IMPACTS OF CLIMATE VARIABILITY AND LAND USE LAND COVER CHANGE ON STREAM FLOW IN THE LITTLE RUAHA RIVER CATCHMENT, TANZANIA

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A DISSERTATION SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN FOREST RESOURCE ASSESSMENT AND MANAGEMENT OF THE SOKOINE UNIVERSITY OF AGRICULTURE. MOROGORO, TANZANIA.

2014

ABSTRACT

A study was conducted to investigate the hydrological impacts of land use land-cover changes and climate variability on stream flow of the Little Ruaha River. Remote sensing and GIS techniques and Soil and Water Assessment Tool (SWAT) model were used. Landsat TM and ETM+ images of 1990, 1998 and 2011 were used to locate and quantify the changes which have occurred in the catchment. The reason to select these periods was to get good and clear images; there were no clear images for 1980.The study revealed a significant change in land use land cover within a period of 21 years. Between 1990and 1998, the woodland and wetland covers declined by 2.6% and 9% per year, and 1998 and 2011 declined by 1.4% and 3.1% per year, respectively .Physical based SWAT model was calibrated for the period 2000 to 2006 based on the available climatic data and was validated for the period 2007 to 2009. The Nash-Sutcliffe model efficiency (ENS) and coefficient of determination (R^2) for annual flow were 58% and 65% respectively during calibration period and 72.68% and 77.35% during validation period respectively. Both land use land cover change and climate variability decreased runoff by 23% and 59.67% respectively. The climate variability influenced the surface hydrology more significantly than land use land cover change in Little Ruaha River catchment. The study concludes that, the modification of the land use and land cover and climate variability has resulted in changes in temporal distribution of runoff. The study highlights the importance of considering effects of land use land cover changes and climate variability on ecosystems and water resources for an informed decision on proper catchment planning and management.

DECLARATION

I, Lucas Theodory, do hereby declare to the Senate of Sokoine University of Agriculture that this dissertation is my own original work done within the period of registration and that it has neither been submitted nor being concurrently submitted in any other institution.

7/11/2014

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The above declaration is confirmed

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ACKNOWLEDGEMENTS

I would like to express my sincere gratitude to my supervisors, Prof. J.J. Kashaigili and Dr. J.Z. Katani for their guidance and constructive comments to the right pass towards the materialization of this study.

My special thanks go to my mother who has always supported me and giving me the confidence to pursue my dreams, encouraged me through all tough moments to ensure that I reach my goal. Special thanks to my research assistant Miss Sylvia Apolinari for her hard working during field work to ensure that I get the correct and reliable data.

Also my sincere thanks go to Chunya District Council for sponsoring my study and the EPINAV programme through Sokoine University of Agriculture by sponsoring my research to mention some of project members Prof. G. C. Kajembe a project leader, Dr. G. C. Mbeyale and other members who accepted me to be part of the project by conducting my research in this wonderful project. My special thanks go to Rufiji Basin Water Board and Tanzania Meteorological Agency (TMA) Iringa office for providing me with data; Iringa Rural District; and Village Executive Officers for the villages I attended during my data collection for their cooperation and for allowing me to carry out my study in a peaceful way. Also my sincere thanks go to Mr. Frederick Mashingia (PhD student) at University of Dar es Salaam for technical support during data analysis. I would like to express my sincere gratitude to my Almighty God as He has always been with me in all my study time, granted me good health and never forsaken me, glory and honour be unto Him.

DEDICATION

I would like to dedicate this dissertation to my beloved mother Anastazia Theodory who laid the foundation of my education as my first teacher and turned my youth into favour of education.

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LIST OF ABREVIATIONS

AoI	Area of Interest
CN	Curve Number
DEM	Digital Elevation Model
EPINAV	Enhancing Pro-poor Innovation in Natural Resources and Agricultural Value chains
ET	Evapotranspiration
ENS	Nash –Sutcliffe model Efficiency
FAO	Food and Agriculture Organisation of the United Nations
FDC	Flow Duration Curve
GIS	Geographical Information System
GPS	Global Positioning System
HRU	Hydraulic Response Unit
HV	Soil Hydraulic Value
LH –OAT	Latin Hypercube One factor at a Time
IPCC	Intergovernmental Panel on Climate Change
KS	Saturated Hydraulic Conductivity
LULC	Land Use Land Cover Change
LRC	Little Ruaha Catchment
MLC	Maximum Likelihood Classifier
SOL-WACS	Soil Water Available Capacity
SWAT	Soil and Water Assessment tool
TMA	Tanzania Meteorological Agency
TM	Thematic Mapper
UNFCCC	United Nations Framework Convention on Climate Change

URT	United Republic of Tanzania
UTM	Universal Transverse Mercator

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background Information

The problem of water shortage and competition is getting increased attention in the field of water management. Good quality ground and surface water may become too scarce to allow for sustainable use for various functions (Palamuleni and Annegarn, 2011). With increasing human activities and climate variability, it is important to understand interactions between hydrological regimes ,Climate variability and associated land use land cover change in the catchment (Boyer, 2004).

Land use land cover change (LULC) and climate variability can have major impacts on catchment hydrology and these impacts can be strongly interrelated (Boyer, 2004). Climate variability and water use competition being even more important considerations in catchment management, improved understanding of sensitivity of the catchment response to climate variability and land cover change is fundamental (Boyer, 2004). This includes understanding the susceptibility of catchment response characteristics to shifts in the magnitude, intensity (Boyer, 2004), and seasonality of rainfall, length of dry spells and temperature increases as well as the impacts of large scale land use change (Rientjes *et al.*, 2011). Climate variability and land cover change are expected to alter regional hydrologic conditions and results in a variety of impacts on water resources system throughout the world (Zhang *et al.*, 2007). Potential impacts may include changes in hydrological processes such as evapo-transpiration, soil moisture, water temperature, stream flow volume, timing and magnitude of runoff, and frequency and severity of floods all of which would cause changes in other environmental variables such as plant growth, and sediments and nutrient fluxes into water bodies (Gao *et al.*, 2012).

The effect of climate variability on stream flow and groundwater recharge varies regionally and between scenarios, largely following projected changes in precipitation (Fohrer *et al.*, 2001). Africa is the region most vulnerable to negative impacts of climate variability and land cover change on water catchment and at the same time has low adaptive capacity (IPCC, 2007). Climate change is one of the great challenges facing the Little Ruaha River catchment area as well as other river catchments in Tanzania (Richard *et al.*, 2011).

The freshwater of Little Ruaha River catchment is vulnerable to the consequences of changing climate such as drought, which is believed to have negatively impacted on the livelihood of people through decreased crop and livestock production, and on the biodiversity. The catchment area is characterized by multiple land uses such as irrigated agriculture, livestock keeping, environmental conservation, wildlife and tourism, a dynamic and extremely complex ecosystem. Land use land cover change and climate variability are key factors to consider in management of fresh water of Little Ruaha River Catchment.

1.2 Problem Statement

Freshwater demand is fast becoming an international crisis, largely brought upon by mismanagement and climate change (Richard *et al.*, 2001; Kashaigili *et al.*, 2013). Land cover changes and climate variability in the catchment can affect water supply byaltering hydrological processes such as infiltration, ground water recharge, base flow and stream flow (Li *et al.*, 2009). A number of studies shows that changes in vegetation cover throughafforestation or deforestration lead to increase or reduction in water yield and such changes have been observed in catchments ofdifferent sizesranging from less than 1 km^2 to over 1000km^2 (Palamuleni and Annegani, 2011; Fahrer *et al.*, 2001; Zhang *et al.*, 2001). Tadele and Förch (2007) reported an increase of mean monthly discharge for wet months by 12.5%, while in the dry season a monthly decrease of up to 30.5% in Hare River Watershed, Ethiopia. Study by Githui (2008) in Nzoia River basin, Kenya revealed that without climate variability, land use land cover changes would account for difference in runoff of about 55-68%. On the other hand, change in climate without land cover change accounted for a difference in runoff of about 30-41%. However combined effects of climate variability and land cover changes to reveal how interactions of climate and land use land cover change may produce different impacts on stream discharge of a catchment is not known (Hua and Tong, 2008). There is a lack of information on links between, precipitation and temperature patterns as well as the role of land use land cover change on stream flow (Khairy and Sensing, 2000). Therefore this study tried to bridge this knowledge gap by assessing the impacts of climate variability and land use land cover change on stream flow in the Little Ruaha River Catchment.

1.3 Justification of the Study

This study assessed and quantified the changes that have taken place (land use land cover change and climates), their impacts on the water resources of the catchment and the future potential impacts of these water resources with respect to the changing environment. The study is important because it adds to the initiatives in catchment management by enhancing the understanding of impacts of various environment (land use land cover changes) and climatic scenarios which, consequently indicate a potential for measurable changes in the conditions that control water yields including rainfall, temperature and stream flow. The study also provides the statistics on water yield of the catchment especially under impacts of significant land use land cover change and climate variability. The findings are very important because could be useful in water resource management of the catchment for sustainable use. The study findings could aid in proper decision making on catchment management, policy making as well as water use plans and will be useful to water managers like Rufiji Basin Water Office, catchment management officials, water user groups like domestic use and agricultural use especially irrigation association groups as well as Mtera hydropower plant, Ruaha National Park, researchers and academicians.

1.4 Objectives

1.4.1 Overall objective

To assess the impacts of climate variability and land use land cover change on stream flows in the Little Ruaha River Catchment.

1.4.2 Specific objectives

The specific objectives of the study were:

i. To assess trends in climate parameters (temperature, precipitation) from the period of 1980 to 2012.

ii. To assess the land use land cover changes in the Little Ruaha River Catchment for the period 1980 to2012.

iii. To determine the impact of land use land cover changes and climate variability on stream flow characteristics (surface runoff, peak flow, seasonal flow) in the Little Ruaha River Catchment.

1.5 Conceptual Framework

Climate variability may cause variations in climatic parameters like temperature, precipitation, which can impact stream flow characteristics like base flow and river flow regimes. However, increased human activities like expansion of agricultural farms and urban settlement result into land use land cover changes that affect stream flow. To understand their compounding impacts on river flow characteristics, modeling through use of distributed and semi-distributed models is inevitable. As such SWAT, a semi-distributed model has been considered (Fig. 1).

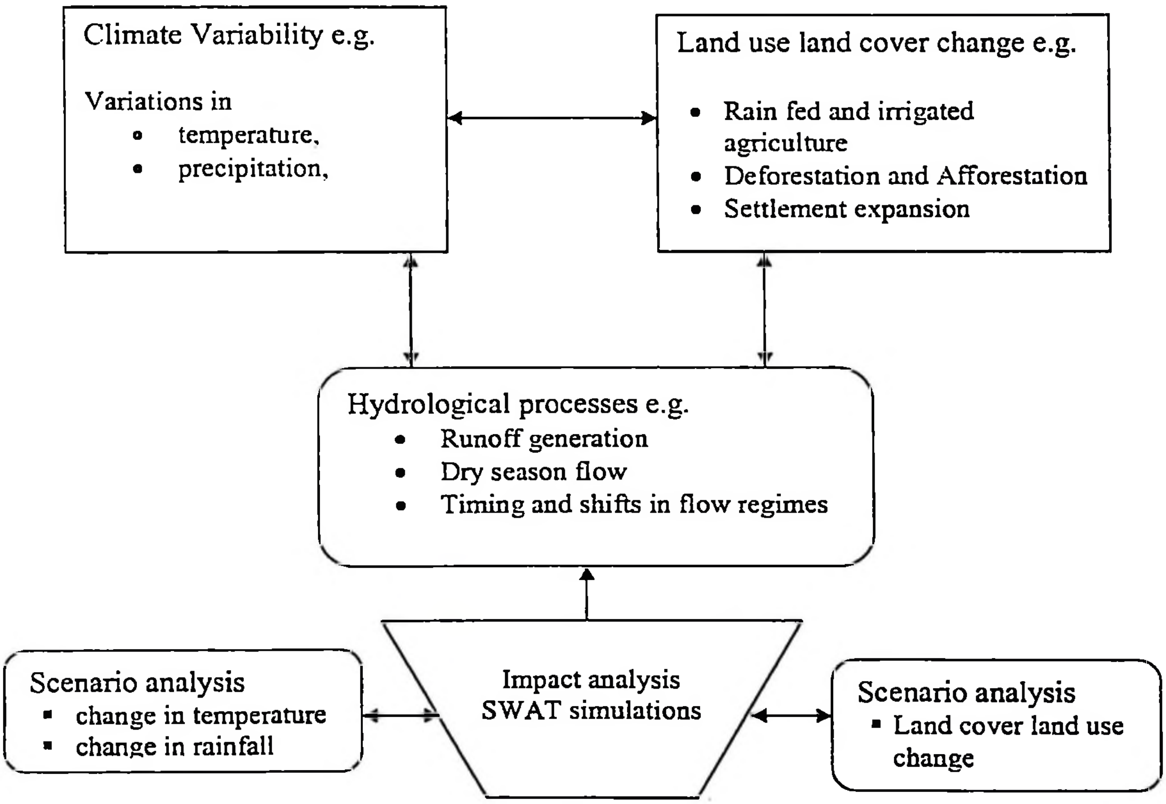

Figure 1: Conceptual framework of the study

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Definitions

(i) River flow

A river is a natural water course, usually freshwater flowing towards an ocean, a lake, a sea or another river. In some rare cases a river could flow into the ground and dry up completely at the end of its course, without reaching another body of water. Small rivers may be called by other names including stream, creek, brook, rivulet and rill. Rivers are part of the hydrological system. Water generally collects in a river from precipitations through a drainage basin from surface runoff and other sources such as ground water recharge, springs and the release of stored water in natural ice and snowpack e.g. from glaciers.

A stream flow or river flow or channel runoff, is the flow of water in streams, rivers and other channels, and is a major element of the water cycle. It is one component of the runoff of water from the land to water bodies, the other components being surface runoff. River can flow down mountains, through valleys (depressions) or along the plains and can create canyons or gorges. The term upriver (upstream) describes the direction towards the source of the river i.e. against the direction of flow. Likewise, the term downriver (downstream) describes the direction towards the mouth of the river in which the current flows.

River flows in a specific geographical region is affected by rainfall, evaporation, topography, lithology, vegetation heterogeneity and other factors, including regional and global climatic fluctuations (Costa and Cadile, 2003). Estimation of river flows variability is important for many practical purposes particularly in water resource management. These include reservoir operations, irrigation management, hydroelectric power generation, flood and drought control and recreational sports. Specifically, knowledge of temporal variability can be used to assess extreme events of floods and drought. Development of appropriate mathematical and statistical models of river flow variability may lead to a better understanding of river flow dynamics and aids in forecasting and strategic planning for control of catastrophic events.

