roles for the community and creating partnership with different interested groups, making integrated discussion among policy makers and flow of information from onesided approaches. Based on Desta et al. (2005) and Azene and Kimaru (2006), confirmed that participatory implies local stakeholders implementing their project in groups, identify their problems and constraint, prioritize their problems, identify possible solutions and identify possible technologies and policies which is suitable for the local conditions, finally evaluate the weakness and strength of watershed project impact.

2.2.2 Concepts of sustainable watershed management

In order to obtain optimum benefit with fewer disturbances to the environment, therefore, sustainable, effective and wise use of resources such as water, land, biomass and ecology possibly conserve and rehabilitated through watershed management. Paul (1997) pointed out that, in ancient times, managing watershed mainly emphasized on medium and large-scale valley management, aimed to reduce rapid runoff, excessive erosion and degradation. However, to adopt compatible and sustainable soil and water conservation management practices, recently watershed development and management program considered as a hydrological unit. Hence, provide adequate and sustainable water resources, protect ecological disturbance and improve the livelihood condition to the society particularly rural farmers mainly their overall livelihoods are depending on natural resources. The recent concept of watershed management is very complex concept than the previous. Therefore, in most developing countries, for sustainable rural livelihood watershed management is a new concept. Watershed management is not limited only on reducing soil erosion and land degradation and increase in vegetation cover, but at the same time it is used to boost agricultural productivities hence stable food security (Farrington et al., 1999). According to Kerr (2002), in semi-arid and tropical regions of Asia as well as Sub–Saharan Africa sustainable watershed management practices have been implemented in order to improve rainfed crop production, natural resources conservation and consequently improve livelihood conditions, where very common in natural resources degradation, low level of agricultural production and frequent drought.

2.2.2.1 Chain of sustainability (watershed sustainability chain)

The issue of watershed sustainability is inclusive of four most important elements (natural resources sustainability, technological sustainability, institutional setup and economic system), which is depicted in Figure 2.2.

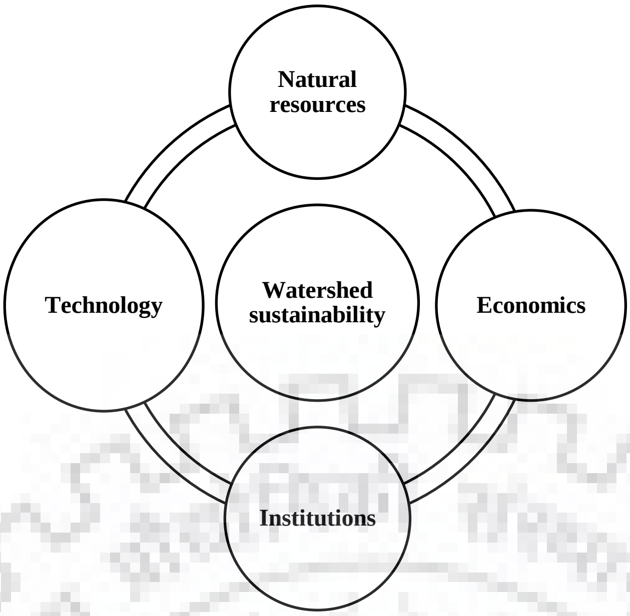


Figure 2.2 Watershed sustainability chain

Protection of natural resource from erosion and degradation and increasing watershed production has enormous contributions for effective and sustainable resources management practices as shown in Figure 2.3.

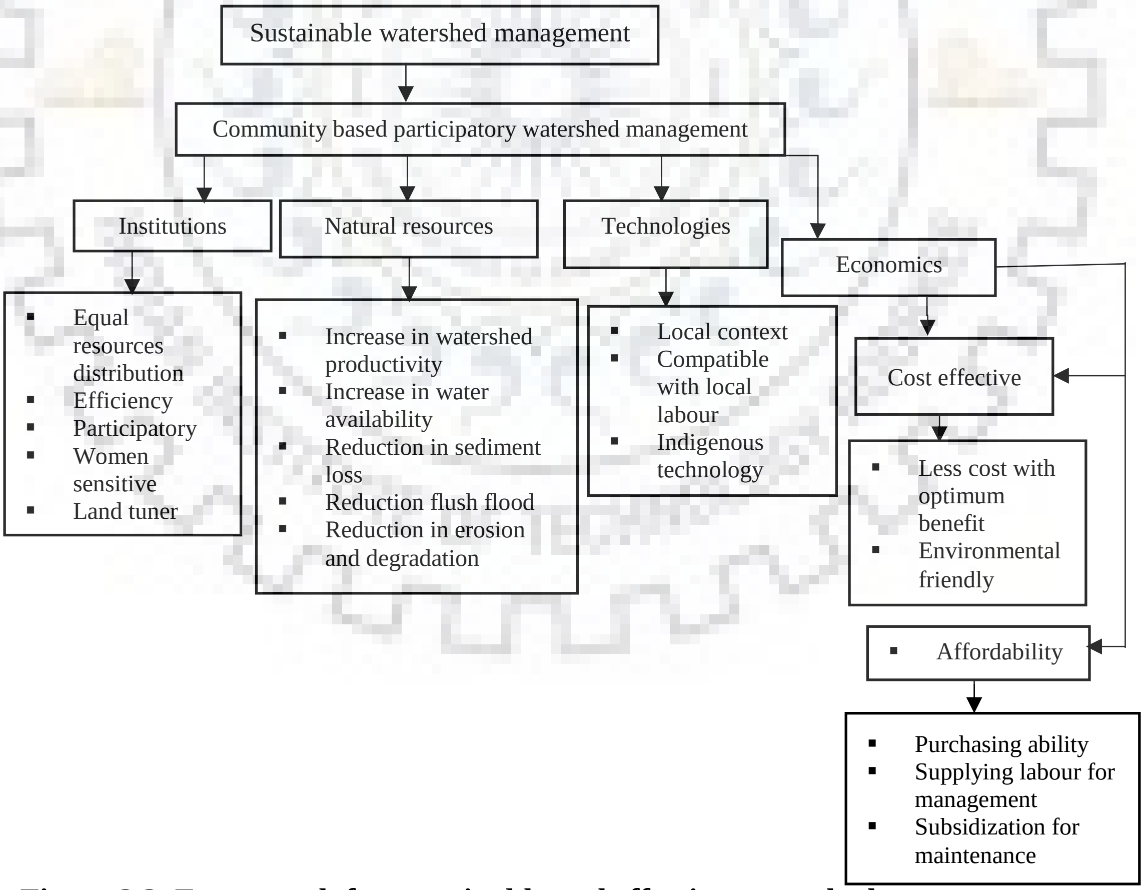


Figure 2.3 Framework for sustainable and effective watershed management

In order to utilize available resources, local level adapted technologies are required with appropriate institutional setting. Therefore, adapted local level technologies should easily manageable and cost effective.

2.2.3 The role of indigenous resources conservation practices

Indigenous knowledge is the sum of different experiences of an individuals which help them to solve their own problems in the way they think (Olokesusi, 2004). It is the way and techniques of knowing and understanding the environment, which is derived from the direct interaction of peoples with their environment. In the same study, indigenous knowledge is an integral system of production and consumption like organized technical skill and knowledge, decision-making, social institution, technology, and management and conservation of natural resources. Practices using indigenous knowledge integrated with new technology has substantial benefit to the local environment. Because of this, farmer has developed practices in line with the status and law of their ecological systems. Local peoples have acquired/inherited and developed their traditional and indigenous knowledge on the context of their natural ecological systems (Tegene, 1998). According to Grenier (1998), for the planning and development process, indigenous knowledge has important contributions for formation and development of partners such as community based organization, non-governmental organization, and private sectors initiatives. Finally, national, regional and local leaders need to recognize and approve it their interaction and with the local community.

Prior to incorporating it with introduced approaches, critical understanding of indigenous knowledge against new technology use to keep the sustainability of conservation practices. Therefore, indigenous knowledge should have preserved properly, transferred, promoted and adopted to social, ecological, and economical context of the particular community (Grenier, 1998). Local level communications are important in the process of local decision and for conservation, adoption, development as well as dissemination of such rich indigenous knowledge.

For instance, at the initial stages soil and water conservation implemented, as a campaign work through food for work program was not succeeded the intended objective because of its many multifaceted drawback and constraints (Campbell, 1991; Rahmato, 1991; Tegene, 1992). The most attributed limitation of conservation and rehabilitation program was, introduced conservation structures were not friendly with the local farming practices. The acceptability of conservation and rehabilitation activities has increased when they incorporate and integrate with indigenous conservation and rehabilitation practices compatible with and adaptable to local environment and farming systems (Critchley et al., 1994; Dewalt, 1994; White and Jickling, 1995).

2.3 THE CONCEPT OF WATERSHED MANAGEMENT IN ETHIOPIA

Against the adverse effects of erosion and degradation problems, in collaboration with donor organizations the government started massive soil and water conservation practices to improve environmental and ecological conditions and hence ensuring the sustainability of food security. Regardless of such massive effort, the base of natural resources is continuously deteriorating and become the most serious causes for vulnerability (Aredo, 1990). During 1970s, soil conservation and hillsides rehabilitation in the Ethiopia highlands were the most extensive in Africa. Against the hazards of erosion and degradation problems intense activities has been made in terms of afforestation, terracing of hillsides and area closure (Tegene, 1998). On the basis of later evaluation, the effort of these initiatives therefore was seen to be insufficient and ineffective in curbing alarming rate of demographic growth, widespread erosion and degradation problems, rainfall variability and hence drought and food shortage. Since 1980, the government of Ethiopia with the support of donor organizations initiated rural land conservation and rehabilitation program through watershed and sub-watershed development (Desta et al., 2005). However, the project was few in numbers. Institutional strengthen was performed by FAO and other NGOs, primarily the goal of support was enhancing the capacity of technical experts at different level and extension agent in rural part of the country particularly in the highlands in which the problem is more severe. This project was the initial step of integrated participatory planning and development of watershed management practices. In the late 1990, to alleviate poverty and diversifying overall rural development of the country watershed planning and development was sought to be key points. The main aim of the program was to address food insecure area through conservation of natural resources, community based forestry, construction of rural infrastructure. Initially the project was identifying food deficit part of the regions where the occurrence of food insecurity is merely severe.

To improve the nutritional food of local farm household, integrated community based watershed management project was implemented in south Gonder of Ethiopia by GTZ-integrated food security project. Biological and physical natural resources conservation and rehabilitation practices as well as expansion of rural infrastructures were the aim of the project. Evaluation of the project indicates resulted for successful gully rehabilitation. Initially success and failure stories of conservation project was used as basis for broad based community based watershed and sub-watershed level development and planning initiatives in the Ethiopian highlands. However, lessons related to institutional arrangement were failed only technological aspects from the previous watershed management projects were adopted. Learned from the past success stories of watershed conservation and rehabilitation project, the recent started project took effort to reorganize affected and concerned bodies to reverse the trends of problems collectively. However, due to its lack of decentralized structure, inflexible technology and absence of institutional arrangements the project result was far below the expected.

2.3.1 Policies towards watershed management practices in Ethiopia

Land resources is the backbone for the survival of majority of population in Ethiopia. Therefore, policy related to land has essential role for rural livelihoods and the government as well. Prior to *Derg* era of 1974, during *feudal* regime land tenure was insecure. It was under the landlords. Therefore, it affects the adoption and continue to use conservation and rehabilitation practices (Bekele and Drake, 2003). In addition, the attention of country's development goal gives emphasis on development of industrial sector; the policy attention towards agricultural sector was less.

In the first two consecutive five-year development plan (1957 to1962 and 1962 to 1967), the government of Ethiopia gave special focus to export items of large-scale commercial farms. Following this, high potential agro-ecological area was selected and invest huge input package in order to earn quick return (Aredo, 1990). However, small holding farmers continuously cultivate farming practices, which was negatively contributed to erosion and degradation did not considered in the policy options. Therefore, insecure land tenure system on one hand and emphasis given to large-scale commercial farms on the other hindered natural resources conservation and rehabilitation efforts (Campbell, 1991). After the over through of *feudal* system in 1974 the military government of Ethiopia, who took over the power declares new land reform under the slogan of *land to the tiller*. The government redistributed the land to farming households previously owned by landlords aimed to achieve equitable distribution of usufruct land use rights. However, frequently redistribution of land decreases access to land and insecure ownership. In addition, the government preserved state ownership of large state farm. Though it was expected to improve attention to conservation and rehabilitation practices, it couldn't achieve the expected outcome (Zewdie, 1999). Each service such as credit, farm input distribution, selling of farm output to market and extension service was emphasized on cooperatives and formation of state farm as well. The government intervene in fixing marketing price and coercive villagization caused in insecure land right. Notwithstanding in fact the reform helped them to have access to farm land, but large scale state ownership and insecure usufruct land use right affected to exploit the potential from the reform policy.

After the over through of *Derg* regime in 1991 and overtook by the Ethiopian People's Revolutionary Democratic Front (EPRDF). Initially, the emphasis was given to maintain policies of the predecessor (*Derg* regime) regarding to natural resources where land was vested to the government and land use right to farm households and livestock owners. However, land sales and collectivization was strictly prohibited, while encouraging village and district level redistribution in order to reduce landlessness, similarly permitting restricted land lease out to be exercised. Recently the land distribution authority was delegated to the regional government. In order to increase rural land tenure security, the regional state began different methods of land redistribution. However, due to the adverse effect of frequent redistribution the federal government of Ethiopia changed in 2005 redistribution is limited only irrigation development in the proclamation No. 456/2005 (Holden and Yohannes, 2002). Unlike the *Derg* regime, in the present government of Ethiopia more attention was given to agricultural sector with inclusive of smallholder farmers. In the mid 1990s, the government embarked on agriculture lead to industrialization as a development extension package, where aimed to improve productivity of smallholder farmers at the same times expanding large scale commercial farms.

In addition to this, the government embarked so far on conservation and rehabilitation of natural resources for the sustainability of agricultural land. However, Agricultural Development Lead Industrialization (ADLI) the country pursuing currently could not attain food security (Bekele and Drake, 2003).

2.3.2 Practices and implications of soil and water conservation in Ethiopia

In Ethiopia, farm household with long experience recognized the implication of removal of soil and degradation on agricultural productivity in particular and overall environment in general. Therefore, resulted for implementation of indigenous knowledge of natural resources conservation practices in Ethiopia (Nyssen et al., 2007; Watson, 2009). The best example in southern part of Ethiopia Konso peoples were much known of indigenous knowledge of terrace construction, which was registered in UNESCO. The landscape of Konso area is manifested by widespread too dry terraces bearing witness to the persistent of community fight to use dry, harsh as well as rocky environment. Well-developed traditional stone terrace use to retain soil from severe erosion, discharging excess water, collect more water and it used to create terraced fields that are used for agricultural production.

Indigenous knowledge of terrace construction was not limited in Konso area, but based on some physical remnants observed conservation practices that has implemented in the northern highland of Ethiopia. However, unlike terrace construction in Konso area, conservation practices implemented in other parts of Ethiopia have limitation and failed without achieving the intended objectives subjected to layout deficiency and poor construction (Nyssen et al., 2007). In recognition of erosion and degradation, in this regard the government of Ethiopia took policy action to reverse the trend using massive conservation and rehabilitation practices. Conservation and rehabilitation practices which has been implemented in the highlands of the country emphasized on both biological and mechanical intervention (Bationo et al., 2006). However, the involvement of farmer in the practices was limited to incentive-based program. Therefore, a success story of conservation and rehabilitation was far below the expected.

2.3.3 The failure of resources conservation efforts in Ethiopia

Community based watershed management guideline has been developed in 2005, where local community participation in any stages of watershed management practices got due consideration for the effectiveness and sustainability of watershed development and management (Desta et al., 2005).

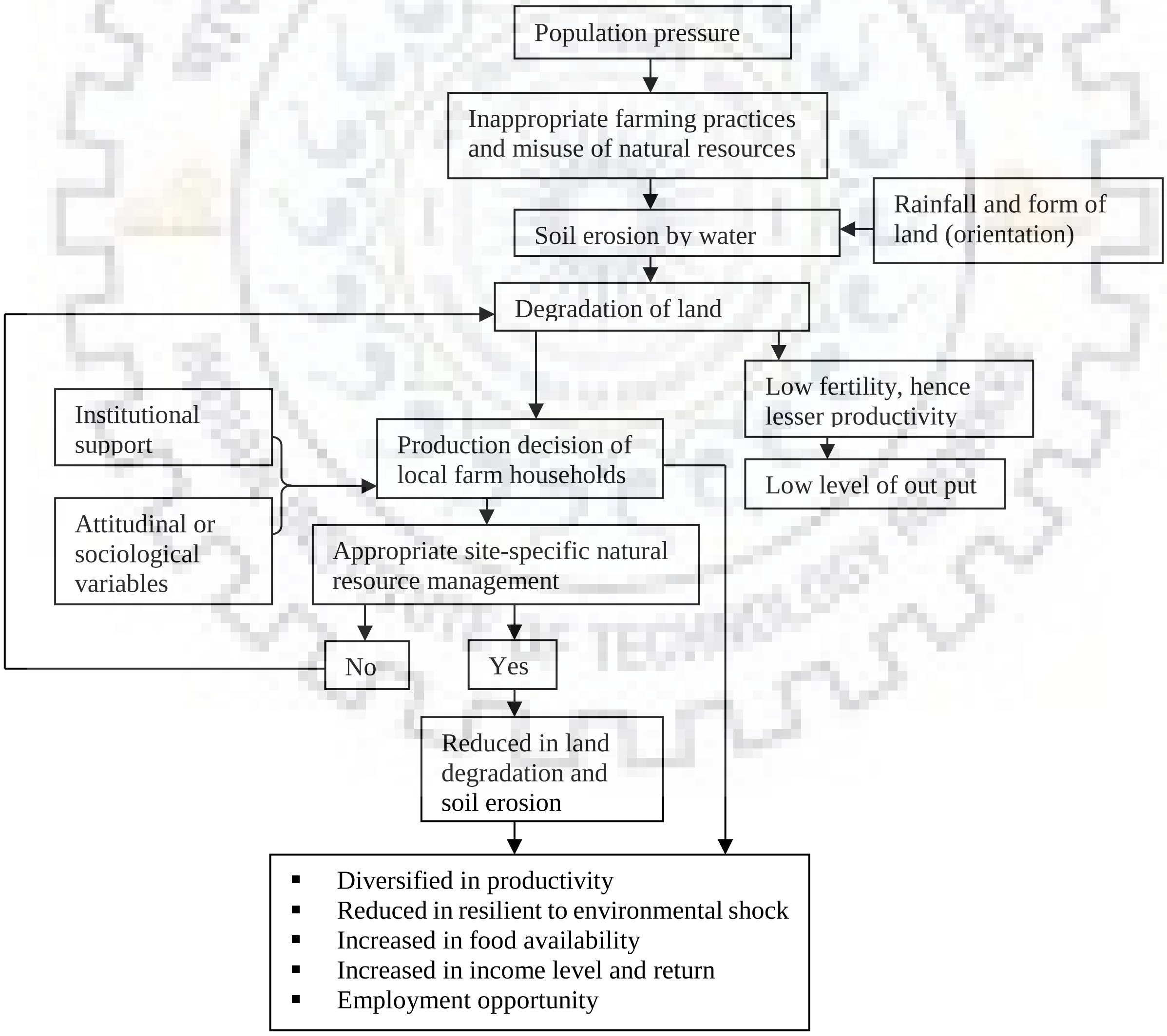


Figure 2.4 Overall conceptual framework of sustainable watershed management

In collaboration with many donor organizations, government made massive efforts with a campaign work through top-down approach. Communities have got incentives for their participation in the conservation and rehabilitation work. Despite massive intervention in many part of the country, the evaluation of success story is far below the expected. Generally, the overall framework of sustainable watershed management already shown in Figure 2.4.

2.4 ASSESSMENT OF LAND USE/LAND COVER CHANGES

During the past few decades, LU/LC changes detection was employed by using conventional techniques, which is time consuming and tedious as well as cost ineffective methods. However, due to the advancement of technology and innovations of powerful computers, RS and GIS software recognized as excellent tools in the study of LU/LC dynamics. Remotely sensed data can be employed for several applications in the area of LU/LC dynamics, water resources management, catchment management and other many more analysis throughout the globe.

In the last few decades due to anthropogenic effects, LU/LC dynamics are significantly under tensions. Therefore, it is essential to detect LU/LC changes starting from the micro scale to lager catchment for effective and sustainable management. To this effect, remotely sensed satellite data have been necessary in order to assess natural resources and observing the changes in the time series. Results derived from integration of RS and GIS substantially important in the planning and monitoring resources based activities. Therefore, the focus of this section is on assessment of historical LU/LC change dynamics studies and LU/LC future prediction.

2.4.1 Use of GIS and RS for LU/LU by different methods

In most parts of the globe, land cover classes are dynamic. Under this situation, availability of accurate and significant data related to land and other natural resources (such as land cover class data, Landsat images, GIS and satellite remote sensing) are significantly important to take actions. The dynamics of land cover classes from one class to other classes and hence mapping of land cover dynamics establishes the baseline to predict future LU/LC class dynamics, current natural resources management and other reclamation practices. The dynamic component of mapping is helpful to indicate the LU/LC changes dynamics in the catchment. In order to identify LU/LC change dynamics from satellite imagery, various studies have been undertaken using different methods. The change of LU/LC dynamics is locally influential and significant ecological and environmental trend (Burns et al., 2007). Some scholars across the globe have conducted various studies in order to evaluate reliability of change dynamic detection techniques to recommend significant methods for LU/LC change dynamic detection; important studies are presented in subsequent sections.

Mendis and Wadigamangawa (1996) Detected LU/LC changes by using the existed and use survey data for the year 1983, Thematic Mapper (TM) data for the year 1992 and aerial photograph of the year 1994 for Nilwala River watershed in Sri Lanka. Maximum likelihood classifier was employed in order to classify Thematic Mapper image of band combination 3, 5, and 7. The focus of this study was to explore the dynamics of LU/LC classes due to application of the Nilwala Ganda Flood protection Scheme. The results revealed that cultivation has been replaced by plantations.

Kucukmehmetoglu and Geymen (2008) Explored the land use dynamics using Landsat imagery for the year 1990 to 2005. Application of RS and GIS techniques were employed to assess the water resources of Istanbul (Turkey). Using this technique, impacts of urbanization on water resources of Istanbul city was carried out. When classifying the images, the main focus was settlement areas and changes of respective settlement areas were analysed. However, this study ignored the association between land use change dynamics, temperature and rainfall of urban areas to explore the water resources in considering the climate changes and variability scenario.

Balamurugan et al. (2014), assessed LU/LC change dynamics for the coastal area of Odisha state using RS and GIS for the period 1990 to 2014 and explored various land use classes such as settlement areas, farmland, water bodies and forestland in order to create RS and GIS database. This study arrived at a conclusion in which settlement areas and industrial growth expansion were identified whereas a continuous decline of forest resources has been observed.

In view of the above studies undertaken in various parts of the world, it can be concluded that several techniques and methods are available for LU/LC classes exploration and classification. Generally, some of the most important LU/LC dynamics classification methods are presented in Table 2.1.

Table 2.1 Land Use/Land Cover change dynamic classification techniques

Authors and Year	Title of work	Major Findings
Meshesha et al. (2016)	LU/LC changes dynamics Using RS and GIS in the Beressa watershed, Ethiopia	Farmland was expanded at the rate of 71.6 ha/year while settlement areas expanded by about 16.8 ha/year in the last 3 decades (1984 to 2015). Whereas, Forestland was reduced at the rate of 5 ha/year while water bodies has reduced at the rate of 0.03 ha/year in the first periods (1984 to1999). Alarming rate in growth of population is the responsible factor for the alteration of LU/LC.
Asres et al. (2016)	Analyses of LU/LC changes in the upper Blue Nile Basin Highland Watersheds.	Interpolation of Landsat imageries for 1973, 1986, 2000, and 2013 have been done using GIS and RS. The results showed that at the expense of pastureland and forestland, cultivated land was increased.
Minale and Rao (2012)	Impacts of LU/LC change in the catchment of Gilgel Abbay, Lake Tana on climate variability.	GIS and RS tools were used in order to assess the trend of change detection in LU/LC. The results revealed that forestland (72.3%), glass land (55%), wetlands (47.2%) and lake areas (6.3%) have been altered into farmland and settlement areas.
Lin et al. (2007)	LU/LC classes dynamics impact on hydrology and the pattern of LU/LC in the Wu-Tu watershed and Northern Taiwan.	Employed integrated approach in which is used to integrate LU/LC model and hydrological model to explore future influence of LU/LC dynamic scenarios on the hydrology as well as the future land use pattern. It confirmed that variability, distribution, intensity as well as magnitude in future hydrological components were substantially affected by LU/LC changes particularly runoff process.
Kiran (2013)	GIS and RS tools have been employed in the process of identifying LU/LC dynamics of Mahananda catchment of West Bengal.	The results revealed that due to anthropogenic effects coverage of dense forest reduced continuously from 58% -33% jus with 8 years (1990 to 2000).
Jat et al. (2009)	RS and GIS based urbanisation assessment and of watershed degradation.	RS and GIS techniques have been employed to verify the condition of two urbanised sub-watersheds over 29 years (1977 to 2005). The study indicate that significant alteration have been found in essential watershed characteristics consequently to the decline of its health. In this, regards RS and GIS tools have been found to be essential RS and GIS tools have been found to be convenient for such studies.

2.4.2 Use of different methods/models for LU/LC prediction

In past few decades, many researchers have used different methods to predict future LU/LC change dynamics based on historic maps and Landsat imagery (Kuemmerle et al., 2006). The magnitude of LU/LC change dynamics in response to alarming rate of population growth and consequently to the environment merit detail explorations of these alterations are necessary (Wu et al., 2006). Land use models are basic focus in the LU/LC. In the last few decades, many researchers created huge set of operating models, which is crucial in the future, LU/LC prediction. However, models are useful not only in assisting the consideration of future land use change dynamics, analysis of scenarios using land use models but also are used to assist planning the land use and policy formulation as well (Samal et al., 2015). In general, land use prediction model is grouped into three main classes, these are statistical as well as empirical models like Markov chains and regression model (Hu and Lo, 2007); Cellular Automata (CA) model (Mitsova et al., 2011); Agent based model as well as system dynamic; integrated model like conversion of Land Use and its effects (CLUE) (Kamusoko et al., 2009).

Kamusoko et al. (2009) forecasted future LU/LC change dynamics for Zimbabwe, the results indicated that barren land continuously increasing and a risk to the sustainability for the community up to 2030. He et al. (2013) explored influence of preserving farmland policies on urban sprawl as well as food availability in many parts of China. The results derived a conclusion that future urban land use could further expand, consequently would results in negative impacts on future land and other natural resources. Guan et al. (2011) identified a decrease in farmland and forest area consequently; settlement area could be increased for the period 2015 to 2042 in the Saga area of Japan. Important studies on the Markov chain model to predict future LU/LC change are presented in Table 2.2.

Table 2.2 Land Use/Land Cover changes future prediction model in different parts of the world

Authors and year	Title and Study area	Methods	Major finding
Kamusoko et al. (2009)	Sustainability of rural area under tension in Zimbabwe- Simulation of LU/LC dynamics prediction of Bindura district	MC automata model	The MC automata model has employed to simulate future LU/LC dynamics to 2030. Prediction results revealed that woodland areas is continuously decreasing whereas, increasing trend of barren land was observed.
Memarian et al. (2012)	Validation of CA-MCM for Simulation of LU/LC dynamics in the Langat Basin of Malaysia	CA-MCM validation has done using validation metrics	CA-MCM has applied and due to uncertainties of the source data, showed poor performance was observed for LU/LC changes.
Mitsova et al. (2011)	A CA- model of LU/LC changes to integrate urban growth with open space conservation	CA-MCM	Using the model LU/LC changes was developed in the process of integration the preservation of environmentally most sensitive areas into projections of urban expansion both at the regional and national level. The scenarios of baseline data is a continuation of the present patterns.
Al-sharif and Pradhan (2014)	Monitoring and forecasting LU/LC an integrated MCM and CA in the GIS tool for the Tripoli Metropolitan City	Integrated Markov chain and cellular automata	CA-MCM has been used in the process of simulating and predicting the quantitative LU/LC changes. The results of the study obtained acceptable model performance and it signifies rapid urban sprawl consequently remarkable reduction of agricultural lands.

2.5 TREND CHANGE OF CLIMATIC VARIABLES

Long-term average increase and decrease in value of time series temperature and precipitation is the trend change, it is the ups and down oscillation in time series. The long-term series signify the observations, which measure the variation in the time of some aspect of different phenomenon (i.e. precipitation, flow, temperature and evapotranspiration). The long-term series analysis contains of the magnitude and intensity of the trend as well as its level of significance in statistical term.

Various researches, related to long-term trend detection of hydrological and climatic variables is determined by using parametric and non-parametric techniques (Parida, 1999). Parametric techniques are on the basis of hypothesis that the long-term time series data with normal distribution follow the error. It used to quantify the data variations. Therefore, relatively compared to non- parametric technique, parametric technique is more powerful to check the trend test but it needs data to be independent and normally distributed. When the long-term series data variables and the errors did not follow the normal distribution, re-sampling time series analysis used to test the level of significance at various significance levels.

Non-parametric techniques are usually employed to identify the monotonic trends in the long series of hydrological data, environmental data and climatic data. It does not quantify the size of the trend as well as the change. As compared to parametric techniques, the reason of applying the non- parametric statistical techniques is believed to be more appropriate for non-distributed available data which is commonly encountered in the hydro-meteorological long term series data and the test has less sensitive to unexpected disruptions due to not homogeneous long term time series (Tabari and Talaee, 2011).

Some of the parametric techniques are: (I) t-test (Longobardi and Villani, 2010), it used to assess and test the slope of linear regression coefficient is considerably differ from zero value. It indicates the presence of the trend of linearity. Therefore, the slope sign coefficient is showing either positive or negative time series trend. (II) Analysis of variance (Scheffe, 1959) and (III) linear regression. Some of the non-parametric techniques which is applied to test trends of long term series are: (I) Mann-Whitney test (II) Mann-Kendall test (MK test), (III) Wilcoxon Signed Rank test, (IV) Anderson-Darling test (Anderson and Darling, 1952), (V) Cohen’s Kappa (Smeeton, 1985), (VI) Kandall’s tau (Kendall, 1975) and (VII) Spearman’s rho (SR). However, MK test is popularly used in order to assess the trend of long-term time series climatic variables. It confirms either positive or negative trends at a given statistical significance level.

2.5.1 Rainfall

Rainfall is the most prominent component of hydrological component (cycle) therefore, it is crucial to know about its variability and intensity. The economy of Ethiopian largely rainfall dependent agriculture. Following erratic nature of rainfall therefore, agriculture in particular and overall economy of the country in general more sensitive in time and space (Seleshi and Zanke, 2004; Kiros et al., 2016). Information related to rainfall variability and intensity in time and space is necessary for better planning and development of appropriate policy and strategies for the country. In many part of the world various studies has been undertaken based on climatic variables trend change detection. These are summarized in Table 2.3.

Table 2.3 Observation of precipitation trend

Author's Name	Regions	Data used	Methods	Results obtained
Cheung et al. (2008)	Whole Ethiopia	42 years (1960 to 2002)	Regression and t-test statistics	During the month of June to Sep., precipitation has shown a declining trend for Southern Blue Nile, Omo-Ghibe Rift valley and Baro-Akobo. However, decreasing trend are not necessarily indicated at the regional level.
Kiros et al. (2016)	Geba River Basin, Northern Ethiopia.	43 years (1971 to 2013)	Mann-Kendal test and Sen's slope estimator	Though statistically insignificant both negative and positive trend of annual rainfall was observed. On seasonal basis, an upward trend of rainfall has shown during wet season.
Kidemu and Rao (2016)	Gamo Goffa, Ethiopia	28 years (1984 to 2012)	Coefficient of variation (CV), Precipitation concentration index (PCI), Standardized anomaly Index (SAI) and Mann-Kendal test (MK)	Moderate annual rainfall distribution has shown, whereas, seasonally low to moderate rainfall was recorded. Likewise, high rainfall variability was shown on the basis of seasonal and monthly rainfall but low variability during annual rainfall.
Ayalew et al. (2012)	Amhara region, Ethiopia	30 years (1978 to 2008)	Application of Coefficient of variation (CV), Standardized anomaly Index (SAI), least square regression, PCI, Spearman's rho test and Inverse Distance Weighting (IDW) technique	Rainfall variation was recorded in each month with spatial distribution ranging from 850 1485 mm/annum. During 1980s and 1990s, the annual rainfall revealed negative and positive anomalies respectively.
Seleshi and Zanke (2004)	Entire Ethiopia	37 yeas (1965 to 2002)	Mann- Kendal test	Central, northern and northwestern parts of Ethiopia no significant trend has shown for annual rainfall, seasonal or any other rainy days for the periods of 1965 to 2002. However, since about 1982 substantial rainfall amount has shown decline trend in the eastern part in annual and June Sept. (137 mm/decades),

				Southern part (119 mm/decades) and south western (257 mm/decades).
Lázaro et al. (2001)	Semi-arid area in south East Spain	31 years (1967 to 1997)	Sen's slope estimator, Thom test cumulative sums of deviations (CSD) and MT test	Annual as well as monthly rainfall have been lower than the average with 36% inter-annual variability and up to 20.7% inter annual variability respectively.
Boyles and Raman (2003)	North Carolina, USA	50 years (1949 to 1998)	Long-term linear time series slope	Precipitation during winter season shown increasing trend and shown decreasing trend during summer in the given time periods.
da Silva (2004)	North East Brazil	78 years (1913 to 1990)	MK test	Decreasing trend has shown in rainfall.
Longobardi and Villani (2010)	Campania region, Southern Italy	81 years (1918 to 1999)	MK test and Student's *t*-test	Annual and seasonal rainfall have shown a decreasing trend with the exception of summer season.
Garbrecht et al. (2004)	Grate plain of USA	71 years (1930 to 2001)	Moving average techniques	Positive slope (upward trend of precipitation has been indicated).
Modarres and da Silva (2007)	Arid and Semi-Arid region of Iran	40 years (1959 to 1999)	Mann Kendal trend test	High variability in precipitation, increasing and decreasing (up and down oscillation) trend has been observed.
Some'e et al. (2012)	28 stations	40 years (167 to 2006	Mann Kendal trend test	Downward trend (negative) of annual rainfall with magnitude and intensity ranged from 2.53 mm/annum to 3.43 mm/annum.
Mondal et al. (2015)	Orissa	40 years (1971 to 2010)	Mann Kendal trend test	An increasing trend of monthly rainfall has been shown during the month of Jan, May, Sept, Oct and Nov. whereas, a decreasing trend of monthly rainfall with parallel decrease of Sen's slope has shown during the month of Feb, Mar, Apr, Jul, Aug and Dec.
Pingale et al. (2014a)	Nira Catchment Maharashtra	109 years (1904 to 2012)	Mann-Kendal trend test	During the study periods up and down oscillation of mean and extreme event of rainfall was observed.
Garbrecht et al. (2004)	Grate pain of USA	1992 to 2001	Moving average method (11 years)	Insignificant or no changes were observed during summer season while during winter and spring months the annual rainfall has been increased.

On the basis of many studies undertaken in many parts of the world on rainfall trend at spatial as well as temporal scale and have shown high to low variability of rainfall (Ayalew et al., 2012; Cheung et al., 2008; Kidemu and Rao, 2016; Kiros et al., 2016). However, the magnitude and intensity of rainfall variability is variable in time and space across the world in general and Ethiopia in particular where rainfall variability has been considerably increased. Therefore, these types of study will help in order to design mitigation and adaptation options.

2.5.2 Temperature

In recent past experience and recently as well climate change is recognized as the global agenda tied with growth, food security, and poverty. Overall production, employment contribution and export earning is significantly dependant on agricultural sector, therefore, the country can be considered prone to climate change, events like recurrent drought, frequent flooding, and increasing temperature are commonly experienced.

Recently it is evident that the global temperature has shown an increasing trend, though the magnitude and intensity is variable in different regions and seasons. According to Solomon (2007), in an IPCC report since in the late 19^{th} century there has been a continuous rising in surface temperature by $0.6 \pm 0.2^{\circ}$C and increased by 0.2 to 0.3^{0}C in the last two and half decades and hence rainfall amount of the globe has declined. Different scholar's in their observation in many parts of the world confirmed that in the last 20^{th} century global climate has been changed. Nicholls and Collins (2006), reported the annual average maximum temperature rise at the rate of 0.6^{0}C for Australia. Likewise, annual minimum temperature increases by about 1.2^{0}C during the year of 1950 to 2004. Kruger and Shongwe (2004), observed the spatial and temporal trend of average temperature of Africa during the period of 1960 -2003. The trend of mean seasonal temperature has shown variable throughout the mentioned time periods with maximum and minimum mean temperature was recorded for autumn and spring respectively. Evans and McCabe (2010), observed using evaluation of regional climatic model using weather forecast model in order to simulate south-eastern part of Australia climatic condition during the periods of 1984 to 2010 and confirmed in the report average temperature of the area was continuously rising. Tabari and Talaee (2011), reported that during the periods of 1966 to 2005 there has been a rising trend of maximum and minimum temperature of Iran during summer season. Keller (2009), found in his study that the temperature of Ethiopia has increased by about 0.2^{0}C/decade. Fazzini et al. (2015), reported that during the year 1981 to 2010 the average temperature has increased by about 1.1^{0}C (which is 0.04^{0}C/year).

2.6 HYDROLOGICAL MODEL

2.6.1 Soil and Water Assessment Tool (SWAT Model)

According to Arnold et al. (1998), SWAT is a semi-distributed, physical algorithms developed in order to estimate runoff and sediment in daily and monthly time step at catchment level. The catchment of an area is divided into smaller watershed and sub-watershed level using HRUs based on different situations viz., soil type, slope classes and land use classes used to allow acceptable and high level of detail simulation. Different data like rainfall, topography, LU/LC map, soil texture and properties are some of the required data used to calculate sediment yield and runoff generation using curve number equation (Abbaspour et al., 2007). The necessity of SWAT has developed to assess sediment yield, runoff and management practices in the smaller and larger watershed and in the catchment (Arnold et al., 1998; Gassmann, 2006). Weather, land management, plant growth, water movement, hydrology, sediment movement and stream routing are some of the major components included in the SWAT model. The interface of SWAT is compatible with ArcGIS (ArcSWAT) which has been developed to use geodatabase approach. Various types of other techniques have been developed to support the implementation of SWAT model simulation. For instance the interactive SWAT software (i-SWAT), conservation reserve program decision support system (CRP-DSS) which was established by Kumar et al. (2006), and generic interface program (i-SWAT) (Abbaspour et al., 2007), that is important for choice of automates parameter and aggregation for continuous iteration of SWAT model calibration and simulation. Presently ArcSWAT 2012 is compatible with ArcGIS 10.2.2 interface.

2.6.2 Adaptation of SWAT model

Following SWAT model development, in order to obtain further improved and accurate prediction of specific process improved SWAT models have been adjusted. SWAT-G (river basin scale model developed for functioning in a daily basis), Extended SWAT (ESWAT), soil and integrated model (SWIM) are some examples of the model (Lenhart et al., 2002; Arnold et al., 1998). A physical based model, which has established to forecast accurately the influence of management practices in the small (meso) to large (macroscale) basins scale level. According to Lenhart et al. (2002), SWAT 99.2 was modified percolation, interflow and hydraulic conductivity to predict flow and further was SWAT-G developed in order to estimate sediment loss.

2.6.3 Application of SWAT model

SWAT model simulate watershed system on the basis of how fit watershed processes are presented in model as well as how well the watershed to be defined by input parameters in the model. Many of the erosion, runoff, sediment and flow models needs the watershed is subdivided into sub-watershed scale or meso (smaller). Even though the size of watershed implication on the homogeneity, the assumption of each of watershed is homogeneous and the entire meso and sub watershed is represented by parameters. According to Singh et al. (2005) and Tripathi et al. (2006), size reduction with increasing number of sub watershed, affect model simulation results on runoff process and sediment yield reduction of the whole watershed.

Several studies have been undertaken using SWAT model by various researchers in different ways for different purposes. Tripathi et al. (2004), used SWAT to simulate runoff process as well as sediment yield generation for smaller Nagwan watershed in the eastern part of India using generated rainfall data. It confirmed that the ability of SWAT model to simulate and evaluated satisfactorily for generated rainfall during the periods of 18 years. Study by Van Liew et al. (2007), in the USDA ARS on experimental watersheds applied SWAT in the process of simulating the influence of sub division of watershed on simulated water balance component (surface runoff process, sediment yield, and evapotranspiration, and percolation loss). Results of the study confirmed perfect water balance for the experimental watershed.

Rosenthal et al. (1995), in their study found that the various properties of watershed related to runoff process and sediment yield generation affected by size of watershed. In order to relate the channel hydraulic properties to the size of the watersheds therefore the authors derived different parameters. On the contrary, Kuhnle et al. (1996), used SWAT to simulate runoff generation and sediment yield generation from Goodwin creek watershed. Results confirmed that number including watershed and sub-watershed size do not have any implication on runoff volume. However, the response of annual sediment yield for watershed subdivision was sensitive.

Easton et al. (2010), in order to forecast runoff generation as well as sediment loss in Ethiopia, Blue Nile Basin of Ethiopia, modified SWAT model has developed. Using daily water balance, the model used to simulates excessive runoff process from the landscape. The spatial and temporal distribution erosion from the landscape is therefore, simulated successfully. As can be seen in Table 2.4, SWAT has been used for different application in different parts of the globe.

Table 2.4 Application SWAT model in different categories

Researcher/s (year)	Broad application category	Study area	Major findings/ remarks
Setegn (2010)	Surface runoff	In the Tana Lake Basin of Ethiopia	The effect of soil, climatic condition, land use system and topography on hydrology of Tana Lake Basin have been analysed using SWAT model and good result was obtained. The simulated results confirmed that base flow is a significant component of discharge of Tana Lake basin therefore, contributes more than surface runoff.
Gebremicael et al. (2013)	Runoff process and sediment yield fluxes	In the Blue Nile Basin, Ethiopia	SWAT has been applied to analyse the influences of land use dynamics on sediment yield and runoff. Calibrated and validated results indicated that SWAT and LU/LC dynamics detection are reliable with the assumption therefore; LU/LC dynamics has been the major cause for runoff process and sediment yield generation in the Blue Nile basin. This finding has substantial contribution for water resources management.
Rosenthal et al. (1995)	GIS linkage with SWAT	Lower Colorado River Basin	Urbanization significantly affect the downstream flow therefore; SWAT model underestimate the extreme events.
Kuhnle et al. (1996)	Surface runoff process and sediment yield generation	Northern Mississippi (Goodwin Creek Research Watershed)	For daily and annual runoff and sediment yield, reliable result was obtained for multiple sub watershed and sub basin.
Chu and Shirmohammadi (2004)	surface and sub-surface runoff and sediment yield	Maryland (Warner Creek watershed)	SWAT model result on monthly basis for sediment yield and flow was poorly simulate.
Alibuyog et al. (2009)	Runoff process and sediment	Manupali River sub	SWAT has applied in the process of modelling the outcome of land use

	yield generation	watershed and test watersheds, Philippines	dynamics in the Philippine watersheds. Results from simulation indicated that LU/LC change significantly affect runoff and sediment yield (conversion of pasture, forest and grassland to agricultural land resulted for increased in runoff generation, increased sediment yield and in reverse decreased in base flow).
Santhi et al. (2008)	Surface runoff variation	Ohio and Arkansas White River Basin, U.S.	Spatially and temporally distributed calibration and validation at sub watershed and stream gages level respectively reasonably good for spatiotemporal hydrological pattern for larger river basin scale.
Pisinaras et al. (2010)	Management scenario	Kosynthos River Watershed, N-E Greece	The validated and calibrated results were used to test the implication of various LU/LC changes on runoff process and sediment yield generation. It is a very flexible and reliable technique for water and related decision-making. Therefore, if SWAT model is properly calibrated and validated used for successful testing of various management scenarios.
Bharati and Jayakody (2011)	Water balance	Gorai River catchment, Bagladesh	They concluded that the major change in the LU/LC classes significantly affect runoff and sediment yield
Khoi and Suetsugi (2014)	Climatic data effects	Dak Bla River central Vietnam	Land use/cover dynamics as well as changes of climate on surface runoff process, sediment yield and water balance component are affect each other. Nevertheless, the components of subsurface flow are more response to LU/LC change than climate changes. Important results to plan rainfall-runoff and sediment management for data scarce regions/ areas.

2.7 LAND USE/LAND COVER CHANGE DYNAMICS IMPLICATION ON SURFACE RUNOFF PROCESS AND SEDIMENT YIELD GENERATION

Expansion of agricultural as well as settlement usually intensify soil erosion, runoff process, and hence the volume of sediment yield from catchment (Ghani et al., 2008; Azamathulla et al., 2013). Population growth rate and the demand for land is interdependent both in negative and positive aspects. Fast increase of population, consequently the demand for land, settlement trend and agriculture are increased (Mkaya, 2013). Consequently, forest, bushes and trees have been removed and cleared (Seguis et al., 2004). Expansion of agriculture and settlement at the expense of other LU/LC classes resulted for subdivision of land cover hence further changes in land use systems. The dynamics of land use pattern resulted for erosion and degradation, resulted for harmfully changed hydrological conditions of catchments in Ethiopia.

According to Woldesenbet et al. (2017), following expansion in farmland, rate of infiltration/base flow has decreased and consequently increased the surface runoff process; in addition to that forest, grass and bush land can also alter the water balance of the Tana sub-basin. Mkaya (2013), in his study found that forest cover was reduced by 57% in reverse 10% in agricultural land and 156% in settlement areas have expanded. Study evaluated implication of LU/LC dynamics confirmed that sediment yield generation increased from 0.43 to 20.10 t/ha as well as surface runoff increased from 4.12 to 110.96 mm within the whole wundanyi river catchment.

Hua et al. (2012), evaluated surface runoff process and sediment yield generation from three-gorge watershed in China using three land use scenarios. The result confirmed that forestland, shrub land and highly covered grass land had less volume of erosion whereas, high sloping (22%) and less grass coverage erosion amount holds 56% ($363.328*10^4$t/yr) and 11% ($71.368*10^4$t/yr) of the total catchment respectively.

The study by Ngo et al. (2015), in the Hoa Binh province of Da River Basin of, Northwest Vietnam reported, due to the change of LU/LC type from forest into agricultural land and urban settlement significantly contributed for the increase of annual average runoff process from 182.5 mm to 342.7 mm while sediment yield increased from 101.3 to 148.1 t/yr/ha. However, due to intensive development of forest coverage as well as adoption in conservation practices both surface runoff process (from 342.7 mm to 167.6 mm) whereas sediment yield generation (from 148.1 to 74 t/yr/ha) was decreased. This study concluded that runoff and sediment yield are influenced by LU/LC changes.

A simulation study of land use scenarios by Alibuyog et al. (2009), when 50% of pastureland and grassland has converted into agricultural land, the volume of runoff and sediment yield has increased by about 3 to 14% and 200 to 273%, respectively. Further, the study confirmed that following alteration of LU/LC classes into farmland, runoff from the catchment increased by 15 to 32%.

A report by Ayana et al. (2014) found that due to conversion of 20% each of forest, grazing and shrubs land into agricultural land in the Fincha watershed of Ethiopia the average monthly surface runoff volume of the catchment increased by about 12.8%, 2.24%, and 4.74%, respectively. Likewise, monthly average sediment yield of the catchment was increased by about 16.20%, 2.07% and 3.80% respectively. The study concluded that LU/LC dynamics in the highlands of Ethiopia have significantly increased in surface runoff process and sediment yield generation from catchment.

Gebremicael et al. (2013) conducted study in the Blue Nile basin, North- Western Ethiopia 1973 and 2000 LU/LC maps, and the catchment has compared and verified that forestland, woodland and grassland have been converted into farmland and barren lands. Consequently, the change of LU/LC classes has modified the runoff process as well as sediment yield generation, resulted in increasing the trend in the catchment. Generally, SWAT is applicable for watershed management in many parts of the world; few important results have discussed using Table 2.5.

Table 2.5 Application of SWAT model for watershed management

Author/s (year)	Broad application/ category	Study area	Major findings
Betrie et al. (2011)	Watershed management	In Ethiopia in the Blue Nile Basin	The model has been run to simulate sediment in Ethiopia of upper Blue Nile to identify soil erosion susceptible parts and used to evaluate implication of best watershed conservation practices scenarios on sediment reduction. The management scenarios were applied maintaining existing conditions, applied stone bunds along terraces. The result of SWAT model confirmed that there has been successful agreement between observed and simulated sediment concentrations on the daily basis.

Ayana et al. (2012)	Water resource planning and management	Fincha watershed, Ethiopia	Validation and calibration results of SWAT model were successfully estimated for sediment yield on the monthly basis. Therefore, it is important tool for waters resource planning and management.
Tesfahunegn et al. (2012)	Reducing soil degradation and linking with GIS	Northern Ethiopia in Mai-Negus catchment	Even though further research is needed with respect to benefit of management approaches, the study concluded that SWAT is the most efficient tool to evaluate watershed management techniques in reducing sediment loss and soil degradation in the catchment.
Pandey et al. (2009)	Watershed management	Banikdih watershed of west Bengal, eastern India	The study concluded that the validation and calibration result of SWAT model was acceptably predicted for daily, monthly as well as seasonal surface runoff process and generation sediment yield.
Behera and Panda (2006)	Watershed management	Kapgari watershed west Bengal, eastern India	The study summarised SWAT model simulate and calibrate daily runoff and sediment yield successfully. Therefore, it used to differentiate the most critical sub watershed hence essential in the development of site-specific watershed management practices.

2.8 CONCLUDING REMARKS

Ethiopia is vast country with various climatic and topographic features. However, factors viz. soil erosion, land degradation, rainfall variability, land cover change dynamics and alarming rate increase in temperature affect the availability of food security. In order to explore and understand such influences or effects on the environment, accessibility of various data are needed. However, assessing the changing nature of the watershed environment along with rainfall variability, increasing temperature, resources degradation and dynamic nature of land use classes and understanding how the influence of such event to the environment have significant role for sustainability and food security. Participatory watershed management and integrated water resources management for better production may also be done based on such factors. Many studies across the globe have been discussed in the previous sections related to watershed management practices success stories and weakness as well, climatic variability and trend, land use change dynamics, resources degradation and its effects on human being and to the environment. Assessment of the collective effect and consequence can provide basic information about the environment.

The present study is based on watershed and integrated water management from other and Ethiopian perspective, climatic variability from historical point of view, with trend analysis and Precipitation Concentration Index, spatiotemporal rainfall and temperature distribution, historical LU/LC change dynamics and future prediction. Soil erosion and land degradation, LU/LC change and its implication on surface runoff and sediment yield generation has been assessed. The results obtained from this study may beneficial in order to design appropriate policy planning options in the future for sustainable resources management leading to food security.

CHAPTER 3
STUDY AREA

3.1 GENERAL

The detail descriptions of the study area are presented in this chapter. The general physiographic characteristics of the study area are explained. Information related to topography, soil types and LU/LC types of the Beressa watershed are also discussed in the following subsections.

3.2 STUDY AREA DESCRIPTION

The area, Beressa watershed, is located in the central highlands of Ethiopia. The watershed is drained by the headwaters of the Beressa River and it is one of the tributaries that forms part of upper Blue Nile basin. Situated between 9^0 34’ & 9^0 42’ north latitude and 39^0 30’ & 39^0 45’ eastern longitude (Figure 3.1).

For this research, Beressa watershed has been selected as case study because it represents the catchments where there is high competition over resources use. Additionally, the watershed can be considered as representative of the catchment of high landscape and various climatic zone varied within short distances. High population growth with constraints natural resources use coupled with significant human interventions in many parts of the watershed makes it reasonable for LU/LC, climatic variability and natural resources management effect analysis on the hydrological regime of the catchment.

3.2.1 Topography

The topography of the study area lies at relatively high altitude ranges from 2747 to 3674 m above sea level, in a zone, which is a part of central plateau of the country. The physiographic characteristics of the area is mixed with steep-sided gullies, plateaus, hills and river gorges. The geological formation of the area is used to define the watershed characteristic. The geology of the country generally encompasses a mixture of the ancient crystalline basement rocks and volcanic rocks.

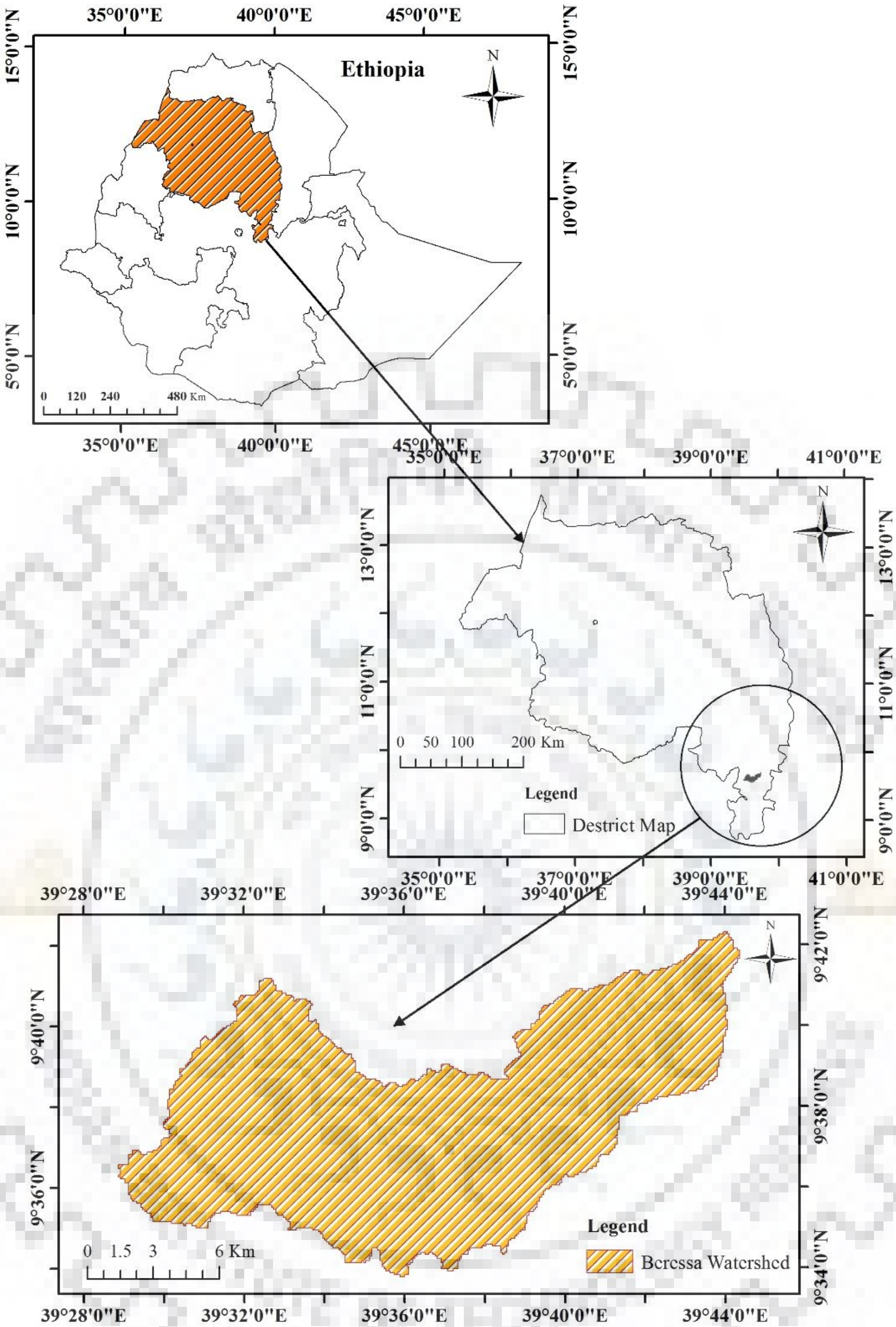


Figure 3.1 Location of the study area

The digital elevation model (DEM) of the Beressa watershed is given in Figure 3.2, which shows highest elevations in the eastern margin and from central and western part shows lowest elevation. The highest elevation is about 3674 m, whereas 2747 m is the lowest elevation in the central and western parts. Figure 3.3 shows the slope distribution of Beressa watershed.

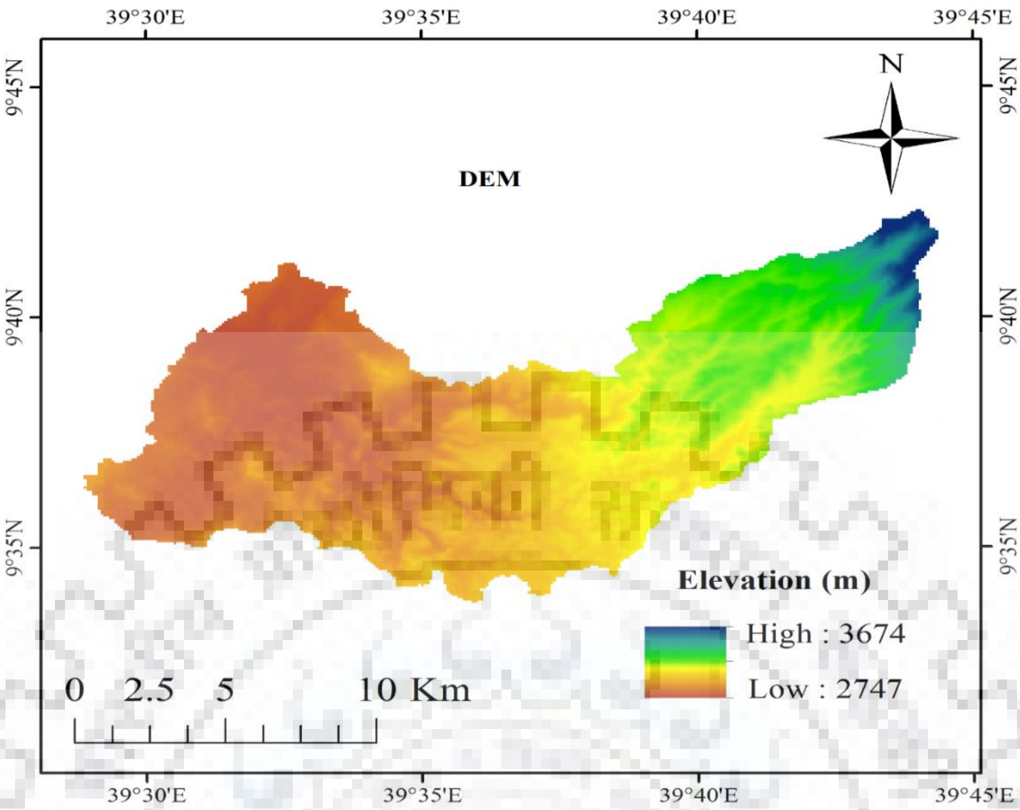


Figure 3.2 Digital Elevation Model (DEM)

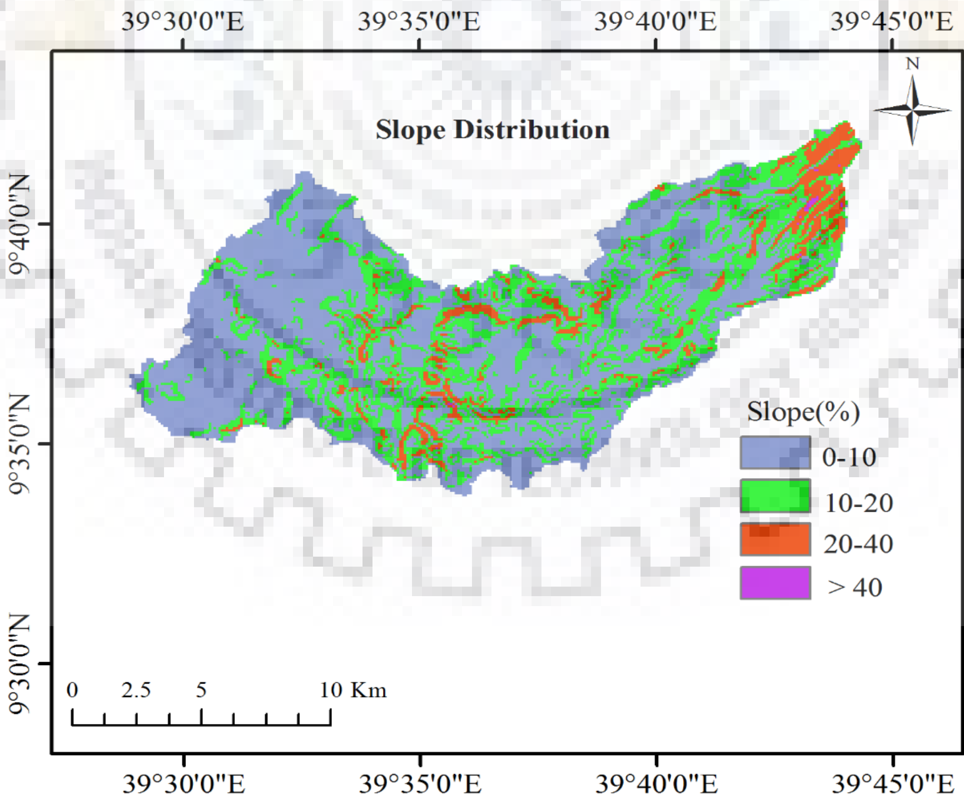


Figure 3.3 Slope Distribution of the Beressa Watershed

3.2.2 Climate

The climatic condition of Ethiopia is largely influenced by changes of Inter Tropical Convergence Zone (ITCZ), sub-tropical pressure cells and the governance of Indian monsoon throughout the year. The two main air streams reason for dry and rainy seasons: in the late June to early September, in which Inter Tropical Convergence Zone is northernmost, hence the equator prevail air stream direction is southeast in southern parts of Ethiopia and south west in the central to the northern Ethiopia. These moist and warm winds result in high evaporation and water vapour saturation of the air mass for both above Atlantic and Indian Ocean respectively. In most parts of the country, the annual rainfall follows a bimodal distribution and the annual pattern of the country is normally distinguished as main rain season (*Kiremit* season) covers June to September; *Bega* season known by dry condition covers October to February; and *Belg* season manifested by small rain (March to May).

Since ancient times based on elevation, Ethiopians have divided their climate into five different zones. Each zone has its own rainfall pattern as well as farming system. Generally, the highland zone encompassing *Dega* and *Wiena Dega* zones, in which crop production is commonly prominent, whereas semi-arid as well as arid lowland zone commonly known as *Kolla* and *Bereha* mostly known by livestock in agro-pastoral and pastoral production systems. The overall agro-climatic zones of Ethiopia is presented in Table 3.1.

Table 3.1 Agro-ecological zone Patterns of Ethiopia

Characteristics	Agro-ecological Zone				
	Bereha (hyper-arid)	*Kolla* (Semi-arid)	*Weyna Dega* (Sub-humid)	*Dega* (Humid)	*Wurch* (Alpine)
Altitude	<800	800-1500	1500-2300	2300-3000	>3000
Temperature (^{0}C)	>20	18-20	16-18	13-16	<13
Rainfall (mm)	<200	200-800	800-1200	1200-2200	>2200
Major crops	Sorghum, maize	Sorghum, maize, *Teff*	*Teff*, maize, wheat, Barely	Barely, wheat, Bean, chick/Peas	Barely, Bean, Lentil, wheat, chick/peas

The climate of Beressa watershed is alpine and temperate. The average annual temperature is 19.7^{0}C and the annual mean maximum and minimum rainfall amount is accounted for1083 mm and 699 mm respectively. Bimodal rainfall distribution is the manifestation of the area, with the main and long rains extended from June to September locally known as *Kiremit* season and small rains occurs during February to May locally called *Belg*. For the area, these two rainy seasons allow to grow per season. The main rainy season holds for more than 80% of the total annual rainfall of area therefore it is more dependable for agricultural crop production than small rainy season.

3.2.3 Land use and farming systems

Knowing the farming system of the area has been considered as the basis for deciding research and various development strategies and priorities, therefore the technologies are designed and development are well planned that will be appropriate to the concerned communities needs and the dynamics circumstances. Land use system of the area will be discussed in detail in chapter 5. Mixed crop-livestock is the common farming system of Beressa watershed possibly the only foundation for the livelihoods majority of the population. Bean, wheat, peas, lentil garlic and chickpea are the major growing crops. Farming system is characterized by rainfed traditional as well as subsistence oriented. Commonly cattle as well as sheep are major types of livestock; however, equines, chickens and goats are also practicing in most of the community. As of the farming system is relied on rainfall, farmers are easily worried and influenced by duration as well as rainfall intensity.

3.2.4 Soil types

The physical properties of soil significantly influence its use and hydrology of the catchment. Its physical properties are influenced by various factors that change the depth (vertically), laterally across the basin in a catchment and temporally in response to manmade and natural activity. Its physical properties is depend on the size, arrangement, amount, and mineral composition of its particles and it may vary significantly under diverse crop types, fertilizer types and rate of application and tillage type including its intensity. Generally, soils of the study area is volcanic in origin and the spatial distribution of soil types are given in the Figure 3.4. Calcaric F soil occupies the largest share throughout the region, which is followed by dystric N and vertic Ca soils, observed in the central part. Eutric C and Eutric Re covers very few areas in the north-eastern parts.

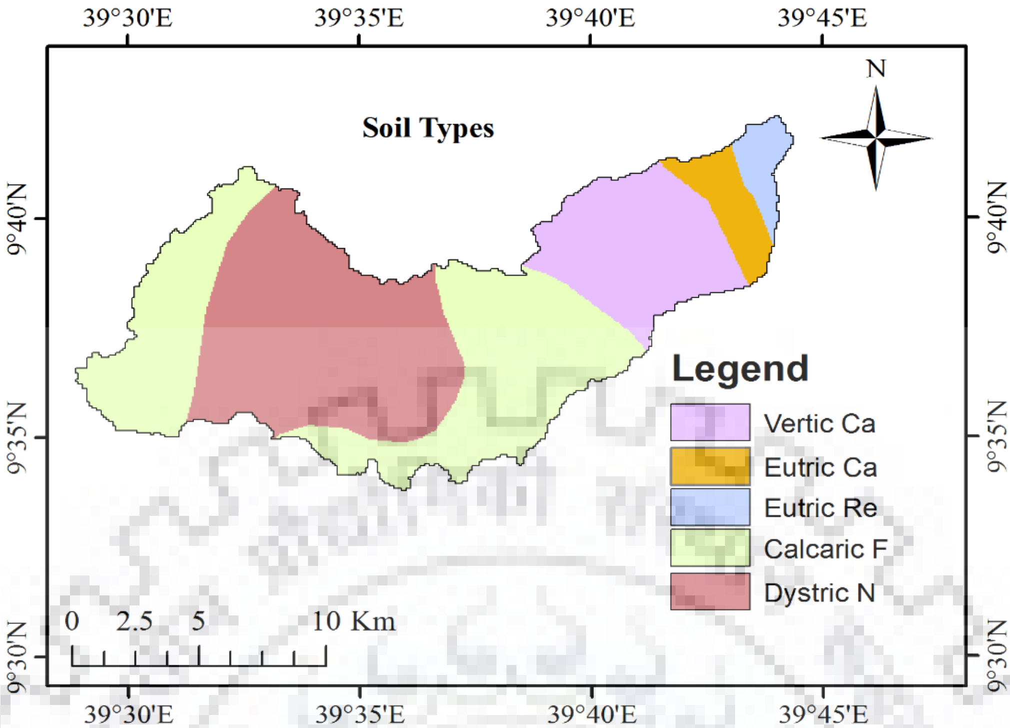


Figure 3.4 Soil types of the study area

Water moves through the soil by numerous different pathways. The water that enters in the soil can be reduced by evaporation, transpiration in the form of uptaking by plants, percolation along soil profiles then aquifer recharge and possibility of contributing stream flows in the form of lateral flow in the soil profile. Therefore, distribution and spatial variability of soil properties are significant in order to predict the ecosystem processes in respect of anthropogenic and natural factors. Generally, the soil properties determine water movement in the soil vertically as well as laterally in the soil profile (Table 3.2).

Table 3.2 The types of soil and its physical properties

SNo.	Name of soil	Hydraulic conductivity (mm/hr)	Soil textural compositions (%)			Bulk density (g/cc)	AWC (cm/cm)	Area of watershed (%)
			Clay	Silt	Sand			
1	Vertic Ca.	6	55	30	15	0.11	1.47	20
2	Eutric Ca.	18	22	44	34	0.18	1.44	15
3	Eutric Re.	110	47	45	8	0.1	1.51	11
4	Calcaric F.	15	40	40	20	0.15	1.43	29
5	Dystric N	2	38	32	30	0.12	1.39	25

CHAPTER 4
HOUSEHOLD LEVEL TREE PLANTING AND ITS IMPLICATION FOR ENVIRONMENTAL CONSERVATION

4.1 GENERAL

Deforestation for human use is one of the most serious challenges of the planet, consequently increase in climate variability and environmental degradation (Dinor et al., 2007). Rural dwellers depending on subsistence agriculture are highly susceptible to natural resources degradation and climate change (Slingo et al., 2005; Meijer et al., 2015). In developing countries, forest resources and various biodiversity are declining. To a large extent, this has resulted from increasing human population, as intensive agriculture pressure increases on natural resources (Ndayambaje et al., 2012; Meijer et al., 2015). Between 2000 and 2005 in the developing countries, especially in Africa more than 4 Mha of natural forest was lost annually (Ndayambaje et al., 2012). Forest degradation in turn resulted for scarcity of fuelwood and other considerable antagonistic consequences, such as watershed functions deterioration, carbon dioxide release into the environment and intensive soil erosion (Jain and Singh, 1999; Heltberg et al., 2000; Pandey, 2002).

According to United Nations Economic Commission for Africa (Bewket, 2005; Hailu et al., 2010), economic growth, self-sufficiency and alleviating poverty is limited in developing countries especially in sub-Saharan Africa due to insufficient provision of energy services. A majority of the population depends on firewood and livestock dung as a source of energy, and thus accelerating the problems of environment and land resources degradation. Fuelwood collected from forest is a common phenomenon and important sources of domestic energy in rural area of the globe. More than half of the world’s population cook with traditional biofuel sources, which provides around 35% of domestic energy supplies in the developing countries (Heltberg et al., 2000). As per assessment made by Pandey (2002), assessment in most rural parts of India the dominant sources of household domestic energy is remained on fuelwood, crop residue and dung cake. However, the share of consumption varies considerably, and largely depends upon the availability, the cost in terms of required time for collection.

Like other developing countries, in both urban and rural parts of Ethiopia, traditional biofuel is a source of energy (Miller, 1986; Bewket, 2005; Berta and Zerga, 2015). For instance, in urban areas the largest share of domestic energy originated from fuelwood (55.4%), the remaining 44.6% of energy is covered from charcoal, cattle dung, and agricultural crop residue, which comprises 9.3%, 8.4%, and 6.8% respectively. The share of modern sources of household energy consumption includes 15.35% of kerosene, 0.28% of diesel and 4.75% electricity, which account 20.38% of the total domestic energy consumption. On the other hand, in rural area where majority of the population live, more than 99% of domestic energy sources is dependent on traditional biofuel. Fuelwood holds more than 81.9% followed by cattle dung and agricultural residue (9.25% and 8.31% respectively) charcoal holds 0.4% (Bewket, 2005). Like agricultural land expansion, the growing demand for fuelwood is a serious cause for high rate of deforestation in Ethiopia. Increase in the traditional fuelwood consumption coupled with insufficient utilization of available resources have led to more pressure on natural resources (Arrow et al., 2004; Godfray et al., 2010; Lin et al., 2011; Mislimshoeva et al., 2014). The share of natural forest coverage in Ethiopia has been decreasing at an alarming rate, from 40% of land area around 50 Mha just before the turn of the last century to 3.6% by the early 1980s (Cheng et al., 1998). The clearance of resources was continuous, and by the early 1990s, much of the cover was destroyed and only 2.3 Mha of land forest cover remained (Bewket, 2005). According to Wood (1990), the rate of reforestation was only 13,000 ha/year; on the contrary, the rate of deforestation was 88,000 ha/year. Similarly, one report indicated that the rate of deforestation was 150,000 to 200,000 ha/year. Davidson (1988) predicted that if deforestation is continuing at the rate of 100,000 ha/year, all the highland parts of Ethiopia would be cleared by the year 2020.

Rapid loss of forestland has raised the concern of local, national, and international communities. Many local communities now work harder to collect firewood and construction materials. In some villages, women spend 6 hrs, walking 10 km each way to collect wood (Cheng et al., 1998) and Heltberg et al. (2000), reported that for collection of fuelwood from forest in India during winter season women make 1 to 8 journeys per a week, which headed-loaded back to their house and it took from 1.5 to 6 hrs. In general, each household especially in rural part of the country in which domestic energy is relied on traditional fuel sources spend over the year range between 34 to 504 hrs averagely 190 hrs. It is obviously a result of deforestation and de-vegetation. Fuelwood shortage has serious consequences as households are forced to replace wood by agricultural crop residue and livestock dung instead of using it to increase soil fertility, which can significantly increase agricultural crop production.

According to Heltberg et al. (2000), in many parts of Asia and Africa, animal dung is used for household energy consumption. However, dung is used as source of manure, and using it for fuel can have significant negative effect on soil fertility. More than 97% of overall food for population of the world originated from natural resources. However, land degradation and soil erosion are striking problems at the global level (Munro et al., 2008; Mekuria et al., 2009). In 1980s, 1 to 1.5 million tons of agricultural crop was lost/year due to use of livestock dung and agricultural crop residue as fuel source instead of using it for soil fertility improvement. Similarly, (Araya and Edwards, 2006) estimated that 600,000 tons of agricultural crop production has been lost/year. In appropriate natural resource use practices, and incompatibility of policies based on local context have been pressing causes of resources degradation (Munro et al., 2008; Mekuria et al., 2009). Serious land degradation has resulted in a reduction of crop productivity, leading to demand for additional food aid (Newcombe, 1987; Mekonnen and Köhlin, 2009).

Due to increase in population, there has been more demand for domestic energy and hence increased in de-vegetation and depletion of fertile soil. Taking this catastrophe into consideration development of energy supply for both rural and urban area should give priority. Even though different literatures have identified a high rate of deforestation in the country (Davidson, 1988; Aklog, 1990), only limited studies have explored the impact of household level tree planting on soil properties, rural household fuel production and consumption (Mekonnen, 1997), energy, growth and environmental interactions (Hailu et al., 2010). A few studies have explored household level tree planting and its impact on environmental conservation. Therefore, the main objectives this section:

i. To assess awareness level on degradation devil and conservation practices

ii. To assess household domestic biofuel consumption

iii. To investigate household and community level tree plantation and its implication on environmental conservation.

4.2 MATERIALS AND METHODS

4.2.1 Study area

The detail of the study area description have been discussed in chapter 3.

4.2.2 Data used and Methodology

The data for this study obtained from structured household survey conducted from May to August 2015. The procedure is as follows, 92 household samples were selected using random sampling techniques while different soil and water conservation work was undertaking. Initially structured questionnaire was prepared and pre-tested for quantitative information. The interview was done by personal interaction with the watershed member's homestead and during watershed management practice. Additional information was obtained through focused group discussion, key informant interview, field observation and informal discussion. The most important and dominant sources of biofuel in the study area is fuelwood and cattle dung. Therefore, in the survey questions included about farmer's awareness of erosion problems, conservation techniques, quantity of biofuel used, source of biofuel, level of tree planting, distance traveled to collect biofuel, and farmer's responses on shortage of biofuel. It is difficult to ask the weight of fuelwood and dung consumed, therefore, during interviews it was asked to mention the number of bundles of wood and basket of dung consumed per week. The size of bundles of wood varies depending upon the person carrying it and the size of basket of dung varies depending upon the size and patterns of stacking the dung cakes. The researchers tried to determine the mean weight of dry wood and cattle dung. According to Bewket (2003a) and as per present study, the average weight of a bundle of wood and a basket of dry dung was 12.5 kg and 6 kg respectively. The survey also included socio-economic data about household size, size of land holding, income from crop production, off-farm income, cattle ownership, sale of wood and trees. After having all the pertinent information, the following methods have been used in the SPSS software version 23.

Chi-Square test: Initially, obtain the expected value of two nominal variables. The expected value of the two nominal variables are obtained as follows:

$$E_{i,j} = \frac{\sum_{k=1}^{c} O_{i,j} \sum_{k=1}^{r} O_{k,j}}{N} \tag{4.1}$$

Where,

$E_{i,j}$ is expected value

$\sum_{k=1}^{c} O_{i,j}$ is the sum of the i^{th} column

$\sum_{k=1}^{r} O_{k,j}$ is the sum of the k^{th} column

N is the number of observation

After having the expected value chi-square can be obtained by the following equation:

$$x^2 = \sum_{i=1}^{r} \sum_{j=1}^{c} \frac{(O_{i,j} - E_{i,k})}{E_{i,j}} \tag{4.2}$$

χ^2 is the Chi-Square test value

$O_{i,j}$ is the Observed value of two nominal variables

$E_{i,j}$ is the Expected value of two nominal variables

Pearson correlation matrix and Least Significance Difference (LSD) test has been used.

Econometric Model: In addition, econometric model (Probit model) has applied in this study to identify household's decision to plant trees, number of trees planted, and biofuel consumption. In the model, household who do not have access to plant trees has considered. The use of probit model is useful to distinguish the determinant of household level decision to plant trees, number of tree planted and domestic energy consumption in their home. The model described in the following ways:

$$y_i^* = x_i'\beta + \varepsilon_i, \sim NID(0,1) \quad (4.3)$$

Where,

y_i^* is unobserved and is referred to as a latent variable

Therefore, the individual i chooses to participate in planting trees at the household and community level when the variation of planting and not plant tree surpasses a certain threshold, null in this case, thus, $y_i= 1$, if and only if $y_i^*> 0$; and $y_i=0$, if $y_i^* \leq 0$. Therefore, the latent variables are depends on the value of x:

$$\Pr\left(y_i = \frac{1}{x_i} \right) = \Pr(y_i^* > 0) = \Pr(u_i \geq x_i'\beta) = 1 - F(-x_i'\beta) = Fx_i'\beta) \quad (4.4)$$

Where,

F($x_i'\beta$*)* is a cumulative distribution function, which is associated with the expected distribution of error term.

According to Wooldridge (2010), the estimate of parameters β are typically originated using maximum likelihood. However, the degree of β value is not particularly meaningful except in the special case. So, both in the continuous as well as discrete explanatory variables, it is significant to know how to interpret the value of β. When the value of β is estimated, the effect of marginal change in the *i*th variables in X, Xj, is described in the form of:

$$\frac{\partial \Pr(Y_i = 1)}{\partial X_{ij}} = f^{/}(X_i^{/}\beta)\beta_j \quad (4.5)$$

The value of marginal effects therefore, depend on the value of Xi. Hence, the mean value of Xi in the observed sample are used to obtain the value of *f* (βX_i). Finally, the effect of X_j

variables on the willingness of the community and household planting trees at the household and community level specified by the magnitude and signs of the marginal effects.

4.3 RESULTS AND DISCUSSION

4.3.1 Awareness on erosion and degradation problems

Household involved in the interview and focused group discussions revealed the acknowledgement of the prevalence of soil erosion and degradation, which considerably contribute to the poor health of farmland hence agricultural productivity. When asked to mention which types of erosion was observed, most of the respondents indicated visible erosion features viz., rill erosion, gullies erosion and mass movement. The chi-square(x^2) test signifies insignificant difference between literacy level and awareness regarding prevalence of erosion and degradation problem (x^2=0.14, *p*=0.98). However, there is statistical significance between age of household and perception on the problem (x^2=19.96, *P*=0.091). As member from the household replied for the interview, the prominent cause for the prevalence of the problems is improper soil and water conservation practices, traditional farming practices, free grazing, over cultivation including population pressure, topography and land fragmentation have been repeatedly mentioned, as a cause for accelerated erosion and degradation. In line with results the present study, Teshome (2014), reported deforestation, unsustainable farming practices, and alarming rate of population growth put a great pressure on natural resources. For instance for over 100 years period from 1950 to 2050 the number of peoples living per km^2 of arable land is expected to increase. If the growth rate continues for the coming 2050, per km^2 of arable land 270 farm households will enforced to live, which is very high compared to 35 in 1950.

4.3.2 Perception of conservation work

Regarding the perception of conservation works, majority (75%) of the respondents recognized that erosion and degradation problems could be controlled by soil and water conservation practices. Thus, it can be concluded that communities are well aware of the evils of soil erosion and land degradation. Hence, farmer's lack of interest in participating soil and water conservation practices cannot be enlighten by a lack of awareness about the severity of the problems. The chi-square test analysis revealed that no significant relationship between literacy rate and willingness to participate in the conservation practices on the one hand (x^2=2.28, *P*=0.51) and age of the farmers as well as willingness to participate in conservation work has significant relationship (x^2=31.66, *P*=0.38) on the other, which makes difference in the awareness level. On the one hand, farmers possessing own farmland likely to adopt and continue to implement conservation activity, whereas short-term tenants do not willing to adopt and participate on conservation activities as they are not likely to obtain immediate return (Kerr and Sanghi, 1992). However, the chi-square test shows that statistical significance does not exist between participation on the conservation activities and absolute private property of land ownership (x^2= 0.07, p=0.78).

4.3.3 Soil and water conservation technologies

In the Beressa watershed, soil and water conservation technologies under implementation were mainly physical and mechanical measures comprising of check dam, terracing, tree planting, counter plugging, soil and stone bund, agro-forestry programs, water way, gully plug, area closure, cut and carry, multipurpose tree plantation and percolation pit. Majority of the surveyed farmers depicted their adoption and participation in the construction of various conservation structures undertaken were against their will. The previous sections revealed that the main reasons for this were not awareness problems about the evils of erosion and degradation problems but this section confirms that the problems were associated with the technology, which is not compatible with local situations. Other reasons that farmer repeatedly mentioned was some of the technology under implementation were a cause for existence of rodent (viz., stone bund). Farmers were using bunds for multiple objectives one of them conservation of soil, for instance farmers using for demarcating their farm plot against the encroachment of the neighbours. This discrepancy in objectives caused difference in soil and water conservation technologies. Indigenous technologies follow boundary based, in contrast the recommended technologies follow contour based. In this regard understanding indigenous soil and water conservation practices and the logic behind them, and critically identify different conditions under which farmers invest in conservation and the constraints inhibiting such conservation technology (Kerr and Sanghi, 1992). Farmer's complaints were rational; it has been observed that construction of percolation pit in their plots of land did not consider the real situations and their active participation. Development agents were simply followed the guideline ordered from the district. However, they did not consider the parcel and fragmented land, the slope angle, amount and intensity of rainfall in the area.