A catchment is an area that catches rainfall and directs it to a stream, river or reservoir (Salehe *et al.*, 2012). Catchment areas vary greatly in size - a big river may have a catchment area of several thousand square kilometers, whereas a smaller tributary will have a catchment area of only a few hectares (FAO, 1997). River basin is the portion of land drained by a river and its tributaries (FAO, 1997). It encompasses the entire land surface dissected and drained by many streams and creeks that flow downhill into one another, and eventually into one river. The difference between a River catchment and River Basin is that, the River Basin is an area of land drained by a River and its tributaries. River Basin has typical features like; tributaries, a watershed, a confluence, source and mouth.

(ii) Climate variability

Climate variability refers to the climatic parameter of a region varying from its long-term mean every year in a specific time period (Kadigi *et al.*, 2004). IPCC (2007) defined climate variability as variations in the mean state and other climate statistics (standard deviations, the occurrence of extremes, etc) on all temporal and spatial scales beyond those of individual weather events. Variability may result from natural internal processes within the climate system (internal variability) or from variations in natural or anthropogenic external forces (external variability) (FAO, 1997). Climate variability is different from climate change. The United Nations Framework Convention on Climate Change (UNFCCC, 2012) defines climate change as a change of climate directly or indirectly attributed to human activity that alters the composition of the global atmosphere in addition to natural climate variability observed over comparable time periods.

(iii) Land use land covers change

The term 'land use' is used to describe human uses of the land, including actions that modify or convert land cover from one type to another.Land cover refers to the physical and biological cover over the surface of land, including water, vegetation, bare soil, and/or artificial structure.

2.2 Impacts of Climate Variability on Stream Flow

There are many different ways in which climate variability may affect catchment behaviour. Examples are such as changes in rainfall totals, locations, seasonality and intensity, effects on temperatures, radiation and evaporation (Roberts, 1998), and effects on drainage density (Moglen *et al.*, 1998). There are indications that the frequency of heavy rainfall events is likely to increase (IPCC, 2001), and studies have shown that variability is expected to increase with changes in monthly totals greater than annual change (Arnell and Reynard, 1996). However, in general, it is difficult to quantify these effects as they occur at higher resolutions in space and time than can be predicted by a global climatic model (Arnell and Reynard, 1996; Sefton and Boorman, 1997). Some of the effects and impacts of climate variability on stream flow (IPCC, 2001) include:

i) Changes in variability, spatial patterns and seasonality of precipitation and changes in temperature will have the effect of changing the soil moisture,

iii) Increased photosynthesis, reduced transpiration due to CO_2 enrichment, leading to increased water use efficiency.

iv) Factors leading to changes in water yields and high stress on water delivery systems include; faster plant growth, increased evaporation from lakes and reservoirs, reduced runoff and reduced groundwater recharge, higher demand for water for irrigation, bathing and cooling due to increased temperatures.

v) Changes in drought and flood hazards will cause changes in seasonal water replenishment, risk in flood plains and the areas affected. These will alter water resources and reservoir operations; river runoff and groundwater recharge, peak runoff and basin hydrology. These will consequently cause changes in projected yield of reservoir systems, water quality, water supply infrastructure and requirement of storage in water supply systems.

2.3 Impacts of Land Use Land Cover Change on Stream Flow

Many studies have been carried out to estimate the effect of LULC changes on the hydrologic response of catchments. The canopy intercepts rain and reduces the force with which it strikes the ground, thereby reducing erosion (Costa and Cardille, 2003). The canopy also reduces wind velocity and therefore wind–caused soil loss. Grasses, shrubs and trees make up the major plant cover types in a catchment, and all are important in catchment management.

In many tropical regions, large-scale changes in land cover involve the replacement of the natural vegetation by crops or pastures (IPCC, 2001). In non arid tropical region, the natural vegetation is depending on the seasonal water deficit, either a tropical forest (evergreen or deciduous), or a cerrado, a savanna-like vegetation. The conversion of tropical forest to agriculture and grassland disrupts the hydrological cycle of a drainage basin, by altering the water yield of the area (Kashaigili *et al.*, 2003). In addition, low-productivity grasses, like natural grassland pasture, have lower leaf area and produce less litter than the original vegetation. With a lower leaf area, the pasture does not intercept as much rainfall as the forest does, and a higher fraction reaches the ground. With less litter, the capacity of surface detention is decreased, and a greater proportion of the rainfall runs off as overland flow. If surface runoff increases substantially and infiltration is critically reduced, soil moisture may also decrease, contributing to a further reduction in the ET.

2.4 Hydrologic Modeling

Hydrologic modeling involves the application of mathematical expressions that define quantitative relationship between inputs (e.g. flow forming factors) and output (e.g. flow characteristics). The scope of hydrologic modeling and its applications has broadened dramatically over the decades. Hydrologic modeling is related to spatial processes of hydrologic cycle and is often used to estimate basin water resources as well as for impact assessment or more precisely water resource management. Many hydrologic models have been developed in the past and more are being developed and they are used to determine the performance of watersheds under inevitable land use changes, climate change and increased climate variability. This is done in the form of sensitivity analysis where baseline conditions of climate, land cover and stream flow are established, and then used to compare the effects on stream flow due to changes in precipitation, temperature, land cover and other climate variables. These analyses provide information on the direction and magnitude of stream flow changes and insight into which variables are most significant in predicting these changes. This would be very important for decision makers who require such information to evaluate management alternatives to support policies about water allocations between various sectors such as agriculture, ecosystems, domestic and industry. The synergism between GIS and remote sensing has enabled hydrologists to model temporal and spatial variations of hydrological processes efficiently, and especially for the distributed hydrologic models. There are many hydrological models used to model River catchments such as Conversion of Land use and its Effects (CLUE) model, Soil and Water Assessment Tool (SWAT) model e.t.c.

2.5 Conversion of Land use and its Effects model

CLUE model is a GIS based modeling system which assesses the effects of land use changes on water quality and socio – economic indicators. The model is subdivided into two modules, namely a non – spatial demand module and spatially explicitly allocation procedures. It allows users to create both land use and farm practices.

Strength

CLUE is a non- commercial model that is made available by its developers. Thus there is no cost implication which makes it suitable for academic research. It covers a wide range of biophysical and human drivers at different temporal and spatial scales. It uses linear regression as model input which can be reproduced, unlike in calibration exercise.

Limitation

One of the weaknesses is the limited consideration of institutional factors, although this could be more important for developed rather than developing countries. Another limitation is the small area extent which it can accommodate, if a large area is to be modeled, then it has to be aggregated and this reduces the analysis resolution.

2.6 Soil and Water Assessment Tool Model

The Soil and Water Assessment Tool Model (SWAT) model is a physically based semi-distributed geospatial hydrologic model (Palamuleni and Annegarn, 2011). It operates as an extension within Arc View or ArcGIS and therefore requires data in GIS formats. The model uses remote sensed and ground observation data (soil, land cover, rainfall and evaporation), and digital elevation data sets describing the land surface to calculate the basin hydrologic water cycle (Arnold *et al.*, 2005). SWAT model is very useful because it has weather engine component to predict the precipitation within an ungaurged watershed based on stochastic and probalistic methods (Arnold *et al.*, 2005). The model consists of two parts: a GIS-based module used for model data input and preparation, and the rainfall-runoff processing module. Calibrating and validating the model, Geographic information system (GIS) data for topography, soils and land-cover are used in the AVSWAT, an Arc View-GIS interface for the SWAT model (Cau and Paniconi, 2007).

2.7 Scenario Analysis and Impact Assessment Using SWAT

Model divides a watershed into sub watersheds or sub basins based on topographic information. The sub-basins are further divided into smaller spatial modeling units known as hydrologic response units (HRU), depending on the heterogeneity of land use and soil types. An HRU is the fundamental spatial unit upon which SWAT simulates the water balance. The hydrological processes modeled in SWAT are surface runoff, soil and root zone infiltration, evapo-transpiration, soil and snow evaporation, and base flow (Arnold *et al.*, 1998).Many studies like Anold *et al.* (1999), Githui, (2008), Palamuleni and Annegarn (2011) have also applied SWAT model in simulation of the impacts of climate variability and land use/cover changes on stream flow and shows successive results.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Materials

3.1.1 Description of the study area

The study was conducted in Little Ruaha River Catchment which runs from Sao Hills forest plantations to Mtera Dam within Iringa Region (Fig. 2).

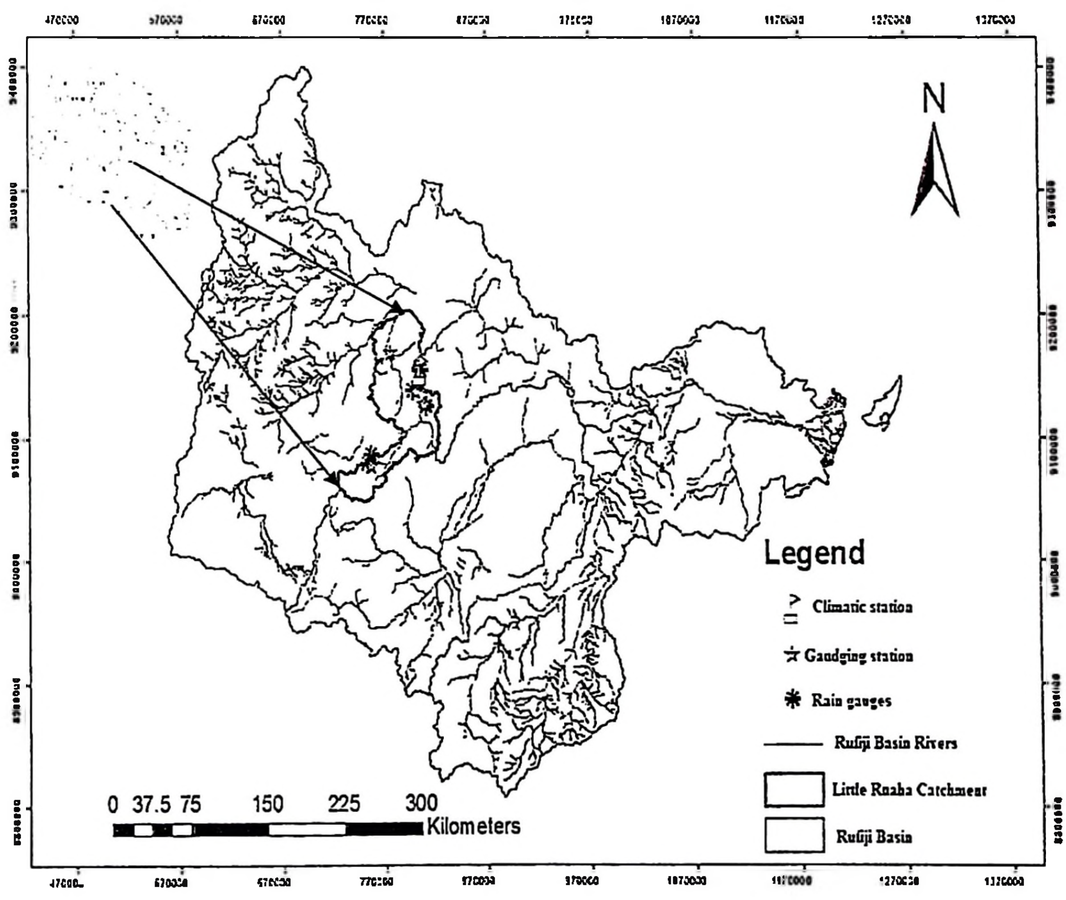

Figure 2: Map of study area (Little Ruaha River Catchment)

Little Ruaha River Catchment is the tributary of the Great Ruaha River which joins Great Ruaha River just after Ruaha National Park (Kashaigili *et al.*, 2003). The Little Ruaha River has a very large catchment area, extending to some 5500 square kilometers (Sanders and Fits, 2011). Little Ruaha catchment serves many uses, including irrigation, livestock, and domestic uses to neighboring villages, fisheries and the aquatic flora and fauna (Sanders and Fits, 2011). The Catchment area is located in the Southern Highlands of central Tanzania, within the Iringa Region and it lies between latitudes 7.2^0 to 8.6^0South of equator and longitudes 34.9^0 to 35.9^0 East of Greenwich.

3.1.2 Climate

Climate is a measure of the average pattern of variation in temperature, humidity, atmospheric pressure, wind, precipitation, atmospheric particle content and other meteorological variables in a given region over long period of time. Climate is different from weather, in that weather only describes the short term conditions of these variables in a given region. Climate of a location is affected by its latitude, terrain and altitude as well as nearby water bodies and their currents. Altitude, topography and vegetation influence climate greatly, resulting in micro climate in specific localities and macro climate in larger areas. Little Ruaha catchment has a climate influenced by several factor.The topography of the area is generally low lying by virtue of its location with an average altitude of 1536.41 masl. The vegetation of the surrounding landscape on which people depend for their subsistence falls under what is generally described as open wooded savannah dominated with shrubs and trees species notably Acacia species. The major land use is Agriculture, Woodland, Bush lands, Grasslands and Settlements. Rainfall is unimodal which falls between December and April. Annual rainfall ranging from 1000 mm to 1600 mm to some part of the catchment while other part is situated in semi-arid area receiving rainfall ranging from 600 mm to 900 mm per annum.

3.1.3 Socio economic activities

Agriculture is the main socio economic activity in the catchment area. Others economic activities are livestock keeping, fish farming, beekeeping, and very minor mining and industries (URT, 2007). There are thirty traditional irrigation schemes, upgraded to semi-improved in 2008, in which majority of them are located along the Little Ruaha River Catchment runs from Mufindi and Kilolo catchment forests to the Mtera dam. Mlenge semi-improved and Mkombozi traditional irrigation schemes are also found along the Little Ruaha River. Paddy is a main irrigated crop, but maize, Irish potato, sweet potatoes, sorghum, cassava, wheat, and finger millet are main food crops in the area

3.2 Methods

3.2.1 Selection of hydrological model

Many hydrological models exist for simulation of water balances and near surface soil micro climates. The complexity and focus of each individual model varies depending on the intended applications. There are many hydrological models for simulation of water catchment such as Soil Water atmosphere Plant (SWAP) model, Conversion of Land use and its Effects (CLUE) model e.t.c but for this study Soil and Water Assessment Tool (SWAT) model has been utilized. SWAT model was chosen because unlike CLUE model can delineate large catchment area and has weather generator engine system which can simulate or fill in the missing data which is the case for many catchments in developing countries Little Ruaha River Catchment included.