4.3.4 Biofuel consumption

4.3.4.1 Fuelwood consumption

Like elsewhere in rural parts of Ethiopia, in the study area fuelwood is the main sources of energy. The entire household fuelwood consumption was ranged from 304 kg/year to 4258 kg/year. The majority of household biofuel consumption comprised of 1825 kg/year and 2433 kg/year respectively (Tabel 4.1). The average household fuelwood consumption was 2280 kg/year. The total fuelwood consumption was 172,868 kg/year, which is equivalent to ~172.868 tonnes/year and mean quantities of 1902.95 kg/year. In line with this study, as reported by Guta (2012), the total annual fuelwood and animal dung consumption as elsewhere in rural part of Ethiopia estimated to be 2154 kg and 1825 kg respectively. Similarly Mekonnen and Köhlin (2009) reported that the total quantity of fuelwood consumption fluctuated between 2004 kg/year and 2143 kg/year in 2005, it was nearly the same with findings of the present study, which indicated that the consumption of fuelwood as a source of domestic energy is increasing over time and negatively related with environment. The annual fuelwood consumption of household was significantly varied among each other, as indicated by Least Significance Difference (LSD) results (f= 2.80, p=0.001) and the variation of fuelwood consumption over time resulted from absence of fuel saving stove (65.2%), other things citreous paribus[1] such as household size, income level, cattle population and number of tree planting. According to Nanda and Khurana (1995) and Saxena (1997) besides increasing in consumption, the use of traditional biofuel expose users causes to health problems such as eye and lung diseases due to kitchen smoke, especially for females, who devote long hours in close proximity to kitchen. Majority of households were using traditional three stone stoves. Only 34.8% of the respondents were using fuel saving stove locally called "Gonze"[2]. Obviously rural people are fulfilling their demand of fuelwood anywhere from agricultural land, natural forest, grazing land and fallow land (Jaiswal and Bhattacharya, 2013). Even though people in all over rural parts of the country in general, the study area in particular depend on natural forest, privately planted trees and community plantation used for fuel sources and construction at large.

Table 4.1 Annual domestic biofuel consumption

Consumption of fuelwood		Consumption of dung cake	
kg/year	% Population	kg/year	% Population
≤ 800	9.80	≤450	23.90
800-1600	32.60	450-900	33.70
1600-2400	19.60	900-1350	16.10
2400-3200	28.30	1350-1800	7.60
≥ 3200	8.70	1800-2250	4.40
		≥2250	13.00

In addition to acceleration of land degradation and loss of agricultural productivity because of clearing of natural forests, degradation contributes negatively for further shortage of fuelwood.

[1] Citreous paribus is an economic term refers to other thing remain constant
[2] Backing and cooking fuel saving stove technology produced from cement and sand mostly used by rural population.

It has been observed that due to deforestation of natural forests, households spent considerably more time in collecting fuelwood over long distances. As a result, households substituted dung cake for fuel consumption, which has important implications for agricultural production. Therefore, participants were asked to assess average time travelling to collect biofuel before and after community based watershed management practices. The estimate of average time may not be accurate so care has been taken during assessment (Figure 4.1). The average return time before the project was 121 minutes. By assuming the average walking of person is 5 km/hour, distance travelled for fuelwood collection therefore was 10.08 km. Recently equivalent distances take 92.3 minutes, which is equivalent to 7.66 km distance for fuelwood. As a result of increasing community plantation around homestead and farm areas respondents approached to private tree plantation for domestic utilization (97.8%) and in turn reduced distance travelled for fuelwood from 10.08 km to 7.66 km.

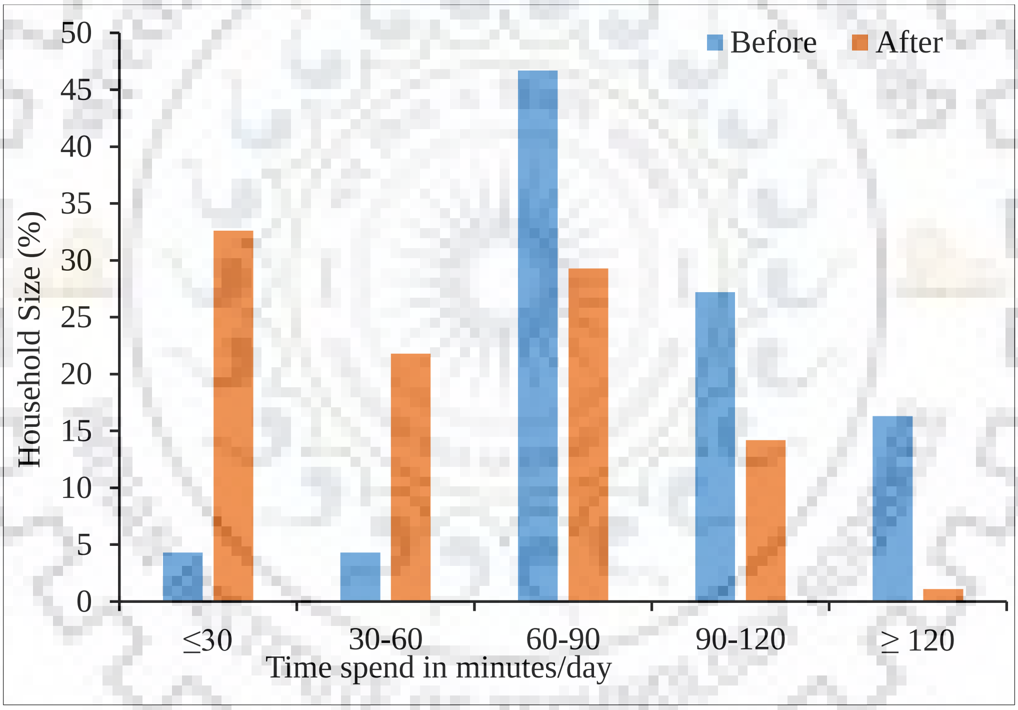


Figure 4.1 Comparison of time spending for fuelwood collection before and after watershed management

4.3.4.2 Dung fuel consumption

Similarly, cattle dung cake holds the most important source of household's energy consumption next to fuelwood. The annual dung consumption of the study watershed ranged from 146-2920 kg/year, with total quantity of 95,192 kg/year ~95.192 t/year (already presented in Table 4. 1). Majority of households used 876 kg/year, which is lower than the average (1533 kg/year) and the mean quantities was 1050.46 kg/year. In contrast, the other studies concluded that the total average quantity of cattle dung cake used as fuel source reduced from 1307 kg/year to 1157 kg/year in 2000 and 2005 respectively (Mekonnen and Köhlin, 2009). Clearing of forest and degradation of land are inter-related with use of fuelwood and cattle dung as domestic energy source, which are the most serious environmental concerns. For instance, using dung cake for energy source negatively contributed for the availability of manure for soil conditioner to boost agricultural productivity (Mekonnen and Köhlin, 2009). One of the most serious constraints of food security was soil fertility depletion. Manure is an important soil conditioner used to enhance soil fertility (Raj et al., 2014). As Fulhage (2000) reported that manure contains N, P, K, Ca, Mg, Fe, Mn, Cu, Zn etc (Table 4.2). These are significant to improve soil tilt, soil water holding capacity and aeration, which in turn are used to increase productivity. Therefore, use of dung as source of domestic energy reduces the opportunity cost of using it as soil fertility improvement.

Table 4.2 Estimated nutrient loss from burning of cattle dung

Source	Nutrient (kg tonne-1 year -1on dry biomass bases)								
	N	P	K	Ca	Mg	Fe	Mn	Cu	Zn
Cattle dung	18.30	4.50	21.30	16.40	5.60	10.78	0.78	0.02	0.09

Lupwayi et al. (2000)

To fill the gap of domestic energy sources, 95.192 tonnes of cattle dung burnt annually. Burning cattle dung for domestic energy source-therefore has negative implication especially for developing country like Ethiopia, which import fertilizer from other countries.

Dung was collected from different places of the study area from private grazing land, communal grazing land, and prepared from privately own cattle in their home. Like elsewhere in rural parts of Ethiopia, in the study watershed in addition to perform household chores and growing children the responsibility of collecting fuelwood mostly handled by females and children too. In general, every family member performed the activity.

4.3.5 Biofuel consumption pattern and socio-economic characteristics

The annual biofuel consumption of the study watershed ranged from 450 to 7,118 kg with the average consumption of 3813 kg/annum. The variation of biofuel consumption is susceptible to various factors. The requirement of fuelwood is subject to population size, availability of biofuel nearby their home, and number of cattle population they have. However, increase in population makes availability of fuelwood lagging behind the need for domestic use.

The use of biofuel consumption in the study area was variable depending on different factors. There was positive correlation between fuelwood consumption and household size, which was statistically significant ($r = 0.47$, $p<0.01$) (Table 4.3), this indicates larger household need additional fuelwood to prepare household food. Similarly, size of households and use of dung cake were significantly correlated (*r*= 0.40, *p*=<0.01), possibly because larger family needs more energy consumption and possibly have free labor to collect dung. The association between size of land holding and biofuel is statistically insignificant (*r= -0.54, p>0.05*), which indicates large landholders do not have better option of getting more biofuel. The association between number of tree planted and fuelwood was statistically insignificant. Likewise, no significant association between dung consumption and number of tree planted. Instead of using wood and trees for domestic energy source, households prefer to earn additional income for selling to nearby market rather than replacing dung cake as a fuel source.

Table 4.3 Correlation matrix indicates biofuel consumption and influencing factors

Characteristic	Fuelwood	*p-value*	Dung cake	*p-value*
Size of households	0.47**	0.00	0.40**	0.00
Size of land holding	-0.54	0.61	-0.30	0.77
Number of trees planted	-0.28	0.79	-0.18	0.08
Livestock ownership (cow and oxen)	-0.20	0.05	0.16	0.11
Income earned (farm produce and off-farm income)	0.20*	0.04	0.19	0.06

** Significant at 0.01level, * Significant at 0.05 level

In the present study, it has been found that cattle ownership is positively correlated with dung cake. Households that owned large number of cattle have additional opportunity for preparing dung cake in their home. On the contrary, it is found that the association between cattle ownership and fuelwood is negatively correlated. Therefore, more the cattle they have, more tendency of using dung for domestic use. In turn positively contribute for having more trees and wood free for home construction and earning additional cash income.

There was a significant positive correlation between income level of households and fuelwood, (*r*=0.048, *p*<0.05). On the other hand, the correlation between income and dung consumption statistically not significant. The possible explanation may be more income from sale of farm produce and off-farm income earned, fuel saving stove used and therefore, using dung as soil fertility amendment hence boosting agricultural production and productivity.

4.3.6 Household level tree plantation to the livelihoods strategies

The number of tree planted per year was variable among households- ranged from 0 to more than 520. Tree planted around farm plots and homestead therefore positively contributed in the last decade for the increase of forest coverage. The total number of trees planted per a year was 11,330 with the average of 243 trees per households (Figure 4.2). In line with the present study, a study by Bewket (2005), reported that in the north-western highlands of Ethiopia of Chemoga watershed inferred in the last four decades private and community level tree planting, has significantly contributed for the increase of forest cover, even though there is difference between planted trees and natural forest cover with averagely 307 trees planting per household. According to Ndayambaje et al. (2012), in Rural Rwanda out 480 of the total households, 350 of them were planting 1to 4 trees species in their farm plots. Similar Sandewall et al. (2015), found average planted tree area conserved and managed by households accounted by about 0.4 ha/hh in China, 0.3 ha/hh in Ethiopia and 0.4 ha/hh in Vietnam. Being, stipulated by market and government favourable policies for climate resilient green economy together with erratic rainfall, households were increasingly decide to tree planting operation in their homestead and around farm plots. Through planting trees and earning cash income for their survival, simultaneously reduced dependence on crops. Similar findings were obtained by Sandewall et al. (2015), accordingly planted trees and natural forest are the second income source after crop production for Ethiopia and 6-25% for Vietnam. However, increase of tree and forest plantation at the expenses of unsustainable farm rises incomes for some, it did not immediately bring household out of food insecurity and shortage.

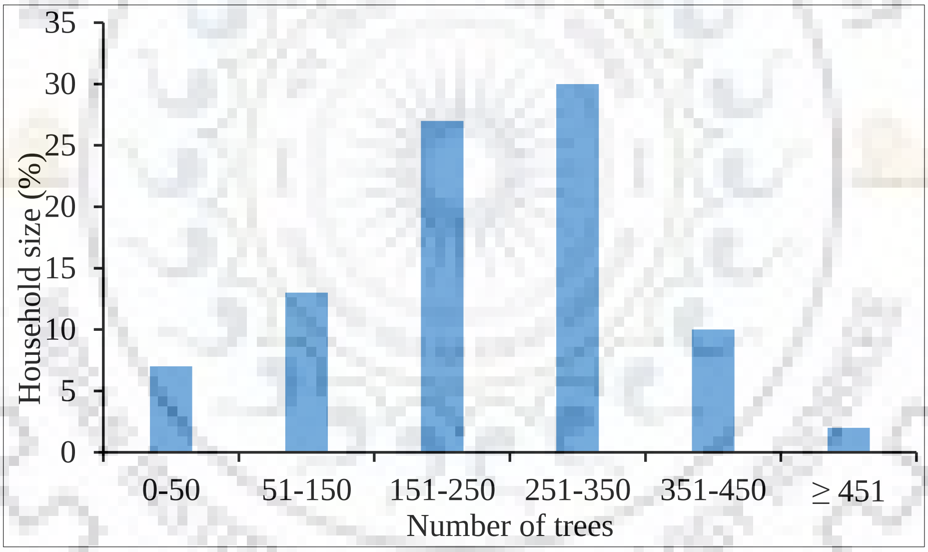


Figure 4.2 Number of trees planted/year

Other reason farmers decided to plant trees compared to producing crops because growing of trees required less labors. *Eucalyptus* tree was the most dominant types of tree planted in the watershed (more than 90%) which is followed by *juniperus procera* tree (locally called *Tid*) to some extent *Sesbania sesban*, *tree Lucerne*, shrubs and grass were recently practiced. Due to fast growing, less time required for treating and less susceptible to climate change farmers preferred *eucalyptus* tree. On the contrary, from long experience farmers expressed *eucalyptus* tree has negative ecological effect, as it needs large volume of water requirement. Many controversial points listed in various studies about the benefit and ecological effect of *eucalyptus* tree. According to Zhang et al. (2012), for instance various biological debris and soil fertility was reduced because of rehabilitation of *eucalyptus* tree. Simultaneously the growth rate of *eucalyptus* tree faster than any other forest and tree species and needs large amount of water– cause for degradation in biodiversity. Similar findings by (Bone et al., 1997; Lemenih, 2004), states that *Eucalyptus* tree negatively affect the ecosystem services for instance reducing soil moisture content and reducing the groundwater. Contrary to this, being planted *eucalyptus* tree precipitation has increased by 152.5 mm/annum, 75.3 mm reduction in evaporation annually.

Regardless of negative ecological as well as environmental effects, which needs further investigation on clear advantage and disadvantages, *eucalyptus* tree was a means of economic relief for households especially during drought period through earning additional cash income (Jagger and Pender, 2003). From the survey, it is concluded that more than 85% of households were sold trees to nearby market to earn additional cash income. Similar study by Holden et al. (2003), states that *Eucalyptus* tree plantation on marginal and degraded lands has positive effects on crop production and land conservation.

To meet the demand especially for home construction household used their privately planted trees near homestead and farm plots (90%). This study inferred that, unlike many other studies on natural forests of the country that simply farm households believed to be the agent for deforestation, this study concluded that rural households were also be the actor for increasing the coverage of forests. Similarly, Kajembe (1994) and Price and Campbell (1997), in their studies elsewhere in many developing countries of the world confirmed that rural households play significant roles in the indigenous tree planting and management of their forest resources. The analysis of association between tree planting and various household socio-economic characteristics showed that there is positive correlation between age of households and number of tree planted, which is statistically significant ($r= 0.245$, $p<0.01$). Household size were positively correlated with tree planting, which indicated that the higher size of household, the more free labors were available for planting trees. The association between education background of household and planting trees was significantly correlated ($r=0.049$, $p<0.05$). Based on statistical analysis farmers who were able to read and write have better information about the benefit of planting trees than who have not. Household income was not significantly related to planting trees ($r=-0.123$, $p= 0.07$). Likewise, the association between the size of land holding and number of tree planting was not significant. This is because planting trees operated around homesteads also. In addition, youngsters who have less farm plots eager to have additional cash income- devote to have more trees.

Based on probit model results indicated that having land use right certificate significantly increase level of tree planting. In line with this, the anticipation of land use certificate is likely householder more self-assured in order to decide growing trees in their own land (Table 4.4). Similarly, previous study by Holden et al. (2009), confirmed that land use certification is likely affect household decision on planting trees.

The results for household-level variables confirmed that household's, education, age, gender, family size, and biofuel consumption were significant variables, which inferred more likely to plant trees. On the other hand, credit accesses, off farm income, size of land holding and number of livestock tending are less likely to influence the household decide to plant trees.

Table 4.4 Probit model results for household level of tree planting

Variables	Probit model results	Variables	Probit model results
Family size	-0.02*	Size of land holding hectares	0.23**
Education level	0.01*	Land use certificate (right)	0.78*
Age of household head	-0.03*	Off farm income	0.12**
Gender of household	0.03*	Biofuel consumption per household	0.01*
Livestock number	0.06**	Credit accesses	0.20**

*= Significant @ 5%, ** = Not significant

4.4 CONCLUDING REMARKS

Elsewhere in developing country, for Ethiopia in general, in the study watershed people relied on traditional biofuel. There has been conflict between natural resources and people dependent on subsistence farming and still unresolved issue in the problems of biodiversity.

Alarming population growth rate and hence accelerating in rate of deforestation of natural forest and the growing demand of household domestic energy sources, household level tree planting used to reverse the scarcity. Likewise, it has positive impact on economic relief and to the environment as well. Due to the growing demand of energy for domestic use, household turned to use dung for energy source. Hence, the use of cattle dung for soil fertility improvement was limited. A possible solution to reverse the problem is encouragement of households to use more efficient fuel saving stove. Therefore, the use of cattle dung as organic fertilizer can be increased and hence agricultural diversification. Besides using of cattle dung for soil fertility improvement and agricultural productivity, it used to reduce foreign currency spending on importing chemical fertilizer from abroad. Therefore, private and community tree plantation should be encouraged as strategy to reduce further pressure on natural forest and ecological and environmental conservation.

Eucalyptus and *juniperus* trees (locally known as *Tid*) are the dominant tree types in the study area, the interviewed households stated that they were unable to get fodder to feed their livestock. To reduce shortage of fodder problems, soil erosion and land degradation, to meet fuelwood requirement, promotion and encouragement of planting multi-purpose and indigenous tree should have done. On the basis of ecological and economic analysis, private as well as community level tree planting, and localized natural resource management should be implemented. Therefore, allocation of barren land, hillside and degraded land for private tree planting at large create more responsibility for local households.

Finally, it can be concluded that household level multi-purpose tree plantation and agro-forestry practices based on local context should be acknowledged. Because, it has significant positive contribution for increasing natural forest coverage, ecological succession, reducing natural resources degradation, increase the availability of fuelwood, earning cash income and then reduce pressure of using dung for domestic fuel sources. Therefore, it has inclusive benefit for not only the landowner but also they will have a chance of getting benefit from the rehabilitated watershed.

CHAPTER 5

MODELLING SPATIOTEMPORAL LAND USE/LAND COVER DYNAMICS AND FUTURE PREDICTION

5.1 GENERAL

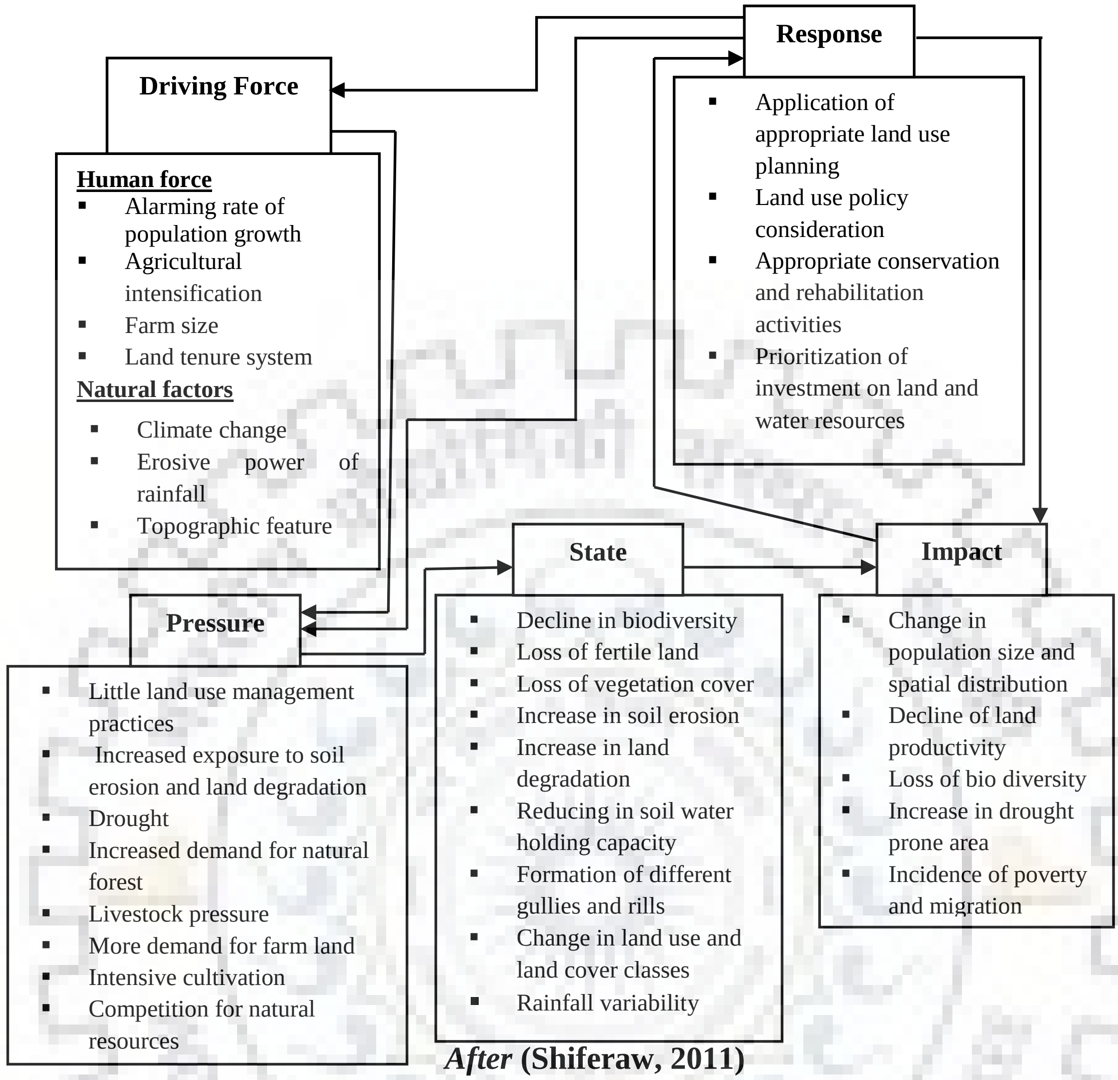
Land cover dynamics has the global concern of the 21th century, with the dramatic implication for human survival. Land cover change is the change in the physical as well as biological characteristics of land which is attributable to management including conversion of grazing and forestland into farmland, pollution, land degradation, removal of vegetation, and conversion to non-agricultural uses (Quentin et al., 2006; Prakasam, 2010; Shiferaw, 2011). Recently research on Land Use/Land Cover (LU/LC) change detection has drawn attention of many researchers (Liang et al., 2002; Ayele et al., 2016). It affects biodiversity, hydrological cycle, land productivity and the sustainability of natural environment (Lupo et al., 2001). In recent times land use dynamics has been playing a wide role of driving force in alteration of the global environment (Baulies and Szejwach, 1998).

The dynamic change is faster, and can have a huge implication on local, regional, national and global environment and consequently affect food availability (Minale, 2013). In the past few decades, the conversion of forest, woodland, grass, pasture land into agricultural and settlement area has dramatically increasing in the tropics (Turner, 1990). Anthropogenic and natural processes accelerate land cover change (Jat et al., 2017; Saxena and Jat, 2017). Similarly, the changes due to the complex interaction of various social, economic and biophysical situations following agricultural diversification, advancement in technology (Reid et al., 2000).

Minale and Rao (2011) and Shiferaw (2011), pointed out that associated population pressure found to be negative result on land use change. Soil erosion, land degradation, destruction of habitat and biodiversity; loss of endemic species due to migration are resulted from land cover dynamics (Meyer and Turner, 1992). Even though many controversies on the factors of land cover dynamics, few research studies concluded that demographic factor is intensively accelerated LU/LC changes (Mather and Needle, 2000; Fasona and Omojola, 2005) and the utilization of this resource by human population is increasing in time and space (Clevers et al., 2005). Alarming rate of population dynamics, insecure land use right, lack of credit facilities and lack of market availability are some of socio-economic factors, which facilitates for the change of land cover classes. For the poor those are living under subsistence farming has no other option other than natural resources. There was mismanagement of natural resources such as overgrazing, de-vegetation and expansion of agriculture into the marginal land as well as steep slope for the survival of their livelihoods (Grepperud, 1996; Minale and Rao, 2012; Asres et al., 2016). Despite the expansion of cultivation from sloping into steeper slope with inappropriate soil and water conservation measure, crop production is still lagging behind by 2.67% annual population growth rate (Asres et al., 2016). Intense pressure on agricultural land, forestland and the availability of fuelwood in the surrounding areas of Ethiopia is the result of spatiotemporal demographic changes; it exerts massive pressure on land use, agricultural productivity, and the use of ecosystem (Minale and Rao, 2011).

In most parts of the world, particularly in developing countries agriculture is the livelihoods of the population in turn primarily the most driver of land use change. However, limited studies have been done on long-term trend of land cover changes (Klein Goldewijk and Ramankutty, 2004) and future prediction (Lepš, 1988; Liu, 2008). For instance, in east Africa in the last 50 years, at the expense of other land uses, there has been intensive expansion of agriculture into marginal land (Yitaferu, 2007). Semi-Arid and sub humid areas were dominated by pastureland with widely scattered settlement and agricultural activity before 1950, but then after there has been a massive change of grazing land into mixed crop-livestock agriculture.

Interaction between various socio-economic conditions of the society, population pressure, physiographic features, and land use types have resulted in land use change, as presented in Figure 5.1. Therefore, land use classification and future prediction used to analyse the interaction between socio-economic and land uses, which is contributed for the dynamics of LU/LC changes resulted from diversified and intensified agriculture and livestock population (Mendoza et al., 2002).



***After* (Shiferaw, 2011)**

Figure 5.1 Conceptual framework on the driving force of land cover changes and associated effect

In the mid-1980s, around 27 Mha highland part of Ethiopia was significantly eroded as the same time around 14 Mha was seriously eroded. It concluded that more than 2 Mha of agricultural lands has reached at the point of zero return. Therefore, analysing the past and predicting the future LU/LC changes at watershed and sub-watershed level using Landsat imagery and identifying the rate and extent of land cover changes and future prediction are critically important (Asres et al., 2016). To monitor LU/LC dynamics, geospatial techniques have important role, therefore, geographic information system tools are used to get information about extent, rate and magnitude of LU/LC changes and disseminate accurate information (Carlson and Sanchez-Azofeifa, 1999; Dezso et al., 2005). Critically analysing the driving force for land cover dynamics of the past trend is important to understand the recent changes and predict for future alteration. The Markov chain model can be used in order to analyse the future LU/LC dynamic behaviour of land use in time and space to forecast future change to provide policy makers for better management (Lepš, 1988; Liu, 2008). Many scholars have utilized Markov chain model for future prediction and revealed strong capability and successfully predicted the LU/LC changes (Lepš, 1988; Yang et al., 2012).

A study of land cover dynamics for the past and predicting for the future and its driving forces in time and space provides favourable foundation for the sustainability of natural resource systems, as of it reflect the state of watershed. Therefore, spatiotemporal land cover change and its driving forces are important inputs for prioritization of natural resources management and appropriate uses. Even though different studies have undertaken about the extent and status of clearing of forest, land cover change and soil erosion in many parts of Ethiopia, poorly documented about spatiotemporal land cover dynamics, future prediction, and its driving forces. Therefore, this study planned with the main objective of spatiotemporal analysis of historical LU/LC change dynamics and its driving forces; and analyse the future LU/LC prediction using Markov chain model.

5.2 MATERIALS AND METHODS

The study area and methodology of the study process has been discussed in the following subsection.

5.2.1 Study area

The detail of the study area description have been discussed briefly in chapter 3.

5.2.2. Data source and methods of analysis

5.2.2.1 Land cover data

The source for LU/LC dynamics was downloaded Landsat imagery from http://earthexplore.usgs.gov. The detail of satellite data are presented in Table 5.1. Landsat 5 and landsat 8, path/row of 168/53 with 30 m spatial resolution were acquired on 17/12/1984, 25/01/1999, and 23/12/2015. The imagery was processed using ArcGIS10.2.2 and ERDAS IMAGE14 software. Initially images were converted into Universal Transfer Mercator and geo-referenced to a datum in which Ethiopia has been selected by WGS-84. To improve the image quality, it was enhanced using histogram equalizations. Then LU/LC change detection of the study watershed has been analysed for the last 31 years. To classify Landsat images supervised classification has used, initially more than 250 signatures extraction have used in order to convert images into thematic land cover class.

Before identifying the actual LU/LC change detection, Thematic Mapper was geo-referenced, transformed and enhanced. To reduce the resolution difference of Thematic Mapper images, using nearest neighbour re-sampling techniques the image was re-sampled into the same size.

Table 5.1 Details and sources of satellite data used for the study

No.	Images	Resolution	Sensor	Path	Row	Acquisition Date of	Source
1	Landsat5	30 m x 30 m	TM	168	53	17/12/1984	http://earthexplore.usgs.gov
2	Landsat5	30 m x 30 m	TM	168	53	25/01/1999	http://earthexplore.usgs.gov
3	Landsat8	30 m x 30 m	TM	168	53	23/12/2015	http://earthexplore.usgs.gov

The topography of the study area was defined by DEM that is used to describe the elevation of points for the given area at a specific spatial resolution. In addition, sub-basin parameters including slope, slope length, slope width and stream network were obtained from the digital elevation models (DEM) as already presented in chapter 3 (subsection 3.2.1, Figure 3.2. Various steps developed and used to analyse, quantify and interpret the maps are presented in Figure 5.2). In this study, Google Earth integrated in the ERDAS Imagine2014 software has been used in order to assess the accuracy for each LU/LC class.

In this study, Kappa coefficient has been used in order to confirm the accuracy assessment of each LU/LU classes. The Kappa coefficient agreement has obtained in the following way:

$$Kappa\ coeffiecient : K_c = \frac{n\sum_{i=1}^{m} P_{ii} - \sum_{i=1}^{m} P_{1+} * P_{+1}}{n^2 - \sum_{i=1}^{m} P_{i+} * P_{+1}} \qquad (5.1)$$

Where; m is the number of rows in the error matrix; P_{ii} is the number of observations in the row i and column i; X_{i+} is the total observation in row of i; X_{+i} is the total observations in column i; n is refers to the total number of observation in the matrix. In this study, the overall Kappa coefficient accuracy of classification varies from 0.79 to 0.85 as shown in Table 5.2. The results of accuracy assessment were confirmed that the use of satellite based LU/LC class maps for prediction of future analysis.

Table 5.2 Accuracy assessment results of LU/LC classification

Accuracy type	LU/LC classes	1984	1999	2015
Kappa coefficient	Water body	0.79	0.82	0.79
	Forestland	0.85	0.81	0.80
	Farmland	0.80	0.83	0.81
	Grazing Land	0.81	0.84	0.84
	Settlement	0.82	0.85	0.85
	Barren Land	0.83	0.83	0.84

Lastly, six LU/LC classes were identified for the watershed and LU/LC changes were determined in Table 5.3. To get additional information about the long-term experience of LU/LC change practice in the watershed focus group discussion and informal interview have done. For the discussions and in-depth interview, elder peoples were purposively selected as they assumed to have better history of information about the trend of LU/LC changes.

Table 5.3 Descriptions of LU/LC classes

S.N.	Land use land cover class	Description
1	Settlement (ST)	Scattered rural settlement closely associated with cultivated land and urban settlement. Trees around homestead mainly *eucalyptus* are included.
2	Farmland (FL)	Land allotted for crop cultivation both annual and perennial crops.
3	Barren Land (BL)	Area with very little or no vegetation cover on the surface of the land. It consists of vulnerable soil to erosion and degradation. It also includes bedrock, which is unable to support cultivation.
4	Grazing Land (GL)	Land surface with small grasses in which predominately-natural vegetation. It consists of area with scattered trees used for grazing purpose.
5	Water Body (WB)	Is having surface water. It includes pond water, streams, rivers, lakes, marshland and riverine trees found along riverbank and streams.
6	Forestland and Plantation (FoL)	Area covered with dense natural forest and plantation forest, it includes *eucalyptus* trees, *juniperus* procera (locally *Tid*) and mixed indigenous bush and trees species.

After having classified images, the geographical extent in terms of hectare for each LU/LC classes were calculated for each mentioned periods. The extent of change in land use type within and between different periods have compared. The change of different LU/LC classes have been done using both ArcGIS10.2.2 and ERDAS IMAGINE14 and finally using the following equation has been used to know the rate of change of area/year and percentage share of each classes in the studied periods:

$$\Delta A = (\%) = \frac{A_{t2} - A_{t1}}{A_{t1}} * 100 \quad (5.2)$$

Where, ΔA (%) = percentage change in area of LU/LC classes type between initial time A_{t1} and time period A_{t2}

A_{t1}= area of LU/LC types at initial time

A_{t2}= area of LU/LC types at final time

As stated by Shiferaw (2011), the rate of change of LU/LC types have calculated by the following formula:

$$R\Delta(ha/year) = \frac{Z - X}{W} \quad (5.3)$$

Where: RΔ= rate of change

Z= recent area of LU/LC type in ha

X= previous area of LU/LC type in ha

W= time interval between Z and X in years.

5.2.2.2 Future prediction of LU/LC Using Markov Chain Model

In order to simulate the LU/LC change dynamics for the year 2030, Markov Chain Model (MCM) was applied in IDRISI software. The MCM is integrated module of the IDRISI Selva, a raster based file support, established by Clark Labs at Clark University. Some inputs data are required in order to run the MCM such as LU/LC maps, Markov transition area files, which were created by the use of Markov Model in IDRISI. The flowchart of the methodology is presented in Figure 5.2.

It is applied (MCM) in order to predict the change of LU/LC classes for the year 2030 using the actual LU/LC image (2015). In addition, the application of such model on the basis of random process, *X*(t), if the Markov process for any instant of the time, $t_1 < t_2 \ldots < t_n+1$, hence, the Markov chain process can be stated by the following equation (Memarian et al., 2012):

$$F_x(X(t_{n+1}) \le X_{n+1} \mid X(t_n) = X_n, X(t_{n-1}) = X_{n-1}, X(t_1) = F_x(X(t_{n+1}) \le X_{n+1}) \mid X(t_n) = X_n \quad (5.4)$$

Where: X(t) is signifies the Markovian chain process for a particular time (t), t_n is the present time while the time for changes in the future is defined by t_n+_1. Likewise, t_1, t_2, ⋯, t_n-1 is used to represents various points of the past.

According to Memarian et al. (2012), stated in the following transition probability matrix from the state i and state j, whereas, X[k] signifies the state (x_1, x_2, x_3…). Nevertheless, many times the Markov chain follow finite number of states (n); in the final case the transition probability matrix can be expressed by the following equation:

$$P_{i,j} = P_r(X[k+1] = j \mid X[k] = i \tag{5.5}$$

$$\begin{pmatrix} P_{1,1} & P_{1,2} ------ & P_{1,n} \\ P_{2,1} & P_{2,2} ------ & P_{2,n} \\ P_{n,1} & P_{n,2} ------ & P_{n,n} \end{pmatrix} \tag{5.6}$$

Due to uncertainty in the process of LU/LC change modelling, it is difficult to use these predicted maps in the process of policy planning. However, it is possible to use in the process of hydrological modelling studies and early warning information in the task of land use planners, developers and managers.

The validation of MCM was done for the year 2015 using the input of LU/LC data of 1984 to 1999 in order to provide assurance in the future LU/LC modelling processes. To assess the level of agreement between simulated as well as reference map, validated module of IDRISI Selva has been employed (Mitsova et al., 2011).

Additionally, to understand the spatial pattern of predicted map, it is necessary to carry out visual assessment of LU/LC classes. The relative comparison method also undertaken with previous studies done by other scholars for better model validation (Guan et al., 2011; Kamusoko et al., 2009; Memarian et al., 2012). Finally, future LU/LC for the year 2030 has been predicted.

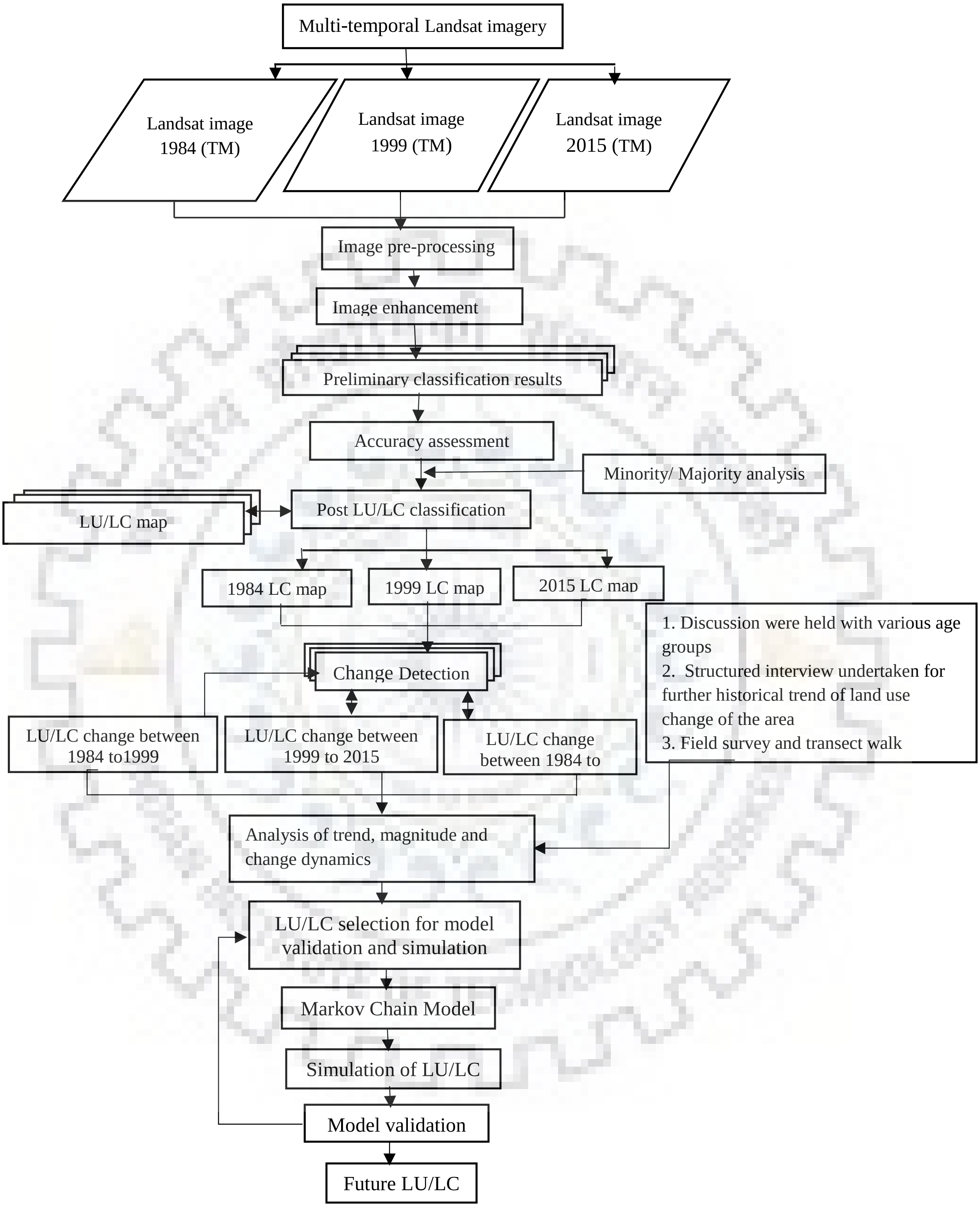


Figure 5.2 General flowchart of methodology for LU/LC classification and prediction

5.3 RESULTS AND DISCUSSION

5.3.1 Land Use/Land Cover maps

Red, green and blue band combinations have been used to display stacked images in the standard colour composite. For the analysis, false colour composite bands 2, 3 and 4 have been used.

In order to meet the requirement of food demand, cultivated land has increased in all parts of the world at the expense of other land use classes such as forest, bush/shrubs, barren land and grazing land particularly in developing countries in which majority of inhabitants are dependent on agriculture for their survival (Lambin et al., 2003). In the present study, similar trends in the watershed have been found, where farmland and settlement areas have increased over time. Significant land use change has been observed since 1970s and probably continue in the future. To show clearly these significant changes over a time span due to various driving forces, the overall changes were presented for the year 1984, 1999 and 2015 in Figures 5.3 and 5.4, Tables 5.4 and 5.5 and future land use prediction has been presented in Figures 5.5 and 5.6.

5.3.2 Historical Land Use/Land Cover dynamics

In the present study, six classes of LU/LC were presented namely farmland, barren land, forestland, grazing land, settlement and water body. The LU/LC dynamics is discussed in the subsequent sections.

Farmland: In the study area agriculture, occupy the largest share of land cover class (57.10%, 61.90% and 67.50% in 1984, 1999 and 2015 respectively). This implies farmland has extensively increased at the expense of other land cover classes. The prominent reason probably due to increased demand for it resulted from population growth. Due to extensive expansion of farmland (18.20%), substantial decrease of grazing and barren land by 50.60% and 60.70% respectively observed (Figures 5.3 and 5.4, Tables 5.4 and 5.5). Due to ever increasing demand of farmland, farmers exert pressure on forest, bushes/shrubs, grazing and barren land, which resulted for further increase of erosion and degradation. Elsewhere, similar study reported alarming rate of population growth resulted in change of land cover classes with time (Turner, 2009). Likewise, Shiferaw (2011) found that the limited access of off-farm employment opportunity has compelled the farmers in clearing of forests and further expanding cultivation into steep slope, grazing land, barren land and other types of land cover classes.

Settlement: Settlement area has shown increased persistently. The total area of the watershed covered by settlement has increased by 24.90% from 1984 to 1999, 28% from 1999 to 2015

(Figures 5.3 and 5.4, Tables 5.4 and 5.5). It can be seen that the expansion of both urban and rural settlement contributed a major share by converting other land use types. In the stated time periods (1984 to 2015) there has been 59.70% increase of settlement areas. Generally, continuous increase of population growth needs additional land for settlement areas, which resulted change of 520.50 ha of other land use types.

Grazing land: One of the dominant land cover class of the watershed was grazing land which holds 12.40% of the total land cover types in 1984; however, in 1999 the coverage has been decreased by about 2.40% (from 12.40% to 10%). Similarly, in the 2015 the share has shrunk to 6.10%, which was double the decrease in the 1999. Overall in the first periods from 1984 to 1999 the shrinkage of grazing land was reduced by 510.20 ha (19.40%); similarly, in the second periods from 1999 to 2015 it has been decreased by 823 ha (38.70%) (Figures 5.3 and 5.4, Tables 5.4 and 5.5).

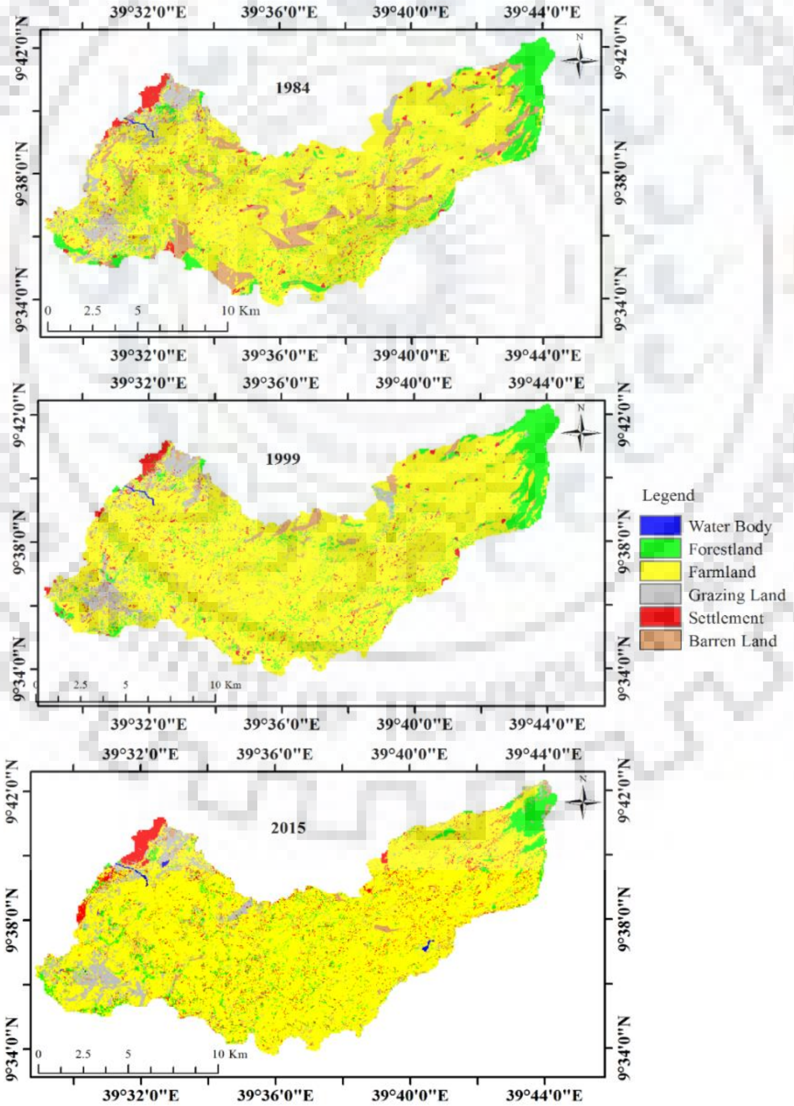


Figure 5.3 Land Use/Land Cover classes distribution for the year 1948, 1999 and 2015

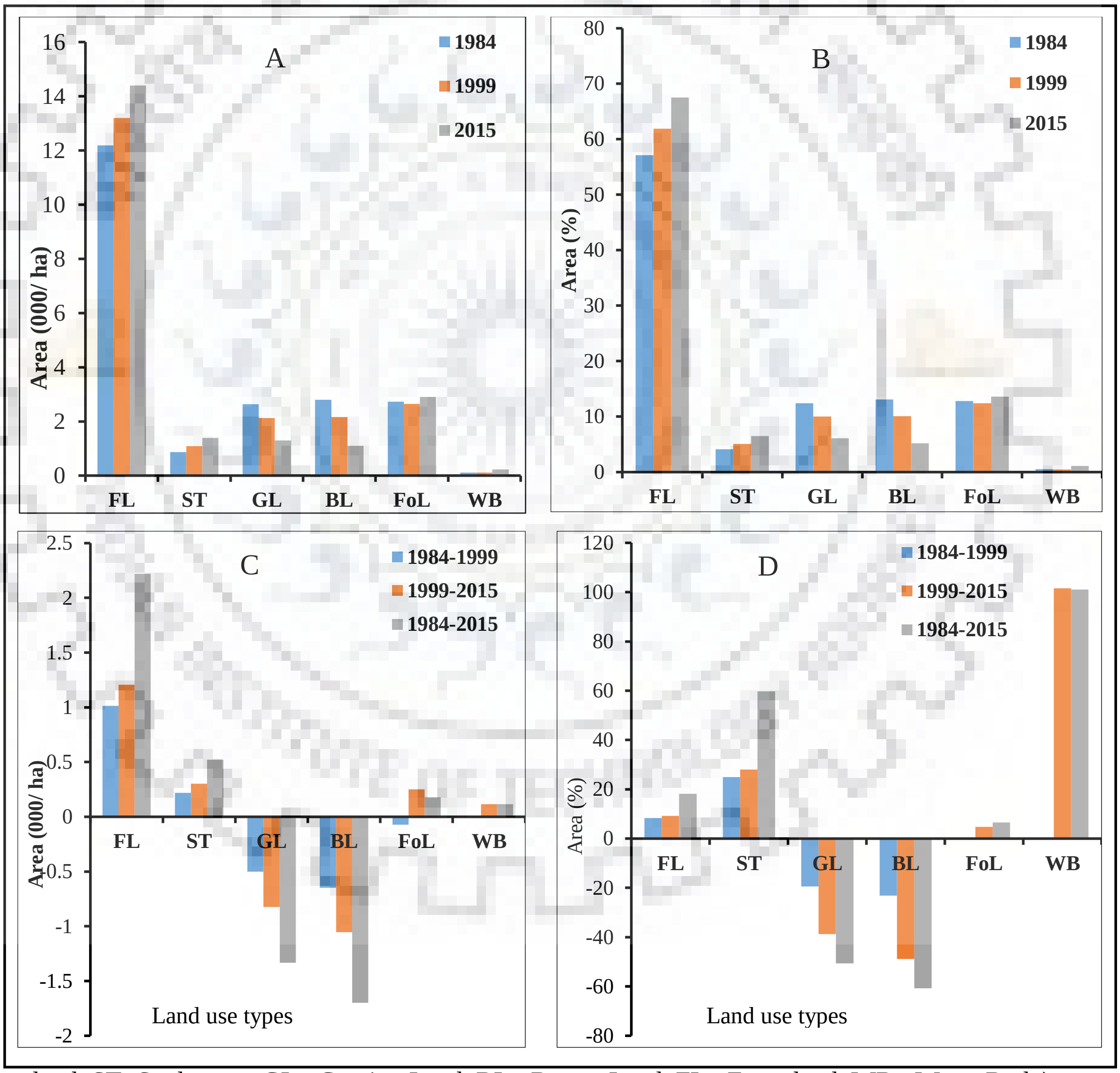
The analysis of LU/LC during the periods between 1984 to 2015 indicated that 50.60% of grazing land has lost. The decrease of gazing land possibly the result of growing demand of more arable land for agricultural cultivation and growing demand for newly formed household for settlement. Thus, conversion of grazing land into farmland and settlement is the common phenomenon practiced in the watershed considered in the present study.

Barren land: Barren land within the stated years has shown continuously decreasing trend from 13.10% in 1984 to 10.10% and 5.20% in 1999 and 2015 respectively. The alarmingly and intensively declining trends can be seen in the first periods from 1984 to 1999 by 23.10% and further in the second periods from 1999 to 2015 declined by 48.90%. Generally, about 60.70% of barren land has discriminated into other type of land cover classes. This is due to availability of fixed plot of farmland coupled with alarming rate of population growth negatively contributed for the decline of barren land.

Forestland: Another dominant LU/LC class of the study watershed was forest, which ranged densely vegetated trees (natural forests), plantations, shrubs and bushes. The area covered by such forests could be evergreen and mixed forestland. From the total area of the watershed in 1984, the share of forest coverage was 12.80%, in contrast the coverage slightly decreased to 12.40% in the year 1999. The decrease in forest coverage is due to increase in population and extensive expansion of farmland. However, unexpectedly in 2015 it has regenerated by 1.20%. The decrease of forest in the first span reconsidered in the study between 1984 and 1999 around by 72.80 ha (0.30%), even though too small, considering the increase in expansion of farmland and population growth, it is contradicted from the expectations. However, in the second periods between 1999 and 2015 the share of forest coverage has increased by 4.70% because the shrinkage of natural forest coverage attributable to regenerated and increased household and community level tree plantation. Therefore, during the periods from 1984 to 2015 the share has increased by about 6.50%. Based on local residents responses obtained from interview and group discussions, various major reasons have considerably contributed for the increases in the share of forest coverage, viz., afforestation, community and private level tree plantations such as *sesbania susban*, tree *Lucerne* and *Eucalyptus* trees are some of them.

It is obviously true that land surface with little vegetative cover exposed to erosion, degradation, runoff and insignificant water retention. The increased in runoff caused for intensive sheet erosion and further extend to rills and formation of gullies. The mass of top soil removed from highland to lowland areas, and cause for intense problems for the downstream siltation of ponds and reservoirs, water borne diseases, water pollution, and sediment deposition on fertile farmlands. In many part of the country, such problems have already manifested.

Water bodies: Water bodies include ponds, springs, streams, and rivers. In the study area, water bodies covered only 0.56% in 1984 and decreased to 0.50% but increased to 1.10% in 2015 (Figures 5.3 and 5.4, Tables 5.4 and 5.5). The possible explanation of this water body fluctuation in the first periods (1984 to 1999 decreased by 0.30%) is due to decrease rainfall pattern of the area. Likewise, the water harvesting habit of local farmers was low. However, in the second periods (1999 to 2015), the availability of ponds and springs have persistently increased by 101.60%. Generally, during the study periods for the last 31 years, it has increased by about 101%.



(FL=Farmland, ST=Settlement, GL= Grazing Land, BL= Barren Land, FL= Forestland, WB= Water Body).

Figure 5.4 Land Use/Land Cover types and area coverage in hectares (A), Percentage share (B), changes in hectares (C) and percentage change (D) from 1984 to 2015

Table 5.4 Area statistics of land use classes of 1984, 1999 and 2015

LU/LC classes	LU/LC (ha) and % share					
	1984		1999		2015	
	Area (ha)	%	Area (ha)	%	Area (ha)	%
Farmland	12179.30	57.10	13192.20	61.90	14400.00	67.50
Settlement	871.60	4.10	1089.40	5.10	1392.10	6.50
Grazing Land	2633.20	12.40	2123.00	10.00	1300.00	6.10
Barren Land	2800.00	13.10	2152.70	10.10	1100.00	5.20
Forestland	2722.80	12.80	2650.00	12.40	2900.00	13.60
Water Body	113.80	0.56	113.40	0.50	228.60	1.10
Total	21320.70	100.00	21320.70	100.00	21320.70	100.00

Table 5.5 Change statistics of land use classes of 1984 to 2015

LU/LC classes	Change in LU/LC (ha) and % share					
	1984 - 1999		1999 - 2015		1984 - 2015	
	Area(ha)	%	Area (ha)	%	Area (ha)	%
Farmland	+1012.90	+8.30	+1207.80	+9.20	+2220.70	+18.20
Settlement	+217.80	+24.90	+302.70	+28.00	+520.50	+59.70
Grazing Land	-500.20	-19.40	-823.00	-38.70	-1333.20	-50.60
Barren Land	-647.20	-23.10	-1052.80	-48.90	-1700.00	-60.70
Forestland	-72.80	-0.30	+250.00	+4.70	+177.20	+6.50
Water Body	-0.40	-0.30	+115.20	+101.60	+115.00	+101.00

5.3.3 Prediction of future LU/LC

The future prediction of LU/LC has been done by Markov Chain model and the corresponding LU/LC for the year 2030 is presented in the Table 5.6. Results obtained from the model show that, decrease in the area of farmland from 67.50% to 62.99% and grazing land from 6.10% to 5.40%. However, increase in settlement from 6.55 to 8.80%, barren land from 5.20% to 7.01%, forestland from 13.60% to 14.70% and water body from 1.10% to 2.40% could takes place from the years 2015 to 2030,the same have been shown in Figures 5.5 and 5.6.

Analysis of the results obtained from the model, similarly, it is expected there may also future LU/LC alteration in the study area. The results signifies the total increase of barren land and continuous expansion of settlement areas (scattered settlement into suburbs and concentrated settlement) could decline farmland by about 6.73%, hence may significantly harm food security in future situation.

Table 5.6 Area statistics (ha and %) under predicted future LU/LC

LULC class	Predicted LU/LC 2030		Change in predicted LU/LC 2015-2030		Change in predicted LU/LC 1984-2030	
	Area (ha)	%	Area (ha)	%	Area (ha)	%
Farmland	13430.0	62.99	-970.00	-6.73	1250.70	+10.26
Settlement	1881.30	8.80	489.20	35.14	1009.70	+115.84
Grazing Land	1150.10	5.40	-149.90	-11.53	-1483.10	-56.32
Barren Land	1497.30	7.01	397.30	36.11	-1302.70	-46.52
Forestland	3131.00	14.70	2310	7.96	408.20	+14.99
Water Body	231.00	1.10	2.40	1.05	117.20	+102.98
Total	21320.70	100.00	-	-	-	-

From the future LU/LC analysis, it has been observed that small amount of water could help for farm productivity as compared to the increases of unsuitable land for cultivation and continuous increase of population hence demand more land for settlement and additional food. Furthermore, farmland could decrease and put intense pressure on food availability. Therefore, different macro and micro catchment water harvesting structures, soil and water conservation as well as integrated water resources management practices need to be established for supplemental irrigation in order to enhance productivity with limited land resources. This would be possible when inter and intra sectoral integration implemented depending on situation specific. Therefore, this study revealed such future focal points, which would be important to prioritize Beressa watershed and implement appropriate interventions for effective, efficient and sustainable site-specific development and management of natural resources.

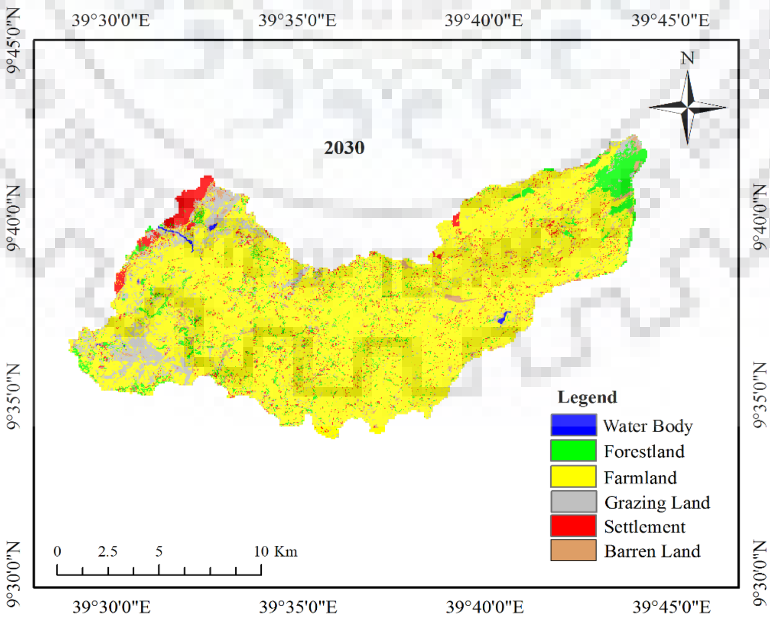


Figure 5.5 Future LU/LC map for the year 2030

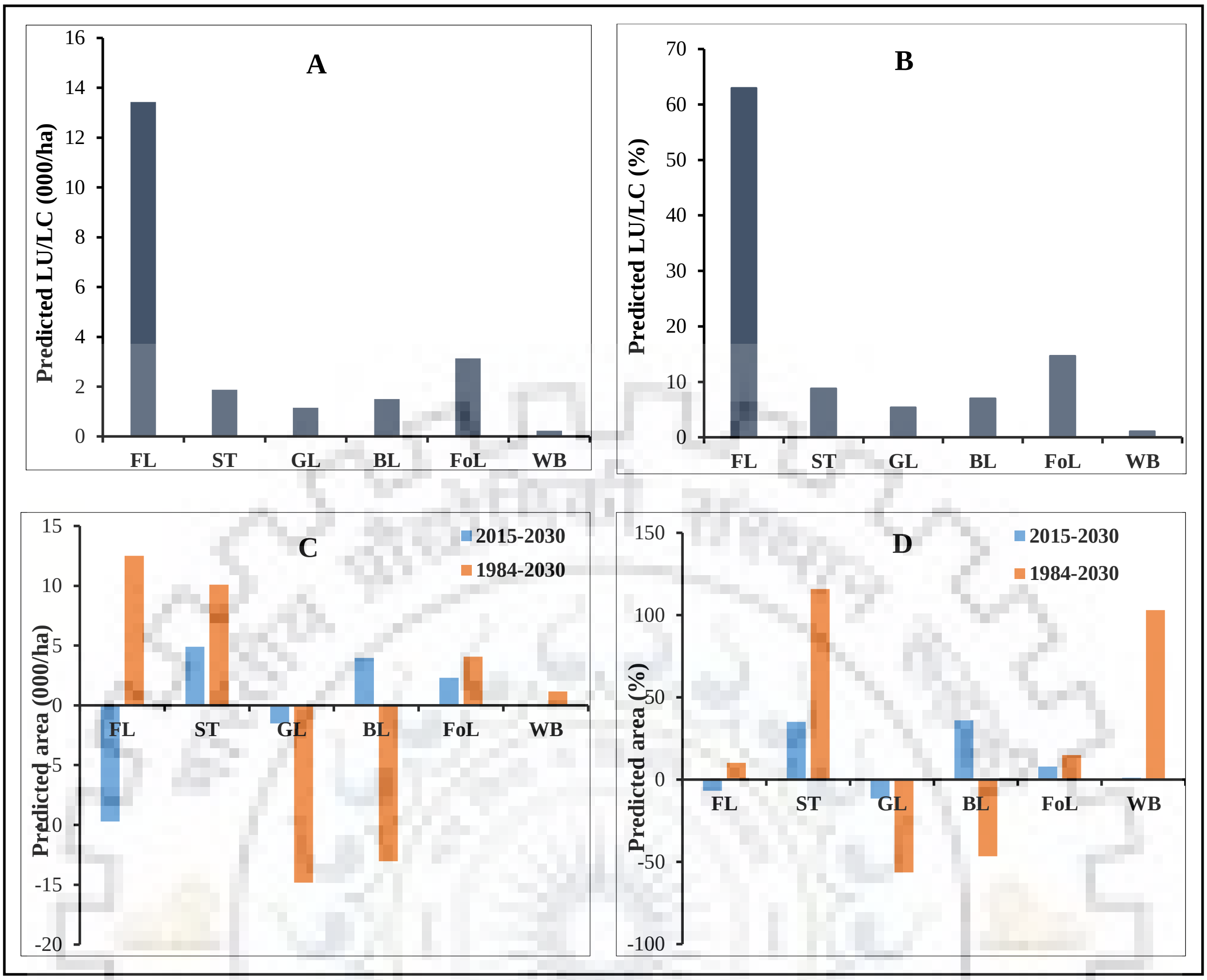


Figure 5.6 Predicted LU/LC types and area coverage in 2030 (A), predicted percentage share of LU/LC in 2030 (B), future change in hectare (C) and future LU/LC percentage change (D) 1984 to 2030

5.3.4 Rate of Land Use/Land Cover change dynamics

The rate of change of LU/LC classes for the study watershed have already presented in Table 5.5. These results indicated that though resources are fixed, there was high rate of changes in different land cover types. Based on the results obtained between 1984 and 1999, farmland and settlement area have increased with the rate of 67.50 ha/year and 14.50 ha/year respectively caused for the outflow of grazing land, barren land and forestland. In the same periods grazing land, barren land, water body and forestland have decreased by about 33.30 ha/year, 43.10 ha/year, 5.00 ha/year, and 0.03 ha/year respectively. Similarly, between 1999 and 2015 expansion of farmland and settlement areas persistently increased with a rate of 75.50 ha/year and 18.90 ha/year respectively. Unlike in the first periods, unexpectedly with increasing rate of settlement and farmland between 1999 and 2015 forestland and water body have increased by about 15.60 ha/year and 7.10 ha/year respectively. In the second span of study years in between 1999 to 2015, the share of forests coverage surprisingly increased which was attributable to household and community level afforestation and reforestation practices. The government of Ethiopia in collaboration with donor organization mobilized the community to give attention for indigenous and multipurpose trees; beside this, households were planting *eucalyptus* trees around homestead and farmland, which has significantly contributed for the present extent of forest coverage. However, grazing and barren land rapidly decreased with the rate of 51.40 ha/year and 65.80 ha/year in between 1999 to 2015 respectively. For the entire period, expansion farmland, settlement area, forestland and water body increased with a rate of 71.60, 16.80, 5.70, and 3.70 ha/year respectively contrary to this the share of grazing land and barren land shrunk with a rate of 43.00 ha/year and 54.80 ha/year respectively (Table 5.7).

Table 5.7 Rate of change in LU/LC classes

LULC classes	Rate of change (ha/year)				
	1984-1999	1999-2015	1984-2015	2015-2030	1984-2030
Farm land	67.50	75.50	71.60	-64.66	27.18
Settlement	14.50	18.90	16.80	32.60	21.95
Grazing land	-33.30	-51.40	-43.00	-9.99	-32.24
Barren Land	-43.10	-65.80	-54.80	26.50	-28.31
Forest Land	-5.00	15.60	5.70	15.40	8.87
Water Body	-0.03	7.10	3.70	0.16	2.55

The results of the finding of the present study particularly for barren land different from the finding conducted by Shiferaw (2011) reported in his study it has been increased by 256 ha/year between 1972 and 1985. Different study elsewhere made by Gashaw et al. (2014), and Dessie and Kleman (2007), indicated that the size of farmland and settlement area have been intensively expanded at the expense of forest cover, barren land and brazing land without significant conservation measures.

As shown in Figures 5.5 and 5.6, and Table 5.7, there could be discrimination of future LU/LC pattern. The results show that farmland and grazing land could reduce by 64.66 ha/year and ~10 ha/year respectively. However, increase in settlement, barren land, forestland and water body by about 32.60, 26.50, 15.40 and 0.16 ha/year respectively could takes place for the years 2015 to 2030.

5.3.5 Causes of Land Use/Land Cover change dynamics

Even though the extent of event occurrence differ, various natural and human factors are the foremost causes for LU/LC dynamics (Meyer and BL Turner, 1994). However, the effect of population growth rate on land cover dynamics is controversial. Elsewhere, in many literatures rapid rate of population growth rate is one of the root causes for the change of land cover dynamics. According to Barbier and Burgess (1996), instead of negatively affecting, rapid population growth has positive role in availability of resources. On the contrary, particularly in the highlands of Ethiopia in which population pressure is intense resulted for resources erosion and degradation (Grepperud, 1996). Likewise, elsewhere in many parts of Ethiopian high lands, pressure associated with population has argued negative implication on forestland, grazing land, barren land, riparian vegetation and farmland (Tekle and Hedlund, 2000). It is true to Beressa watershed where rapid growth of population brought shortage of land, removal of forest cover, soil erosion and land degradation. However, local communities were motivated by afforestation practices consequently slow increase in forest coverage. In addition, shortage of land resources forced them to cultivate gazing land, barren land and steep slopes. Therefore, resources become more vulnerable for further erosion and degradation consequently shifted to other LU/LC classes.

5.3.6 Implication of Land Use/Land Cover change dynamics

The change of historical LU/LC classes may not necessarily result in land degradation and soil erosion. However, if the change of LU/LC classes is rapidly expanding into farmland, grazing and barren land, fertile soil is more susceptible to massive erosion and degradation, particularly the land surface without dense forest (Tegene, 2002; Maitima et al., 2009). Based on classified images, changes has detected in different land use classes between 1984 and 2015 indicated that grazing land, barren land and forestland cover classes were transferred into farmland and settlement areas. This indicated that how LU/LC classes change overtime accelerate soil erosion, degradation and associated consequences. The shift of other LU/LC classes into farmland is the root cause for intensive erosion, massive degradation, siltation, water borne disseise, and flood.

Likewise,Tegene (2002) explained that rapid expansion of agricultural land into steeper slope has aggravated for erosion and degradation in Ethiopia. Similarly, Amede et al. (2001) illustrated destruction of vegetative cover because of expansion of farming practices into steeper slopes particularly in the highlands of Ethiopia in which intensive farming practices undertaken without appropriate conservation practices has resulted for depletion of fertile soil. Expansions of farmland at the expense of grazing land resulted for insufficient availability of fodder for livestock and affect livestock productivity. Similarly, absence of animals for land preparation and transportation service. Likewise, due to the outflow of gazing land and forced farmers reducing livestock number. Consequently, reduced availability of manure for soil fertility improvement and hence reduced in crop production. The changes of LU/LC classes significantly aggravated the surface runoff, soil erosion, land degradation, sedimentation, siltation, drought, migration, desertification loss of biodiversity, decrease in productivity and increase in famine and could continue as frequent problem of the area for the future. In summary, the study has indicated the causes and consequences of LU/LC changes with overall environment of the study as watershed presented in Figure 5.7.

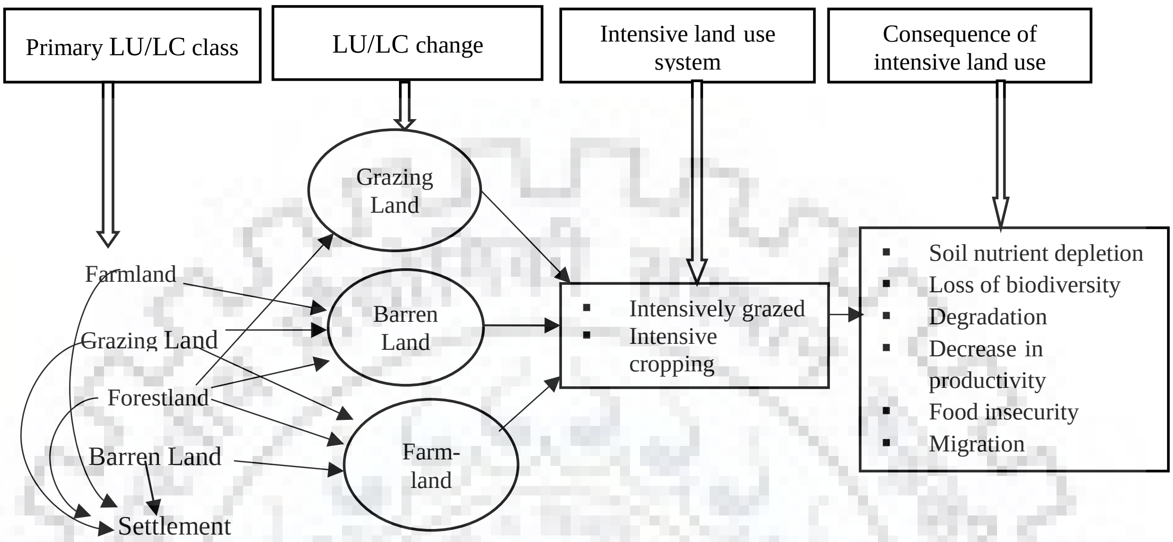


Figure 5.7 Conceptual linkage of cause and consequence of LU/LC changes

5.4 CONCLUDING REMARKS

During the study periods, LU/LC dynamics have undergone considerable changes in the Beressa watershed. The LU/LC dynamics observations showed the expansion of farmland and settlement land areas. On the contrary, grazing land and barren land have declined. In contrast to the findings of other studies elsewhere, Minale and Rao (2012), Garede and Minale (2014) and Asres et al. (2016), even though farming and settlement was rapidly expanded, the trends of forest cover was increased. Increasing of forest cover was possible due to community and household level indigenous tree plantation. The support of government and the efforts of communities are admirable because it is yielding positive impacts in preserving the ecology and the economic wellbeing of the community. The LU/LC dynamics beyond onsite implications, it has offsite environmental implication because of massive soil erosion and land degradation has no limited boundaries. The increasing forest cover is also affecting offsite environmental condition because massive soil erosion and land degradation has reduced. This could be possible due to proper integrated approach of upstream and downstream community under national and international support for environmental and ecological protection. Future prediction of LU/LC was successfully done using Markov Chain model. The model validation was done for the year 2015 using the input of LU/LC data of 1984 to get assurance in the prediction of future land use modelling. Based on future LU/LC change, model simulation results for the year 2030, it can be considered that if the existing trends of land cover dynamics continue without any conservation measures reduction of suitable land for agriculture coupled with rainfall variability and population growth will harm the rural community. Therefore, site-specific management practices and awareness creation about appropriate uses of available resources as well as conservation and rehabilitation of the environment proved to be very effective.

CHAPTER 6

SPATIOTEMPORAL TREND ANALYSIS OF RAINFALL AND TEMPERATURE, AND ITS IMPLICATION ON CROP PRODUCTION

6.1 GENERAL

Change and variability of climate, associated impact and vulnerabilities are the growing environmental issues of the world in the 21st century (Stocker et al., 2013; Pachauri et al., 2014). The issues of global warming is a serious environmental problem, the world experiencing recently (Parry, 2007; Solomon, 2007; Liang et al., 2011; Pachauri et al., 2014). For the achievement of Millennium Development Goal (MDG) with respect to decreasing food insecurity, global warming become greatest constraint. Many countries of the world, particularly sub-Saharan African countries are already affected by the variability of climatic conditions (Conway and Schipper, 2011; Kløve et al., 2014). For instance, the variability, intensity and duration of temperature and rainfall remains variables in crop production especially for developing countries particularly sub-Saharan countries in which the livelihoods of the population are depending on subsistence and rainfed farming (Hulme et al., 2005; Batisani and Yarnal, 2010; Randell and Gray, 2016). For most developing countries of the world, agriculture is the basis of the economy. More than 70% of the world's population the primary source of the livelihoods has originated from weather sensitive agriculture (Suarez et al., 2012; Fazzini et al., 2015). Therefore, the uncertainty of world climatic variability is cause for the impediments of sustaining food security and livelihoods of world's populations (Gebre et al., 2013; Irannezhad et al., 2014).

According to report made by Intergovernmental Panel on Climate Change (Parry, 2007; Pachauri et al., 2014), due to industrialization, anthropogenic emission of different poison gases has been increased and caused the world surface temperature rise by about 1^{o}C. This global warming (increase in surface temperature) may influence the long-term precipitation pattern, in addition to that increase in frequency and intensity of weather shock has led to increase in sea level on the one hand and impacting on water availability (Barnett et al., 2005). In the years to come the adverse effect of global warming will increase unless and otherwise possible measures put into practices (Kumar et al., 2013; Pingale et al., 2014b).

The analysis of vulnerability to climate change for Ethiopia imply in the coming few decades' climate variability and volatility intimidate to social and economic sector (damage to natural resources, agricultural productivity, water resources and ecosystems); therefore, the incidence and intensity of drought and famine occurrence is likely to increase. In the last few decades, incidence of climate change related hazards have manifested in the form of recurrent drought, erosive rain, rainfall variability and flood events (Kenabatho et al., 2012).

Annual, seasonal rainfall, and temperature is influenced by forward and retreat pace of ITCZ and causing interannual rainfall variability over Ethiopia. Therefore, the consecutive occurrence of frequent tropical depression over SWIO (South West Indian Ocean) overlapped with the recurrent drought of Ethiopia (1972 and 1984). For instance *belg* (spring) rain constrained by cyclonic activity than *kiremit* (summer season) rain. When the tropical depression is observed in the SWIO, the daily rainfall is significantly decreased. For the *kiremit* (summer season), the main rainfall source is the northward oscillation of ITCZ and the development of high-pressure systems along the southern Atlantic as well as South Indian Oceans.

Over the past decades, the minimum and maximum average temperature of Ethiopia has increased by about 0.25^{o}C and 0.1^{o}C respectively. Likewise, in the last 50 years the rainfall pattern has manifested by highly variable and volatile (Wu et al., 2016). The fact of climatic variability in the past has been increasing and from the trends suggested in different studies, may further increase in the near future, urgently give emphasis about how the community perceive the extent of climate change in order to design copping and adaptation strategies (Belay et al., 2005). According to climate models applied by various researchers it is found that Ethiopia will see additional warming in all seasons between 0.7^{o}C and 2.3^{o}C by the 2020s and 1.4^{o}C and 2.9^{o}C by the 2050s and the timing, concentration, intensity, duration, and volume of rainfall will vary over the entire parts of the country (Conway and Schipper, 2011; Simane et al., 2012). It has predicted that climate change decreases the GDP growth of the country by about between 0.5 and 2.5% in each year unless climatic shock and variability resilient mechanisms considered (McSweeney et al., 2010; Simane et al., 2012).

The intensity and trend of climatic variability of the study watershed during the last decades is matching with the country and global level conditions; it caused for drastic change of various hydrological parameters (i.e. rainfall, temperature and evaporation) which would have considerable impact on crop productivity, water resources and the overall assets of the community.

Therefore, long-term analysis of climatic trends have been used to characterize the situations (Singh et al., 2008; Subash et al., 2011; Jain and Kumar, 2012; Suryavanshi et al., 2014; Kishore et al., 2016). Many researchers have undertaken trend analysis study of climate in some other parts of Ethiopia (Addisu et al., 2015; Wagesho and Yohannes, 2016). Most of the studies about rainfall and temperature characteristics limited by short-term and long-term time series available for most parts of the regions. Some of the studies conducted based on areal averages of spatial climatic variability (Seleshi and Demaree, 1995; Osman and Sauerborn, 2001). Whereas, other studies emphasised on very limited stations and arrived at a conclusion of fully the characteristics of spatial climatic variability of the whole regions (Gamachu, 1988; Meze-Hausken, 2004), others have done on specific topics particularly on climate change and its effects (Fazzini et al., 2015). Some other studies used seasonal or annual rainfall and temperature trend and variability analysis (Conway and Schipper, 2011). It is inconclusive due to diversity of geography and the role of elevation has significantly influence rainfall and temperature distribution of the region (Gamachu, 1988; Gebre et al., 2013). However, local farmers evaluate climatic variability in relation to their crop productivity. However, such studies ignored the localized trends of rainfall and temperature particularly in most highlands of Ethiopia. Additionally, studies of rainfall and temperature variations in general emphasized on larger areas would be of insignificant use for the local level agricultural production (Gebre et al., 2013).

Therefore, knowing clear information about the annual and seasonal rainfall distribution are significantly important for policy planners and local users. In this regards, Precipitation Concentration Index (PCI) is widely used methods employed by many scholars across the globe (Oliver, 1980; Apaydin et al., 2006; Rashid et al., 2015). Results obtained from PCI signifies that the higher values, higher annual and seasonal rainfall concentration and vice versa. Generally, local scale spatiotemporal climatic variability and its implication on crop production in Ethiopia particularly in the Beressa watershed is yet not known and remains to be studied. Therefore, information related to various climatic parameters of the area to the local level has paramount important in order to plan other development issues. Therefore, this study has undertaken with the main objectives of spatiotemporal analysis of climatic parameters (rainfall and temperature) and its impact on crop production using various analysis techniques.

6.2 MATERIALS AND METHODS

6.2.1 Description of study area

Detail study area descriptions have been already discussed in chapter 3

6.2.2 Data used

The rainfall and temperature of daily record of 35 years (1980 to 2014) for Beressa watershed obtained from the National Meteorological Service Agency of Ethiopia (NMSA) for seven stations; hence, monthly, seasonally as well as rainfall on annual basis were derived from daily data. The long-term trend rainfall was assessed for monthly, seasonally viz., *kiremit* season (June – September), *belg* season (March–May), *bega* season (October–February) and annually for all subdivisions. While the long-term trend of temperature was assessed for annual average, annual minimum and maximum temperature. The available data of crop production (Q/ha) for 18 years (1997 to 2014) for the major crops such as barley, wheat, beans, peas, lentil and chickpea have obtained from district office of Agriculture and Central Statistical Authority (CSA). In this study, to manage the data quality, data series was plotted in order to identify the outliers. Afterward visual identification of the outliers, each of the value has obtained using normal ratio technique. Additionally, serial correlation was tested. Therefore, based on the results obtained no need of filling the data; all the series were without gap.

6.2.3 Methodology

6.2.3.1 Precipitation Concentration Index (PCI)

In order to know the variability, heterogeneity and concentration of rainfall in time and space, the Precipitation Concentration Index (PCI) has employed. The guidelines for interpretation has presented in Table 6.1

The Precipitation Concentration Index has used as indicator of concertation and variability of rainfall was obtained as follows (Oliver, 1980; Murugan et al., 2008; Iskander et al., 2014):

$$PCI_{annual} = \left[\frac{\sum_{i=1}^{12} P_i^2}{(\sum_{i=1}^{12} P_i)^2} \right] * 100 \qquad (6.1)$$

Where:

Pi= the amount of rainfall in ith months

∑= summation of precipitation for over the 12 months.

The interpretation of PCI value as suggested by (Oliver, 1980) as follows:

Table 6.1 Interpretation of PCI results

PCI value	Interpretation
<10	Uniform distribution of precipitation (Low concentration)
11-16	Moderate distribution of precipitation (Moderate concentration)
16-20	Irregular distribution of precipitation
>20	Strong irregularity of precipitation distribution

According to Michiels et al. (1992), calculation and evaluation of precipitation concentration index in the form of seasonal and annual based. For seasonal PCI, the Ethiopian seasons are divided into three seasons. Therefore, the PCI obtained on a seasonal scale also viz., *belg* season (spring, March to May), *bega* season (winter, October to February) and *kiremit* season (summer, June to September) using the following formula:

$$PCI_{belg\ season} \left[\frac{\sum_{i=1}^{3} p_i^{2}}{\left(\sum_{i=1}^{3} p_i \right)^{2}} \right] * 25 \tag{6.2}$$

$$PCI_{bega\ season} \left[\frac{\sum_{i=1}^{5} p_i^{2}}{\left(\sum_{i=1}^{5} p_i \right)^{2}} \right] * 42 \tag{6.3}$$

$$PCI_{kiremit\ season} \left[\frac{\sum_{i=1}^{4} p_i^{2}}{\left(\sum_{i=1}^{4} p_i \right)^{2}} \right] * 33 \tag{6.4}$$

6.2.3.2 Trend analysis

Rainfall and Temperature data indicates the long-term change pattern or change of the data in a given temporal and spatial time scale. Therefore, in order to describe the increasing, decreasing trend or no trend over time, MK trend test has employed. It is one of the most widely used method of non-parametric statistical test used to check the trend of randomness against the detection of trends over time (Mann, 1945; Kendall, 1975). Such statistical test is popular and important tool in detecting the trend used by many other scholars for related applications (Hirsch et al., 1982; Burn and Elnur, 2002; Yue et al., 2002; Suryavanshi et al., 2014; Mondal et al., 2015; Pingale et al., 2016).

The trends of Mann-Kendall (S) statistic test used to detect normalized *p*-value for the significant test. Sequential order data should be required to perform the Mann-Kendall trend analysis. First, decide the sign of sample results (difference between series successive samples). Sign (X_j-X_k) is used to display the function resulted in the values 1, 0, or -1 on the basis of X_j-X_k, in which j>k, the function is computed using the following equations:

$$S = \sum_{k}^{n} \sum_{j=k+1}^{n} \left(X_j - X_k \right) \tag{6.5}$$

Where,

$$sign\,(X_j - X_k) = \begin{cases} 1, X_j > X_k \\ 0, X_j = X_k \\ -1, X_j < X_k \end{cases} \tag{6.6}$$

Where:

X_j and X_k are the value of sequential rainfall and/or temperature in the month of j and k (j >k) respectively.

While, the positive value is used to show increasing trend on the other hand the negative value reveals a decreasing trend.

Let X_1, X_2, X_3…………. X_n signifies 'n' data points (for monthly as well as annually), in which X_j signifies the data point at time of j.

These test statistics represent the difference between positive and negative difference. According to Helsel and Hirsch (1992), for the samples in which large in number (N>10), the statistical test is employed using normal distribution with mean E(S) as well as variance Var(S), in which, E(S)=0

$$E(S) = 0 \tag{6.7}$$

$$Var(S) = \frac{1}{18}\left(n(n-1)(2n+5) - \sum_{k=1}^{m} t(t-1)(2t+5) \right) \tag{6.8}$$

Where:

N= number of tied observations

m is the number of tied groups (in which a set of data samples having the similar values in the observations)

t is the data points tied in k^{th} group

When the value of S is positive value, it confirms sign of upward trend, whereas when there is negative value, which specifies a downward trend. A standardized test statistic of Z has obtained by the following formula:

$$Z = \begin{cases} \frac{S-1}{\sqrt{VAR(S)}} & if\ S < 0 \\ 0 & if\ S = 0 \\ \frac{S+1}{\sqrt{VAR(S)}} & if\ S < 0 \end{cases} \quad (6.9)$$

Z_0 is null hypothesis which signifies the trend is not significant, it is recognized if Z statistics is insignificant statistically ($-Z\alpha/2 < Z < Z\alpha/2$), where $Z\alpha/2$ is standardized normal differ. For the purpose of this study, two different level of significance has considered (at 1 and 5% level of significance).