3.2.2 Data collection

The data collected includes stream flow and meteorological data and spatial data.Hydrological and meteorological data were collected from Rufiji Basin Water Office in Iringa and the Tanzania Meteorological Agency (TMA), Iringa station. Spatial data were downloaded from image suppliers (USGS GLOVIS).

(i) Stream flow and meteorological data

Stream flow data was available for four Stations 1KA32A, 1KA31, 1KA2A and1KA21A (Appendix 1, 2, 3 and 4) respectively. The stations had data ranging in time from 1980 to 2012, though they had missing data, the missing data were filled by weather generator engine of SWAT model during simulation process. Table 1 gives the summary of the stream flow data and the percentage of missing data to show the quality of data used in the study.

Table 1: Summary of available stream flow data for Little RuahaRiver Catchment

Gauging Station	Name	River	Period Recorded	Percentage of Missing data (%)
1KA32A	Makalala	Little Ruaha	1980 -2012	3.0
1KA31	Mawande	Little Ruaha	1989 -2012	6.4
1KA21A	Ihimbu	Little Ruaha	1980 -2010	13.1
1KA2A	Ndiuka	Little Ruaha	1980-1998, 2002 -2012	14.8

Rainfall data were available for four rainfall recording stations in the basin, which are Iringa Maji, Iringa meteorological station (Nduli), Mafinga Bomani and Mafinga National Service (Appendix 5, 6, 7 and 8) respectively. The collected data spanned a period between 1980 and 2012, though there was quite a number of missing data. The other weather data used include temperature data (daily maximum and minimum) for the Iringa Airport Meteorological stations (Appendix 9 and 10). Tables 2 and 3 gives the summary of the weather data used for this study.

Table 2: Summary of available daily rainfall data for Little Ruaha River Catchment

Rainfall Station	Name	Period Recorded	Percentage of Missing data (%)
9735014	Iringa Maji	1980 -2012	2.73
9735013	Iringa Met.	1980 -2010	0.26
9835033	Mafinga Bomani	1980 -2010	3.44
9835039	Mafinga National Service	1980 -2010	2.22

Table 3: Summary of available monthly maximum and minimum Temperature data for Little Ruaha River Catchment

Meteorological Station	Weather Parameter	Period Recorded	Percentage of Missing data (%)
Iringa Airport	Maximum temperature	1980 -2012	8.95
	Minimum temperature	1980 -2012	0.41

(ii) SWAT input database data

The basic data sets that are required to develop an input database for SWAT model are: topography, soil, land use and climatic data. A Digital Elevation Model (DEM) gives the elevation, slope and defines the location of the streams network in a basin. A Digital Elevation Model (DEM) of the study area at a 30x30 metre resolution was obtained from the Rufiji Basin Water Office at Iringa.

(iii) Soil Map and data

The soil data as required by SWAT to predict the stream flow should include the relevant hydraulic conductivity properties: the soil bulk density, the saturated hydraulic conductivity and the soil available water capacity (SOL_AWCS). The soil data was obtained from the Tanzania soil map of 2001 (Fig. 6).

3.2.3 Data analysis

(i) Trend analysis

Trend analysis of stream flow records is important to evaluate whether climatic factors and human interference significantly affect the hydrological regimes of the catchment (Fish and Road, 2010). A non parametric trend test method i.e. Mann-Kendal test was used to analyze the monotonic trend of annual and monthly precipitation and mean temperatures as well as stream flow data for the catchment as shown by the following equations.

$$S = \sum_{i=1}^{n} \{ (\sum_{i=1}^{n} \mathrm{sgn}(Rj - Ri) \} \quad \text{.......... (1)}$$

$$\text{Where } Sgn = \begin{pmatrix} 1 & if & X & >0 \\ 0 & if & X = & 0 \\ -1 & if & X = & <0 \end{pmatrix} \quad \text{.......... (2)}$$

$$VAR(S) = \frac{1}{18} (n(n-1) * (2n+5) - \sum_{i=1}^{n} tp(tp-1)^{*}(2tp+5)) \quad \text{..........(3)}$$

Where tp is number of data values in the pth group and n is number of periods in years. The values of S and variance (S) were used to compute the test statistic Z as follows:

$$Z = \begin{pmatrix} \frac{S-1}{\sqrt{VAR(S)}} & if & S & >0 \\ 0 & if & S = & 0 \\ \frac{S+1}{\sqrt{VAR(S)}} & if & S = & <0 \end{pmatrix} \quad \text{..........(4)}$$

A negative or positive value of Z indicates an upward or downward trend. To test for either an upward or downward monotonic trend, a two tail test statistics at alpha level of significance was done, Ho were rejected for the absolute value of Z greater than $Z_{1-\alpha/2}$ where α =0.001, 0.01, 0.05 and 0.1

(ii) Remotely sensed data, processing and change detection

The land use land cover data combined with the soil cover data generates the hydrologic characteristics of the basin or the study area, which in turn determines the excess precipitation, recharge to the ground water system and the storage in the soil layers. To understand the impacts of climate variability and land use land cover changes with time and its impacts in stream flow in the Little Ruaha River catchment, analysis of remotely sensed data (satellite images) was done and involved the following procedures:

(i) Image selection and acquisition

In consideration of cloud cover, the seasonality and phonological effects (Kashaigili, 2006), image listed in Table 4 were selected for image processing and change analysis. The image selected were both from dry season in order to acquire images with minimum cloud cover and also to avoid differences due to season effects. In this study land sat images of 1990, 1998 and 2011 was used for land use land cover change classifications. The reason was to get clear images, there were no clear images for 1980, and also from historical background of the catchment from 1990s and 2000s is where the catchment experiences many land use land cover changes due to introduction of irrigated agriculture (Kadigi, 2006).Development of irrigated agriculture in the study area has attracted immigrants from other areas. This inturn has contributed in increasing human population as well as demand for water and land for farm expansions.

Table 4: Imagery data

Image	Path/Row	Date of acquisition	Season
Landsat TM	168/65	11/7/1990	dry
Landsat TM	168/66	11/7/1990	dry
Landsat TM	168/65	21/9/1998	dry
Landsat TM	168/66	30/7/1998	dry
Landsat TM	168/65	9/7/2011	dry
Landsat TM	168/66	10/7/2011	dry

(ii) Image processing

Image processing involved three stages,these were: Image pre-processing, rectification or georeferencing and image enhancement.

Image pre-processing: The methods for image analysis required the use of both visual and digital image processing. Prior to image processing images were extracted from the full scenes using ERDAS Imagine software, Version 2011 to subset scenes into area of interest (AOI) followed by rectification.

Image rectification: Image rectification was perfomed in order to correct data for distortion or degredation which may result from the image acquisition process. To ensure accurate identification of temporal changes and geometric compatibility with other sources of information, the images were geo-coorded to the coordinate and mapping system of the national topographic maps, i.e. UTM coordinate zone 36 south, Spheroid clarke 1880, Datum Arc 1960, based on aprevious georeferenced Landsat TM images of 11^{th} July 1990. Since the images had already been corrected for radiometric distortions and available asgeo-cover datasets with no apparent noise, the created sub-scenes were only subjected to geometric correction.

Image enhancement: In order to reinforce the visual interpretability of images, a colour composite (Landsat TM bands 4, 5, and 3) was prepared and its contrast was stretched using a Gaussian distribution, a 3x3 high pass filter was applied to the colour composite to further enhance visual interpretability of linear features e.g. Rivers, and land use features like agricultural land, forests etc. All image processing were carried out using ERDAS Imagine software version 2011.

(iii) Preliminary Image classification and ground truthing

Preliminary Image classification: Within the scope of this study, image classification is defined as the extraction of differentiated land use and land cover categories from remote sensing data. Before going to field, to implement ground truthing, preliminary image classification was performed to roughly identify vegetation types and other land use and land cover classes using satellite images of 1990. Supervised image classification using Maximum Likelihood Classifier (MLC) was used to create base map which was then used for ground truthing. The maximum likelihood classifier was selected since unlike other classifiers it considers the spectral variation within each category and the overlap covering the different classes (Kashaigili *et al.*, 2006).

Ground truthing: Ground truthing was done in order to verify and modify land use land covers obtained during preliminary image interpretation. Ahand-held GPS was used to locate sampled land cover observations. During the ground truthing, the following major land cover classes were identified: closed woodland, open woodland, irrigated agriculture, natural forest, plantation forest, bushland, cultivated land, cultivated woodland and wetlands/vegetated swamps.

(iv) Final image classification

Supervised classification process involved selection of training sites on the image was carried out. Training sites are sites of pixels that represent specific land classes to be mapped (ERDAS, 1999). They are pixels that represent what is recognised as discernable pattern or potential cover classes. Training sites were generated by on-screen digitizing of selected areas for each land cover class identified on the colour composite. Training was iterative process, whereby the selected pixels were evaluated by performing an estimated classification. Based on the inspection, training samples were refined until a satisfactory result was obtained. The objective was to produce thematic classes that resemble or can be related to the actual land cover types on the earth's surface.

(v) Classification of Accuracy Assessment

Land cover maps derived from classification of images usually contain some sort of errors due to several factors that range from classification techniques to methods of satellite data capture. Hence, evaluation of classification results is an important process in the classification procedure (Yesserie, 2009).Among the common measures used for measuring the accuracy of thematic maps derived from multispectral imagery, error/confusion matrix was used. An error matrix is a square assortment of numbers defined in rows and columns that represent the number of sample units assigned to a particular category relative to the actual category as confirmed on the ground

(vi) Preparation of land use land cover maps

Classified images were recorded to respective classes (i.e. wetland, forest, water, woodland, bush land, grassland, settlement, cultivated land). Following the recoding, images were filtered using a 3 x 3 majority-neighbourhood filter. The classified images were filtered in order to eliminate patches smaller than a specified value and replace them with the value that is most common among the neighbouring pixels. A mosaic operation was performed to multiple classified images to produce one map for the entire study area. The image mosaicking involved the joining of geo-referenced images together. The input images contained the same map and projection information with the same number of layers. After mosaicking, sub-setting was performed in order to break out a portion of a large image file into one or more smaller files. Often, image files contain areas much larger than a particular study area. In these cases, it is helpful to reduce the size of the image file to include only the area of interest (AOI). This not only eliminates the extraneous data in the file, but it speeds up processing due to the smaller amount of data to process (ERDAS, 1999).

(vii) Land use land covers change detection analysis

Change detection is a very common and powerful application of satellite based remote sensing. Change detection entails findings the type, amount and location of land use changes that are taking place (Kashaigili, 2006).

In this study, post classification comparison was used to quantify the extent of land cover changes over the 21 years period (1990, 1998, and 2011). The advantage of post classification comparison is that it bypasses the difficulties associated with the analysis of the images that are acquired at different times of the year, or by different sensors and results in high change detection accuracy (Li *et al.*, 2007).

(viii) Assessment of the rate of cover change

Estimation for the rate of change for different land covers was computed based on the following formulae (Kashaigili and Majaliwa, 2010).

$$\%\,Change_{year\,x} = \frac{Area_{i\,year\,x} - Area_{i\,year\,x+1}}{\sum_{i=1}^{n} Area_{i\,year\,x}} x\,100 \quad \text{...(5)}$$

$$Annual\,rate\,of\,change = \frac{Area_{i\,year\,x} - Area_{i\,year\,x+1}}{t_{years}} \quad \text{... (6)}$$

$$\%\,Annual\,rate\,of\,change = \frac{Area_{i\,year\,x} - Area_{i\,year\,x+1}}{\sum_{i=1}^{n} Area_{i\,year\,x}\, x\, t_{years}} x100 \quad \text{.. (7)}$$

Where;

Area $_{i\,year\,x}$ = area of cover i at the first date,

Area $_{i\,year\,x+1}$ = area of cover i at the second date,

$\sum_{i=1}^{n} Area_{i\,year\,x}$ = the total cover area at the first date and

t_{years} = period in years between the first and second scene acquisition dates.

(c) SWAT Model setup and simulation options

This analysis was carried out in four steps. First, a database was established and land use land cover maps for the years 1990, 1998 and 2011 were produced to analyse the land use land cover change. Second, a SWAT simulation run was carried out using a set of input variables, and a sensitivity analysis was performed to identify parameters that influence the predicted stream flow the most. Third, the efficiency of the model was assessed by comparing simulated and observed annual and monthly stream flow. Fourth, in order to test the assumption that land use/cover change and climate variability has affected the watershed stream flow; further simulations were performed using both maps and climate data for the same period to carry out scenarios analysis. The procedures are described in the subsequent sections.

(i) Watershed delineations

The DEM was used to delineate the topographic characterisation of the watershed and to determine the hydrological parameters of the watershed such as the slope, flow accumulation, flow direction, and stream network. Arc SWAT 2009, an ArcGIS interface, was used to delineate the watershed. To capture the heterogeneity in physical properties, the watershed was subdivided into 29 (twenty-nine) sub-watersheds or sub basins (Fig. 3).

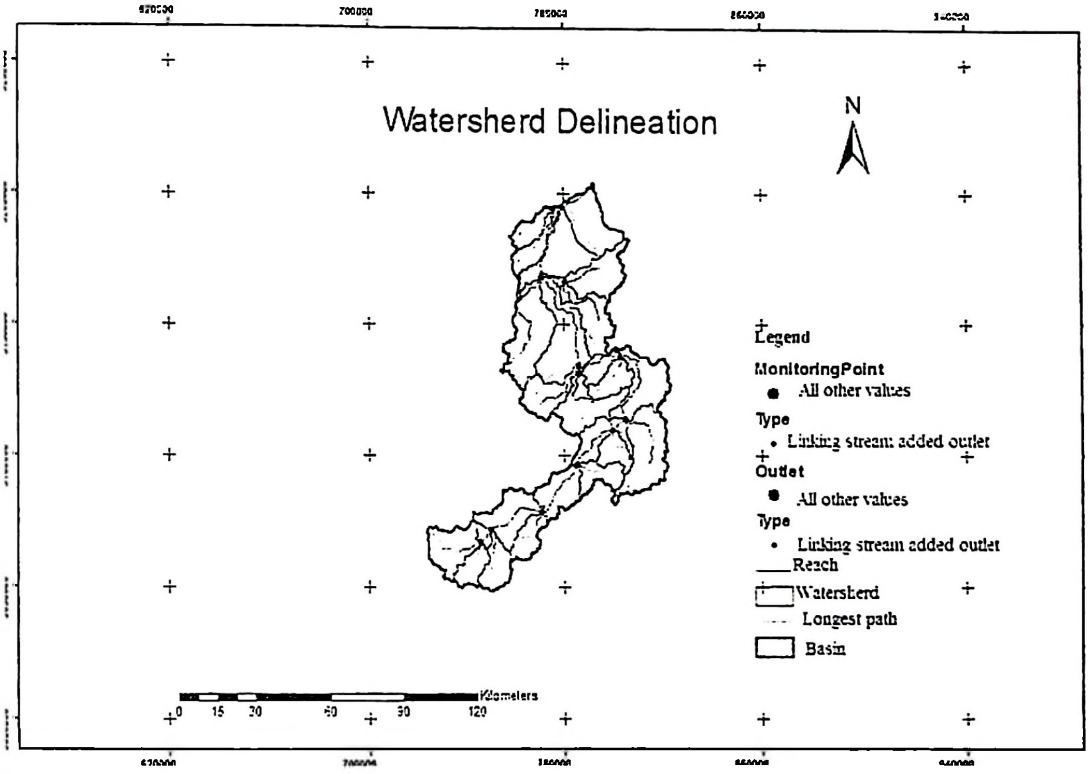

Figure 3: Watershed delineation

(ii) Hydraulic Response Unit (HRUs) Definitions

Before defining the HRUs the Landuse data (Fig. 4) were reclassified to match with the SWAT land use classification (Table 5). SWAT requires land use and soil data to determine the area and the hydrologic parameters of each land-soil categories simulated within each sub watershed. Therefore, land use, slope and soil maps were overlaid. This study uses a dominant of land use and soil definition to create the Hydrologic Response Unit (HRU) for each sub basin. The abstraction data used was distributed as per sub basin and entered into SWAT interface independently for reach/river and ground water/boreholes each one of the sub-watersheds were partitioned into Hydrologic Response Units (HRUs) that consist of homogeneous land use, management, and soil characteristics whereby watershed was divided into 753 HRUs (Fig. 5).

Table 5: Little Ruaha Land use classes matched with the SWAT land use classes.

USGS Land use class	SWAT Land use class	Land use Class	% total catchment area (ha)
Residential	URBN	Built-up area	15778.47
Wetlands-Non-Forested	WETN	Wetland	40868.84
Range-Brush	RNGB	Bush lands	88949.07
Range-Grasses	RNGE	Woodland	177202.58
Agricultural Land-Generic	AGRL	Cultivated land	172870.22
Wetlands-Forested	WETF	Riverine forest	13391.96
Agricultural Land-Close-grown	AGRC	Cultivated woodland	18521.84
Pasture	PAST	Grassland	41814.98
Forest-Mixed	FRST	Natural forest	19255.42
Water	WATR	Water	5483.28
Forest-Evergreen	FRSE	Plantations	18981.52

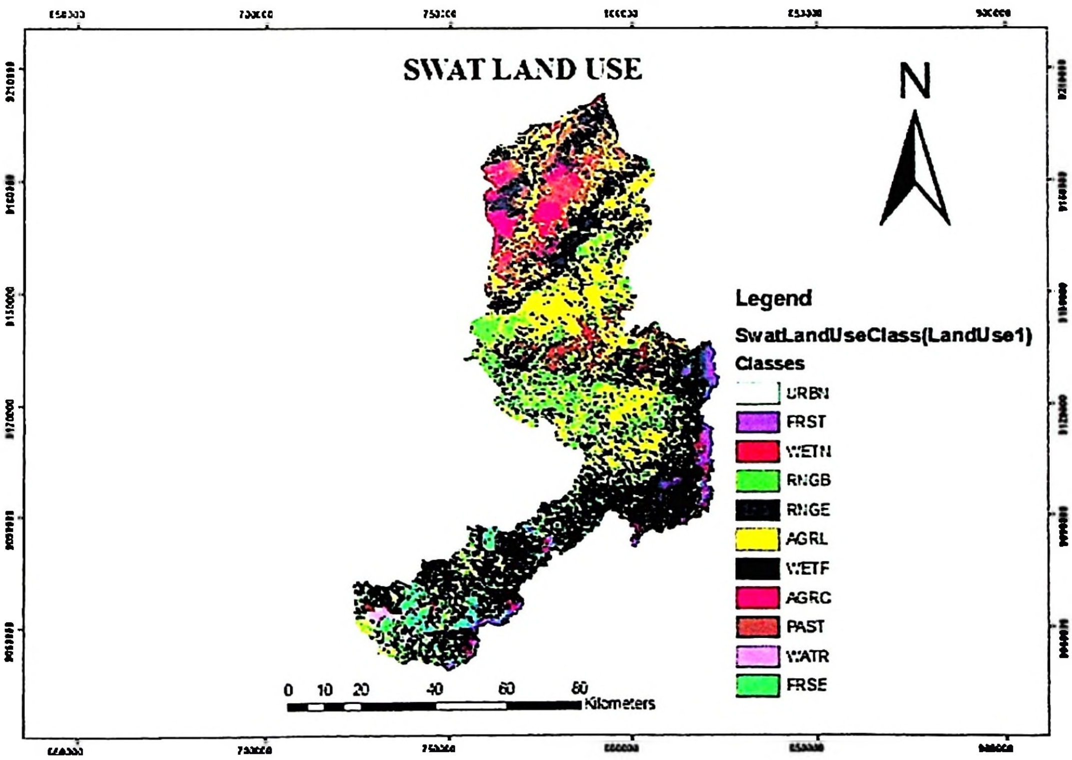

Figure 4: SWAT Land use map.

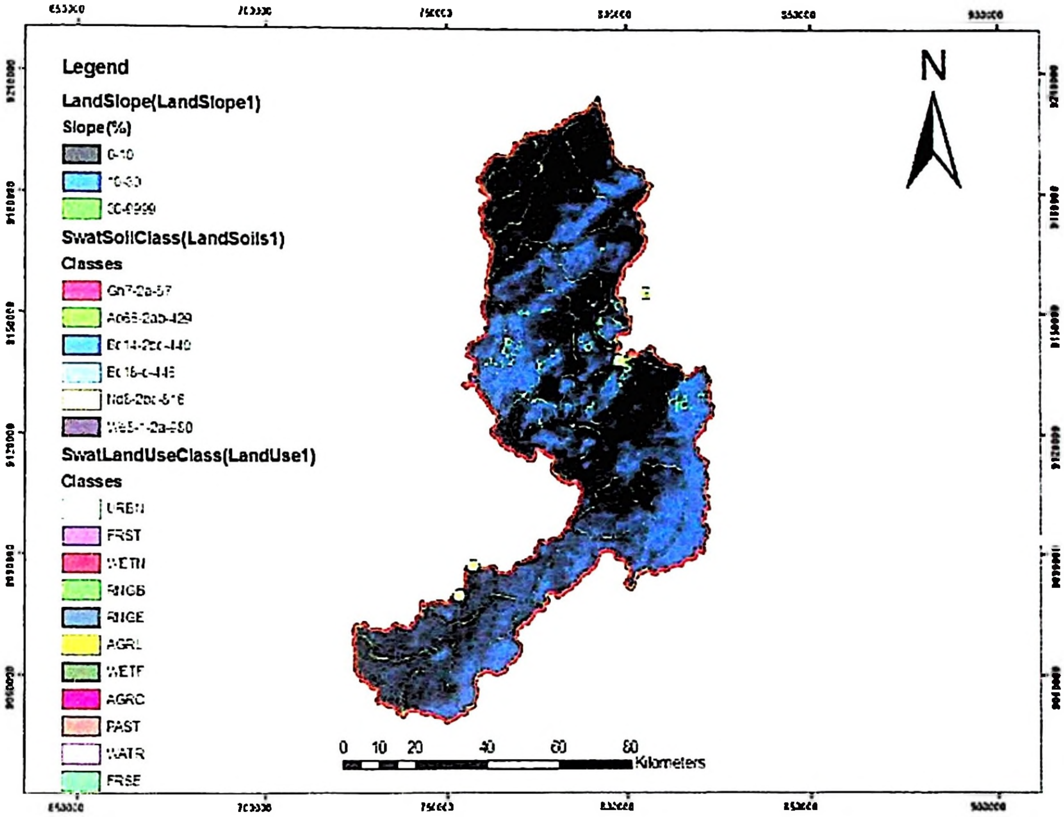

Figure 5: Hydraulic Response Unit (HRUs).

(iii) Write input tables

Before SWAT input tables were written in the model, input data set files were prepared whereby land use data files, dem data files, climatic data files, soil data files and lookup tables (land use and soil lookup tables) were prepared (Fig. 6). SWAT input data were written under write the input tables model interface and precipitation and temperature were used as input data while other datasets were parameterized using weather generator engine of SWAT model. After weather data were inputted into the model and under write all interface the model was able to prepare all input data files.

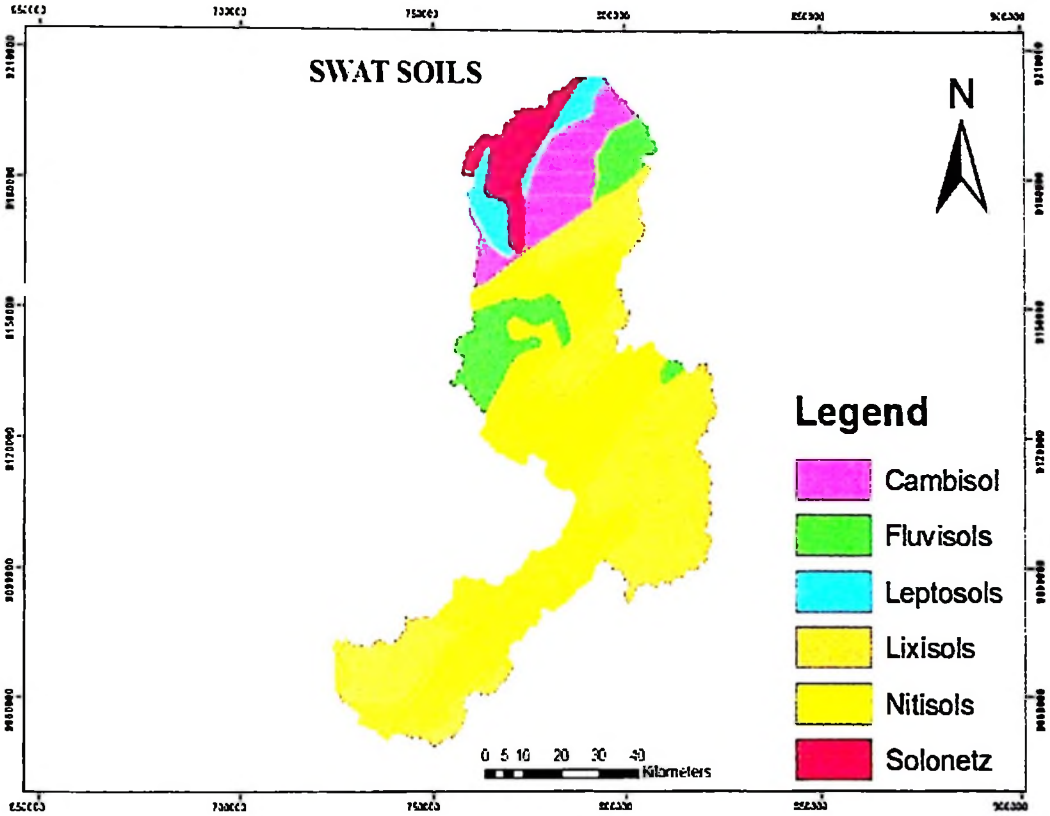

Figure 6: Soil map of Little Ruaha River Catchment

(iv) Edit SWAT Input

Some SWAT input files were edited in order to adjust some parameters like sub basin data and watershed data.

(v) Simulation and Sensitivity analysis

Simulation of the stream flow

The hydrological processes simulated by sub basins as included in the water balance equation are precipitation, surface runoff, evapo-transpiration, percolation and return flow. The daily weather data required by SWAT are precipitation, temperature (maximum and minimum), solar radiation, relative humidity and wind speed. After inputting precipitation and temperature data, weather generator then generates solar radiation and relative humidity for the day. Finally wind speed is generated independently. Runoff is simulated separately for each of the HRU and combined to give the total stream flow for the other sub basin which is then combined with stream flow for the whole basin. Through delineating sub-watershed and creating Hydrological Response Unit (HRU), the SWAT model simulated the water balance of the catchment. SWAT predicts the surface runoff using the modified SCS Curve number method. In this study the SCS Curve Number which is a function of the soil permeability, land use and antecedent moisture condition was used for simulation of infiltration and potential evapo-transpiration. The basic equation used by SCS curve number:

$$Q = \frac{(R-I)^2}{R-I+S} \quad (8)$$

Where Q is the accumulated surface runoff or excess rainfall (mm), R is the rain depth for the day, I is the initial abstraction which includes the surface storage, interceptions and infiltration prior to the surface runoff (mm) and S is the retention parameter (mm)

Sensitivity analysis

Quantifying model sensitivity to parameter changes is an important step in understanding model performance, and a crucial undertaking prior to model calibration; therefore, addressing whether the appropriate quantity and quality of data can be obtained to provide realistic model outputs given parameter sensitivity (Tracy and Scott, 2013). Sensitivity analysis was done prior to auto calibration and model validation in order to identify parameters which influence model the most .Different lengths of observed data records have been used in this study to assess the influence of data adequacy in parameters identification. Initially, four SWAT parameters were chosen to test surface runoff response sensitivity that include: curve number (CN), percent land cover, saturated hydraulic conductivity (Ks), and soil hydrologic value (HV). Latin Hypercube sampling based on one factor at a time (LH-OAT) which is incorporated in AVSWAT as an extension was used to identify parameters that have a significant influence on model simulations (Fish and Road, 2010).

(vi) **Model calibration and validation**

Calibration is tuning model parameters based on checking results against observations to ensure the same response over time (Zeray *et al.*, 2007). This involves comparing model results, generated with the use of historic meteorological data, to recorded stream flows. In this study coefficient of determination (R^2) and Nash-Sutcliffe model efficiency (ENS) values were checked to see the model performance. New SWAT project was built from the land use land cover map and database files of climatic data for Little Ruaha River Catchment was used for model calibration. Annual runoff of 2000-2006 and land use land cover map of 1998was used for model calibration, and annual runoff of 2007-2009 and land use land cover map of 2011 was used for model validation. Nash–Sutcliffe model efficiency (ENS) and the coefficient of determination (R^2) were used to assess the predictive power of the SWAT model.