Sen's Slope Estimators

In the process of determining the trend magnitude and variability of rainfall and temperature throughout long-term time series, Sen's slope estimators widely used method (YUE et al., 2003; Partal and Kahya, 2006), using the following equations:

$$T_i = \frac{x_j - x_k}{j-k} \quad (6.10)$$

For i=1, 2, 3,…N

Where:

The value of X_j and X_k is used to represent the data value at the time of j as well as k in which j is greater than k, the median of the N values of Ti termed as estimator of Sen's slope of slopes, the value can be calculated by the following formula:

$$\beta = \frac{1}{2}\left(T_{\frac{N}{2}} + T_{\frac{N+2}{2}}\right) \quad if\ N\ is\ even \quad (6.11)$$

$$\beta = T_{\frac{N+1}{2}} \quad if\ N\ is\ odd \quad (6.12)$$

Where:

If the β value is positive, infer upward trend in reverse the negative value indicates decreasing trend of climatic variables in the long-time series.

The percentage change for over a periods of time can be obtained from Sen's median slope and mean by assuming the linear trend in the long-term series using the following formula:

$$\%\ Change = \left(\frac{\beta * length\ of\ \ period}{mean}\right) \quad (6.13)$$

Where: β is Sen's slope

6.2.3.3 Moving average

In statistical term, moving average is also known as running an average, used in order to explore a set of various data by creating average value of various subsets for data set. Moving average possibly acquired by initially considering the initial subset average. Value of fixed subset is hence moved forward, in order to create a number of new subset, known as average. Such process is repetitive for the whole data sequence. The line connecting the fixed average is known as averagely moving. Therefore, moving average value is referring not a single number; rather it shows a set of numbers.

6.2.3.4 Rainfall and temperature spatial analysis

Inverse Distance Weighted interpolation methods (IDW) has used in order to analyse annual and seasonal rainfall and temperature. According to Gemmer et al. (2004), the theory of interpolation surface would likely more influenced by nearby stations and vice versa. Therefore, average annual and seasonal rainfall were interpolated using ArcGIS 10.2. The value of IDW (Yavuz and Erdoğan, 2012) obtained by the following general formula:

$$Z(S_0) = m\sum_{i=1}^{N} \lambda_i Z(S_i) \tag{6.14}$$

Where:

The prediction value of $Z(S_0)$ is used for the location of S_0 ; N is the number of measured points encompassing prediction location; λ_i is the weight, which is alloted for each of the measured points; Z(Si) used to indicates observed values in the Si location.

The value of weighting referred to as the function of the inverse distance. To determine the weighting the following general formula is employed (Yavuz and Erdoğan, 2012):

$$\lambda_i = \frac{d_{i0}^{\ -p}}{\sum_{i=1}^{N} d_{i0}^{\ -p}} \tag{6.15}$$

The IDW techniques needs the choice of the parameters as well as a search radius. The power parameters (p) controls measured values significance on the value of interpolation on the basis of the distance of output points (d) (Yavuz and Erdoğan, 2012). Selection of comparatively larger power parameters confirms higher degree of local impact hence give the output surface in further detail. Finally, in order to get better insight about crop production, seasonal and annual rainfall and temperature relationships with crop production Pearson correlation analysis has used.

6.3 RESULTS AND DISCUSSION

6.3.1 Rainfall trends and variability

To study temporal and spatial climate pattern of Beressa watershed, trend analysis associated with seasonal and inter-annual rainfall, and annual mean, minimum as well as maximum temperature time series climatic variables have been investigated.

6.3.1.1 Seasonal rainfall pattern

The total annual rainfall of the Beressa watershed varies from 698.5 mm to 1100 mm in the last three and half decades. Even though the rainfall indicates seasonal and inter-annual variability, the area is characterised by bimodal rainfall regime, with maximum rainfall concentration during *kiremit* (summer) season, which extends from June to September. The *belg* (spring) season known by small rainy season covers three months extend from March to May and on the other hand dry season known as *bega* (winter) season covers from October to February. During these seasons, rainfall are highly variable than the main rainy season of the area.

Results from coefficient of variations shown in Table 6.2 revealed that in comparison with *kiremit* rainfall season, during *bega* and *belg* seasons rainfalls vary much more. Elsewhere, in other parts of Ethiopia similar concluding remark driven by Merasha (1999); Seleshi and Zanke (2004), that *bega* and *belg* rainfall seasons are highly variable than main rainy season (*kiremit* season). Study by Mekasha et al. (2014), arrived at a concluding remark that a general tendency of increasing warm temperature and extreme variability and inconsistence trend of precipitation has recorded in Ethiopia.

The share of *kiremit* season to annual rainfall of the study area extends to 85% and the *belg* season also has considerable share to the total annual rainfall contribution, however, it has manifested by fluctuation throughout the years.

Calculated Precipitation Concentration Index (PCI) for seasonal as well as inter-annual rainfall distribution for the spatiotemporal time series shown using Table 6.2. The rainfall distribution during *belg* and *kiremit* season, it is found that there has been moderate concentration of precipitation throughout all the seasons, which inferred that there is no uniform distribution. Whereas, during the *bega* season significant change of Precipitation Concentration Index has shown, thus concentration of precipitation is increasing and therefore, rainfall become more erratic. In line with Rashid et al. (2013), elsewhere in South Australia of Onkaparinga sub catchment and catchment, monthly rainfall heterogeneity was tested using PCI and interannual and seasonal variability of PCI was observed.

Table 6.2 Summary of annual and seasonal rainfall, coefficient of variation and Precipitation Concentration Index

Stations	Annual			*Kiremit*			*Belg*			*Bega*		
	Average	CV	PCI	Average	CV	PCI$	Average	CV	PCI	Average	CV	PCI
DB	1083	0.17	23.98*	740	0.277	12.13	135.9	0.471	11.31$	62.1	1.2	19.26#
DBS	1096	0.17	20.00#	188	0.18	13.20	57	0.55	12.40$	13	0.54	22.10*
SH	1012	0.51	21.00*	185	0.17	11.50	64	0.61	11.80$	15	0.78	20.50*
GIN	1089	0.21	19.50#	201	0.11	12.00	70	0.54	16.40#	28	0.91	20.90*
ENW	1097	0.13	20.70*	227	0.21	13.20	94	0.63	13.40$	18	0.66	18.60#
HG	1081	0.21	19.00#	212	0.31	11.60	87	0.50	15.00$	30	0.72	21.00*
SD	1007	0.11	20.00#	194	0.24	12.70	77	0.51	14.50$	20	0.82	19.20#

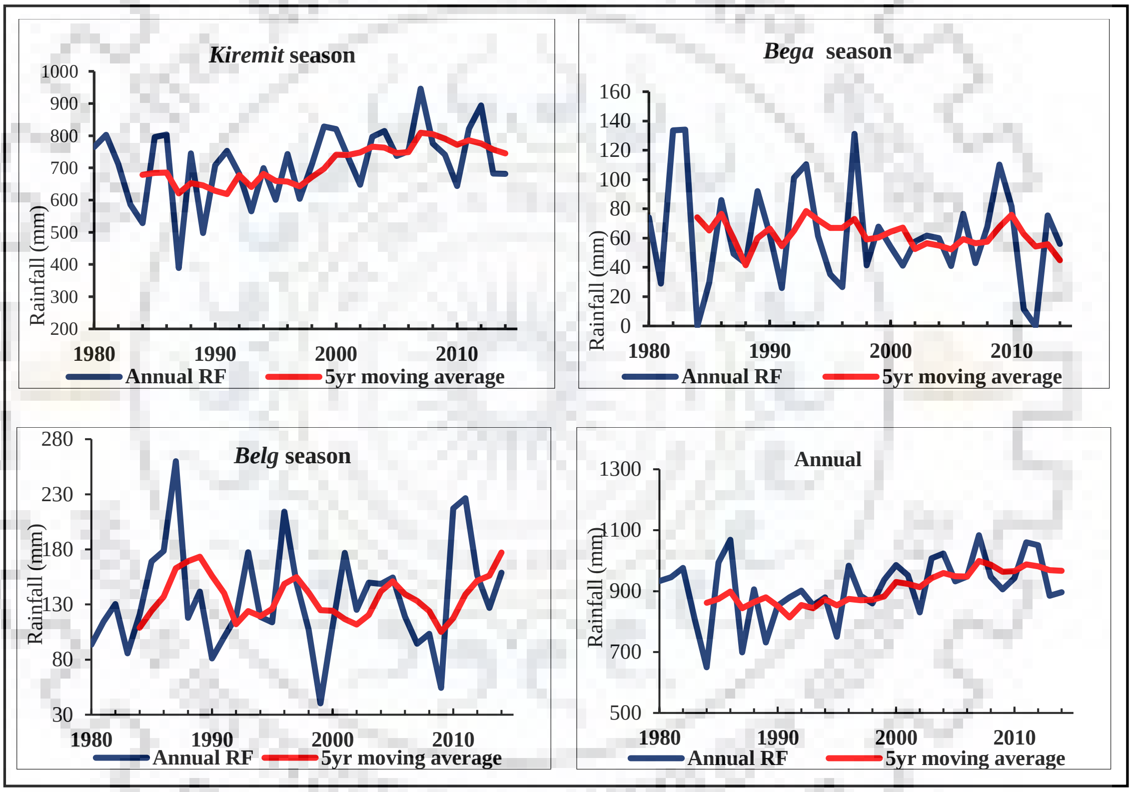
Where; $ is moderate; # is irregular; * is strongly Irregular

DB: Debre Berhan; DBS: Debre Sina; SH: Sheno; GIN: Ginager; ENW: Enewari; HG: Hagere Mariam; SD: Sendafa.

Likewise, as presented Table 6.2, the distribution of annual rainfall has shown very low values with high Precipitation Concentration Index. Therefore, the interannual rainfall distribution has irregular and very erratic.

6.3.1.2 Trend and variability of seasonal and annual rainfall

As shown in Figure 6.1, during the period 1980 to 2014 the seasonal rainfall trend of Beressa watershed, for the *kiremit* season shows less rainfall variability throughout the study periods. Contrary to *kiremit* season, the 5yrs moving average annual rainfall of the *bega* season during the periods of 1980 to 2014 indicates highly variable. However, in the *belg* season during the periods of 1980 to 2014 5yrs average moving annual and seasonal rainfall considerably variable. The variation for *belg* season has presented in Figure 6.1.



NB: *Kiremit*: Summer; *Belg*: Spring; *Bega*: winter

Figure 6.1 5yrs moving average rainfall (1980 to 2014)

From all the subdivision of 5yrs moving average long-term seasonal rainfall except *bega* season shown positive trend during the 35 years periods. During the *belg* (small rainy) season rainfall the subdivision indicates slightly increasing trend and *bega* season (dry season) shows negative trend as already presented in Figure 6.1. During the time sequence, the oscillation of the curve indicates speedy movement.

Average annual aerial rainfall of Beressa watershed is 891 mm, with the coefficient of variation of 30.6% and standard deviation of 227 mm. The periodic pattern of rainfall is manifested by changing of dry as well as wet years. Of total observation of 35 years periods, record of 16 years (45.7%) has been lower than the total annual rainfall of the area on the other hand 19 years (54.3%) recorded more than the annual average rainfall. The incidence of negative anomalies happened in the periods during 1980s and 1990s (14 from 16). In the year between 1981 and 1984, the annual total rainfall has far lower than the mean long-term rainfall. During the year 1985 and 1986 the rainfall has been recorded slightly above the mean. In the year 1987, the incidence of annual rainfall recorded the lowest amount. Even though some recovery has been emerged in the year during 1988, 1992 and 1996, until the year 1998 the long-term annual rainfall has been lower than the mean. However, after 1999 and onward recovery in the long-term average rainfall have been emerged higher than the average mean except the experience of drier condition for the year 2002 and 2013 which is lower than the long-term mean. In line with study by Wu et al. (2016), overall in the last 35 year period 5yrs moving average of the long-term average annual rainfall shows a slight variation (Figure 6.1).

6.3.2 Annual temperature trend and variability

The time series of 5yrs moving average minimum and maximum temperature was analysed during the periods of 1980 to 2014. Temperature variability significantly exhibit in the Beressa watershed during 35 years period. Beside high level of temperature variability, the overall average temperature of the area has significantly increasing throughout the years. Before 35 years, the maximum temperature has been 19.40°C and the minimum temperature has 6.20°C with the average temperature of 12.80°C, while the time series maximum temperature has increased to 20.50°C and the minimum temperature has increased to 7°C with the average temperature recorded 13.75°C (Figure 6.2). From the Figures, it is confirmed that the maximum temperature has continuously increasing by about 1.10°C whereas the minimum temperature has increased by about 0.70°C. The trend of increasing maximum temperature has stronger than the minimum temperature. In overall, the 5yrs moving average trend of average annual temperature of the study watershed is increasing by about 0.95°C. The present results have been in agreement with (Parry, 2007). They stated due to prolonged increase in emission of gasses through human activities and expansion of industry consequently the surface temperature increased by about 1°C. Likewise, the increase of surface temperature adversely affecting the availability of water resources, distribution, intensity and magnitude of rainfall in the long run (Barnett et al., 2005).

The rate and variability of increasing temperature have dramatically faster, make worse and difficult between local community to foresee the intensity and magnitude of temperature even for the next few years. In another study by Di Falco et al. (2012), it has found that due to changing of the global climate the eastern part of Africa including Ethiopia drying out. There is a continuous decrease in duration and distribution of rainfall during the last thirty-five years. In reverse, the surface temperature has significantly increasing. Generally, as can be seen from Figure 6.2 there has been high increase of overall temperature, which may result in decrease in productivity and food insecurity.

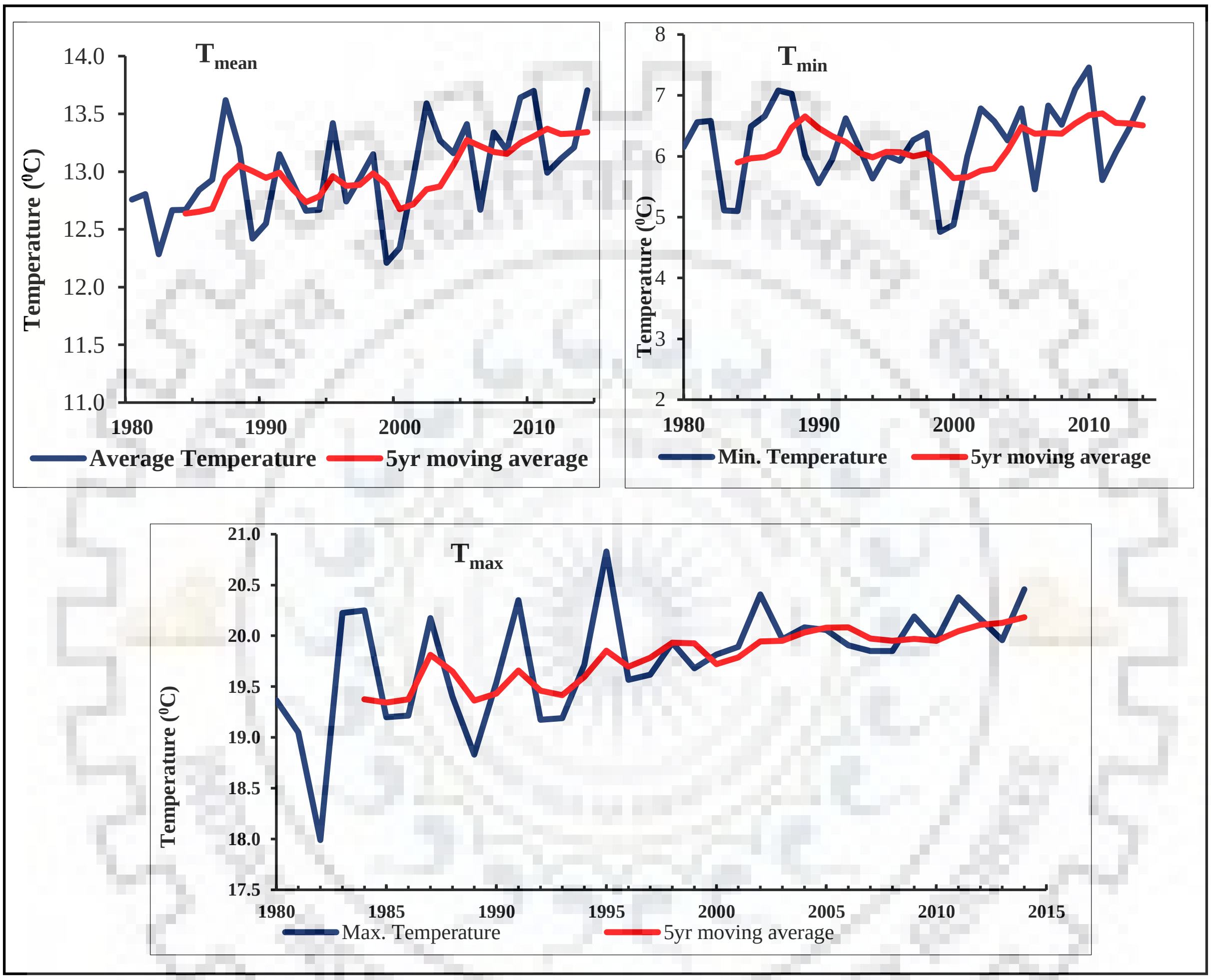


Figure 6.2 5yrs moving average temperature (1980 to 2014)

6.3.3 Mann-Kendall test statistics

According to Anderson (1942), to exclude the influence of serial correlation, before using MK test statics, serial autocorrelation are tested by Lag-I autocorrelation using different level of significance (0.01%, 0.05% and 0.1%). Depending on the test, the observed data are serially independent therefore to detect the trend at 1%, 5% and 10% level of significance the MK trend test has been used to the actual data series (Xu et al., 2007; Fu et al., 2009).

The statistics of MK test on seasonal as well as annual rainfall, and minimum and maximum temperature for Beressa watershed are presented in Tables 6.3 and 6.4 respectively. The spatiotemporal rainfall and temperature distribution are presented in Figures 6.3 and 6.4 respectively. The detail of test statics are discussed in the subsequent sections.

The MK test statistic (Z_{mk}) of the annual rainfall trend analysis has showed statistically significant only in two stations out of seven stations (one station at 5% and one at 10% level of significance) and in three stations the annual rainfall showed decreasing trend, while in four stations showed increasing trend. The detail of these seven stations are already presented in Table 6.2. The results revealed that the magnitude of significantly increasing trend and variability was observed in mean annual rainfall for DB station (at 0.28 mm/year and 1.07%). However, the magnitude of significant decreasing trend was observed in HG station (at -8.62 mm/year and -27.88%).

Seasonal analysis of rainfall obtained from MK test statistic results are presented in Table 6.3. Out of seven stations, one station revealed statistically significant increasing at 5% during *kiremit* season. Out of seven rainfall stations, only two stations (one at 5% and one at 10% level of significance) showed significant trend during *belg* season and during *bega* season, four stations (three at 5% and one at 10% level of significance showed a significant trend.

The Sen's slope estimator has employed after Mann-Kendal test statistics in order to figure out the change and variability of rainfall and temperature as per unit time observed trend throughout the time series. As presented in Table 6.3, the Sen's slope estimator indicates upward trend in four stations and downward trend in three stations for annual rainfall. While positive trend of *kiremit* season rainfall showed in all stations and the trend of rainfall during *belg* season revealed the positive trend in six stations out of seven stations. However, during *bega* season the trend of all stations showed downward trend. This is probably due to the fluctuation and variability of seasonal and inter-annual rainfall pattern of the Beressa watershed during the last few decades as indicated in Table 6.3, which is similar to others study (Muhire and Ahmed, 2015; Zhao et al., 2015). The negative trends shown in each seasons inferring seasons becoming into dry condition in the last 35 years. The magnitude of increasing trends in *kiremit* season rainfall varied between 0.33 mm/year and percentage change of 6.13% (DBS station) to 1.62 mm/year and 31.79% (DB). However, the magnitude of significantly decreasing trend was observed at SD station (-0.90 mm/year and -16.20% change) and significantly decreasing trend of *belg* season rainfall varied between -0.12 mm/year and -10.00% in GIN station to significantly increasing trend 0.40 mm/year and 30.00% in DB station. The results of *bega* rainfall trends revealed that significantly decreasing trend in four stations out of seven stations. The magnitude of decreasing trend found to be -0.06 mm/year and -7.50% in GIN station,

-0.05 mm/year and -8.80% at SD station,-0.11 mm/year and -12.70% at HG station, -0.13 mm/year and -29.00% change at SH station, -0.19 mm/year and -53.00% in DB station, -0.19 mm/year and -35.00% and -0.20 mm/year and -56.40% change in DBS station. Even though the slope of Sen's estimator for *kiremit* season, annual rainfall, and *belg* season rainfall indicate positive trend, it does not reflect sufficient availability of rainfall, as the rainfall distribution has erratic, irregular and variable in distribution (as already indicated by Figure 6.1 and Table 6.2). Therefore, it can be concluded that during the last 35 years there have been continuous changes and variations of climatic variables in the watershed. On the basis of results obtained from the MK test (Z_{mk}), it is a key agenda to discuss the intensity and magnitude on the economical and socio-ecological impacts of climatic variability in the Beressa watershed, if the seasonal rainfall variability continuously increasing in the future. Particularly for the local community in which the economy is susceptible to variability and erratic nature of annual and seasonal rainfall, water shortage, and recurrent drought are the common phenomenon. Therefore, appropriate adaptation strategy designed has to be inclusive in the development agenda to reverse the trend. Unless and otherwise the vulnerability of the local community further expose to environmental shock.

Based on the Mann-Kendall's test (Z_{mk}) results, the mean annual temperature revealed the statistically significant increasing trend in five stations (two stations at 5% significance level whereas three stations at 10% significance level). The long-term minimum temperature has shown increasing trend, which is significantly increasing at 5% and 10% level of significance in four stations and one station out of seven stations respectively. Long-term annual maximum temperature, out of seven stations (three stations at 5% significance level while two stations at 10% significance level) have shown significantly increasing trend.

The significant increasing trend of mean annual temperature (Table 6.4) found in all stations; with the trend magnitude vary from 0.03°C/year to 0.14°C/year respectively. The percentage changes of mean annual temperature was found to be at maximum for SD station (31.30%) and at minimum change for DB station (7.60%). Significantly, increasing trend in minimum temperature has observed with minimum value of 0.005°C/year in GIN station to maximum value of 0.12°C/year in DBS station. The percentage changes in minimum temperature was found to be at minimum (1.90%) and maximum (52.40%) in GIN and DBS stations, respectively. Likewise, the magnitude of increasing trends of maximum temperature were observed in all stations with minimum value of 0.023°C/year in GIN station with the maximum value of 0.21°C/year in ENW station. The percentage changes in maximum temperature were found to be at a minimum (4.00%) and maximum (37.60%) in the GIN and ENW stations respectively. Significantly, increasing long-term annual minimum and maximum temperature during the study periods indicates that it is more likely this would contribute to the increase of mean annual temperature.

Table 6.3 Summary statistic of MKs test (Z_{mk}), Sen's Slope estimator (β) and change in % of annual and seasonal rainfall (1980 to 2014)

Stations name	Rainfall (mm)											
	Annual			Seasons								
				Kiremit			*Belg*			*Bega*		
	Zmk	β	%change	Zmk	β	%change	Zmk	β	%change	Zmk	β	%change
DB	0.26*	0.28	1.07	0.35*	1.62	31.79	0.07**	0.40	30.00	-0.04**	-0.19	-53.00
DBS	-2.00	-0.99	-3.16	0.42	0.33	6.13	0.06	0.23	13.69	-1.50*	-0.21	-56.40
SH	0.42	1.20	4.14	0.60	0.96	18.10	0.31	0.20	10.57	-0.50	-0.13	-29.00
GIN	-3.10	-2.10	-6.74	0.30	1.02	17.70	-1.12*	-0.21	-10.00	-1.20*	-0.06	-7.50
ENW	0.30	1.21	3.85	0.40	1.50	23.00	0.42	0.31	11.00	-1.70*	-0.19	-35.00
HG	-3.50**	-8.62	-27.88	0.51	1.08	17.80	0.05	0.04	1.50	-0.64	-0.11	-12.70
SD	1.50	1.04	3.62	-0.12	-0.90	-16.20	0.80	0.06	2.80	-0.55	-0.05	-8.80

Where, * shows significant and ** significant at 5% and 10% level of significant respectively. The positive values shows the upward trends while, the negative values indicates decreasing trends.

Table 6.4 Summary statistic of MKs test (Z_{mk}), Sen's Slope estimator (β) and change in % change of mean annual, annual minimum and annual maximum temperature (1980 to 2014)

Stations name	Temperature (°C)								
	T_{mean}			T_{min}			T_{max}		
	Z_{mk}	β	%change	Z_{mk}	β	%change	Z_{mk}	β	%change
DB	0.06	0.03	7.60	0.05*	0.07	34.12	0.05**	0.064	10.95
DBS	0.13**	0.11	27.60	0.06	0.12	52.40	0.31	0.12	21.10
SH	0.92**	0.09	21.50	0.20	0.03	11.20	0.50**	0.08	13.80
GIN	0.04*	0.04	9.40	0.40*	0.005	1.90	0.62	0.023	4.00
ENW	0.06	0.05	11.50	0.23**	0.06	37.90	0.54*	0.21	37.60
HG	0.01*	0.061	13.40	0.31*	0.05	24.20	0.33*	0.12	19.90
SD	0.12**	0.14	31.30	0.07*	0.06	22.80	0.07*	0.031	5.70

T_{mean} is represent the mean annual temperature; T_{min} is minimum annual temperature; T_{max} is maximum annual temperature.
Where, * shows significant and ** significant at 5% and 10% level of significant respectively. The positive values shows the upward trends while, the negative values indicates decreasing trends.
The detail of these stations is already presented in Table 6.2.

6.3.4 Spatiotemporal rainfall and temperature distribution

Assessing the long-term spatiotemporal rainfall distribution pattern is the most significant components in the climate analysis in a certain country more specifically at the local and regional level. Therefore, exploring spatial analysis has a significant role in understanding the local as well as the regional climatic pattern (Boyles and Raman, 2003).

The spatial distribution pattern of annual and seasonal rainfall for Beressa watershed is shown in Figure 6.3. As can be seen from this figure during summer season locally called *kiremit* season the distribution of rainfall slightly better than spring and winter season, which is varied from 45-95 mm/season and 12-31 mm/season respectively. The annual rainfall distribution also variable in time and space. The coefficient of variation is higher during *bega* and *belg* season rainfall than rainy season (*kiremit* rainfall season) as already presented in Table 6.2. The variability of annual rainfall distribution is may be due to the variability of spring and winter rainfall distribution.

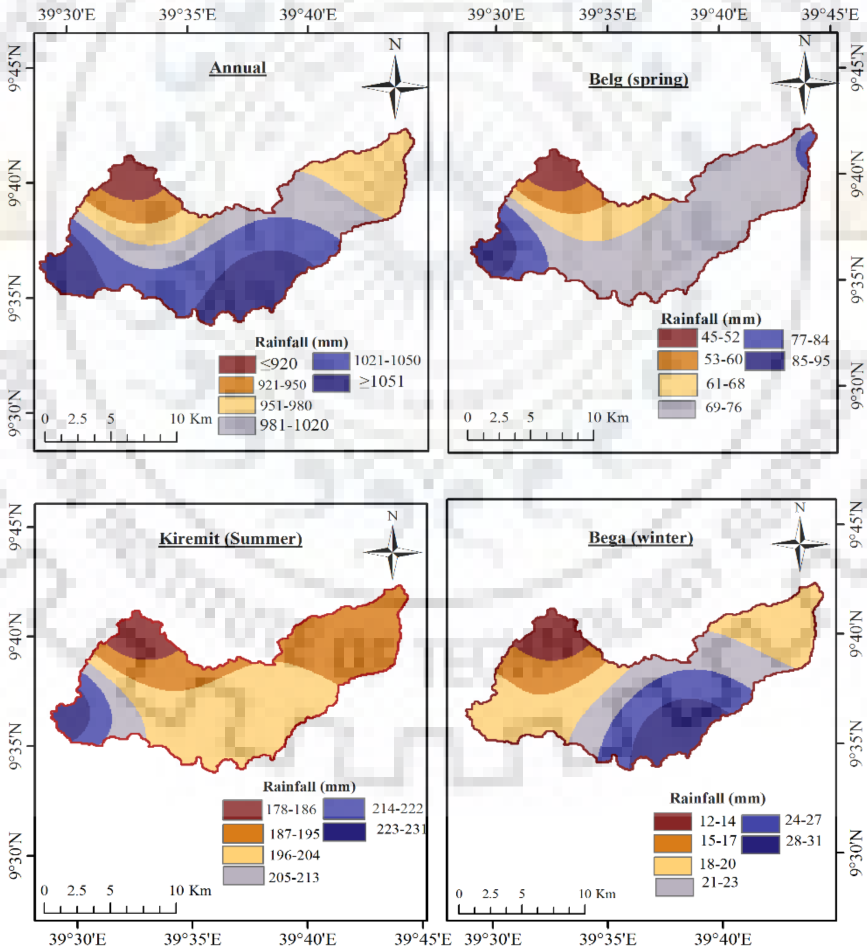


Figure 6.3 Spatial rainfall distribution

Figure 6.4 showed the spatiotemporal distribution of mean annual, minimum and maximum temperature of Beressa watershed. From the results of MK test statistics and IDW revealed that variability and continuous increase of temperature have registered. The mean annual temperature varied between 13^{o}C to 15.5^{o}C, as well as the annual minimum and maximum temperature varied between 5^{o}C to 9.5^{o}C respectively.

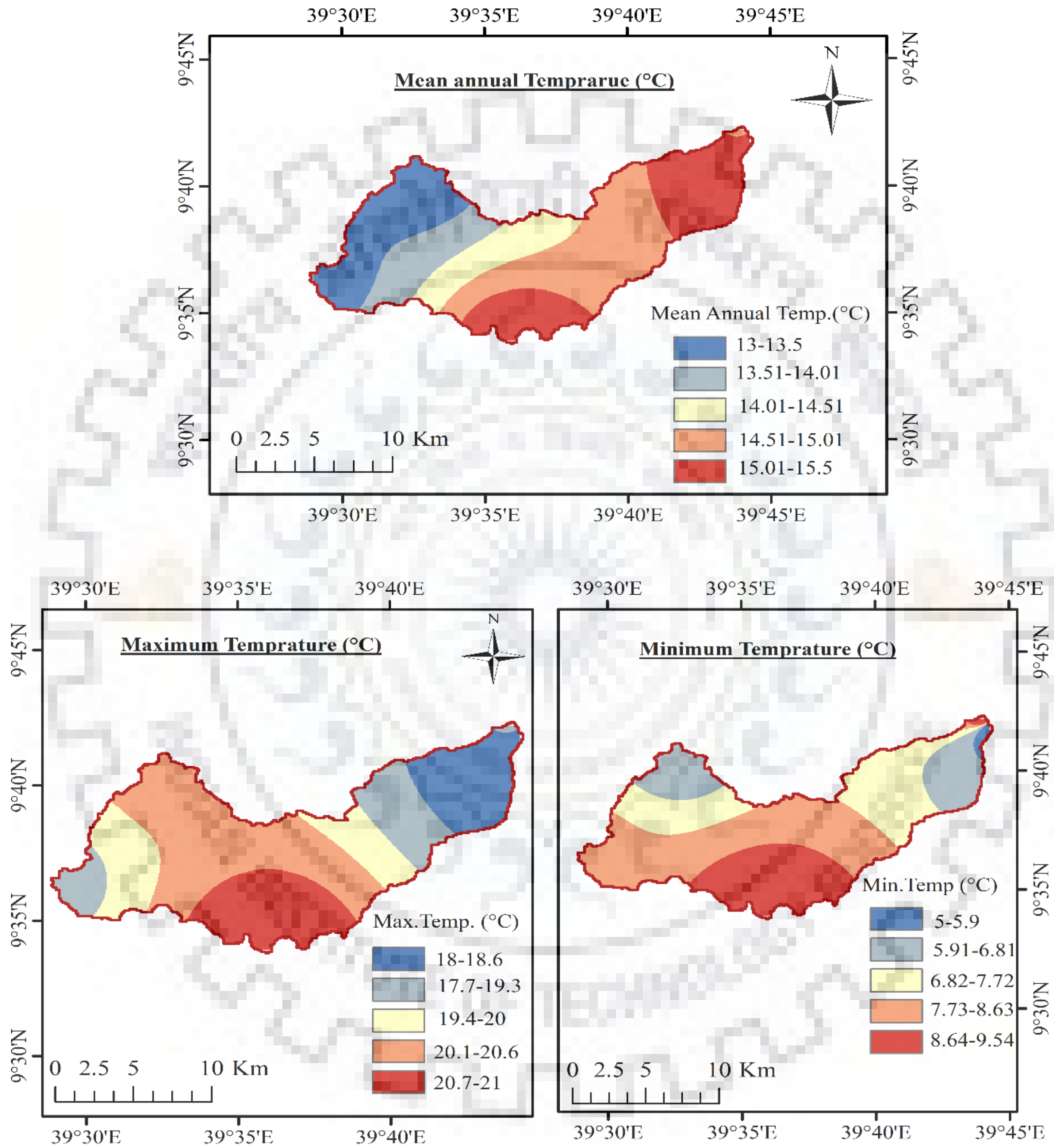


Figure 6.4 Spatial distribution of temperature

6.3.5 Climate-Crop production relationships

The results of correlation analysis between crop production and climatic variables (rainfall and temperature) during the periods of 1997 to 2014 are given in Table 6.5. All the given crops shows considerably high correlation with *belg* rainfall. Rainfall registered annually shows weak correlation with crop productions. In order to know the yields therefore, annual rainfall has less contribution for prediction. With respect to statistical significance level, only barley and wheat crops have significantly related with *belg* and *kiremit* rainfall, which have stronger correlation between them. The correlation between rainfall during the month of May to September and crops has positive relationships except bean, peas and chickpeas shows inversely correlated with rainfall during the month of June. Barley and wheat production shows considerably high correlation with rainfall during the months of May and June. All crops production shows considerably high correlation with maximum temperature and stronger correlation with barley, while in case of minimum temperature, poor correlation observed for all crops.

Table 6.5 Correlation between crop production, and rainfall and temperature (1997 to 2014)

Variables	Barley	Wheat	Bean	Pea	Lentil	Chickpea
Rainfall						
Annual	0.05	0.02	0.12	0.12	0.12	0.02
Belg	0.35*	0.32*	0.29	0.24	0.25	0.25
Kiremit	0.61*	0.56**	0.12	0.07	0.13	0.03
May	0.46**	0.45**	0.28	0.19	0.14	0.28
June	0.48	0.48	-0.09	-0.04	0.02	-0.06
July	0.12	0.09	0.19	0.10	0.12	0.19
August	0.07	0.03	0.08	0.001	0.10	0.04
September	0.15	0.22	0.14	0.09	0.11	0.18
Temperature						
T_{min}	0.28	0.27	0.27	0.35	0.25	0.28
T_{max}	0.51*	0.31	0.47*	0.41	0.41	0.48*

*significant @ 0.05 level, ** significant @ 0.01level

Although correlation coefficients of crop production and climatic variables are positive, in terms of statistical significance most of them shows insignificant correlation, except barley and wheat, which are significantly correlated with *belg, kiremit* season and during the month of May. Barley, bean and chickpea shows significant correlation with maximum temperature. The possible reason may be monthly, sub-monthly time scale, temporal and spatial distribution of rainfall and temperature, which are determinant factors of production. According to Al-Bakri et al. (2011), rainfall dependent agriculture particularly in developing countries are highly susceptible and vulnerable to the increase in temperature and in reverse decreasing in rainfall hence, adversely affect crop production. Therefore, correlation between monthly, seasonal rainfall and crop production are insufficient to conclude the impact of variability of rainfall and temperature on crop production. In the study area, June is the sowing period for barley and wheat crops. This cereal crop shows stronger correlation with the *kiremit* rains. The production of wheat was less than 18 years mean in eight years out of eighteen, whereas, barley crop production was lower than 18 years mean in nine years out of the total eighteen years as of *kiremit* rainfall.

Bean, peas, chickpeas and lentil productions are particularly related to *kiremit* rains in all stages because of the fact that this crops are sown in the second week of June, the rain of *kiremit* season is critically essential but it extend to *bega* season during harvesting stage. The production of beans was below 18 years mean in nine years out of eighteen, which accounts 50% of the total bean production, in respect of *kiremit* rainfall pea, chickpea, and lentil production (50%, 50% and 55.5% respectively) was below its 18 years mean. As can be seen in Figure 6.5 the growth of annual crop production is nearly stagnant.

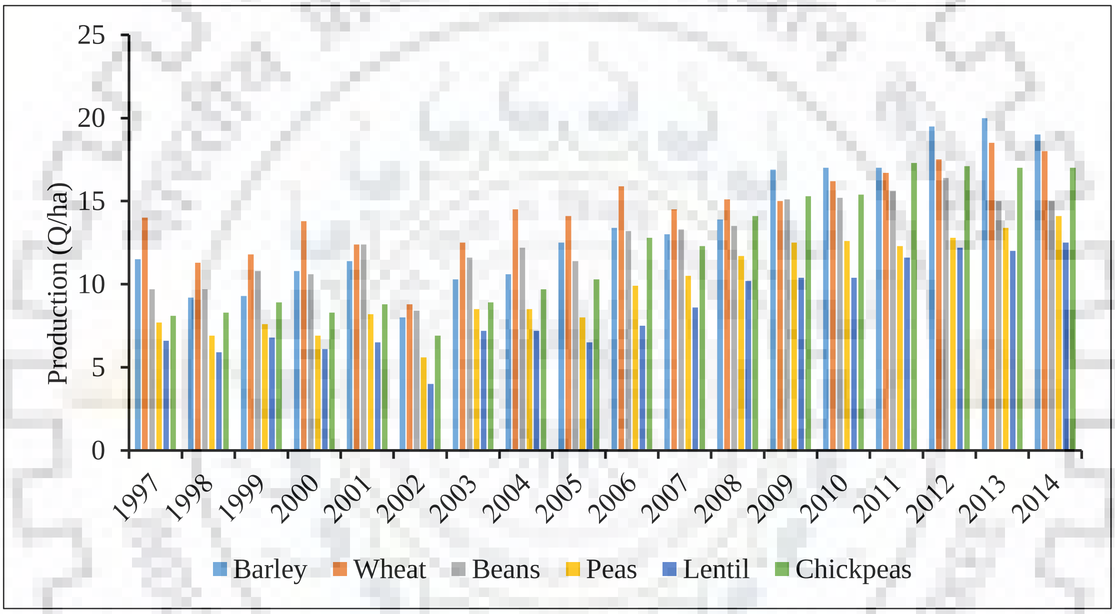


Figure 6.5 Major Annual crop production (1997 to 2014)

Fluctuating productivity hence food insecurity for the area is due to long-term variability in the annual and seasonal rainfall. Therefore, in order to reduce the bottleneck for food insecurity short-term as well as long-term copping and adaptation strategies needs to be attempted.

6.3.6 Copping and adaptation strategy

Given the prolonged variability of rainfall and temperature in time and space, to reduce the susceptible of the community short-term and long-term copping and adaptation strategies are required, which is discussed in subsequent section.

Copping strategies: Developed from the long experience community have and dealing with the variability of weather condition with the season and between different seasons. On other hand, **adaptation strategies** is not limited on the current weather condition (single season rainfall and temperature) rather it extends for the communities to retort to new set of prolonged climatic variability over time (Cooper et al., 2013; Muhire and Ahmed, 2015). According to Griggs and Noguer (2002), Babel et al. (2011) and Manandhar et al. (2011), adaptation strategies are important mechanism of managing climatic change and variability, on the other hand obtaining the benefit of the prospects presented by climate variability. Such strategies have immense benefit for the communities in order to cope with variability of climate over times from short-term (seasonal as well as annual variability) to long-term variability (across decades and centuries climatic variability). The essence of adaptation measure is enhancing the capacity and ability of the community to survive the shocks of climatic variability (Nhemachena and Hassan, 2007; Mubiru, 2010; Ranger et al., 2011). The seasonal and inter-annual distribution of rainfall is irregular with high level of Precipitation Concentration Index as already presented in Table 6.2. As already seen in Table 6.3 from Mann-Kendall trend test of mean annual, seasonal rainfall, as well as annual mean, minimum and maximum temperature of Beressa watershed, the condition of climate is variable for the last few decades during the study periods. Therefore, given the prolonged climatic variability of Beressa watershed the following copping and adaptation mechanism are suggested:

1. Livelihoods diversification and employment opportunity: Biological and physical soil and water conservation structures are used to enhance copping intensity and a way to find alternative solutions to increase their incomes and protect from environmental shock. Therefore, community based soil and water conservation practices help the communities to diversify their livelihood activity. It has enormous contribution and inciting for the local communities with various employment opportunity. They organize and increase their practices as far as they obtain worthy return. Farm communities should involve in beehive, irrigation, and small-scale trade activities. This will help in fighting the vulnerability due to vulnerable to climatic shocks and variability. If the income from one source lost still have other income source which make them economic relief and capable to cope and adapt to climatic variability (Kelly and Adger, 2000).

2. Water harvesting and integrated water resources management: In order to reduce vulnerability of rural communities that arises from spatiotemporal water shortage and rainfall variability, rainwater harvesting has significant benefits. Water harvesting is important particularly for less rainy season and integrated water management, will provide supplemental irrigation during deficit.