(vii) SWAT model scenario analysis

The SWAT model was used for scenario analysis under climate variation and land use land cover change by running the calibrated SWAT model for each of the four combinations of two time-periods and two land use land cove maps. The land use land cover map of 1990 and climate (temperature and precipitation) of 2000–2006 were used to quantify the effects of land use land cover change and climate variability on stream flow characteristics. The influences of the land use land cover and variations in climate (temperature and rainfall) were quantified on monthly and annual time step by comparing SWAT outputs to baseline run(the SWAT run using base map).

To evaluate the effect of land use land cover change and climate variability on hydrology, the approach of one factor at a time was used (i.e., changing one factor at a time while holding others constant). Meteorological data of the two time epochs of 1981–1990 and 1991– 1999 were selected, and each time epoch included one land use land cover map. The land use maps of 1998 and 2011 were used to represent the land use land cover patterns of 1990s and 2000s for the two time epochs respectively. The calibrated SWAT model was run for each of the four combinations of two time epochs and two land use land cover maps (called four scenarios hereafter). The influences of the land use land cover change and climate variability were quantified by comparing the SWAT outputs of the four scenarios as follows:

S1: 1998 land use land cover and 1981–1990 climate data.

S2: 2011 land use land cover and 1981–1990 climate data.

S3: 1998 land use land cover and 1991–1999 climate data.

S4: 2011 land use land cover and 1991–1999 climate data

The contrast between the results of S1 and S2 indicated the influence of land use land cover change between the two periods. The contrast between S1 and S3 indicated the influence of climate variability on stream flow characteristics and S1 and S4 indicated the combined effects of land use land cover change and climate variability on stream flow.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Annual Rainfall and Discharge for the Little Ruaha River

The time series of annual rainfall over the Little Ruaha Catchment are presented inFig.7whileFig. 8presents the time series of mean annual flows of the Little Ruaha River at Mawande station.

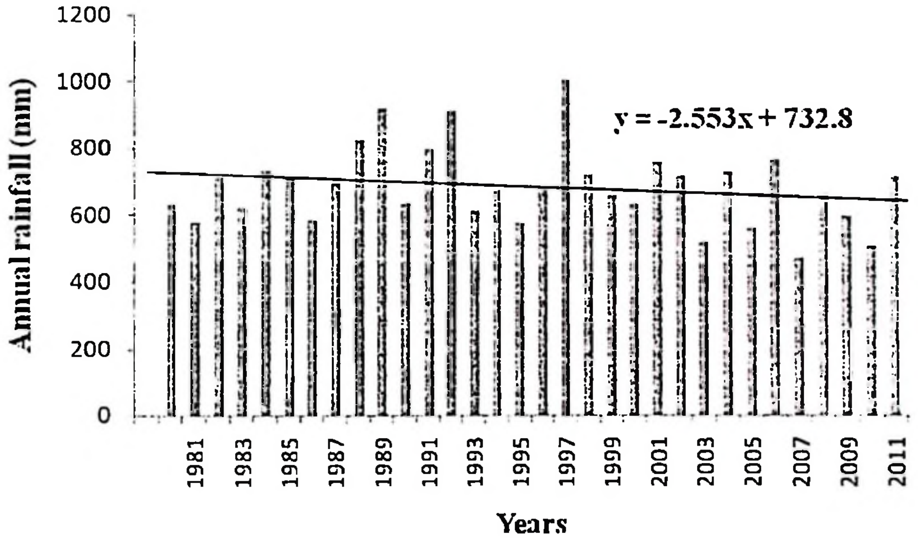

Figure 7: Annual rainfall at Iringa Maji station for the period 1980 -2012.

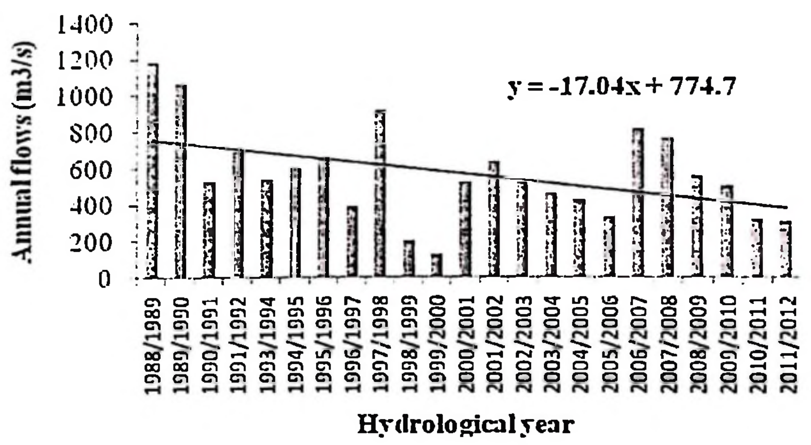

Figure 8: Mean Annual flows at Mawande station (1988/1989 -2010/2011).

Annual rain fall (Fig. 8) as recorded at Iringa maji station does not show much variation in total rainfall. The slightly decrease in annual rainfall as shown by negative slope could be partly be explained by the increase in rainfall in the upper catchment and lesser rainfall received in lower catchment. This also can be due to higher temperatures experienced in the catchment, especially in lower catchment or downstream. The mean annual flows as recorded at Mawande station (Fig. 8) shows variation in magnitude of flows between years. The slope is negative indicating that flood discharges are infrequent or not sustained for long period of time during dry periods. The progressive decrease in mean flow is a good indication to the changes of hydrological balance upstream in the Little Ruaha River Catchment and which is associated with their increase in change in land use land covers. This also can be the case of continued diversion of water to irrigation areas during the dry season which was the major factor in reducing inflows to the catchment.

4.2 Statistical Trend Analysis Results on Rainfall and Flows

Table 6 presents results of trend analysis on rainfall over the Little Ruaha river catchment and selected stations in the catchment while Table7 presents results of trend analysis on annual flows at four gage stations. The results in Table 6, indicates that there was significant decreasing trend in the annual rainfall in the catchment at the 95% level of significance at all three stations except on Mafinga Bomani station which show no significant increasing trends for the period 1980–2010.

Table 6: Summary of statistical trends in annual rainfall at some stations in the Little RuahaRiver catchment

Station	Start year	End year	Number of years	Slope of trend	Z-statistics at 95%CI	Remarks
Iringa Maji	1980	2012	33	-0.044	-3.50	Significant decreasing trend
Iringa meteorological station	1980	2010	31	-0.044	-3.50	Significant decreasing trend
Mafinga Bomani	1980	2010	30	0.171	0.54	Not significant increasing trend
Mafinga National service	1980	2010	31	-0.044	-3.50	Significant decreasing trend

This could be partly explained by decreasing in rainfall downstream stations e.g. Iringa Maji which shows negative slope (Fig. 7) and within this part of the catchment lesser rainfall is received. The results in Table 7 indicate that there was significant decreasing trend in the annual river flows for the Little Ruaha River at the 95% level of significance. This could be explained partly by more water abstractions in the catchment to sustain socio-economic activities such as irrigated agriculture, thus reducing stream flow.

Table 7: Summary of statistical trends in annual flows at some stations in the Little Ruaha River catchment

Station	Start year	End year	Number of years	Slope of trend	Z-statistics at 95%CI	Remarks
Mawande	1989	2012	23	-0.002	-2.273	Significant decreasing trend
Makalala	1980	2012	32	-0.025	-3.783	Significant decreasing trend
Ihimbu	1980	2011	31	-0.025	-3.783	Significant decreasing trend
Ndiuka	1980	2011	31	-0.004	-2.474	Significant decreasing trend

Also this might be due to decreasing in rainfall over years especially in downstream catchment as indicated by negative slope at 95% significant level in downstream station of Iringa Maji (Fig.7). Stream flow is known to reflect the integrated response of the activities of the entire river basin where rainfall serves as one of the major input into the runoff processes (Githui, 2008). However, other activities occurring within the catchment e.g. river water abstractions for agricultural purposes during the prolonged dry periods could cause reduced stream flow amounts.

It was also revealed that the changes in land use land cover in the catchment contributed to decrease of dry season flows. A study by Kashaigili *et al.* (2006) on land use land cover changes in the Usangu area has revealed that there has been a great change in land use land cover mainly caused by increased anthropogenic activities within the catchment. The results on land use land cover change in this study shows that, there is significant changes in landuse land cover in Little RuahaRiver Catchment especially expansion of cultivated land and settlement while bush land and woodland has decreased which might have caused reduced in stream flows.

4.3 Flow Duration Curves for the Little RuahaRiver

The daily flow duration curves at Mawande station represented by Fig.10 to illustrate clearly the differences between low flows in the two different time periods. The slope of the flow duration curves are relatively steeper at higher discharges indicating that flood discharges are infrequent or not sustained for long period of time. Comparing the post 1999 and pre 1998 periods, the latter period slope of the Flow Duration Curve (FDC) at higher discharges is much steeper as compared to the former. This is an indication of the effect of land cover removal that results into flush runoff during the rainy season.

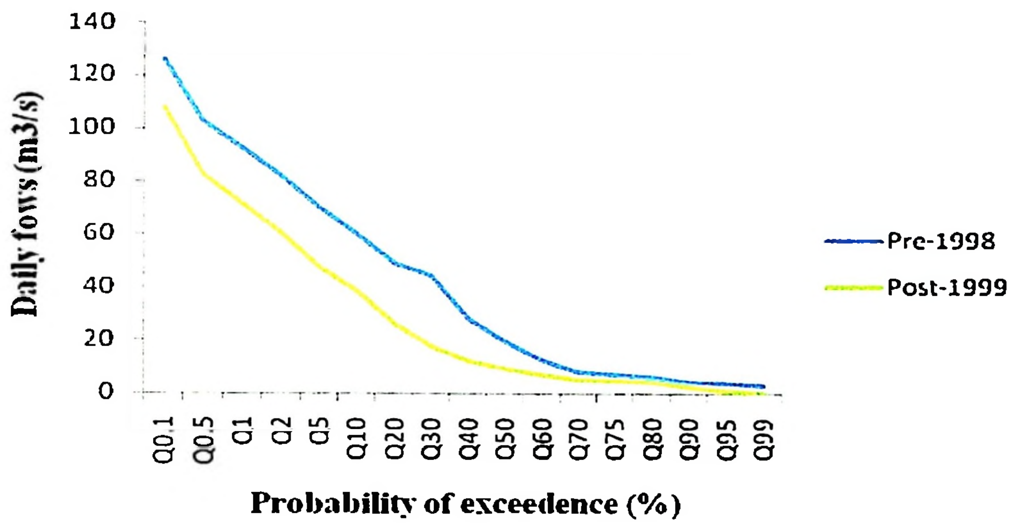

Figure 9: Mean monthly flow duration curve of Little Ruaha River at Mawande gauging station for the periods (1980-1998) and (1999-2009)

Although the latter period contains *El Nino* flows of 1998, the steeper FDC slope at higher discharges could be attributable to effects of land use land cover change. The conversion of tropical forest or woodland to grassland disrupts the hydrological cycle of drainage basin by altering the water yield of the area (Zhang *et al.*, 2007).This conversion of land cover disrupts hydrological cycle of drainage by altering the balance between rainfall and evapo-transpiration, and consequently the runoff response of the area. In general the curves flatten out considerably at lower discharges indicating well sustained stream discharges over extended periods of time that could partially be attributable to the storage within the catchment. Flow duration curves are useful for determining the variability or flashiness of stream flow as well as how the discharge of a stream is sustained over time (Kashaigili and Majaliwa, 2013).

Table 8 presents the flow characteristics as extracted from the monthly flow duration curves. The median flow Q50 has changed by 10.255 m^3/s while the 25th percentile flow has changed by 21.43 m^3/s between the two periods.

Table 8: Indices of flow characteristics extracted from monthly FDC

Period	Flow indices						
1980 1998	Q10	Q25	Q50	Q75	Q90	Q95	Q99
	60.36	43.09	19.7	6.86	4.2	3.62	2.85
1999 -2009	39.17	21.66	9.45	5.01	2.42	1.21	0.29

4.4 Linkage between Land Use Land Cover and Flow Regimes Changes

The analysis from this study has revealed the change in the hydrological regime for Little Ruaha River for 1980 -1998 and1999-2009. The most pronounced change is the shift in the peaking with peak flows being attained earlier in January for the latter period (1999-2009) unlike the former (1980-1998) which had peak flows in December. The trend analysis revealed a statistical significant decreasing trend in annual rainfall and flows which is supported by the change in river flow patterns associated with early attainment of peak flows in later period.The variation in peak flows indicates that increased land conversion has an impact on flow characteristics of the catchment. Kashaigili and Majaliwa, 2013 revealed that the change in flow is mainly due to reduced infiltration rate when the land cover is converted to other land uses.

4.5 Accuracy Assessment and Land Cover Maps

Among the common measures used for measuring the accuracy of thematic maps derived from multispectral imagery, error/confusion matrix was used. In this study accuracy assessment was done using reference data from ground truthing to check the overall accuracy, overall users and producer's accuracy as well as kappa coefficient. The results show a good overall classification result with overall accuracy of 85.92% and a Kappa coefficient of 0.83.The land use land cover maps for the year 1990, 1998 and 2011 are presented in Figs. 11, 13 and 14. Generally, the maps show the variation in land use land cover coverage between the three time periods under consideration.

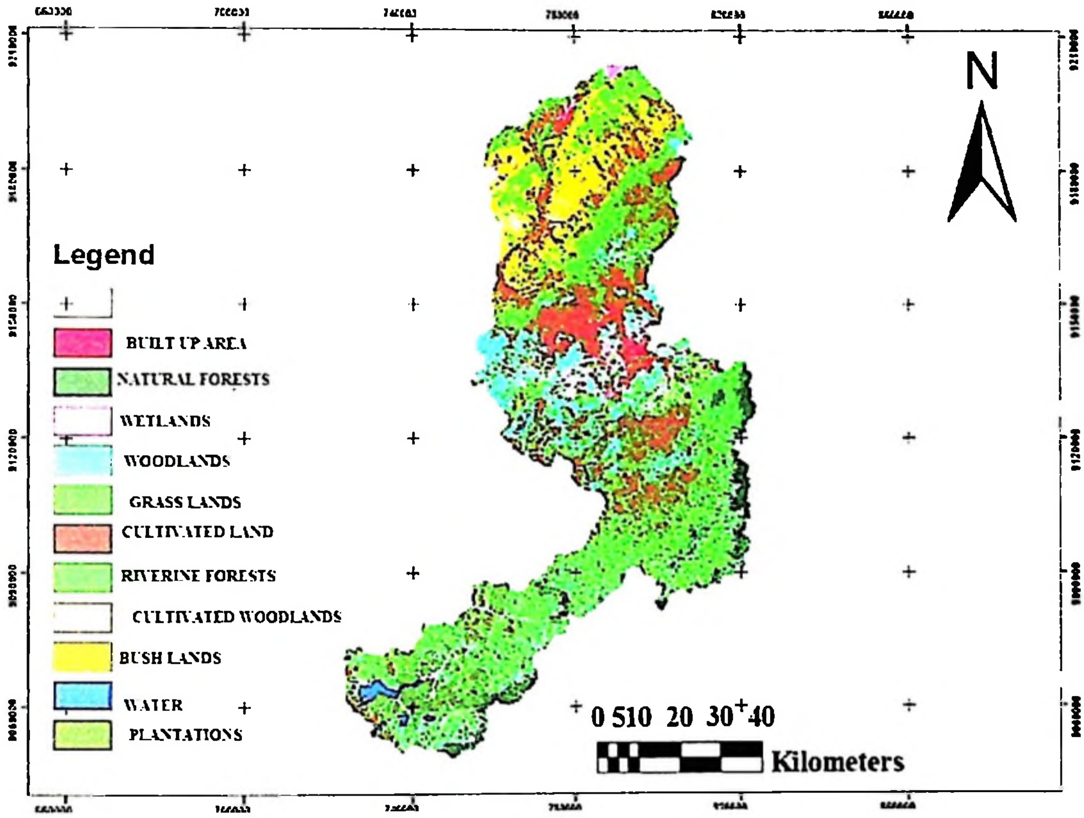

Figure 10: Land use land cover map for year 1990

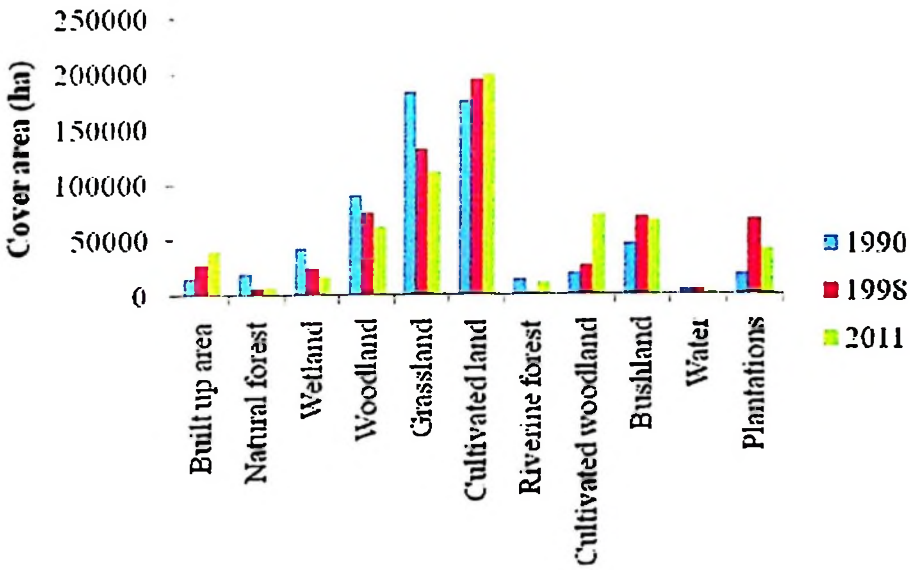

Figure 11: Distributions of land cover classes at different years of analysis

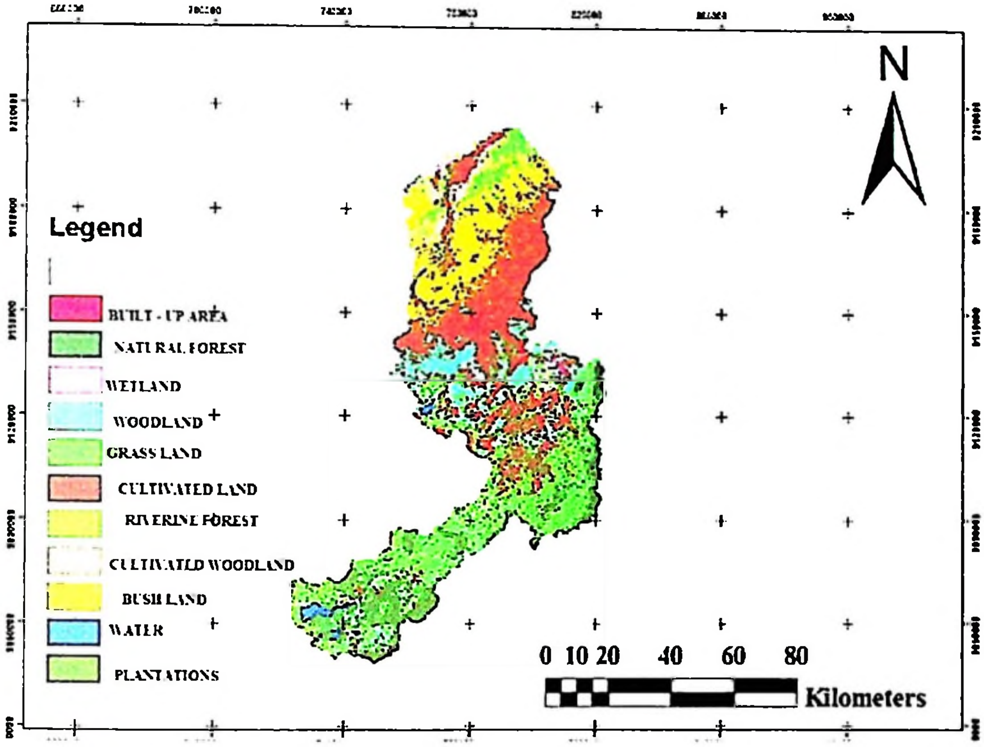

Figure 12: Land use land cover for year map 1998

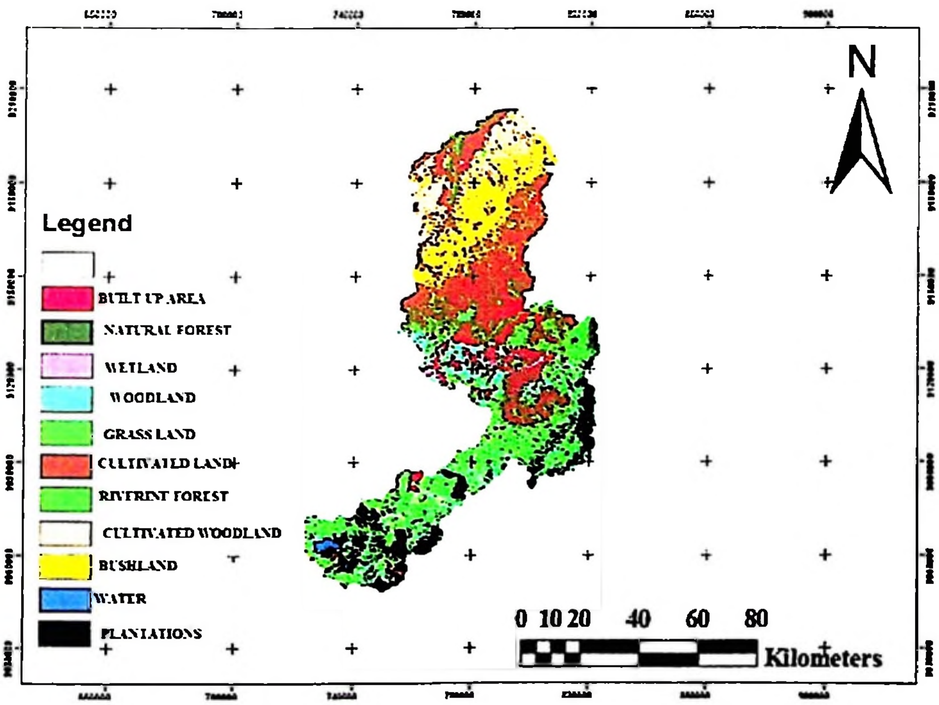

Figure 13: Land use land cover map for the year 2011

4.6 Change Detection Results

Land use land cover class distribution for 1990, 1998 and 2011 are presented in Fig 12. Table 9 shows the proportion of each land cover category in the different years of analysis. In the year 1990 grassland dominated the area by covering 28.86% followed by cultivated land 27.56%,woodland 14.34% , bush land 7.38%, wetlands 6.68%, natural forest 3.21%, while cultivated woodland, plantations, Riverine forest, built up area and water covered 3.12%, 3.03%, 2.4%, 2.57% and 0.84%, respectively.

Table 9: Distribution of land use/covers classes in hectares for 1990, 1998 and 2011

Cover class	1990		1998		2011	
			Cover coverage			
	ha	%	ha	%	ha	%
Built-up area	16390.3	2.6	28093.3	4.4	40901.7	6.4
Natural forest	20474.3	3.2	6602.74	1.0	7989.92	1.3
Wetland	42581.1	6.7	24712.8	3.9	17557.1	2.8
Woodland	91410.3	14.3	75537.9	11.9	62526.4	9.8
Grassland	183909	28.9	131714	20.7	111591	17.5
Cultivated land	175601	27.6	195544	30.7	199235	31.2
Riverine forest	15299.8	2.4	2705.3	0.4	11621.4	1.8
Cultivated woodland	19876.8	3.1	26721.5	4.2	72912.1	11.4
Bush land	47043.1	7.4	71019	11.1	67199	10.5
Water	5381.07	0.8	6059.27	1.0	4252.11	0.7
Plantations	19291.6	3.0	68314.3	9.0	42085.6	6.6
Total	637258.37	100.0	637024.1	100.0	637871.3	100.0

In the year 1998, cultivated land dominated the largest area than other land use land cover classes occupying 30.7%, followed by grasslands 20.7%, woodlands 11.9%, bush lands 10.5%, plantations 9.0%, built up area 6.6%, cultivated woodlands 4.2%, wetlands 3.9%, natural forest 1.01%, water 1.0% and Riverine forests 0.4%.In the year 2011, cultivated land occupied the largest area 31.2%, followed by grasslands 17.5%, cultivated woodlands 11.4%, bush lands 10.5%, woodlands 9.8%, builtup area 6.4%, plantations 6.6%, wetlands 2.8%, Riverine forests 1.8%, natural forests 1.3%, and water 0.7%.

4.7 Land Use Land Covers Change between 1990 -1998 and 1998 -2011

Fig.15 and Table 10summarize the extent of land use land cover change. The amount of increase is represented by positive signs (+) and the amount of decrease is indicated by negative sign (-) and the percentage of change is based on initial values of individual land use land cover change for the year 1990, 1998, and 2011.

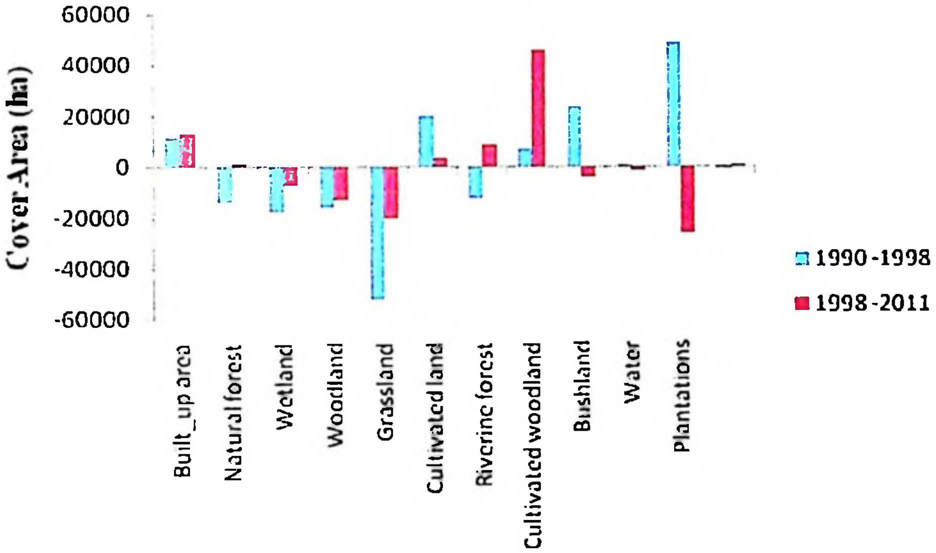

Figure 14: Land use land cover change between 1990 -1998 and 1998 -2011

Table 10: Land use land cover changes between 1990 -1998 and 1998 -2011

Cover class	1990 -1998		1998 -2011	
	Area(ha)	%	(ha)	%
Built-up area	+11703	+ 1.8	+12808.4	+2.0
Natural forest	-13871.5	- 2.2	+1387.2	+0.2
Wetland	-17868.3	- 2.8	-7155.7	-1.1
Woodland	-15872.4	- 2.5	-13011.5	-2.1
Grassland	-52195	- 8.2	-20123	-3.2
Cultivated land	+19943	+ 3.1	+3691	+0.5
Riverine forest	-12594.5	-2.0	+8916.1	+1.4
Cultivated woodland	+6844.7	+ 1.1	+46190.6	+7.2
Bush land	+23975.9	+ 3.8	-3820	-0.6
Water	+678.2	+0.1	-1807.2	-0.3
Plantations	+49022.7	+ 6.0	-26228.7	-2.4

Woodlands decreased by- 2.5 % between 1990 and 1998 and between 1998 and 2011 decreased by -2.1%.This decrease was due clear felling of trees for expansion of agricultural farms also for charcoal making as a fuel wood as revealed during ground truth. Built up area increased in periods of 1990 -1998 and 1998 -2011 by+ 1.8 % and 2.0%, the reason of this was rapid expansion of town centres like Iringa, Kilolo and Mafinga. Natural forest is another land cover which experienced notable changes between two periods. The results shows that, natural forest cover decreased by - 2.2 % between 1990 and 1998, this is caused by encroachment of people for timber and firewood. Between 1998 and 2011, natural forest cover increased by and0.2%, wetland decreased by - 2.8 % in year 1990 to 1998 and continued to decrease by -1.1% in year 1998 to 2011.The decrease in wetlands caused by drying up as a result of decreasing in rainfall as revealed by trend analysis. Grassland decreased by - 8.2 % between 1990 and 1998 and continued to decrease by -3.2% in the year 1998 to 2011. Riverine forest decreased by -2.0 % between 1990 and increased by+1.4% between 1998 and 2011.Bush land increased by + 3.8 % between 1990 and 1998 and decreased by -0.6% between 1998 and 2011. Water increased by +0.1 % between 1990 and 1998 and decreased by -0.3%

between 1998 and 2011.Plantations increased by + 6.0 % between 1990 and 1998 and decreased by -2.4% between 1998 and 2011,the fluctuation in plantations was due harvesting and planting new trees and expansion of tree plantations. Cultivated land increased by + 3.1%between 1990 and 1998 and continued to increased by ÷0.52% between 1998and 2011.