3. Soil management: Soil erosion and degradation reduces crop productivity for traditional farming practices (particularly for mountainous area like Beressa watershed), erosion and degradation occurs at a higher rate than fertile soil formation. Therefore, soil management practices is one of the most important mechanisms for adaptation strategies of climate change because crops grown on fertile soils with a deeper soil profile and structure can store extra moisture and have longer zone for crop roots to grow, which enables to access sufficient amount of water.

4. Controlled grazing: Intensive, permanent and continuous grazing facilitate erosion and loss of fertile soil and hence low productivity and further shortage of grazing land. Management of grazing land such as cut and carry feeding systems including use of buffers, which used to rehabilitate and conserve riparian areas are the tools that can help to mitigate and adapt to climate change and variability. Social fencing is another mechanism which can be adopted in the region.

5. Awareness creation: The communities in the watershed are depending on natural climate, therefore, availability of climatic information is a precondition in order to mitigate and adapt the impact of climatic variability. Ensuring information for farm communities related to climatic variability can adjust their farming practices. Improving awareness about variability and adverse implication to their environment therefore, farmers can modify their resources management practices and efficient use of available water for better crop production.

6. Saving institutions: Saving habit is a guarantee that farm communities deal with, the income of the household per heads determine how they are far the communities can cope with climatic variability and shocks. Therefore, saving is insurance at time of climatic hazards and used to overcome barriers to adaptation and increase the degree of resilience.

In general, climate change and variability adaptation mechanisms are compost preparation, site-specific community base soil and water conservation, area closure protection, cut and carry feeding system, rotational grazing systems, conserving indigenous forest, water harvesting and integrated water resources management. Likewise, promoting high yield and disease resistance crops, having new and high breed animals. Moreover, using improved fuel saving stove and creating alternative source of income such as beehive activities and other off farm income. All these copping and adaptation mechanisms are important at the local level in order to increase resilience capacity of the communities and ecosystems to the variability and irregularity of climatic shocks (Abramovitz et al., 2001; Kurukulasuriya and Mendelsohn, 2008).

7. Hydro-meteorological instrumentation for instances monitoring of quality data, which will be early warning system, forecasting/projection and disaster response by timely information.

6.4 CONCLUDING REMARKS

This study involves observation of climatic variables viz., seasonal, mean annual rainfall, including mean, minimum and maximum temperature spatiotemporal trend as well as its impacts on crop production of Beressa watershed from 1980 to 2014 for 35 years. Both increasing and decreasing trends of climatic variables were observed. The magnitude of significantly increasing trend of mean annual rainfall 0.28 mm/year and 1.07% (DB station) recorded, whereas significantly decreasing trend of mean annual rainfall was observed with the value of -8.62 mm/year and -27.88% (HG station).

Kiremit season rainfall revealed significantly increasing trend by about 1.62 mm/year and 31.79% at DB station and the magnitude of significantly decreasing trend at -0.90 mm/year and -16.20% in SD station. The magnitude of increasing trend during *belg* season was found to be 0.40 mm/year and 30.00% in DB station as well as significantly decreasing trend was found to be -0.12 mm/year and -10.00 in GIN station. Significantly declining trend of *bega* season rainfall observed in all stations with the trend magnitude of -0.61 mm/year and -7.50% in GIN station to -0.21 mm/year and -56.40% in DBS station. The findings of the study indicates that there are significant rainfall fluctuations positive and negative trends in long time series including moderate to higher Precipitation Concentration Index. For instance, during the year between 1981 and 1984, the trend of annual rainfall has been lower than the mean long-term rainfall, though slight recovery have shown between 1985 and 1986. Significantly increasing in annual mean temperature observed in all stations, with the magnitude of varied from 0.03°C/year and 7.60% in DB station to 0.14°C/year and 31.30% SD station. The annual minimum temperature has significantly increasing trend with the value varied from 0.005°C/year and 1.90% in GIN station to 0.12°C/year and 52.40% in the DBS station. Similarly, significantly upward trend of maximum temperature were observed in all stations varied from 0.023°C/year and 4.00% in GIN station with the maximum value of 0.21°C/year and 37.60% in ENW station.

Continuously increasing temperature with the variability and fluctuation of seasonal and inter-annual rainfall is a root cause for decrease and fluctuation of crop production. Over the 18 years (1997 to 2014), in which data available for crop production, the patterns of seasonal and annual variability including fluctuations on major crop production (barley, wheat, bean, pea, lentil and chickpea) produced in the area reflect similar trends of seasonal, annual rainfall and temperature conditions. Crop production show high correlation with *belg* and *kiremit* rainfall, only annual rainfall and barley crop shows stronger correlation. Minimum temperature has higher correlation with crop production and stronger correlation between crops and maximum temperature.

The production of each crops indicated by significantly correlation with each other, show that rainfall and temperature is the most important factors of production as other factors of production are constant (viz., Fertilizer, soil type, seed quality, insects and pest). High correlation existed between crops and rainfall, and temperature, would have direct impact on the communities particularly rainfed dependants. Therefore, more sensitive and vulnerable to food shortage and lack of malnutrition conditions are related to prolonged increase in climatic variability. Therefore, there is a need for cropping and adaptation strategy for the community such as; adopting community based soil and water conservation strategy, water harvesting strategy, increasing diversified crops, high value and market oriented crops, fast growing crops and climate resistant crops, which are less susceptible to future climatic variability.

CHAPTER 7
MODELLING RUNOFF-SEDIMENT RESPONSE TO LU/LC CHANGES USING SWAT MODEL

7.1 GENERAL

Land Use/Land Cover (LU/LC) dynamics whether for short or long time period in the catchment is significant because of its implication on the hydrological and ecological aspects. The dynamic nature of LU/LC change is resulted from expansion of farmland, prolonged change in climate, increase in human and livestock population, and decrease in forest cover (Getachew and Melesse, 2012; Sajikumar and Remya, 2015), consequently affects the overall hydrological response of the catchment (Booth, 1991; Asbjornsen et al., 2011; Abbas et al., 2015). Therefore, quantity, intensity and velocity of runoff increased due to continuous increase in deforestation, settlement areas, intensive cultivation of annual crops on steep slopes coupled with poor conservation practices and other anthropogenic practices (Booth, 1991; Hörmann et al., 2005; Abbas et al., 2015). As indicated (Meshesha et al., 2016), alarming growth rate of human and livestock population in the study watershed resulted from intensive deforestation and expansion of agriculture at the expenses of other LU/LC classes.

In many parts of the globe, there has been drastic change in the LU/LC classes for the last few decades and hence change in the hydrological and ecological behaviour of the area. As per report by (Bronstert et al., 2002; Khare et al., 2015), the change of LU/LC classes impact on the overall environment of the catchment as it changes hydrological processes viz., recharge, runoff, sediment and infiltration. Due to man-made and natural activities, the change of runoff and sediment characteristics have significant role to know the impact of LU/LC change dynamics on the overall hydrological conditions (Shi et al., 2007; Samal and Gedam, 2013; Samal and Gedam, 2015). Hence, distinguishing implication of land cover dynamics from the current runoff process and sediment yield generation is a particular challenge (Samal and Gedam, 2012; Azamathulla et al., 2013). Therefore, in the process of knowing future impact of LU/LC class changes on the overall runoff process and sediment yield generation, it is essential to identify continuous LU/LC change have had on the overall runoff process and sediment yield characteristics (Wang et al., 2014). To assess runoff and sediment yield response to LU/LC changes, hydrological model (SWAT) has been used in different parts of the globe (Eckhardt et al., 2003). A study by Fohrer et al. (2001) in the Dietzhblze watershed stated that even though the impact of LU/LC dynamics on different time steps (annual and monthly) relatively small on water balance, it used to show the effects of LU/LC dynamics in order to support sustainable development and effective land resources use system. In the Upper San Pedro River Basin, Arizona Kepner et al. (2004), used an uncalibrated model and evaluated the impacts of LU/LC and resulted consequences, and suggested that LU/LU dynamics significantly change the overall hydrological response from catchment due to faster rate of urban growth as well as discrimination of forest cover for other land use systems. in the Maarkebeek and Zwalm river basins, Heuvelmans et al. (2004) presented SWAT model scenarios in the processes of estimating the implication of land cover dynamic effects on overall catchment hydrology of a certain sub-watershed and watershed. To evaluate the effects of land use dynamics, Mishra et al. (2007) employed SWAT model in the mixed land use, which is found in the sub-humid subtropical regions of India. The results revealed that the watersheds with high forest cover generate less surface runoff and sediment yield, while, higher rate of surface runoff and sediment yield observed from the surface of subsistence farmland.

The SWAT model is a comprehensive model designed to simulate successfully a range of various parameters, viz., evapotranspiration, surface runoff, sediment yield, and groundwater as well as soil water (Zahabiyoun et al., 2013). Basically, the model established to evaluate effects of management undertaken on land resources and hence on runoff process, water resource as well as sediment yield generation in larger and for ungauged catchments. Similarly, SWAT model accurately simulate sediment yield generation (Setegn, 2010; Du et al., 2013; Song et al., 2011; Lu et al., 2012), runoff process (Zhan et al., 2011; Mbonimpa et al., 2012; Zhang et al., 2012). Elsewhere, few studies have been conducted on the hydrological impacts of LU/LC using SWAT model and successfully predicted for Zanjanrood basin (Ghaffari et al., 2010; Oeurng et al., 2011).

Therefore, identifying the relationships between LU/LC classes and the condition of hydrology in the catchment used to show the quantity, intensity and velocity of water flowing in the watershed. Therefore, scientific studies is necessitate in order to reveal the impact of LU/LC dynamics on surface runoff and sediment yield is of paramount importance. Clear information about the influence of LU/LC change on the catchment hydrological and ecological characteristics will play critical role for the local leaders and policy planners to formulate site-specific policy options to reduce the effect of LU/LC changes. Keeping this in mind, the following are the objectives derived for this subsection:

(A) To evaluate applicability and capability of SWAT model for small watershed,

(B) To assess the issues of LU/LC change dynamics and its effect on surface runoff process and volume of sediment yield characteristics,

(C) To quantify surface runoff process and sediment yield generation of Beressa watershed.

7.2 MATERIALS AND METHODS

7.2.1 Description about Beressa watershed

Detail of area descriptions have already discussed in chapter 3.

7.2.2 Data sets and Methods of analysis

7.2.2.1 Hydrological modelling

Hydrological (SWAT) model is a semi distributed time series, continuous time, hydrological and spatially distributed model within the ArcGIS interface established by USDARS suggested by Arnold and Fohrer (2005). Pertinent information required for the model are soil data, weather data, land use map and topographic map in order to simulate physical processes related to quantity and velocity of flow and sediment transport (Haverkamp et al., 2005). Presently in many part of the globe to apply in the interdisciplinary watershed modelling, SWAT model has got worldwide acceptance. It is a versatile model to integrate various environmental process and used for effective watershed management (Gassman et al., 2007). In the Ethiopian context according to Chekol (2006) and Setegn (2010), SWAT model is applicable for larger watershed. In SWAT, a basin and watershed are divided into various sub-basin and sub-watersheds, in addition divided into HRUs with homogeneous soil characteristics and land uses (Neitsch et al., 2011). In the process of simulating the hydrological cycle, water balance equation has done in SWAT model in the following way:

$$SW_t = SW_0 + \sum_{i=1}^{t} (R_{day} - Q_{surf} - E_a - W_{sweep} - W_{gw}) \qquad (7.1)$$

In which SW_t refers to final soil water content in mm; whereas SW_0 infers soil water content initially in mm; time represented by t in days; while R_{day} referred as precipitation volume in specific days of i in mm; the volume of runoff on specific days i represented by Q_{surf} in mm; the volume of evapotranspiration happen in a day i is represented by E_a (mm); W_{sweep} shows percolated water amount to the vadose zones through soil on a day i in mm; W_{gw} represent volume of return flow volume in a day i in mm.

In order to predict runoff process from Hydrological Response Units (HRUs), there are three different options exist. However, SCS curve has employed to predict runoff process from daily rainfall (USDA-SCS 1972). Since SWAT model is comprehensive, various studies across the globe have been applied to estimate runoff processes as well as volume of sediment yield.

Therefore, in this work surface runoff processes and peak runoff rate for each hydrological response unit have been simulated by using SWAT model.

SWAT used in the processes of runoff estimation by SCS-CN. The equation of SCS-CN is derived using the following equation:

$$Q = \frac{(P - I_a)^2}{(P - I_a) + S} \tag{7.2}$$

In which, Q shows volume of runoff depth in mm; while effective precipitation (mm) represented by P; initial water abstraction (mm) is represented by I_a; maximum potential retention is represented by using S. However, water abstraction initially I_a is a function of optimum potential retention S. Hence,

$$Ia = \lambda S \tag{7.3}$$

Where;

λ = a constant value usually = 0.2 or 0.05 (in this study 0.2 was used)

Therefore,

$I_a = 0.2S$

Integrating equ.2 and equ.3, we can have:

$$Q = \frac{(P - 0.2S)^2}{(P + 0.8S)} \tag{7.4}$$

The occurrence of runoff happens when P > 0.2S. Depending on soil types, topography and slope of the catchment, and land use practices, maximum potential retention is variable. Therefore, the maximum potential retention of S is correlated with dimensionless parameter curve number expressed in the following equations:

$$S = \left(\frac{25400}{CN} \right) - 254 \tag{7.5}$$

The results of SWAT are evapotranspiration, infiltration, percolation, water balance, interception storage and surface runoff, which have been validated. However, the focus of this study was associated with the implications of LU/LC dynamics on the processes runoff volume as well as generation of sediment yield.

From the landscape components, Modified Soil Loss Equation (MUSLE) employed in order to obtain sediment fluxes using SWAT model (Neitsch et al., 2011) expressed in the following equation:

$$Sed = 11(Q_{surf}.q_{peak}.area_{hru})^{0.56}.K_{usle}.C_{usle}.P_{usle}.LS_{usle}.CFRG \tag{7.6}$$

The volume of generated sediment yield at particular day (metric ton) represented by sed; Q_{surf} shows volume of runoff amount in mm/ha; whereas peak rate of runoff (m^3/s) is represented by q_{peak}; $area_{hru}$ is HRUs area in ha; while, K_{usle} represent universal soil loss equation errodability factor (0.013 metric ton m^2 h/(m^3-meteric ton cm)); whereas USLE cover factors is shown by C_{usle} is the USLE cover factors; P_{usle} dipcts USLE support practice factor; LS_{usle} represent USLE topographic facotr whereas CFRG represent coarse fragment factor.

The rate of peak runoff process is predicted by modified rational method. The hypothesis of a given rainfall intensity i instantaneously begin at the time of t=0 and indeterminately continuous, thus rate of runoff process will increase up to time of concentration in t_{conc}., when flow contributed from the whole parts of sub-basins to basin outlet. The peak runoff rate is obtained by the following equation (Neitsch et al., 2011):

$$q_{peak} = \frac{a_{tc} * Q_{surf} * Area}{3.6 t_{conc}} \tag{7.7}$$

Where:

q_{peak} is peak rate of runoff measured using m^3/s; a_{tc} is daily rainfall fraction occurring during concentration time; Q_{surf} is volume of surface runoff in mm; whereas the area used to indicates sub-basins area in km^2; while t_{conc} shows concentration time for sub-basin in hrs and the value of 3.6 indicates a unit used as a conversion factor.

The sediment yield flux transport is measured by instantaneous operations in the processes of degradation and deposition. Such processes indicates the volume of sediment yield transported out from each sub-basins, deposited sediment is estimated by stream power theorem of Bagnold (Bagnold, 1977) and calculated using the following formula:

$$Sed_{dep} = (Conc_{sed,ch,i} - Conc_{sed,ch,mx}).V_{ch} \tag{7.8}$$

In which, Sed_{dep} refers to deposited sediment yield amount measured (metric tons); while $Conc_{sed,\, ch,\, i}$ infers volume of initial generated sediment yield deposition originated from reach measured (ton/m^3 or kg/L); $conc_{sed,\, ch,\, mx}$ refers to optimum volume of deposited sediment which is carried by water expressed (ton/m^3 or kg/L and V_{ch}) is used to shows the total water volume in each reach section in m^3. The total volume of concentrated sediment estimated as follows:

$$Sed_{\deg} = (Conc_{sed,ch,mx} - Conc_{sed,ch,i}).K_{CH}.C_{CH} \tag{7.9}$$

In which, Sed_{deg} indicate volume of re-entrained sediment yield (metric tons); where as K_{CH} shows the erodibility factors of channel and C_{CH} is cover factor in the channel.

7.2.2.1.1 SWAT model input

For hydrological modelling, the preliminary data required as inputs are stream flow, climatic data (precipitation, temperature, wind speed and relative humidity), land use data, topographic data and soil data. Land use change dynamics has obtained from Landsat imageries from 1984, 1999 and 2015. The overall data set used for this study are as follows:

7.2.2.1.2 Digital Elevation Model (DEM)

In order to define the topography, 30m resolution DEM (Digital Elevation Model) obtained from Ministry of Water, Irrigation and Electric Ethiopia (MoWIE). To acquire pertinent information about stream network, stream length, watershed drainage pattern, the width of the channel within the watershed, slope and reach length DEM was employed. The DEM of the area has already given in Chapter 3 section 3.2.1.

7.2.2.1.3 Landsat image

The source for the LU/LC data for the years 1984, 1999 and 2015 have generated from satellite images obtained from http://earthexplore.usgs.gov. Detail discussion related to study area have been given in chapter 3 subsection 3.2 and the detail of data used for LU/LC analysis are already presented in chapter 5 subsection 5.2.2.1.

7.2.2.1.4 Soil data

The soil map of Beressa watershed was acquired from Food and Agriculture Organization (FAO). Five common soil classes for Beressa watershed were identified including their physical properties. On the basis of available soil parameters, the detail of soil physical properties have been estimated at various layer. Software like SPAW (Soil Plant Air, Water) established by USDA has been used to support in the process of obtaining soil physical properties. The detail of soil data and types discussed in detail in chapter 3 subsection 3.2.4.

7.2.2.1.5 Meteorological data

All the pertinent information related to weather data have obtained from Ethiopian National Meteorological Agency. To fill the missing values in the weather data, SWAT model weather generator model; WXGEN has employed. For the study periods, weather data were organized in dbf format before imported into the SWAT database.

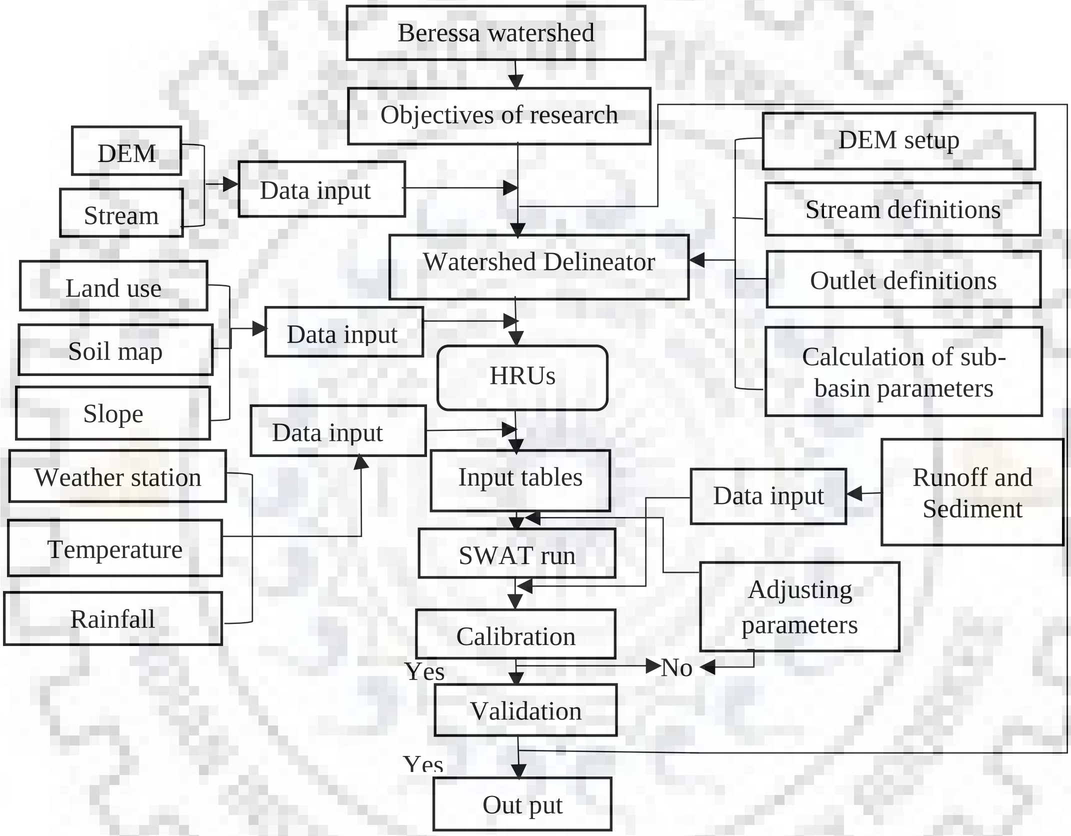
7.2.2.2 SWAT Model set up

7.2.2.2.1 Delineation of the watershed

The initial stage of generating model input is watershed delineation using DEM. In order to obtain specific sub-watershed and watershed, DEM was imported into the model and masking was done manually in ArcGIS. In the process of watershed delineation, there are five major steps. These includes setup of DEM, outlet as well as inlet definition, stream definition, selection of watershed outlet, definition and calculation of each sub-basin and basin parameters. The methodology of watershed delineation process using SWAT is illustrated in the flow chart as shown Figure 7.1.

7.2.2.2.2 Hydrological Response Units (HRUs)

On the basis of land use, soil types, and slope from each grid, Hydrological Response Units (HRUs) are employed to divide the catchment watershed into homogeneous unit. The HRUs are used to setup soil layers, slope and land use map into the project. Delineated watershed in the ArcSWAT and LU/LC classes as well as soil layers were exactly overlapped.



***After* (Getachew and Melesse, 2012)**

Figure 7.1 Application and development of SWAT model set up processes

Hydrological (SWAT) model requires soil and LU/LC data to determine HRUs of each sub-basin. To specify the LU/LC layer, LU/LC category was employed while soil lookup table used to identify soil types, which was modelled in each category. In order to link with the parameters in the SWAT database, the LU/LC, slope and soil map reclassifications were conducted. Finally, different parameters threshold settings were used for this study therefore, for land use (20%), soil (10%) and slope (20%). Threshold values were adopted based on multiple HURs delineation methods in order to define HRUs. The thresholds values correspond fit to all slope categories, soil types and LU/LC classes considered in the processes of SWAT model simulation to illustrates runoff process as well as sediment yield generation. In this study, application as well as development of SWAT model simulation processes already illustrated in Figure 7.1.

7.2.2.3 Sensitivity analysis

Parameters of uncertainty (for instance measured data, parameter and model uncertainty) were verified by SUFI-2. The value of *r*-factors as well as *p*-factor were used to assess the degree of uncertainty and goodness fit. The value of *p*-factor is expressed as percentage of both observed and simulated data in which bracketed by 95% of prediction uncertainty, while, the value of *r*-factor expressed using average thickness of 95ppu (percentage prediction uncertainty) band divided by standard deviation value of predicted and observed data (Abbaspour, 2008). The values of *p*-factor extends from 0 to 100% whereas, the *r*-factor extends from zero to infinite (0 to ∞). Therefore, *r*-factor of zero and *p*-factor of one are indicators of correctness of simulation, which corresponds to observed and measured data. Hence, in order to judge capability of model calibration process to what extent the simulated results deviates from these values, *p*-factor as well as *r*-factor were employed. Hence, the balance must be between the two values, if so, the parameters uncertainties are in the desired ranges; they are acceptable (Abbaspour et al., 2007).

7.2.2.4 Model application

In the processes of model application, the simulation, calibration and validation were run for each LU/LC maps (1984, 1999 and 2015) while fixing (keeping constant) other variables like DEM, soil data and climatological parameters. The results obtained from the model were employed to estimate the impacts of LU/LC dynamics on surface runoff processes and sediment generation.

7.2.2.5 Model performance evaluation

The goodness of fit is quantified by using coefficient of determination (R^2), Nash and Sutcliff Efficiency (NSE) (1970), Root Mean Square Error (RMSE), measured and simulation standard ratio (RSR), as well as the percentage bias (PBAIS). The perfection of linear relationships between simulated and observed have shown by R^2 value. The values ranges between zero to one, hence the higher value, the good is agreement, while (NSE) simulation coefficient shows the degree to what extent the observed and simulated values fit 1:1 line. The value of R^2 is calculated as follows:

$$R^2 = \left[\frac{\sum_{i=1}^{n} (O_i - O_{avr})(P_i - P_{avr})}{\left[\sum_{i=0}^{n} (O_i - O_{avr})^2 \sum_{i=1}^{n} (P_i - P_{avr})^2 \right]} \right]^2 \tag{7.10}$$

Where:

R^2 is Coefficient of determination, O_i is ith observed value, O_{avr}, shows the average observed value of total periods; P_i infer ith modelled value, P_{avr} represent average modelled value of the total periods.

NSE is used to determine the magnitude of residual variance relative to actual data variance. The value of NSE is obtained as follows:

$$NSE = 1 - \left[\frac{\sum_{i=0}^{n} (O_i - P_i)^2}{\sum_{i=1}^{n} (O_i - O_{avr})^2} \right] \tag{7.11}$$

According to Nash and Sutcliffe (1970), the value of NSE reveals that how fine simulated results and observed data fit the one: one line, the value varies from $-\infty$ to 1. The value which is lower than or very close to 0 reflecting poor model performance, while perfect performance if the value is equal to1.

As reported by Legates and McCabe (1999), value of mean absolute error as well as root mean square are absolute error of goodness fit indicators employed to define difference between the simulated as well as measured results. The values is calculated as follows:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n} (O_i - P_i)^2}{n}} \tag{7.12}$$

Where: the value of n indicates the number of time steps in months and years.

Similarly, Gupta et al. (1999) stated that the PBIAS used to assess tendency of observed data whether it is grater or lower than simulated one. The optimal value of PBIAS is 0.0, and the lower value implies the more reliable simulation of the model (Moriasi et al., 2007). Gupta et al. (1999) reported that the negative value implies model overestimation bias, while the positive value shows the model underestimation bias. PBIAS calculated in the following way:

$$PBISA = \left[\frac{\sum_{i=1}^{n} (O_i - P_i) * 100}{\sum_{i=1}^{n} (O_i)} \right] \tag{7.13}$$

Standard deviation of observation ratio (RSR) used to standardize the RMSE using the observation of standard deviation. Likewise, important to combine the index error as well as further information, which is recommended in Legates and McCabe (1999). The values of standard deviation of observation ratio (RSR) are obtained as ratio between RMSE and standard deviation of observed data; RSR values are obtained as follows:

$$RSR = \frac{RMSE}{STDEV_{obs}} = \frac{\left[\sqrt{(\sum_{i=1}^{n} O_i - P_i)^2}\right]}{\left[\sqrt{\sum_{i=1}^{n} (O_i - O_{mean})^2}\right]} \tag{7.14}$$

The values of RSR ranges from zero to one, it shows zero RMSE, and therefore it implies perfect simulation, to the larger positive values. Therefore, the lower RSR and RMSE shows perfect simulation performance. The comparisons of different model performance parameters are given in Table 7.1.

Table 7.1 Performance rating in the process of model calibration and validation

Model used	value	Rating performance	Modelling stages	Reference
	NSE			
	≥0.65	Very good	Calibration and validation	Saleh et al. (2000)
	0.54 to 0.65	Adequate	Calibration and validation	Saleh et al. (2000)
	>0.50	Satisfactory	Calibration and validation	Santhi et al. (2001)
	PBIAS			
	<10%	Very good	Calibration and validation	Van Liew et al. (2007)
SWAT	<10% to <15%	Good	Calibration and validation	Van Liew et al. (2007)
	<15% to <25%	Satisfactory	Calibration and validation	Van Liew et al. (2007)
	>25%	Unsatisfactory	Calibration and validation	Van Liew et al. (2007)
	RSR			
	0.00<RSR<0.50	Very good	Calibration and validation	Moriasi et al. (2007)
	0.50<RSR<0.60	Good	Calibration and validation	Moriasi et al. (2007)
	0.60<RSR<0.70	Satisfactory	Calibration and validation	Moriasi et al. (2007)
	RSR > 0.70	Unsatisfactory	Calibration and validation	Moriasi et al. (2007)
	R^2			
	>0.5	Very good	Calibration and validation	Moriasi et al. (2007)
	<0.5	Unsatisfactory	Calibration and validation	Moriasi et al. (2007)

7.3 RESULTS AND DISCUSSION

7.3.1 Model sensitivity analysis

Model sensitivity analysis is one of the required issue in the process of calibration phases. In order to identify the most sensitive parameters affecting runoff and sediment, sensitivity analysis had been identified (Kannan et al., 2007). Parameters values (lower and upper bond, and fitted value) used for model sensitivity analysis were found within the rage of the suggested SWAT user’s manual (Neitsch et al., 2001). In the processes of identifying the most sensitive parameters, which have significant influence on the performance of the model, twenty-seven hydrological parameters were tested using one-factor- at- a time global sensitive analysis techniques (van Griensven and Meixner, 2006). In order to calibrate the model, thirteen (six for surface runoff and seven for sediment yield generation) most sensitive parameters were adjusted within the ranges until acceptable agreement between observed and simulated values were obtained. The description of the range of variations and the test of most sensitive parameters are presented in Table 7.2.

Table 7.2 Calibrated parameters values on the observed data (1980 to 2014) and SWAT model parameterization (fitted value)

Rank	Parameters name	Physical descriptions	Lower and upper bond	Fitted value	Units
		Runoff processes			
1	CN2	Initial curve number value (II)	±0.20	0.0684	none
2	ALPHA_BF	Bases flow Alfa factor	0.0 to 1.0	0.847	days
3	GW_DELAY	Ground water delay	30.0 to 50.0	48.9	days
4	GWQMN	Threshold water depth in the shallow aquifer for flow	0.0 to 2.0	0.458	mm
5	RCHRG_DP	Deep aquifer percolation fraction	0.0 to 1.0	0.47	fractions
6	SUR-LAG	Surface runoff lag time	0.0 to 10.0	3.02	days
Rank		**Sediment yield**			
1	HRU_SLP	Average slope steepness	±0.2	0.045	mm
2	USLE_K	USLE soil erodibility factor	0.15–0.35	0.20	(0.013mtr t m^2 h/(mtr.ton-cm))
3	ULSE_P	USLE support practice factor	0.1 to 0.8	0.53	none
4	USLE_C	Min value of USLE_C factor applicable to the land cover/plant	±0.2	0.20	none
5	C_CH	Channel erodibility factor	0 to1	0.54	cm/h Pa
6	CH_N	Channel Manning factor	0.15 to 0.025	0.05	none
7	SPCON	Linear re-entrainment parameter for channel sediment	0.01 to 0.001	0.006	none

7.3.2 Model calibration and validation

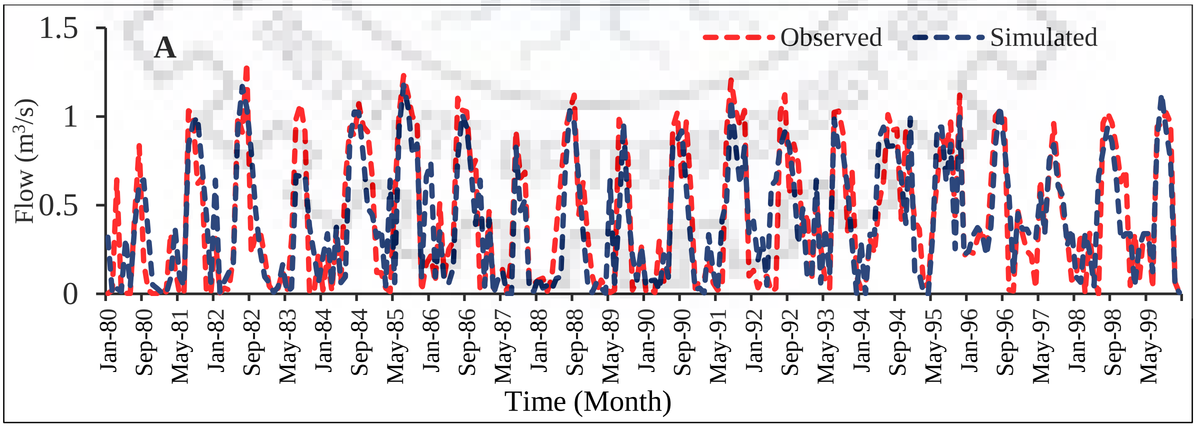
During model calibration and validation, graphical as well as statistical tests have been conducted. The total simulation length of 35 years with the warmup periods of 3 years, the first 20 years periods including the warmup periods were used for calibration whereas, the last 15 years periods were used for validation. Automatic calibration using SUFI2 (Sequential Uncertainty Fitting) was used to calibrate and validate the model in SWAT-CUP2012 version 5.1.6. Model performance evaluation for the watershed have shown in Figures 7.2 A, B and 7.3 A, B.

Based on the model performance evaluation of the *p*-factor, *r*-factor, R^2, NSE, RSR, PBIAS results as shown in the Table 7.3, the model of runoff and sediment yield simulation provides assurance for further application of the model in order to assess the influence of LU/LC change dynamics on surface runoff process and sediment yield generation. The detailed values of all the parameters under different LU/LC change scenarios are described in the Table 7.3.

Table 7.3 Summary of model performance during calibration 1980 to 1999) and validation (2000 to 2014) periods under different LU/LC scenarios

Parameters	Evaluation of statistics of parameters			
	Runoff		Sediment	
	Calibration	Validation	Calibration	Validation
p-factor	0.39	0.22	0.36	0.28
r-factor	0.45	0.50	0.402	0.55
R^2	0.72	0.68	0.68	0.65
NSE	0.67	0.64	0.71	0.67
RSR	0.52	0.56	0.58	0.62
PBIAS %)	3.90	7.60	4.20	8.30

According to Moriasi et al. (2007), if the value of NSE and R^2 are above 0.5, and percent PBIAS are within the range of 15% (most of the time the value of percent PBIAS are within the range of ±10%), it is confirming about very good model performance. The measure of model efficiency in the monthly default simulation indicated better than the acceptable range. Therefore, it can be concluded that the model has strong predictive capability. The results obtained during calibration and validation periods between observed and simulated outputs for monthly runoff and sediment yield were shown in Figures 7.2 A, B and 7.3 A, B. In the Figures 7.2 A, B and 7.3 A, B, the observed and simulated data have shown similar trends. Therefore, depending on SWAT calibration and validation results, it can be concluded that the SWAT is applicable to the Beressa watershed.



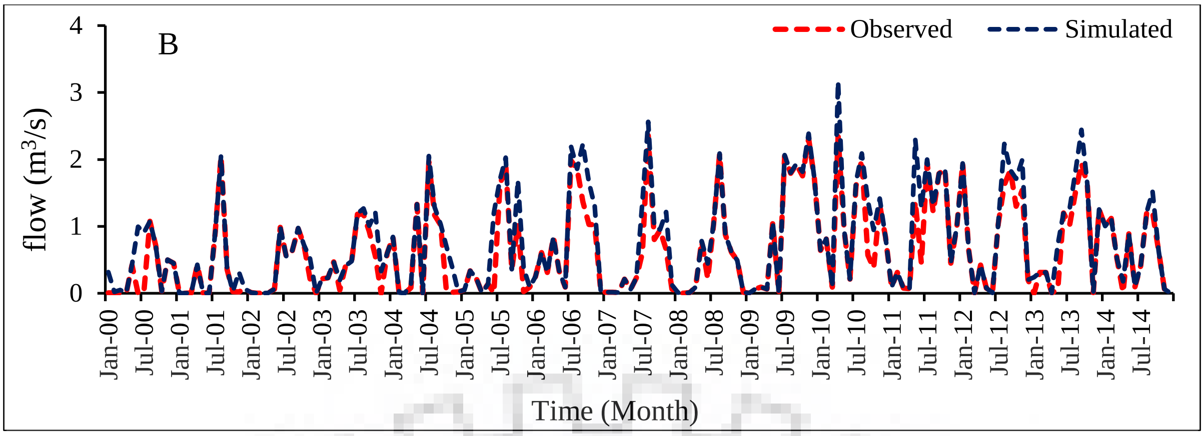


Figure 7.2 Calibration (A) and Validation (B) of runoff

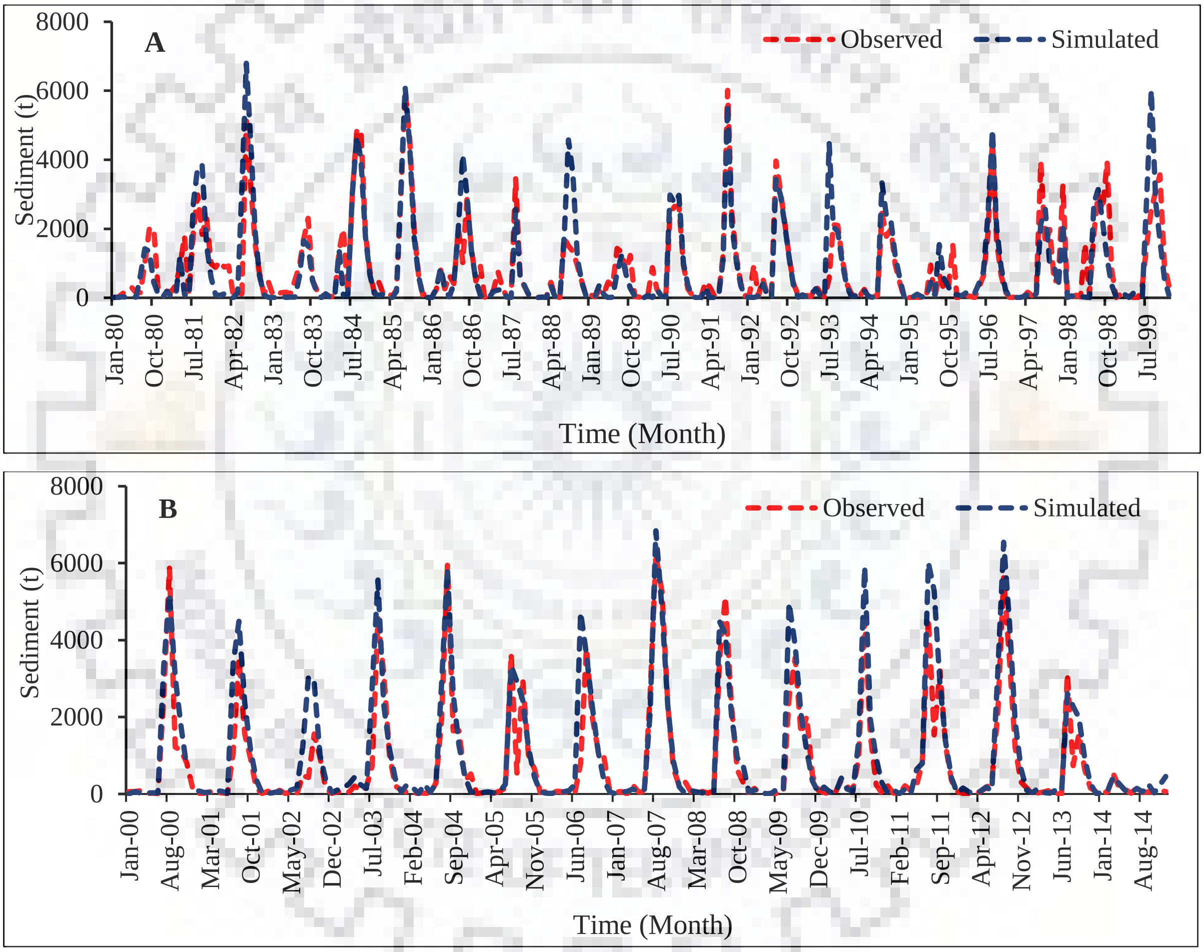


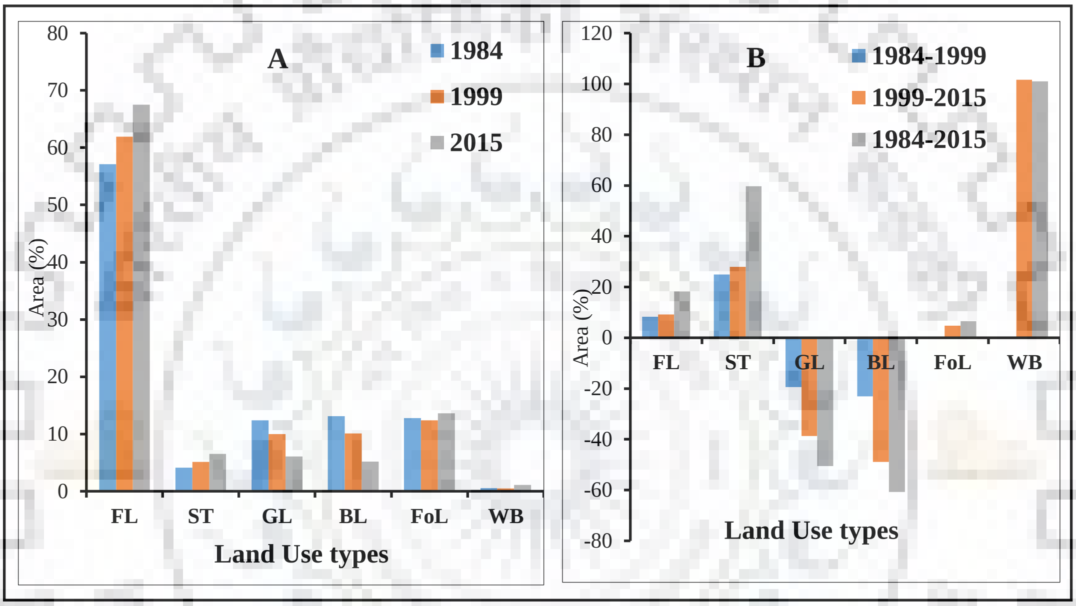
Figure 7.3 Calibration (A) and Validation (B) of sediment

7.3.2 Land Use/Land Cover dynamics between 1984 and 2015

The proportion of LU/LC dynamics and corresponding percentage shared during the periods of 1984, 1999 and 2015 has been discussed in the subsequent sections and presented in Figures 7.4 and 7.5.