Table 11: Net area change between 1990 and 1998, and 1998 and 2011 and percentage annual rate of change

Land Cover class	Net area change				Annual rate of change			
	1990 -1998		1998 -2011		1990 -1998		1998 -2011	
	Area(ha)	%	Area(ha)	%	Area(ha/year)	%	Area(ha/year)	%
Built up area	+11703	+1.8	+12808.4	+2.0	+1462.875	+5.2	+985.3	+2.4
Natural forest	-13871.6	- 2.2	+1387.18	+0.2	-1733.95	- 26.3	+106.7	+1.3
Wetland	-17868.3	- 2.8	-7155.7	- 1.1	-2233.54	- 9.0	- 550.4	- 3.1
Woodland	-15872.4	- 2.5	-13011.5	- 2.1	-1984.05	- 2.6	- 1,000.9	- 1.6
Grassland	-52195	- 8.2	-20123	- 3.2	-6524.38	- 5.0	- 1,547.9	- 1.4
Cultivated land	+19943	+3.1	+3691	+0.5	+2492.875	+1.3	+283.9	+0.1
Riverine forest	-12594.5	- 2.0	+8916.1	+1.4	-1574.31	- 58.2	+685.9	+5.9
Cultivated woodland	+6844.7	+1.1	+46190.6	+7.2	+855.5875	+3.2	+3,553.1	+4.9
Bush land	+23975.9	+3.8	-3820	- 0.6	+2996.988	+4.2	- 293.8	- 0.4
Water	+678.2	+0.1	-1807.16	- 0.3	+84.775	+1.4	- 139.0	- 3.3
Plantations	+49022.7	+7.7	-26228.7	- 4.1	+6127.838	+9.0	- 2,017.6	- 4.8

4.8 Variations on Detected Changes and Interpretations

Table 12 presents a summary on changed and unchanged cover areas between 1990 and 1998 and Table 13 present summary of changed and unchanged area between 1998 and 2011. The percentage changed indicates the percentage area of a particular cover which changed to other covers while the percentage unchanged represents the percentage area of the original area of a particular cover which remained unchanged for a given period.

Table 12: Percentage covers of changed and unchanged of individual land use land cover for the period between 1990 and 1998

Cover type	Cover unchanged	Cover changed	%Unchanged	%Changed
Built-up area	3936.3	28 077.4	12.3	87.7
Natural forest	5 451.0	2 230.9	71.0	29.0
Wetland	6 256.4	24 726.4	20.2	79.8
Woodland	31 939.0	46 446.1	40.7	59.3
Grassland	61 701.6	64 697.5	48.8	51.2
Cultivated land	96 661.8	95 024.3	50.4	49.6
Riverine forest	1 388.0	1 835.2	43.1	56.9
Cultivated woodland	3 017.1	23 632.1	11.3	88.7
Bush land	25 675.8	44 681.9	36.5	63.5
Water	4 030.5	1 919.3	67.7	32.3
Plantations	15 224.9	48 494.7	23.9	76.1

From Table 12, the forest cover changed to other land covers by 29.0%, while bush land changed by 63.5%, grassland by 51.2%, settlement and cultivation by 87.7% and 49.6% respectively. The woodland and wetland changed by 59.3% and 79.8% respectively between the periods under consideration. Nevertheless, some cover areas remained unchanged between 1990 and 1998 (Table 12).

Table 13: Percentage covers of changed and unchanged of individual land cover for the period between 1998 and 2011

Cover type	Cover unchanged	Cover changed	(%) Unchanged	(%) Changed
Built-up area	8942.2	31 914.3	21.9	78.1
Natural forest	4543.34	3 427.9	57.0	43.0
Wetland	1931.02	15 619.8	11.0	89.0
Woodland	21589.6	40 909.6	34.5	65.5
Grassland	48702.6	62 827.4	43.7	56.3
Cultivated land	122266	76 889.7	61.4	38.6
Riverine forest	1767.36	9 840.3	15.2	84.8
Cultivated woodland	15521.6	57 377.2	21.3	78.7
Bush land	46552.9	20 636.4	69.3	30.7
Water	3858.71	392.9	90.8	9.2
Plantations	27220.5	14 835.4	64.7	35.3

From Table 13, the forest cover changed to other land covers by43.0 %, while bush land changed by 30.7 %, grassland by 56.3%, settlement and cultivation by 78.1 % and 38.6 % respectively. The woodland and wetland changed by 65.5 % and 89.0 % respectively between the periods under consideration, while water, plantations, cultivated woodlands and Riverine forest changed by 9.2%, 35.3%,78.7 %,and 84.8 % respectively between 1998 and 2011. Some cover areas remained unchanged between 1998 and 2011 (Table 13). From the study and data obtained from the satellite imagery for little Ruaha catchment, it shows that the catchment has undergone numerous land use land cover changes in recent decades (Table 10). Results from change detection matrix (Table 14 and 15), indicate that, there is gradual decreasein the area under woodland and bush land. This change might be linked to clearing of trees for expansion of farms and charcoal making as revealed during ground truthing.

Table 14: Change detection matrix for the period of 1990 to 1998

Cover 1990 (ha)	Cover 1998 (ha) SET	FO	WET	WD	GR	C	RF	CWD	BS	WAT	PL	Total
SET	(5518)	224	1544	6572	11124	11944	461	2	5	21	88	37 503
FO	2	(5324)	153	131	545	11	12	0	0	4	223	6 404
WET	400	330	(5617)	4231	6674	3008	2237	178	354	228	521	23 779
WD	1 207	935	9844	(35438)	16566	7117	1782	8	4	163	736	73 801
GR	5 237	1226	5576	16383	(70694)	25543	1977	1053	2399	152	748	130 989
C	3 111	372	10868	19756	43115	(104598)	3004	2043	4363	22	652	191 903
RF	37	0	55	46	34	876	(1264)	79	104	0	0	2 494
CWD	85	0	120	3	6606	4595	126	(3051)	12190	0	0	26 775
BS	86	0	226	332	14068	15500	77	13426	(27584)	0	0	71 298
WAT	26	24	294	928	232	157	301	0	0	(4163)	33	6 159
PL	572	11953	8192	7432	13883	2088	3979	0	0	623	(16279)	65 001
Total	16 282	20 389	42 489	91 251	183 541	175 436	15 220	19 840	47 002	5377	19 280	636 106

SET=Settlement; FO= Forest; WET= Wetland; WD =Woodland; GR= Grassland; C= Cultivated land; RF = Riverine forest; CWD = Cultivated woodland; BS= Bush land; WAT= Water; PL =Plantations

Table 15: Change detection matrix for the period of 1998 to 2011

Cover 1998 (ha)				Cover 2011 (ha)								
	SET	FO	WET	WD	GR	C	RF	CWD	BS	WAT	PL	Total
SET	(7534)	48	621	1839	5249	19220	29	7	10	380	3278	38214
FO	2	(4701)	11	62	211	0	0	0	0	0	2544	7532
WET	3286	85	(1836)	3002	4335	1643	0	0	0	823	1294	16306
WD	5486	278	3711	(24245)	16511	4885	0	0	0	348	10962	66426
GR	11872	300	7696	16185	(60212)	16728	0	2	0	248	10979	124221
C	7800	50	7018	17026	13200	(115509)	1064	10995	7189	282	2277	182409
RF	102	48	645	6078	77	2623	(1392)	0	1	36	29	11030
CWD	843	1	1077	2412	25693	5601	22	(15750)	15789	40	2093	69320
BS	21	0	36	291	48	24685	0	35	(48317)	0	0	73434
WAT	3	1	50	56	24	7	0	0	0	(3958)	113	4212
PL	573	916	1088	2611	5381	981	0	0	0	44	(31490)	43083
Total	37523	6428	23788	73806	130939	191882	2507	26788	71307	6160	65059	636187

SET=Settlement; FO= Forest; WET= Wetland; WD =Woodland; GR= Grassland; C= Cultivated land; RF = Riverine forest;
CWD = Cultivated woodland; BS= Bush land; WAT= Water; PL =Plantations

Table 16 and 17 presents the detected changes of one land cover to another land cover between 1990-1998 and 1998 and 2011.

Table 16: Detected changes in percentage for some selected cover for the period 1990-1998

Change (from–to)	1990 -1998 (ha)	% of cover
WET → WD+GR	14342.02	46.3
WET → C+SET	5017.83	16.2
WET → RF	2382.47	7.7
WD → SET+C	11918.60	15.2
WD → WET	9533.93	12.2
GR → SET	5186.53	4.1
GR → FO	1622.98	1.3
GR → WET+BS	8869.53	7.0
BS → SET+C	16111.42	22.9
BS → CWD	12608.80	17.9

SET=Settlement; FO= Forest; WET= Wetland; WD =Woodland; GR= Grassland; C= Cultivated land; RF = Riverine forest; CWD = Cultivated woodland; BS= Bush land; WAT= Water; PL =Plantations

Table 17: Detected changes in percentage for some selected cover for the period 1998–2011

Change (from–to)	1998-2011(ha)	% of cover
WET → WD	3421.10	19.5
WET → GR	4629.59	26.4
WET → C+SET	4771.83	27.2
WD → SET	3759.14	6.0
WD → C	6734.08	10.8
WD → GR	14114.70	22.6
WD → FO	509.18	0.8
WD → WET	4634.63	7.4
WD → PL	10855.20	17.4
BS → SET+C	19406.54	28.9
GR → SET+C	27798.75	24.9
GR → WET	8559.86	7.7

SET=Settlement; FO= Forest; WET= Wetland; WD =Woodland; GR= Grassland; C= Cultivated land; RF = Riverine forest; CWD = Cultivated woodland; BS= Bush land; WAT= Water; PL =Plantations

From Table 16, 46.3% of wetland changed to woodland and grassland, 16.2% to settlements and cultivation, 7.7% to Riverine forest. 15.2 % of woodland was converted to cultivated land and settlement 12.2% was converted to wetland and 65.5 %, remained unchanged. These shifts of wetland to other land cover might be due to encroachment of riverbanks for subsistence agriculture. About 4.1% of the grassland was converted to settlement area, 1.3% was converted to forest, and 7.0% to wetland and bush land 48.8% remain unchanged. About 22.9% of bush land was converted to cropland and settlement and 17.9% was converted to cultivated woodland areas while 36.5% remained unchanged. The results on analysis of land use land cover change for the period 1998 - 2011 is provided in Table 17. Wetland changed by 19.5% to woodlands, 27.2% into settlements and cultivated land, and 26.4% was converted to grasslands, 6.0% of woodland was converted to settlement and only 57.0 % of the forest remained unchanged.

About 10.8% of the woodlands were converted to cultivated land, 22.6% to grassland, 7.4% to wetland, 17.4% to plantations, 34.5 % remained unchanged. Furthermore, 43.7 % of the grassland remained unchanged, while 24.9% was converted to settlements and crop land, 7.7% to wetlands. The bush lands lost 28.9% to agriculture and settlements, and 69.3 % remained unchanged.

4.9 Linking Detected Changes to Causes

Changes due to anthropogenic activities

It is clear from Table 11 that the forest area decreased consistently over the years (1990 - 1998) while cultivated area increased at a rate of 283.9 ha/year (0.1%/year).Assuming a linear increase, cultivated woodlands and settlement increased at a rate of 283.9 ha/year (0.1%/year) and 985.3 ha/year (2.4%/year), respectively over an average period of 13 years (1990 and 2011). The increase in cultivated area and decrease in woodland and bush land might be due to clear felling of woodland and bush for farm expansion especially irrigated agriculture and tobacco farming in some parts of the catchment as revealed during ground truthing. The increase in settlement indicates that there is increase in population growth.There is a close link between ecosystem change and the increased anthropogenic activities (Yesserie, 2009). The increase in anthropogenic activities reflects an increased population.The growth in population reflects on the water consumption and diversification of human socio-economic activities that require more water use (Kashaigili, 2006). Agricultural expansion is among the reported activities, which have significant effect on natural vegetation (Ngalande, 2002; Dai *et al.*, 2010). The continuous increase in cultivated land is also reflected in an increased area under settlements. Increase in population size leads to demand for more resources and area for cultivation which has an implication on settlements expansion (Nzunda *et al.*, 2013). According to Tanzania census of 2012, Iringa Region population was found to increase from 840 404 (1988 -2002) to 941 238 (2002 -2012) with Mufindi and Iringa District having high population of 265 829 and 254 032 in 2002 (URT, 2013) census. Population growth rate has declined from 1.6% in 2002 to 1.1% in 2012 compared to nation population growth which has declined from 3.1% in 2002 to 2.8% in 2012.

The forest cover decreased consistently at a rate of 1733.95 ha/year (26.3%/year) over an average period of 8 years (1990 and 1998) assuming a linear decrease. It is possible that the decrease in forest and increase in settlement cover is attributed to increased demand for suitable land for cultivation (Kashaigili *et al.*, 2006). This rapid increase was due to clear felling of trees for firewood, poles, charcoal and increased settlement and agricultural activities (irrigated agriculture). During ground-truthing exercise ascertained this, and most woodland and bush land areas were found cleared for agriculture and charcoal making. The increasing population as a result of immigration from other districts in Tanzania for searching fertile land for farming has had impact on land use land cover transformation at Little Ruaha Catchment.

4.10 Impacts of Land Use Land Cover Change and Climate Variability

4.10.1 Sensitivity analysis

Results of sensitivity analysis for this study are presented in Table 18. Therefore in this study SCS curve number (CN2) was identified as very important parameters, base flow alpha factor (ALPHA-BF), soil available compensation factor (ESCO), soil available water capacity (SOL-AWC) and soil depth (SOL-Z)as important parameters which retain a rank between 2 and 6. Parameters like, manning's value for main channel (CH_N), channel effective hydraulic conductivity(Ch- K2), threshold water depth in the shallow aquifer for flow (GWQMN) and maximum canopy storage (CANMAX)', etc were identified as slightly important parameters and the rest parameters do not influence model output. Although Table 18shows different parameter rankings between using measured flow data (sum of the squares) and without observed flow data (Average flow) but the entire set of sensitive parameter is retained. Another notable observation from the table is that there is no significant difference in parameter ranking between the two simulation experiments. This suggests that identification of hydrological controlling parameters can be conducted using SWAT model sensitivity tool without observed flow data. This suggests that sensitivity analysis tool built in SWAT model is robust and can be applied in ungauged catchment for identifying hydrological controlling factors.