For the Beressa watershed, the agricultural land formed the largest percentage of all land use classes i.e. 57.10%, 61.90% and 67.50% in 1984, 1999 and 2015 respectively. It is confirmed that a significant expansion of subsistence cultivation has been observed in the area during the last centuries and in reverse barren land, grazing land, forestland and plantation shows shrinking. More specifically, higher rate of population growth needs more food together with inappropriate conservation measures could be considered as triggers for the expansion of cultivation. In the first period (1984 to 1999), farmland increased by 8.30% (1012.90 ha), while in the second periods (1999 to 2015), it increased further by 9.30% (1207.80 ha) (Figures 7.4 and 7.5). Consequently, the net change in agricultural land for the last 31 years (1984 to 2015) increased by about 18.20% (2220.70 ha). In the entire study period, there has been an increase of settlement area by about 24.90% from 1984 to1999 to 28% from1999 to 2015. Mainly the increase in settlement areas took at the expense of other LU/LC classes. Like agricultural land, expansion of both rural and urban settlement took the largest share of the study watershed with putting pressure on forest, bushes and shrubs, grazing land and barren land. During the given time periods (1984 to 2015), settlement area has increased to about 59.70% which took additional 520.50 ha from other land use categories (Figures 7.4 and 7.5).

Another largest share of LU/LC classes for the study area is grazing land, which was accounted as 12.40% (2633.20 ha) during 1984; in contrast during 1999 it shrunk by about 2.40% (12.40% to 10%). Similarly, in the 2015 the coverage of the grazing land further reduced to 6.10%. Generally, during the first periods (1984 to 1999), the area of grazing land was reduced by about 510.20 ha (19.40%); likewise, during the second periods (1999 to 2015), the decrease further increased by about 823 ha (38.70%). Overall, during the last three decades (1984 to 2015), 1333.20 ha (50.60%) of grazing land has been converted into other LU/LC classes. The increase in the demand for farmland and settlement area is a common phenomenon in the conversion of grazing land. The share of barren land for the study watershed reduced from 13.10% in 1984 to 10.10% and 5.20% during 1999 and 2015 respectively. It decreased seriously by 23.10% during 1984 to1999 and further reduced by 48.90% in the second periods 1999 to 2015. Generally, during in the study periods the share of barren land continuously converted into other LU/LC cover classes. As can be seen in Figures 7.4 and 7.5, the share of forest cover in the study catchment comprised of densely vegetated natural forest, plantation, shrubs and bushes. In the first periods (1984) accounted for 12.80%, slightly reduced into 12.40% during the second period. In contrast, to the study by Tesfaye et al. (2017), it is confirmed that the forest coverage regenerated by 1.20% during 2015. Generally, during the first periods 1984 to 1999, 72.80 ha (0.30%) of forest cover has been lost. However, in the second period 1999 to 2015 unexpectedly the coverage of forest has increased by 4.70%. Adoption of household and community level trees plantation has significantly contributed for the regeneration of forest cover. Therefore, during the last 3 decades (1984 to 2015), the share of forest cover increased by 6.50%. The water bodies such as spring, streams ponds and small rivers accounted for the share of only 0.56% during 1984 and reduced into 0.50%. However, increased to 1.10% during 2015 (Figures 7.4 and 7.5). People awareness about top soil loss, soil erosion and land degradation are the most attributable reason for the continuous change of LU/LC classes.



Abbreviation for Land use types are already mentioned in chapter 5, Figure 5.4.

Figure 7.4 Area statistics of LU/LC types and area coverage in hectare (A) and Percentage change (B) from 1984 to 2015

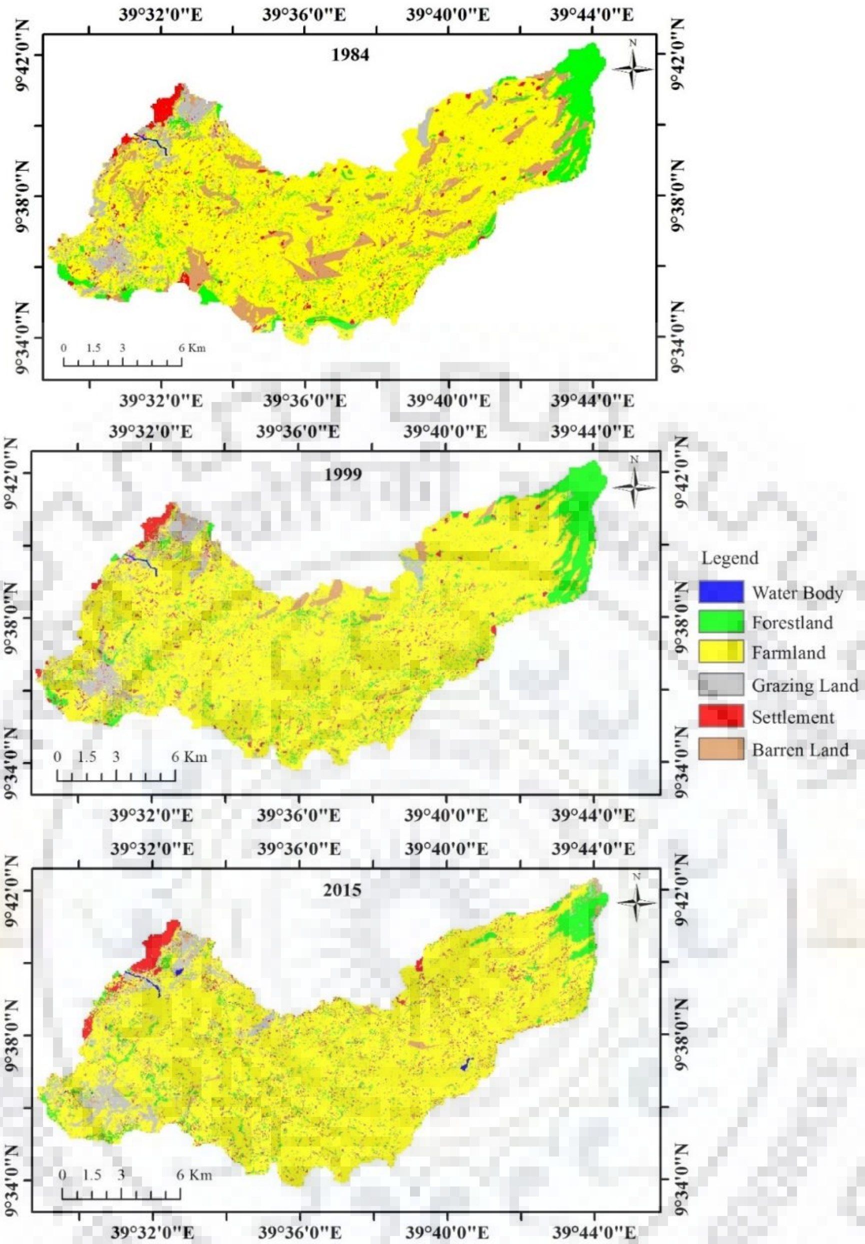


Figure 7.5 Land Use/Land Cover classes

7.3.3 Patterns of runoff and sediment yield relationships

In order to analyze runoff and sediment yield relationship, annual runoff data and sediment from 1980 to 2014 are presented in Figure 7.6. During the1980s, sediment yield and runoff process were high compared to the mid 1990s (during 1995 and 1996 slightly reduced); whereas compared to 1980s and 1990s, during the periods from 2000 to 2009 both sediment yield and runoff process were lower than the expected.

The possible reason of lowering sediment yield and runoff in the first decades of 2000s, is the increment in the share of natural forest and plantation. Similarly, community based soil and water conservation practices undertaken in the area significantly contribute to arrest runoff process then sediment yield. However, after 2010 and onward increased considerably due to significant increase in the percentage share of agricultural land and expansion of settlement areas. More specifically, LU/LC changes particularly expansion of farmland and settlement areas considered as a trigger for significant increase of runoff and sediment yield in the Beressa watershed.

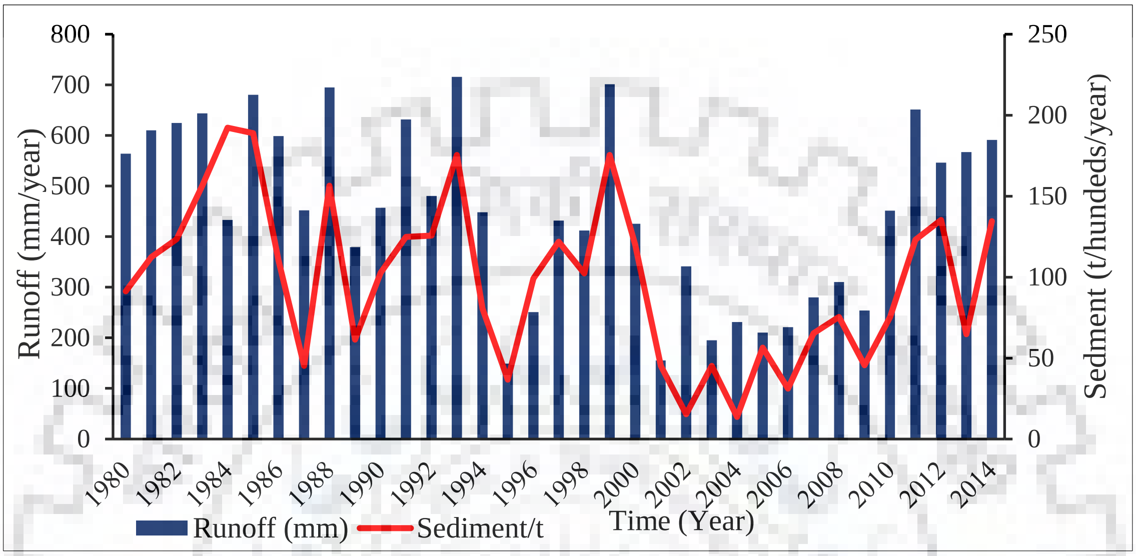


Figure 7.6 Annual sediment yield and runoff generation for the periods 1980 to 2014

In terms of months, runoff and sediment yield present a bimodal optimum; one is in the month from March–April with major peaks during the main rainy season (July–September, particularly the highest peak during August). As depicted in Figure 7.7, there was strong overlapping pattern existed between runoff and sediment yield implying that mainly sediment yield is a function of runoff process.

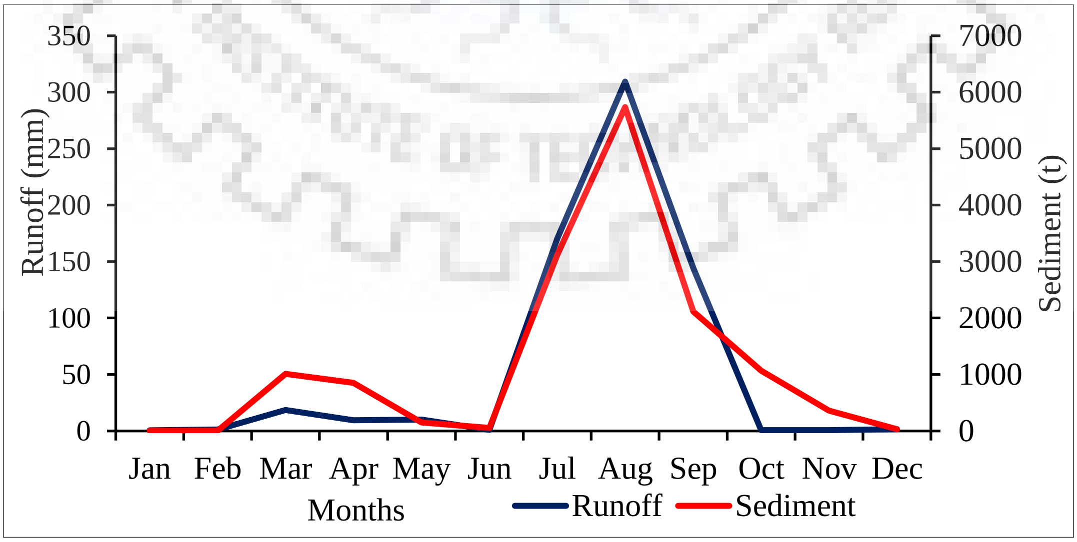


Figure 7.7 Average monthly sediment and runoff during the period of 1980 to 2014

7.3.4 Impacts of LU/LC changes on surface runoff and sediment relationship

As already indicated in Figure 7.4 and LU/LC changes, agricultural land and settlement areas were continuously increasing at the expense of other LU/LC classes (barren, grazing and forestland) during 1984 to 2015. The change of LU/LC types between 1984 to 1999 from forestland, barren and grazing land into farmland and settlement areas have significantly contributed to increase of surface runoff and sediment yield for 1984 land cover by 4% and 6.03% respectively. The evaluation of SWAT model results indicated that surface runoff and sediment yield for 1999 land cover further increased by about 6.50% and 8.20% respectively. Between 2000 and 2009, a decrease has been found for both surface runoff from 4.25% to 2.54% and sediment yield from 6.28% to 5.48% respectively. The decrease of surface runoff and sediment yield is probably due to regeneration of forested areas and adoption of community based soil and water conservation practices. However, further dynamics in LU/LC changes significantly contributed for drastic increase in surface runoff and sediment yield during the periods from 2010 to 2014, runoff increased from 4.51% to 6% and sediment yield increased from 6.30% to 7.65%. In general, during the study periods the increase of farmland and settlement areas by about 18.20% and 59.70% respectively at the expense of other LU/LC classes resulted for the increase of runoff by about 158.10 mm/year and increase of sediment yield by about 4332 t/year.

Elsewhere, other studies by Alansi et al. (2009) confirmed that the conversion of forestland into agricultural land has resulted in increase of yield of water as well as base flow. Likewise, according to Ngo et al. (2015), in Da River Basin of Hoa Binh province Northwest Vietnam, due to conversion of forest to agricultural land and settlement (urban and rural settlement) there have been an increase of surface runoff during the period of 1995 to 2005. Contrary to this, related to reduction in agricultural land and increase in the share of forest cover possibly reduce surface runoff. According Adimassu et al. (2014); Biratu and Asmamaw (2016) and Mengistie and Kidane (2016), runoff and sediment yield of the area are sensitive to the change of LU/LC change dynamics of the catchment LU/LC classes and various soil and water conservation management practices undertaken in the watershed. The complex nature of catchment, and fragmentation as well as spatial distribution of different LU/LC class types which can affect the runoff process and sediment yield. Therefore, it can be concluded that, spatial and temporal distribution of LU/LC classes, govern runoff amount as well as contribute for the change in the sediment yield. A substantial LU/LC class alteration in the form of expansion of subsistence farming and settlement areas at the same time shrinkage of forest cover and other land cover classes have to the enormous incidence of surface runoff and sediment yield. In conclusion, two LU/LC classes i.e. farmland and settlement areas have less potentials for recharge and high for runoff and sediment yield generation as compared to forest and plantation. Therefore, it indicates that surface runoff and sediment yield are sensitive to LU/LC, soil, and water conservation practices.

7.4 CONCLUDING REMARKS

ArcGIS software integrated with SWAT model have been used to evaluate the influence of LU/LC dynamics on the runoff and sediment yield of Beressa watershed. SWAT model for Beressa watershed successfully calibrated and validated for runoff and sediment yield analysis as shown by the results of R^2, NSE, RSR, and PBIAS during calibration and validation monthly basis, which are under the range of acceptable value. Therefore, under fixing other variables, SWAT model is an important tool to simulate the temporal status of runoff process and sediment yield under different LU/LC change dynamics (1984, 1999 and 2015), implying in the data scarce situation such as Ethiopia, it provides a useful tool for sustainable watershed management practices.

The analysis of results showed that the watershed experienced significant LU/LC change dynamics between 1984 and 2015. Land cover classes continuously shrunk and shifted into farmland and settlement areas. In turn, increase of the surface runoff and sediment yield particularly during wet season and hence reduced base flow during dry season. However, in the first decade of 2000s, runoff process and sediment yield have slightly reduced. The possible reasons were significant conservation practices such as household and community level tree plantation and various soil and water conservation practices. It was observed that the increase in farmland and settlement areas including decline in forest covers and other land use classes have resulted in an increase of surface runoff process and sediment yield generation by about 4.51% to 6% and 6.30% to 7.65% respectively during the years between 2010 to 2014. This significant increase in surface runoff process and removal of topsoil in the form of sediment yield resulted for losses of fertile soil, sedimentation to the lower stream and reduction of water available in the soil.

Generally, LU/LC changes dynamics is a serious environmental threat to the watershed. Therefore, continuous change of LU/LC change dynamics should deserve more attention. Therefore, sustainable, site specific, demand driven and integrated watershed conservation measures are necessitated in order to arrest the distractive consequences of LU/LC change dynamics. Further intensive conservation measures should be considered in order to stabilize the changes hence runoff and resulting sediment yield. This study simulates both runoff and sediment change in response to LU/LC changes and its effect on catchment management. Thus, it is a new insight to consider other researchers for further research and hence would be provide helpful inputs for policy planners and stakeholders, particularly to Ethiopia.

CHAPTER 8

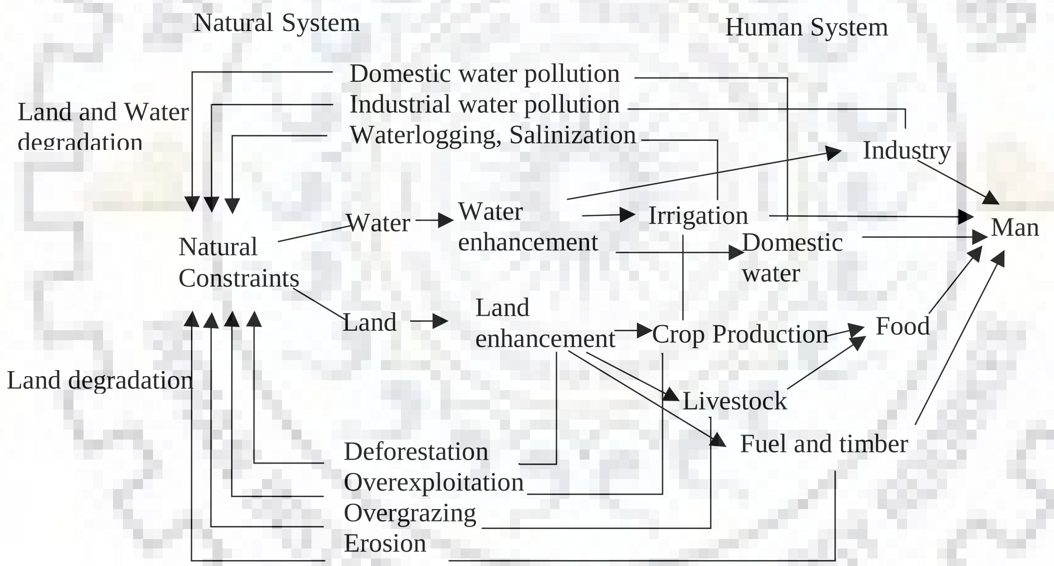
TOWARDS INTEGRATED WATER RESOURCES MANAGEMENT CONSIDERING HYDRO-CLIMATOLOGICAL SCENARIOS: AN OPTION FOR SUSTAINABLE DEVELOPMENT

8.1 GENERAL

This chapter uses the scenario outputs from chapter 4 to 7. Detail discussions have been made in chapter 4, 5, 6 and 7, community's awareness on erosion and degradation, LU/LC change, climate variability, and runoff and sediment scenarios have considerably contributed on the water resources availability, environment and productivity in the Beressa watershed, which needs proper attention. These conditions become more worsen in the future if appropriate solution oriented mechanisms are not amended. Thus, it necessitate appropriate approach of water harvesting and integrated water resources management that consider the economic livelihoods as well as natural environment influences to downstream. Environment, water and land resources are the most fragile components of the earth. In order to secure the sustainability of adequate availability of water, sustainable food supply and public health as well as the interaction between these fragile resources have significant influence, therefore properly managed, because the quality of people life is directly depending on how well these resources are conserved and managed (Matondo, 2002).

In the development of human life, water has considerable contribution. During the ancient time human civilization has grew up along Euphrates and Tigris, Indus and Nile river valley. Even though it played a major role in the human endeavour, planning and management of these resources was limited for single purpose only. Due to increase in competing over resources resulted from rapid population growth and the higher demand for productivity, consequently multi-purpose water resources planning is emerged. In the last decades water resources planning and management is one-way (top-down) approach particularly in the developing countries like Ethiopia. In this approach the people has no much say on the issues related to planning and implementation of water resources project. Integrated water resources management considered as a participatory, technically as well as scientifically organized mechanisms for conservation. Involvement in any activities of water resources project, stakeholders are the focal point in the integrated water resources planning and management approach. To address specific local issues empowered local communities has responsibility in a coordinated and integrated way.

During the ancient periods, the plan of water related projects did not pay attention for the rest of the environment and hence resultant negative consequences to the environment. The environmental impact assessment therefore is vital parts of water resources planning and management. To satisfy goal and objectives of the society for present and future as well as preserving the integrity between environmental, ecological and hydrological system, sustainable water resources systems planning and management are designed (Loucks, 2000). According to Simonovic (2000) and Wurbs (1998), the future water resources related problems will actually become more complex. As can be seen in Figure 8.1 alarming rate of population growth, social and environmental consideration, climatic variability, transboundary issues of water sharing consideration and resources degradation accelerate the complexity of water resources planning and management problems.

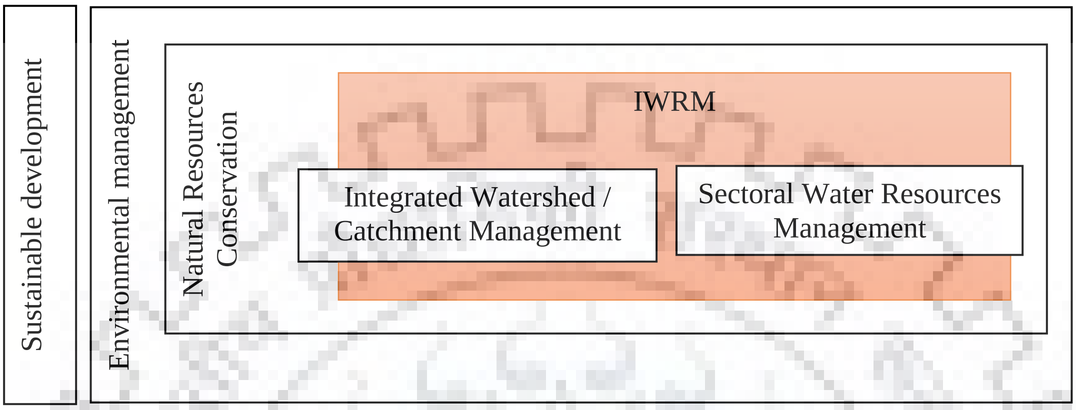


***After* (Falkenmark, 1986)**

Figure 8.1 Complex nature of interactions and feedbacks between the natural and human system

8.1.1 Integrated water resources management and sustainable development

Integrated water resources management is an important element of natural resources management, considered as one of the tools of environmental management (Figure 8.2). The optimal and efficient use of water resources for agricultural development is critical points in the process of integrated water management as it integrates the development of water and land resources, and the development of economic and social aspects for the watershed. It used to coordinate and harmonize between human activities, undertaken in the watershed, and the conflicting interest among users through increasing the benefit obtain. Therefore, the concept and essence of integrated water resources planning and management in boosting productivity obtaining from agricultural and other sectors within the constraints, which imposed by the social , ecological, environmental and economical context of a certain watershed (Gorantiwar and Smout, 2005; Gorantiwar et al., 2006).



***After* (Dourojeanni et al., 2002)**

Figure 8.2 Integrated water resources management and sustainable development

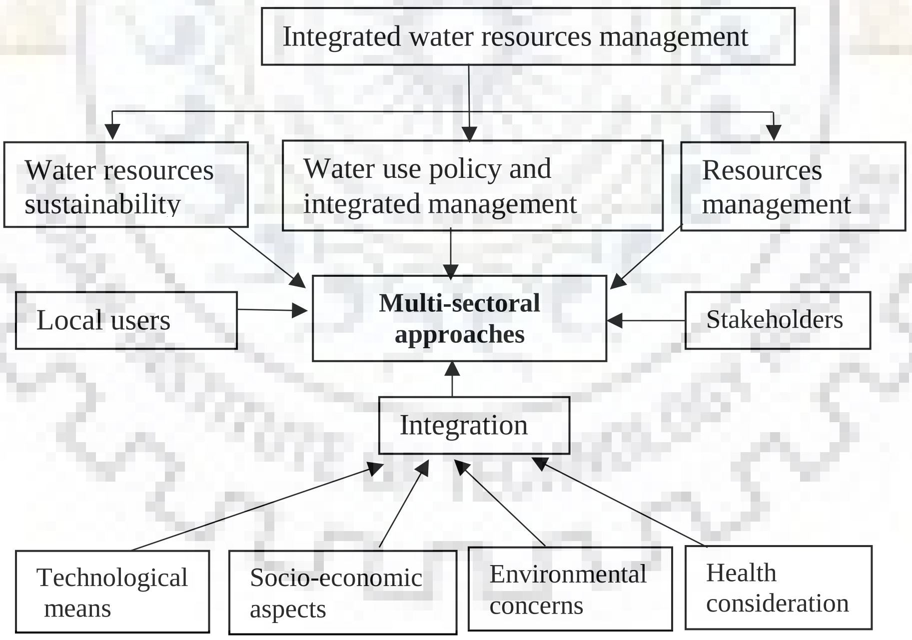
Molden et al. (2003), demonstrated how water management at the field level, watershed level and irrigation system level can integrate in different ways to optimize the productivity of water. They advocated consideration related to principles of irrigation scheduling, which is an opportunity for communities using irrigation practices to cope with the natural resources pressure that have been put on them to utilize available water optimally and consideration to the downstream natural resources users.

According to Khare et al. (2007) and Tantawy et al. (2007), several methodologies have been established in order to prepare for the allocation and distribution of irrigation water during the planning and management process. The objectives of allocation and distribution plans is to optimize the uses of water and hence land resources. In these methods, to obtain optimum benefit from irrigated agriculture, the water and land resources have optimized. Even though the distribution models were mostly concerned with enhancing the productivity of agriculture from irrigation projects, it did not give attention issues related to water distribution for all communities found within the watershed particularly at the time of limited water available.

Awulachew et al. (2005), made a study for Ethiopia stated that due to poor and unsustainable water harvesting and management in all parts of the country, agricultural productivity is vulnerable to rainfall variability, consequently illustrates itself in the form of extended dry periods and persisted droughts. In addition to that, related to inefficient water management in the country empirical evidences have identified. Girma and Seleshi (2007), identified inefficient management and low performance of some irrigation projects from Awash and Blue Nile basin Checkol and Alamirew (2008), explained poor water management and inefficient water utilization at the Geray irrigation project in the Northern part of Ethiopia. However, Awulachew et al. (2005) recommended sustainable water harvesting, management, and efficient use of water resources for agriculture could offer opportunities in order to handle the impact of climatic variability therefore improved crop productivity.

8.1.2 Integrated water resources management –As demand driven approach

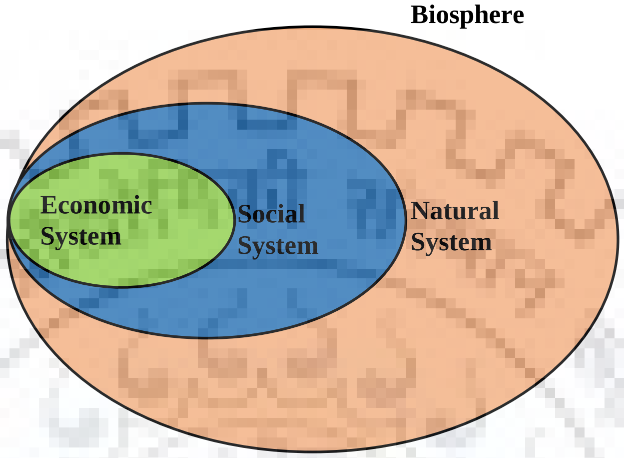
Integrated water resources management considered as a key component in which all relevant natural resources issues (land and water resources) taken into consideration, the concerned parties along with specific socio-economic as well as environmental issues integrated together, with sustainability of integrated natural resources management. The key assumption of IWRM approach, which formulate the foundation for sustainable development is the basis for multi-disciplinary groups at various levels (i.e. local level, regional level, national and international level) in order to discuss on various issues related to conservation, efficient use and management of natural resources (water, land resources and ecosystems) (Figure 8.3).



***After* (Al Radif, 1999)**

Figure 8.3 Integrated water resources management flow chart

In the context of sustainable development, integrated water resources management, environmental management and natural resources have significant contribution as already shown in Figure 8.2. The assumption of sustainable development includes of various components like environmental, economic and social components (Singh and Bhallamudi, 1998). As shown in Figure 8.4, the economic system component is included (embedded) within the social component, whereas, both system components are embedded within the natural systems (Dourojeanni, 2001; Dourojeanni et al., 2002; Hooper, 2006; Pingale et al., 2014a).



***After* (Kranz et al., 2004)**

Figure 8.4 Social, economic and natural components

8.1.3 Irrigation water use and management: A watershed perspective

The watershed of a certain catchment integrates the downstream with the upstream in the form of water flowing as a part of the overall hydrological cycle of the watershed. The concern of upstream parts of the watershed are increasing the returns of agriculture productivity and other benefit. Communities obtaining their benefit from water diversion, over cultivation and expansion of agriculture into marginal land from the upstream parts of the watershed are now worried about resulting consequences to the downstream resources availability. However, over exploitation of natural resources in the upstream parts of the watershed negatively contribute for the downstream. Even though increasing the benefit and productivity for the whole catchment in a certain watershed, requires assessment of resources demand as well as equitable share of available resources in a rational perspective. Besides this, allocation of available resources need the participatory planning and management that consider the involvement of concerned stakeholders in the watershed. In determining the benefit of upstream water availability to the downstream farming systems is the basic problems in which the watershed planners are facing. Likewise, it is difficult to determine how the availability of these resources might change over time as the upstream users consume more resources. Therefore, the benefit obtained from irrigated agriculture in the watershed can increase through minimizing the amount of available water used and optimizing the timing of water application for crops in the form of irrigation scheduling based on crop water requirement (Reca et al., 2001; Letcher and Jakeman, 2003; Duan et al., 2004; Pingale et al., 2009; Kumar et al., 2012).

To reduce the pressure of water shortage conservation planning and water management at watershed level is critical. Likewise, natural resources conservation management practices is helpful for the communities to determine the optimal amount of water resources consumption at the irrigation fields is therefore a key issue. As a result, there is a need to do more jobs related to water harvesting and management on the one hand and optimize the benefit from agriculture on other hand. Without enhancing the efficiency of water use, continuous and over exploitation of natural resources may result for conflicting interest among users within and between watersheds. Hence, to demonstrate the sustainable development it is desired to compute crop water requirements of major crops, describe the possibilities and opportunities of water harvesting and implementing integrated water resources management. The results presented are based on the findings of author's results and numerous empirical lessons from relevant literatures.

8.2 MATERIALS AND METHODS

8.2.1 Study area

Detail description of the study area have been already discussed in chapter 3.

8.2.2 Methods used

8.2.2.1 CROPWAT 8.0 model

The reference evapotranspiration (ETo) of different crops obtained by FAO Penman Monteith methods, using the decision support system software known as CROPWAT 8.0 model, developed by FAO. The program incorporates modules to estimate the reference crop evapotranspiration as well as crop water requirement at the same time used to allow in order to simulate crop water use under various conditions (i.e. crop, climate and soil) (Singh et al., 2006; FAO, 2009).

In this study, Penman Monteinth methods has been applied using the following equation:

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma\left(\frac{900}{T+273}\right)U2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u2)} \qquad (8.1)$$

Where: ET_O is the reference evapotranspiration [mm/day], T is the mean daily air temperature (^{0}C), Rn is net radiation at the crop surface [MJ m-2 day-1], G is soil heat flux density [MJm-2 day-1], e_s is saturation vapour pressure [kPa], e_a is actual vapour pressure [kPa], Δ is slope vapour pressure curve [kPa °C-1], γ is psychrometric constant [kPa^{0}C-1].

Crop water requirements/season (CWR/mm) obtained for different crops. It is used to define as the depth of water, which is needed to satisfy the loss of water through evapotranspiration of crops, growing in the farm field under in a condition of non-restricting soil including fertility and soil water and hence obtaining maximum production potential in a certain growing environment (Doorenbos, 1977). Crop water requirement obtained using the following equation:

$$CWR = \sum ET_c = \sum (K_c * ET_o) \tag{8.2}$$

Where: Kc is the crop coefficient at different growth stages of crops, ET_0 (mm) is reference evapotranspiration, which is reported by FAO, ET_c is the specific evapotranspiration.

The meteorological data like temperature (^{0}C), relative humidity (%), sunshine (hrs) and wind speed (km/day) has been used for this study as the same authors used chapter 7.

The major crops of the area are bean, wheat, barely, lentil, pea, chickpea and garlic. The value of crop coefficient (Kc) are taken from FAO. Crop coefficient (Kc) values for initial, development, mid and late growth stages of annual and seasonal crops are used.

The net irrigation requirement has been obtained for the specific cropping periods, it is the difference between a certain crop evapotranspiration (ETc) in a certain conditions and effective rainfall. It is obtained using the following equation:

$$NIR = ET_c - ER - GE \tag{8.3}$$

Where: NIR is net irrigation requirement, ETc is crop evapotranspiration, ER is effective rainfall, Ge is the groundwater contribution from the water table (however, it is not considered in the calculation as it has not significant contribution so it is negligible).

In order to recognize the potential contribution of rainwater availability for cultivation, Rainfall Contribution Index (RCI) has obtained by the following techniques:

$$RCI = \frac{\sum_{i=1}^{n} \frac{PE_i}{ETc_i}}{n} \tag{8.4}$$

Where:

PE is effective rainfall in mm; ETc is crop water requirement in mm; n is the total time step for the growing periods and i is the time step; the highest RCI (~1) rainfall is sufficient for crop growth; whereas lower RCI values indicates rainfall is insufficient for crop growth. Crop water requirement of crops can obtained by equation 8.2.

The volume of effective precipitation which is used to represent the portion of total amount of precipitation in which plants are used to satisfy crop water requirement (consumptive use of water) has been found by the United State Department of Agriculture soil conservation methods (USDA) using the following equation:

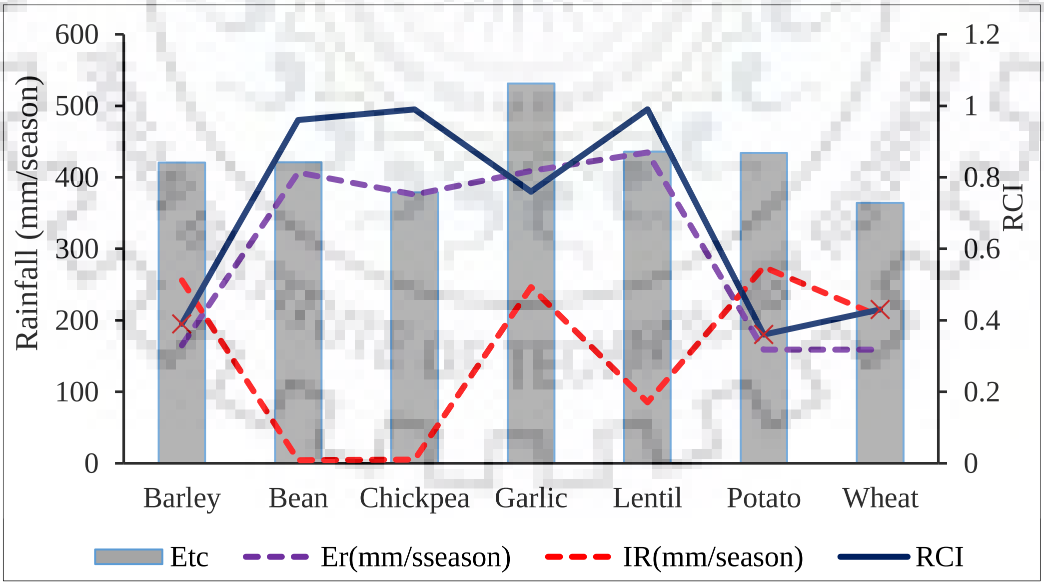
$$PE = P_{tot} = \frac{125 - 0.2P_{tot}}{125} \qquad for\ P_{tot} < 250mm \tag{8.5}$$

$$PE = 125 + 0.1P_{tot} \qquad for\ P_{tot} > 250mm \tag{8.6}$$

Where: PE is the volume of effective precipitation (mm) and P_{tot} is the total precipitation (mm).

8.3 RESULTS AND DISCUSSION

In the present study, estimation of crop water requirements for seven major crops was undertaken for the study area. Notwithstanding the fact that most of the agricultural practices in Ethiopia is rainfed, attempt has been made to assess irrigation water requirement of crops. The following are discussion of this study for each crops using CROPWAT 8.0 model results. The crop irrigation and water requirement were simulated for each growth periods in various climatic conditions for each cropping season in order to quantify the amount of water consumed and needed to sustain crops growth for better production without and with the occurrence of rainfall. As can be seen from Figure 8.5 the irrigation requirement of crops is strongly variable among different crops per season. Bean, chickpea and lentil crops are among the lowest irrigation water requirement in the area accounted for 4.4, 5.2 and 85.3 mm/season respectively.



^{x}effective rainfall is insufficient in all growth stages (needs supplemental irrigation)

Figure 8.5 Crop water and Irrigation Requirements

This is due to the cropping calendar for these crops, in which the planting date during the main rainy season (June to September) which is significantly contribute for lower irrigation water requirement.

On the other hand, barley, wheat, potato and garlic crops are among the common crops during less rainy season extended from February to June. Therefore, those crops are among the highest irrigation requirements with the values of 255.90 mm, 205.40 mm, 274.60 and 246.70 mm/season respectively. Similarly, the highest crop water requirements has also been observed in each cropping season. As observed from Figures 8.6 and 8.7, and Table 8.1 during the month of January to June there is relatively high potential evapotranspiration. Similarly, during these months higher temperature has observed which been has considerably contributed for high crop water requirement.

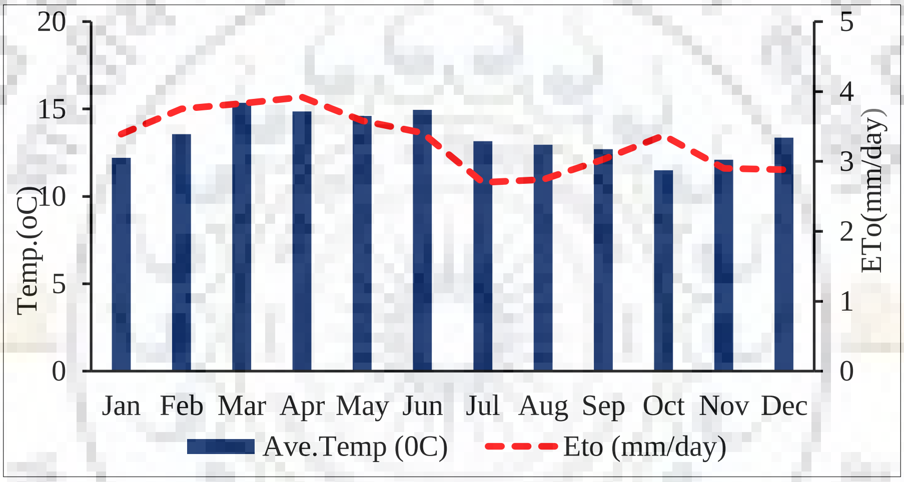


Figure 8.6 Mean monthly temperature and evapotranspiration

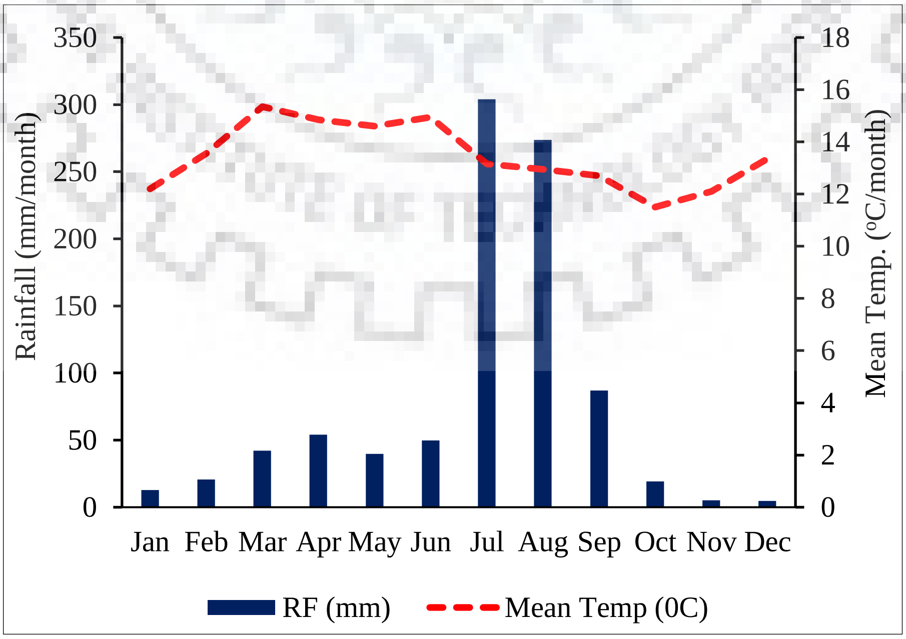


Figure 8.7 Patterns of Rainfall and temperature in the area

Table 8.1 Monthly reference evapotranspiration (ETo)

Month	Min Temp	Max Temp	Relative Humidity	Wind speed	Sun	Rad	ETo
	°C	°C	%	km/day	hours	MJ/m²/day	mm/day
January	3.60	20.80	80.00	72.00	10.10	22.20	3.39
February	5.20	21.90	70.00	73.00	9.60	22.80	3.75
March	8.60	22.10	83.00	85.00	8.40	22.20	3.83
April	7.50	22.20	92.00	70.00	8.60	22.80	3.92
May	7.20	22.00	85.00	74.00	7.30	20.30	3.58
June	7.90	22.00	84.00	70.00	6.60	18.90	3.41
July	8.70	17.60	95.00	73.00	4.50	15.90	2.70
August	8.50	17.40	95.00	58.00	4.50	16.20	2.74
September	6.30	19.10	95.00	59.00	5.70	18.00	3.03
October	4.20	18.80	92.00	55.00	8.60	21.60	3.37
November	3.70	19.00	88.00	81.00	7.30	18.40	2.90
December	1.30	19.10	83.00	80.00	8.20	19.00	2.88
Average	6.10	20.20	87.00	71.00	7.50	19.90	3.29

During small rainy season, since crop evapotranspiration is high due to higher temperature; therefore, the crop water requirement is relatively high as compared to rainy season. This indicates that the crops growers have been discouraged and the same experience will be continuing not to grow the crops as the irrigation and water requirement of crops will increase and likely to result in more competition over water sharing among local users. The major crop characteristics collected for this study along with FAO reference has been summarized in Table 8.2. Therefore, due to this highly inconsistent temporal and spatial variability of rainfall occurring over the entire growing season, there is a need for supplemental irrigation using rainwater harvesting even in the wet and rainy season for better production.

Table 8.2 Crop characteristics data for model inputs

S.No.	Crop types	Initial stage		Dev't stages		Mid-Season		Late-season		Crop height (m)
		(Days)	Kc	(Days)	Kc	(Days)	Kc	(Days)	Kc	
1	Barley	20.00	0.300	25.00	1.15	60.00	1.13	30.00	0.25	1.00
2	Bean	20.00	0.40	30.00	1.15	40.00	1.10	20.00	0.35	0.60
3	Chickpea	15.00	0.50	25.00	1.15	35.00	1.09	15.00	1.10	0.50
4	Garlic	30.00	0.70	55.00	1.00	55.00	0.99	40.00	0.70	0.30
5	Lentil	20.00	0.40	30.00	1.00	60.00	0.95	40.00	0.30	0.50
6	Potato	25.00	0.50	30.00	1.15	45.00	1.14	30.00	0.75	0.60
7	Wheat	30.00	0.30	30.00	1.15	40.00	1.12	30.00	0.30	1.00

Rainfall Contribution Index (RCI) for each crops from different planting dates has been already shown in Figure 8.5. According to Wang et al. (2008), the highest value (~1) of RCI indicates the amount of effective rainfall is sufficient for crop growth in a cropping season, while the smaller Rainfall Contribution Index/RCI/ value reflects that the available rainwater is insufficient for the whole crop growth stage. Therefore, for the crops sown during small rainy season (barley, Garlic, potato and wheat) based on the value of RCI, the availability of effective rainfall is insufficient to satisfy the full growth stages of crop water requirement. Therefore, there is a need for supplemental irrigation practices as well as rainwater harvesting and a necessity for integrated water resources management particularly during small rainy season in which during high water requirement periods.

8.3.1 Water harvesting for IWRM- An option for stabilizing food shortage

8.3.1.1 Existing Scenarios

It has been found in the present study that, currently communities in the Beressa watershed are facing challenges with numerous interrelated difficulties. In the earlier chapters, it is observed there is rising need for additional production and income in order to cope with alarming rate of population growth with fixed and limited natural resources available in the area (Chapter 4-7). Generally, some of the most pressing problems that affect efficient and sustainable production for the area includes:

- Rainfall variability,
- Removal of forest and therefore soil erosion particularly on the upland areas hence flood event for the lower areas,
- Fragmented land holding and therefore expansion of farming into sloping and marginal land,
- Dependant of dunk cake as household biofuel consumption, therefore low level of, and generally declining, the status of soil fertility conditions,
- Inadequate and insufficient access to off farm income and therefore high pressure on land resources and other natural resources,
- Weak and unsustainable water harvesting and management practices and
- Lack of site-specific soil and water conservation practices.

These aggravating problems specify the degree to which the communities are confined in a multifaceted web of environmental challenges. Therefore, the condition becomes serious to the subsistence in which the susceptibility to risk is so enormous. However, controlling and reducing the aggravating problems not only depends on local level actions by the community, but also needs the integration of all the stakeholders at various levels of decision- making process.

8.3.1.2 Towards water harvesting: A relief to rainfall variability

The erratic nature of rainfall pattern particularly during the dry season has been the bottleneck for food production and this further exacerbated by climatic change in which expected to manifested in the form of rainfall variability (Oweis and Hachum, 2006) (Chapter 6). As can be seen from Figure 8.8, the distribution of annual rainfall is decreasing while the mean annual temperature is increasing.

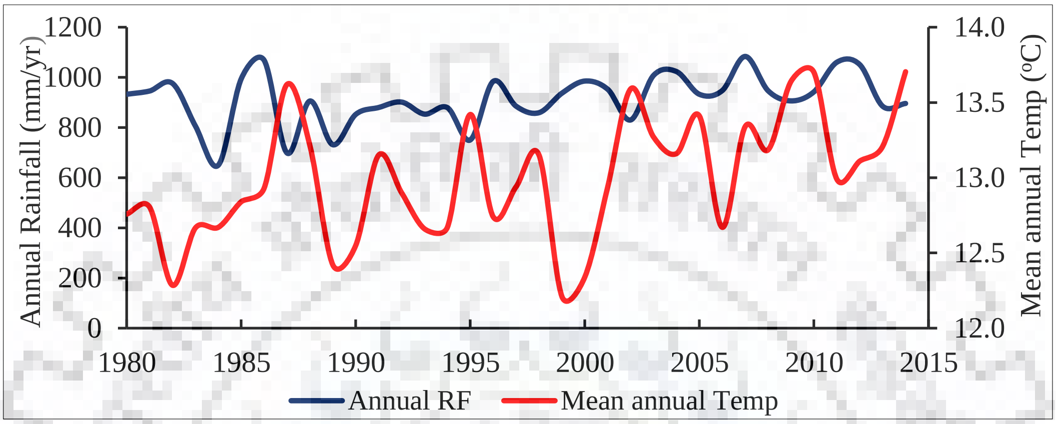


Figure 8.8 Annual rainfall and temperature variability

The intensity of rainfall during rainy season can often be higher (Figure 8.7) than the rate of infiltration and water holding capacity of the soil, which is a cause for excess surface runoff, erosion and degradation hence high sediment generation that has experienced in the area (Figure 8.9). In many parts of Ethiopia where rainfall intensity and variability are high, unpredictability and further decline of normal rainfall also expected due to global warming.

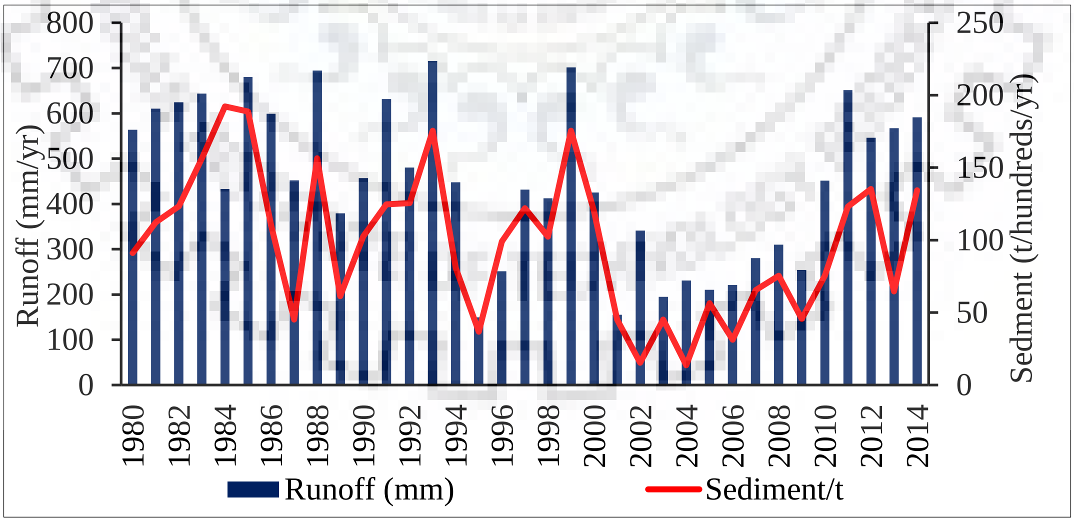


Figure 8.9 Annual sediment yield and runoff generation

Therefore, rainwater harvesting and integrated water resources management is gaining importance and drought power as a supplement to irrigation and other benefit. Water harvesting is a collection and concentration of runoff in order to support agriculture, livestock watering, pastureland, fodder, tree production and domestic use in the area of erratic and variable rainfall. It is the aim of reducing the pressure of temporal and spatial rainfall shortage to satisfy household and productive use. In agricultural production systems, water harvesting is composed of an area of runoff producing is known as catchment area and utilization of runoff area is also known as cropped basin. In-situ water harvesting, internal catchment water harvesting (micro catchment) and external catchment (macro catchment) water harvesting are some of the major categories of water harvesting according to distance catchment area and cropped basin (Oweis and Hachum, 2006). Water harvesting systems are categorize into two main types: in-situ water conservation and management practices, small basins, bunds, and runoff based systems (Figure 8.10).

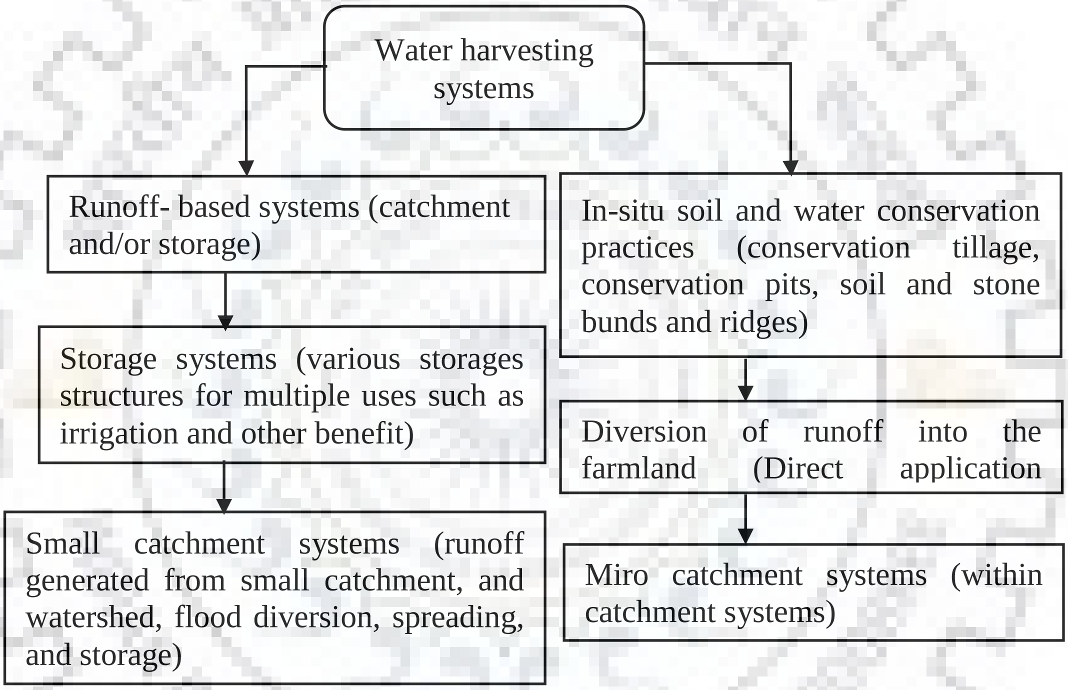


Figure 8.10 Classification of water harvesting system

The in-situ water harvesting also known as soil and water conservation practices, in which the method used to increase the amount of stored water in the soil profile. It includes small movements of rainwater as a surface runoff to arrest the water where and when it is demanded most. For agricultural purpose, it has achieved in different ways such as conservation farming, conservation tillage and conventional tillage. It is an efficient and effective strategy in order to manage excess floods in the in-situ and ex-situ, especially in the highland parts of Ethiopia. Hence, water harvesting possibly satisfy water needs during dry spells and create additional access for multiple water uses. According to De Fraiture and Wichelns (2010), estimation 78% of water consumed by agriculture originated from rainfall. Miro-catchment water harvesting is most widely used techniques of water harvesting in the form of contour ridges (with an interval of 5 m to 20 m between contours), soil and stone bunds (trapezoidal and semi-circular bunds). Percolation pits (digging holes usually 5 cm to 20 cm deep), and small runoff basins (with an optimal dimension of 5 m to10 m wide by10 m to 25 m long) are some of the prominent techniques of water harvesting techniques applied for rainfed area for the sustainability of agriculture (Oweis and Hachum, 2006). In order to supplement for the regeneration as well as plantation of forages, trees and grasses particularly on medium slopes to high slopes contour ridges has significant contribution. To overwhelm the difficulties of contouring, semi-circular as well as trapezoidal bunds are typically used. The shape of the bund in the form of semi-circular or trapezoid facing (fronting) directly upslope are formed at a spacing, which allows adequate catchments to provide vital runoff water, which collects in the bund, therefore plants are growing. According to Oweis and Hachum (2006) and Mishra and Singh (2007), the diameter between the two consecutive ends of the bunds ranged between 1 m and 8 m with 35 cm to 50 cm high, therefore the water (runoff) captured here and can be stored into the plant root zone. The principle of designing micro-catchment water harvesting in order to concentrate water from rainfall, runoff and other source. It involves a catchment area and cultivated area, which receives and concentrate water from the given catchment area for agricultural supply and other benefit. In terms of size, association between catchment and cultivated area has determined by rainfall and available runoff (Figure 8.7). Therefore, to make system effective and efficient in a sustainable way it is better to obtain the ratio between catchment and cultivated area if the data related to rainfall, runoff and crop water demand, are available (Moges, 2004). Therefore, the ratio between the two have determined by the following equation:

$$\frac{cat}{cu} = \frac{CWR - DR}{DR * k * ef} \qquad (8.7)$$

NB: cat is catchment area, cu is cultivated area, CWR is crop water requirement, DR is design rainfall, k is runoff coefficient and ef is efficiency factor

The value for crop water requirement already obtained by equation 8.2.

Where, Design rainfall is total amount of rainfall during the cropping season, if the actual rainfall is during the cropping season is less than the design rainfall, there will be moisture stress in the crops; if the design rainfall is less than actual rainfall there will be surplus runoff and cause for erosion and degradation. The rainfall depth that has assigned to a chance of occurrence or exceedance has been denoted as the design rainfall. This parameter is one of the input parameters used to design a model for determining the ratio of catchment area to cultivated areas. The value has obtained by means of a statistical probability analysis using the following equation (Plotting position formula):

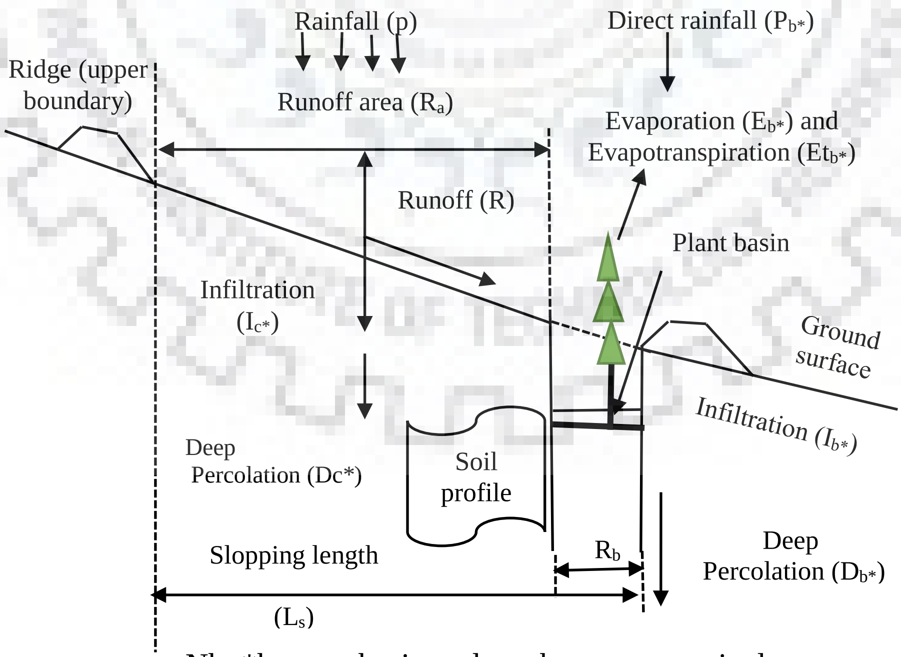
$$P(\%) = \frac{m - 0.375}{N + 0.25} * 100 \quad (8.8)$$

Where, N is year of observation, which is used to obtain the total annual amount of rainfall for the cropping season. The value of total rainfall ranked from the largest (m=1) to the lowest (m=x) and P (%) is the probability of occurrence.

The design rainfall is based on higher probability, which refers to the lesser design rainfall thus the system is more reliable and efficient. Therefore, the concentrated water can satisfy the water requirement of crops per cropping season. However, the probability of frequent flooding occurrence may affect the system efficiency particularly when rainfall surpass the design rainfall unless proper care should take into consider. Runoff coefficient is the share of total rainfall, which is flowing as surface runoff. It is relied on vegetation cover, slope degree, rainfall duration, soil type, soil moisture and rainfall duration. The value of runoff coefficient ranges between 0.1 and 0.5, which is obtained by the following techniques:

$$K = \frac{Yearly\ (seasonally)\ total\ runoff\ (mm)}{Yearly\ (seasonally)\ total\ ra\inf all\ (mm)} \quad (8.9)$$

The efficiency factor is used to measure whether the system is efficient or not. When the area is level as well as smooth the efficiency of the system is more effective.



After **(Ali et al., 2010)**

Figure 8.11 Sketch of water harvesting process in a micro catchment

The value of efficiency factor is ranges from 0.5 to 0.75. For the Beressa watershed the runoff coefficient, efficiency factor, and design rainfall with the probability of 52.84% are 0.48, 0.5, and 931.4 mm respectively. Therefore, based on the available data catchment area: cultivated area have been drown as of knowing this ratio is useful for water harvesting in which crops area intended to grow. Crop water requirements for all crops already presented in Figure 8.5. The catchment area for barley and bean must be 2.28 times larger than the cultivated area, which means the catchment: cultivated area ratio is 2.2:1. As the ratio between the two is moderate the system can be designed to harvest water with the assumption of low runoff coefficient.

For garlic, the area of catchment should be approximately 2 (actual value is1.8) times higher than the cultivated area. For micro catchment system, the ratio are always lower due to the higher efficiency of water use as well as higher runoff coefficient. Using a design rainfall of with the probability value of 52.84% with the ratio of 1.8:1. In general, the sketch of water harvesting process in a micro watershed has shown in Figure 8.11.

8.3.1.3 Optimization of supplemental irrigation

In the area during the last 35 years, based on the author's observations, the distribution and pattern of rainfall could be classified as uneven, irregular and erratic. Therefore, it has considerably contribution to low crop production, food shortage and insecurity (chapter 6). Thus, depending on the historical trend of rainfall variability and prolonged increase of surface temperature, optimization of supplemental irrigation from harvested water would be useful during excess rainfall and runoff when rainfall is over. The following three important points are taken into consideration while optimizing supplemental irrigation for rainfed agriculture.

(1) Since rainfall is the main sources of water for agriculture and other purpose, supplemental irrigation applied when the amount of rainfall is insufficient to satisfy crop water demand and stable crop production during the growing season,

(2) Water is essential to rainfed agriculture, which is used for production without irrigation,

(3) The volume and techniques of supplemental irrigation are planned not only to apply moisture stress-free situations during the whole crop growing season, but also it is to secure a minimum volume of water accessible during the critical periods of crop growth that would allow optimal instead of maximum production.

8.4 CONCLUDING REMARKS

In the high land parts of the country, particularly during dry and less rainy season, in which water shortage is very high, land and other natural resources are fragile. Resources degradation, rainfall variability, inadequate and insufficient access to off-farm income and lack of site specific soil and water conservation practices are very high, therefore recurrent drought and food shortage can cause the most pressing hardship on the rainfed agriculture. Likewise, techniques and technologies of water harvesting during excess rainfall season coupled with fragmented approach to water resources management is the aggravating problems specifying the degree to which the communities are confined in a multifaceted web of environmental challenges. Therefore, the conditions becomes serious to the subsistence in which the susceptibility to risk is so enormous. As indicated from CROPWAT 8.0 model results, the irrigation requirements of crops during dry and less rainy season is high. Similarly, the results of Rainfall Contribution Index (RCI value far from 1) confirmed that during less rainy season the availability of rainfall is insufficient to satisfy the crops water requirements for the whole crop growth stages. Therefore, farmers during such season has been discouraged and the same experience will be continuing not to grow the crops as the irrigation and water requirement of crops will increase and most likely to result in more strong competition for available water sharing among local users. Therefore, due to this highly inconsistent temporal and spatial variability of rainfall occurring over the entire growing season, there is a need for supplemental irrigation using rainwater harvesting even in the wet and rainy season for better production. Additionally, it can laid a foundation for water management approaches to reduce the adverse effects of food shortage in Ethiopia. Harvesting rainfall including surface runoff and using it in an integrated way can reduce intense pressure on crops and therefore can reduce negative economic consequences in rural communities. Policies and concerned institutions are necessary to overwhelm the adverse problems. Therefore, it is essential that the concerned stockholders and communities should be involved in every phase of planning and implementing water-harvesting process. Generally, integrated water resources management plays a significant role in order to integrate and address various aspects of water shortage and sustainable use of harvested water for supplemental irrigation during less rainfall and dry season.

CHAPTER 9

SUMMARY, CONCLUSIONS AND RECOMENDETIONS

9.1 GENERAL

The main aim of the present study is to address different issues within Beressa watershed which primarily contains existing socio-economic conditions, management practices, historical as well as future land cover change dynamics, climate change and variability, runoff process, sediment yield generation, and hence to demonstrate the necessity of implementing integrated water resources management etc. Hydro-climatological condition assessment particularly in the highlands of Ethiopia like Beressa watershed has paramount important for sustainable integrated water resources management in order to attain better household livelihood and overall environment. The studies of assessment of socio-economic conditions and management of natural resources in the watershed has been done. Historical and future LU/LC dynamics, including climatic trend and variability (temperature and rainfall) analysis have been done. Study of runoff processes and sediment yield in any catchment at watershed and sub watershed level have significant role in the processes of watershed management practices. Taking into consideration, watershed hydrological modelling has been undertaken using SWAT model. In view of all these hydro-climatological scenarios into consideration, an attempt has made about integrated water resources management and water harvesting, which would be an option for sustainable development. Generally, the overall summary and conclusions of this study and specific recommendation for future study are presented in the following subsequent sections.

9.2 SUMMARY

9.2.1 The existing socio-economic conditions and watershed management practices

Natural resources degradation and the trend of change in the coming few decades have not been beneficial to the environment and hence food security. Mostly the highlands of Ethiopia has severely affected because of hosting more human and livestock populations. More than 99% of household energy sources originated from traditional biofuel. Population growth consequently additional energy demand needed hence threat for natural resources sustainability, which further, worsen for food security. However, following huge ambitions of the government participatory watershed management practices have been started. Local communities devoted to have private trees near by their home and farmland, consequently significantly contribute for forest regeneration. Therefore, the aims of the present study was to understand farmer's awareness about erosion, degradation, perception of conservation work, conservation technologies, local level tree planting, energy consumption at household level, and assess implication for environmental management. Chi-square test, correlation matrix, least significance difference and econometric model (Probit model) have been used in order to recognize household decision to plant trees, management practices, energy consumption and number of trees planted. With respect to perception of conservation work by the community, the evil of erosion and degradation problems possibly controlled by soil and water conservation practices. Therefore, community's lack of interest in the management practices cannot be enlightened by lack of awareness about the severity of the problems. The results obtained from the watershed revealed that fuelwood and dung is fully the major sources of domestic energy. The quantity of domestic biofuel used sensitive to socioeconomic, household size and number of cattle owned variables. The decline in natural forest and increase in demand for fuelwood motivated people to have privately planted trees.

9.2.2 Spatiotemporal analysis of LU/LC change dynamics and future prediction

Land Use/Land Cover change dynamics has been carried out in the Beressa watershed for the year 1984, 1999 and 2015 and future prediction for the year 2030. The overall land use of the watershed are classified into six classes, viz., farmland, settlement, water body, forestland, grazing and barren land. Satellite images have been classified using supervised image classification techniques. Initially around 250 signatures extraction employed to change the images into thematic LU/LC classes. Prediction of future land use classification for the year 2030, Markov Chain Model has been used on the basis of past and present land use system. The results of classified images show that farmland and settlement areas have been expanded at the rate of 71.60 ha/year and 16.80 ha/year respectively. The share of forest cover decreased at the rate of 5 ha/year in the year between 1984 and 1999. While water bodies has decreased at the rate of 0.03 ha/year. However, in the second period the year between 1999 to 2015 the share of forest cover has been regenerated by the rate of 15.60 ha/year. Likewise, water bodies has regenerated at the rate of 7.10 ha/year. The share of grazing land has been reduced to 10%in 1999. Similarly, barren land has been reduced to 10.10% in the year 1999, the share further discriminate to 6.10% of grazing land and 5.20% of barren land in 2015 compared to 12.40% of grazing and 13.10% of barren land in 1984. The overall Kapa coefficient indicating accuracy for supervised land use classifications system is 0.8171, 0.83 and 0.822 for the year 1984, 1999 and 2015 respectively. The possibility trend of the land cover classes shows that the patterns of farmland and grazing land decline in 2030. There will be discrimination of future LU/LC patterns. During the year between 2015 and 2030, due to increase in settlement areas (35.14%)

and barren land (36.18%), which facilitate the decline in farmland (6.73%) and grazing land (11.53%), even though forestland and water body slightly increase, it is insignificant. Farmland and grazing land could reduce by 64.66 ha/year and ~10 ha/year respectively. However, the increase in settlement, barren land, forestland and water body by about 32.60, 26.50, 15.40 and 0.16 ha/year respectively could takes place for the years 2015 to 2030. The possibility of future LU/LC cover dynamics lead to destruction of natural resources and severely affect the availability of food production.

9.2.3 Spatiotemporal trend analysis of climatic variables (rainfall and temperature) and its implication on crop production

This study at local level undertake both seasonal and annual trends of climatic variability viz., rainfall *(kiremit* (summer), *belg* (spring), *bega* (winter) and annual) and temperature (minimum, maximum and mean) from seven stations in the Beressa watershed. MK test statistics and Sen's slope estimator have been employed in order to detect the trend of rainfall and temperature for the last 35 years (1980-2014). To identify the distribution and heterogeneity of seasonal and annual rainfall pattern, Precipitation Concentration Index (PCI) method has used. Pearson correlation analysis between climatic variables and crop production has been analysed. Finally, moving average and spatiotemporal variation of rainfall and temperature has been done using Inverse Distance Weighted (IDW) techniques. Based on MK test statistics results out of seven stations, only two stations are statistically significant (one at 5% and the other at 10% level of significance). The magnitude of significantly increasing trend and variability have observed in the mean annual rainfall at Debre Berhan (DB) station (0.28 mm/year and 1.07%). However, the trend magnitude of significantly decreasing trend were observed in Hagere Mariam (HG) station at -8.62 mm/year and -27.88%. The trend of seasonal rainfall obtained from MK test statistics showed that only one station showed significant increasing trend at 5% level of significance during *kiremit* season. However, during *belg* season two of the station showed significant trend (one at 5% and other at 10% level of significance). On the other hand, during *bega* season, four stations (three at 5% and one at 10% level of significance showed a significant trend. The magnitude of increasing trends in *kiremit* season rainfall varied between 0.33 mm/year and percentage change of 6.13% Debre Sina (DBS) station to 1.62 mm/year and 31.79% (DB). However, the magnitude of significantly decreasing trend was observed at SD station (-0.90 mm/year and -16.20% change and significantly decreasing trend of *belg* season rainfall varied between -0.12 mm/year and -10% in Ginager (GIN) station to significantly increasing trend 0.40 mm/year and 30% in DB station. The magnitude of decreasing trend during *bega* season found to be -0.06 mm/year and -7.5% in GIN, -0.05 mm/year and -8.80% at SD station, -0.11 mm/year and -12.70% at HG station, -0.13 mm/year and -29% change at Sheno (SH) station, -0.19 mm/year and -53% in DB station, -0.19 mm/year and -35% and -0.20 mm/year and -56.40% change in DBS station. The MK test, Sen's slope and spatial analysis of temperature trend indicate that stronger increasing trend has been observed in the Beressa watershed. The magnitude of increasing trend in mean annual temperature varied from 0.03°C/year to 0.14°C/year with percentage change found to be maximum at Sendafa (SD) station (31.30%) and minimum change at DB station (7.60%). Likewise, significant increasing trend of minimum temperature were observed with the minimum value of 0.005°C/year and 1.90% in GIN station to 0.12°C/year and 52.40% maximum value in DBS station. The magnitude of increasing trends of maximum temperature were observed in all stations with minimum value of 0.023°C/year and 4% in GIN station with the maximum value of 0.21°C/year and 37.60% in Enwari (ENW) station. Generally, based on the trend analysis during the last 35 year in the Beressa watershed, it signifies that decreasing trend and variability as well as irregular distribution of rainfall (both annual and seasonally) and stronger increasing trend of temperature is experiencing and possibly continue in the future. Therefore, it is essential to understand the magnitude of climatic change and variability impact on the natural resources and crop production, and therefore the effect of these changes is extremely helpful for improving appropriate management strategies viz., water harvesting, integrated water resources management, and other options, which could be reducing the adverse effect of climate change and variability.

9.2.4 Runoff-sediment response to LU/LC change dynamics

Land Use/Land Cover (LU/LC) dynamics has significant influence on runoff and sediment characteristics of any catchment. It influences the overall environment of the catchment as it changes hydrological processes viz., recharge, runoff and infiltration. Hence, distinguishing implication of land cover dynamics from the current runoff process and sediment yield process is a particular challenge. Runoff and sediment is an integral component of overall environmental systems, as of playing significant role in ecological, physiographic and hydrological conditions of a river basin. Therefore, runoff-sediment response to LU/LC change dynamics has been carried out for Beressa watershed. Hydrological model (SWAT) integrated with ArcGIS known as ArcSWAT has been used. The work of this study is performed based on LU/LC change dynamics on runoff and sediment response to the dynamics of land cover classes. To describe the topography, 30m spatial resolution DEM used, to differentiate the trend of runoff process and sediment yield three different land use classes for year 1984, 1999 and

2015 were used generated from Landsat images. Additionally, input like soil data and weather data have been imported into SWAT model.

The model has calibrated and validated in SWAT-CUP. The data from 1980-1999 were used for calibration while, from 2000-2014 used for validation including warmup periods. The model has successfully simulated and calibrated for runoff process and sediment generation. In the calibration and validation periods multi-objective function statistics: R^2, RSR, NSE and PBIAS values have shown acceptable value. Therefore, it provides assurance for further application of the model in order to assess the influence of LU/LC change dynamics on surface runoff process and sediment yield generation. Three land use scenarios (1984, 1999 and 2015) used with fixing other variables in runoff and sediment simulation process. The results indicate that runoff process and sediment yield generation have considerably attributed to LU/LC change dynamics. The dynamics of farmland and settlement areas have direct relationships with runoff and sediment dynamics. However, opposite relationship exists with forestland.

9.2.5 Integrated water resources management considering hydro climatological scenarios: an option for sustainable development

In the rainfed areas, water is the foremost restraining resources for better agricultural production to satisfy the growing demand of food and other needs. Water harvesting and enhancing productivity of available water, and not volume of yield per units of land, is therefore a better solution for rainfed agriculture particularly during small rainy season. Under these circumstances, it is necessary to implement efficient and effective integrated water resources management practices. The detailed discussions are already given in chapter 4 to 7. As already discussed in detail in the previous subsections, LU/LC changes, climate variability, and runoff and sediment scenarios have considerably negative contribution on the water resources availability, environment and productivity in the Beressa watershed. Therefore, to overcome the problems CROPWAT 8.0 model has been used for different major crops of the area. To recognize the potential contribution of rainwater availability for better productivity, Rainfall Contribution Index has been used. The following are some of the most pressing problems that specify the degree to which the communities are confined in a multifaceted web of environmental challenges:

i. Rainfall variability, increased rate of temperature,

ii. Fragmented land holding and cultivation of marginal land,

iii. Inadequate and insufficient access to off-farm income,

iv. Poor and unsustainable water harvesting and management practices and

v. Weak site-specific soil and water conservation practices.

The results obtained from Rainfall Contribution Index (RCI), the available rainwater is insufficient for the whole crops growth stage particularly crops sown during small rainy season (barley, garlic, potato and wheat). Therefore, it is necessary to use supplemental irrigation practice and rainwater harvesting including integrated water resources management. Even high PCI has observed during rainy season.

9.3 CONCLUSIONS

Based on the main findings of the study, the following specific conclusions have been drawn;

(i) Empirical studies have shown that there are enormous interlinked problems of erosion and degradation in the Beressa Watershed. The demand of household domestic energy sources is entirely relied on traditional biomass sources, which has negative contribution for reduction of forest cover and hence has high interaction with erosion and degradation problems and affecting food security. Therefore, encouraging private and community level plantation should get attention in the future economic incentive and availability of fuelwood. Similarly, for soil fertility management, natural fertilizer from dung is available.

(ii) During the study periods, LU/LC change dynamics have been experienced significant changes in the watershed. The dynamics LU/LC class change observations showed that farmland and settlement areas have been expanded. However, grazing land as well as barren land have discriminated. Pressure associated with rapid rate of population growth put pressure on forestland, grazing land, barren land, plantation and farmland. Between 1984 and 1999, farmland has increased at the rate of 67.50 ha/year. Similarly, settlement areas has been increased at the rate of 14.50 ha/year, caused for the outflow of other land cover classes. Overall, the whole study periods, expansion farmland, settlement area, forestland and water body have been observed 71.60 ha/year, 16.80 ha/year, 5.70 ha/year and 3.70 ha/year. In contrast, the share of grazing land has been discriminated at the rate of 43 ha/year. Likewise, the share of barren land has been shrunk at the rate of 54.80 ha/year. Future projection for the year 2030 has been done using Markov chain model. Unexpectedly discrimination of farmland possibly expected (67.50% to 62.99%) and grazing land could reduce from 6.10% to 5.40%. on the other hand, expansion of settlement from 6.55 to 8.80%, barren land from 5.20% to 7.01%, forestland from 13.60% to 14.70% and water body from 1.10% to 2.40% could takes place from the years 2015 to 2030.

(iii) In the Beressa watershed, the experience of decreasing trend and variability of rainfall as well as an increasing trend of temperature are observed. Rainfall during *bega* season reveals stronger decrease, while during *kiremit* season shows slightly increasing trend even though it is variable in distribution and high in concentration. Three of the stations out of seven stations in the district shows the mean annual rainfall has a decreasing trend in the year between 1980 to 2014. During the *belg* season significant decreasing trend was observed -0.12 mm/year and -10% at GIN station and increasing trend was observed in DB station (0.40 mm/year and 30%). Even though some of the stations shows increasing trend of rainfall, it does not imply the available rainfall is sufficient for crop production because of irregularity in the distribution.

The trend of temperature revealed increasing trend in all stations for the last 35 years. The significant increasing trend of mean annual temperature found in all stations, the magnitude of the trend varied from 0.03°C/year to 0.14°C/year. Significantly, increasing long-term annual minimum and maximum temperature during the study periods indicates that it is more likely contribute to the increase of mean annual temperature.

(iv) Using hydrological model (SWAT2012 model) thirteen most sensitive parameters, which govern the process of surface runoff (six parameters) and sediment yield generation (seven parameters) in the studied watershed have been pointed out. The process of model calibration and validation using SWATCUP have shown satisfactorily affirmed the model were capable to estimate surface runoff and sediment yield generation and assurance for further application of the model in order to assess the influence of LU/LC change dynamics on surface runoff process and sediment yield generation. Therefore, under fixing other variables, SWAT model is an important tool to simulate the spatiotemporal status of runoff generation and sediment yield under different LU/LC change dynamics (1984, 1999 and 2015), implying that in the data limited situation like Ethiopia, it provides a useful tool for sustainable watershed management practices. The results revealed that LU/LC change dynamics significantly affect runoff and sediment yield. A significant LU/LC class alteration in the form of expansion of subsistence farming and settlement areas as well as discrimination of forest cover and other land cover class at the same time provide extensive contribution for enormous incidence of surface runoff and sediment yield. In conclusion two LU/LC classes— farmland and settlement areas have less potentials for recharge and high for runoff and sediment yield generation as compared to forest and plantation. Therefore, it indicates that surface runoff and sediment yield are sensitive to LU/LC including soil, and water conservation practice.

(v) The impact of climatic variability, LU/LC changes and hydrological dynamic scenarios have considered and evaluated the influences on availability of water for crop production and other purposes. The results from climatic parameters shows that decreasing trend as well as variability of rainfall and increasing trend of temperature have been the incidences for the Beressa watershed. Likewise, continuous change of land cover classes have occurred and consequently discrimination of suitable farmland is a common phenomenon. Similarly, the incidence of runoff and hence sediment generation is a matter of concern for the downstream users. The limited availability of water call for water harvesting, integrated water resources planning and optimal available water resources utilization for better production without compromising the resultant ecosystem.

9.4 MAIN RESEARCH CONTRIBUTIONS

The main contributions of the present study incorporate detail of socioeconomic condition, watershed management practices, climate change trend and variability analysis, analysis of land use and runoff-sediment response to land use changes. Generally, the major contributions of this study are pointed out in the following ways;

(i) Soil erosion and land degradation is entwined problems for the Beressa watershed on the one hand, and implementation of management practices on the other. Therefore, this study emphasized on watershed management techniques. Implication for environmental conservation, compatibility of conservation technology with local context and household domestic energy consumption have a significant role for policy formulation to identify appropriate technology that fit to the local context.

(ii) The analysis of spatiotemporal land use/land cover change dynamics as well as prediction of future land use system have significant role in order to analyse anthropogenic influences on natural resources of past, present and for the future, which has been successfully demonstrated in the present study.

(iii) Analysis of spatiotemporal distribution of rainfall and temperature, and long-term trend analysis using different non-parametric test has been done at the local scale. The uncertainty of spatiotemporal climatic variability and its impact on crop production has been studied, which is an essential aspect of climate study.

(iv) SWAT model has been simulated and calibrated successfully for the Beressa watershed. This model can be replied in other homogeneous watershed to identify and evaluate runoff-sediment response to LU/LC change dynamics at smaller watershed scale, of Ethiopia where limited data were available.

(v) Based on consideration of hydro-climatic scenarios, water harvesting and integrated water resources management have been suggested at the local scale. The output of the present study is expected to have wide application to different stakeholders including water resources planners, socio-economic fraternity and other experts in order to overcome their problems.

9.5 RECOMMENDATIONS AND FUTURE SCOPE

Based on the main findings of this study, the following recommendations have been suggested;

- Land use/land cover dynamics resulted particularly from anthropogenic factors in the Beressa watershed and the whole country in general. The community in most parts of the country will no longer sustained by the current farming systems. Therefore, alternative sources of income, which reduce pressure on natural resources, creating awareness about the impacts of natural resources degradation are paramount importance. Future study may carry out with employing high multi-temporal Landsat images in order to predict accurately.

- The availability and data quality should take much consideration while using the hydrological models. The applications of SWAT2012 model was a challenging while availability of limited data was one of the major concerns in this study. Without appropriate data, implementation of the model is very challenging. Therefore, particularly for developing countries there should be new data collecting techniques so that the local as well as regional communities can possibly take parts in integrated, organized and coordinated data collecting and compilation.

- Considering hydro-climatological scenario including water harvesting and integrated water resources management suggested for sustainable development option in this study, can serve as important framework for other studies not only for the study watershed but also for other watersheds. Therefore, in the future there has to be additional efforts on proper resources utilization on the basis of available water and land resources that produce better integration between researchers, policy planners and local community.

<u>**List of Publications in Referred Journals**</u>

1. **Meshesha, T.W.,** Tripathi, S.K. and Khare, D., 2016. Analyses of land use and land cover change dynamics using GIS and remote sensing during 1984 and 2015 in the Beressa Watershed Northern Central Highland of Ethiopia. *Modelling Earth Systems and Environment*, *2*(4), p.168.

2. **Worku, Tesfa,** S. K. Tripathi, and Deepak Khare. "Household level tree planting and its implication for environmental conservation in the Beressa Watershed of Ethiopia." *Environmental Systems Research* 6.1 (2017): 10.

3. **Worku, T.,** Khare, D. and Tripathi, S.K., 2017. Modelling runoff–sediment response to land use/land cover changes using integrated GIS and SWAT model in the Beressa watershed. *Environmental Earth Sciences*, *76*(16), p.550.

4. **Tesfa Worku Meshesha**, Sangharsh Kumar Tripathi, Farmer's Perception on Soil Erosion and Land Degradation Problems and Management Practices in the Beressa Watershed of Ethiopia, *Journal of Water Resources and Ocean Science*. Vol. 5, No. 5, 2016, pp. 64-72. doi: 10.11648/j.wros.20160505.11.

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