Table 18: Sensitivity analysis results for 21 simulation years between 1989 and 2009.

Parameter		Measured flow data(sum of squares)		Without observed flow data(average)		
Name	Description	Rank	mean sensitivity index[-]	Rank	Mean sensitivity index[-]	Sensitivity category
Cn2	SCS runoff curve number	1	0.532	1	0.18	Very important
Alpha_Bf	Base flow alpha factor	2	0.334	2	0.723	
Esco	Soil evaporation compensation factor	3	0.172	2	0.907	
Sol_Z	Soil depth	4	0.137	3	0.492	Important
Gwqmn	Threshold water depth in the shallow aquifer for flow	5	0.954	4	0.477	
Sol_Awc	Available water capacity	6	0.67	5	0.287	
Surlag	Surface runoff lag time	7	0.507	15	0.965	
Ch_N2	Manning's n value for main chanel	8	0.501	17	0.603	
Ch_K2	Channel effective hydraulic conductivity	9	0.332	8	0.711	
Gw_Delay	Groundwater delay	10	0.234	14	0.11	
Gw_Revap	Groundwater "revap" coefficient	11	0.208	10	0.617	
Blai	Maximum potential leaf area index	12	0.175	9	0.645	Slight important
Epco	Plant uptake compensation factor	13	0.114	11	0.564	
Canmx	Maximum canopy storage	14	0.108	12	0.388	
Sol_Alb	Moisture soil albedo	15	0.996	13	0.129	
Revapmn	Threshold water depth in the shallow aquifer for "revap"	16	0.97	6	0.915	
Biomix	Biological mixing efficiency	17	0.202	19	0.436	
Sol_K	Saturated hydraulic conductivity	18	0.152	16	0.808	
Slope	Average slope steepness	19	0.921	18	0.453	
Slsubbsn	Average slope length	20	0.707	20	0.574	
Smfmn	Melt factor for snow on Dec-21	27	0	27	0	
Smfmx	Melt factor for snow on Jun-21	27	0	27	0	Not important
Smtmp	Snow melt base temperature	27	0	27	0	
Timp	Snow pack temperature	27	0	27	0	
Tlaps	Temperature lapse rate	27	0	27	0	

4.10.2 Auto calibration and model validation

All important parameters with mean sensitivity index greater than zero, were considered for optimization. In this study Alpha_Bf, Cn2, Epco, Sol_z, Gwqmn, Ch_n2, Esco, Sol_Awc and Surlag parameters were optimized for model calibration. The Nash and Sutcliffe (R^2) and coefficient of determination for calibration period were considered satisfactory since the model was capable of producing about 58% and 65%respectively of the variance on daily observed records as shown in Fig. 16.

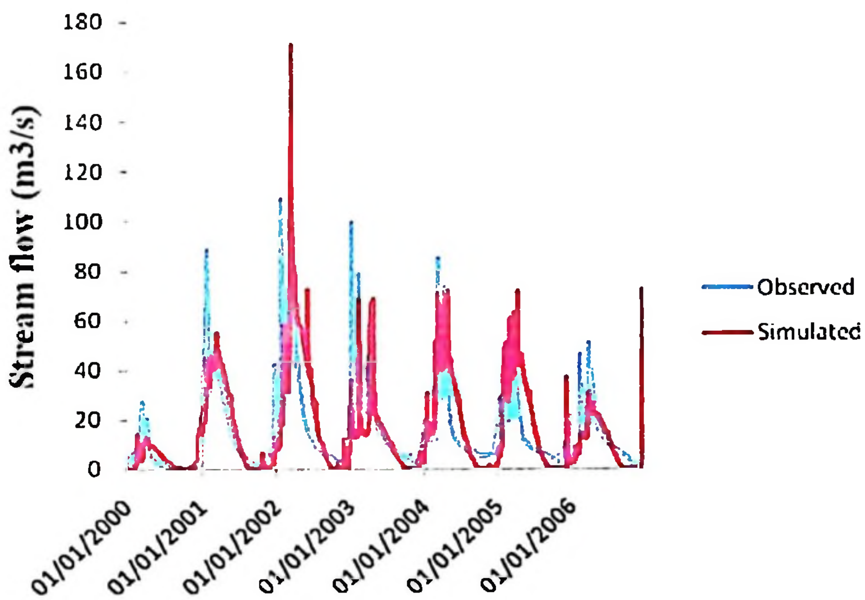

Figure 15: Comparison of daily stream flow for calibration period (2000 -2006), Nash (R^2 =58%)

The long time annual flows between observed and simulated were comparable with a mean of14.28m^3/s and 15.68m^3/s respectively. After model calibration followed by model validation whereby Nash R^2 and coefficient of determination registered 72.68% and 77.35%, respectively. Model performance with respect to monthly flow predictions during the calibration and validation period (i.e.R^2= 65 and 77.35%) is comparable to Birhanu (2005) calibration results (i.e. R^2=75.9%), Ndomba *et al.*, 2005 (R^2 =65%). In comparison to the results of this study, it clearly indicates that optimal parameters as derived from Auto calibration procedure and 7 years of data from the model performance were assessed and found to be appropriate and can be used to simulate stream flow in Little Ruaha Catchment. According to modelling experience by Water Resources Engineering Project based at University of Dar es salaam (Ndomba *et al.*, 2005), percentage missing of data greater than 15% is not recommended for modelling and this has not affected this study since data from all stations used for simulations has percentage of missing data less than 15%. The model evaluation shows good agreement between the observed and simulated stream flow although model over estimate flow especially in 2002. Through close examination of the data revealed that rainfall records in some stations were low and observed flow was high especially during rainy season. The modelling suggests that using processed or adequate and reliable spatial rainfall data, long period of calibration flow data, settling up a fully distributed watershed i.e. increasing number of sub basins and more rainfall stations records model could improve the results of this study.

4.10.3 Hydrological impacts of climate variability and land use land cover change

Table 19 shows annual water balance while Table 20 shows annual mean runoff simulated by SWAT under different land use and climate scenarios.

Table 19: Average annual water balance 1981-1999.

	Scenarios			
Variable	S1	S2	S3	S4
Total Water Yield (WYLD) (mm)	238.67	268.64	270.76	276.76
Surface Runoff (SURQ) (mm)	136.89	141.27	145.89	149.89
Base flow (GWQ) (mm)	8.26	8.66	8.235	8.45

Table 20: SWAT output scenarios

Scenario	Stream flow (mm)
S1	44.19
S2	46.06
S3	49.04
S4	52.32

The contrast between S1 and S2 indicated the influence of land use land cover change between the two periods. The land use land cover change decreased runoff by 1.87 mm which accounted for 23%. The contrast between S1 and S3 indicated the influence of climate variation. The climate variation decreased runoff by 4.85 mm, which accounted for 59.67% of the total runoff reduction. The contrast between S1 and S4 indicates the combined effect of land use land cover change and climate variability which accounted 8.13mm reduction in runoff. The above results showed that, the land use land cover change and climate variability during 1990s and 2000s both decreased runoff, but the contribution of climate variability was far greater than that of land use land cover change. It should be pointed out that, simulation of measured runoff reduction caused by both climate variability and land use land cover change (6.72 mm) was slightly smaller than simulated combined effect. This result can be compared with Zhi *et al.* (2009) which obtained that the effect due to land use land cover change accounted for 9.6% and effect due to climate variation was 95.5%. Also a study by Githui (2008) in Nzoia River basin, Kenya revealed that without climate variability, land use land cover changes would account for difference in runoff of about 55-68%. On the other hand, change in climate without land cover change accounted for a difference in runoff of about 30-41%.

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

This study investigated the impacts of land use land cover changes and climate variability in theLittleRuaha River catchment. This was an integrated assessment that used combined GIS and remote sensing methodological approaches as well as physical based hydrological model (SWAT) in understanding the land resources change and climate variations and their resulting effects on stream flow characteristics. The findings have revealed that the study area has undergone notable changes in terms of land use land cover for the period 1990, 1998 and 2011. The woodland areas were found to be highly impacted, notably by the increased anthropogenic activities. The settlement and cultivated land was found to have consistently increased between the two periods under investigation as well as the cultivated woodland. Results from hydrological modelling revealed that both land use land cover changes and climate variations have reduced the stream flow by 23% and 59.67%, respectively. There have been significant changes in land use land cover in the catchment as well as hydrological characteristics of the catchment. The results revealed the fact that the amount of flows generated from the high catchment has statistically changed over the time. SWAT proved to be a useful tool for assessing the effects of environmental changes including land use land cover changes and climate variability in the Little Ruaha catchment. The Nash-Sutcliffe model efficiency and coefficient of determination (R^2) were 58% and 65% as well as 72.68% and 77.35% for calibration and validation periods respectively; indicating that SWAT performance in Little Ruaha catchment was very good. The study highlights the importance of integrating remote sensing techniques and hydrological modelling in understanding the catchment resources dynamics and generating information that could be used to overcome the catchment problems for the sustainability of the catchment resources.

5.2 Recommendations

Based on the findings of this study, it is recommended that:

i. There is a need for changes in the catchment management and formulation of implementable strategies of the catchment resources management.

ii. There should be a close monitoring of water abstractions from both water users groups as well as use of improved irrigation infrastructures in order to reduce temporal distribution of runoff in the catchment.

iii. There should be initiative for both catchment beneficiaries within the catchment on how to use catchment resources sustainably. Sustainable catchment management strategies should be formulated together with land use plans.

iv. Analysis of flows from flow duration curves at little Ruaha catchment confirm the progressive decrease in dry flows for the pre 1998 and post 1999 thus a good indication of changes to the hydrological balance upstream in the Little Ruaha catchment and which is associated with their increased change in land use and covers. The study recommends the need to consider the effects of land use land cover change and climate variability on ecosystems and water resources for informed decisions on proper planning and management of the catchment

REFERENCES

Arnell, N. W. and Reynard, N. S. (1996). The effects of climate change due to global warming on river flows in Great Britain. *Journal of Hydrology* 183(4): 397 – 424.

Arnold, J. G. and Allen, P. M. (1999). Validation of automated methods for estimating base flow and groundwater recharge from stream flow records. *Journal of American Water Resources Association* 35(2): 411 – 424.

Arnold, J.G., Srinivasan, R., Muttiah, R. S. and Williams, J. R. (1998). Large area hydrologic modeling and assessment model development. *Journal of American Water Resource Association* 34(1): 73 – 89.

Boyer, K. L. (2004). Linearized vegetation indices based on a formal statistical framework. *Transaction on Geoscience and Remote Sensing* 42(7): 1575 –1585.

Birhanu, B. Z. (2005). Application of a GIS based SWAT model in simulating the available water resources in a Pangani basin sub catchment. Dissertation for Award of MSc Degree at University of Dar es Salaam, Tanzania, 212pp.

Costa, M. H. and Cardille, J. A. (2003). Effects of large-scale changes in land cover on the discharge of the tocantins river, Southeastern Amazonia. *Journal of Hydrology* 283(4): 206 – 217.

Cau, P. and Paniconi, C. (2007). Assessment of alternative land management practices using hydrological simulation and a decision support tool: Arborea agricultural region, Sardinia. *Journal of Hydrology and Earth System Sciences* 4: 747 – 775.

Dai, Z., Trettin, C. C., Li, C., Amatya, D. M., Sun, G. and Li, H. (2010). Sensitivity of stream flow and water table depth to potential climatic variability in a coastal forested watershed. *Journal of American Water Resources Associations* 46(5): 1036 –1048.

ERDAS Field Guide (1999). *Earth Resources Data Analysis System.* ERDAS Inc., Atlanta, Georgia. 628pp.

FAO (1997). *Climate Variability and Change: Adaptation to Drought in Bangladesh. A Resource Book and Training Guide.*Asian Disaster Preparedness Center, Bangladesh. 23pp.

Fish, E. and Road, L. (2010). *SWAT Modeling Thief River Watershed, Minnesota Numerical Modeling and Evaluation of Management Scenarios*. Houston Engineering Inc., Maple Grove Minesota. 26pp.

Fohrer, N., Eckhardt, K. and Haverkamp, S. (2001). Applying the SWAT model as a decision support tool for land use concepts in peripheral Regions in Germany: *In selected Papers from the 10th International Soil Conservation Organization Meeting held at Purdue University and the USDA -ARS National Soil Erossion Research Laboratory* 24 - 29 May 1999, German. pp. 994 – 999.

Gao, Z. L., Fu, Y. L., Li, Y. H., Liu, J. X., Chen, N. and Zhang, X. P. (2012). Trends of streamflow, sediment load and their dynamic relation for the catchments in the middle reaches of the Yellow River over the past five decades. *Hydrology and Earth System Sciences* 16(9): 3219 – 3231.

Githui, F. W. (2008). Assessing the impacts of environmental change on the Hydrology of the Nzoia catchment, in the Lake Victoria Basin. Thesis for Award of PhD Degree at VrijeUniversiteit Brussels Belgium, 209pp.

Hua G, and Tong, Q. (2008). Annual and seasonal stream flow responses to climate and land-cover changes in the Poyang Lake basin, China. *Journal of Hydrology* 355: 106– 122

IPCC (2001).*Impacts, Adaptations and Vulnerability.*IPCC Third Assessment Report Cambridge University Press.Cambridge.398pp.

IPCC (2007).*Impact, Adaptation and Vulnerability, Contributions of Working group II to the Fourth Assessment Report of the IPCC on Climate Change.* (Edited by Parry, M. L., Canziani, O. F., Palutikof, O. F., vander J. P. Linden, P. J. and Hanson, C. E.), Cambridge University Press, Cambridge. 437pp.

Kadigi, R. M. J., Mdoe, N. S., Lankford, B. A. and Morardet, S. (2004). *The Value of Water for Irrigated Paddy and Hydropower Generation in the Great Ruaha Tanzania.* International Water Management Institute, Morogoro, Tanzania. 16pp.

Kadigi, R. M. J. (2006). Evaluation of livelihood and economic benefits of water utilization.The case of Great Ruaha River Catchment, Tanzania.Thesis for Award of PhD Degree at Sokoine University of Agriculture, Morogoro, Tanzania, 213pp.

Richard, K., Mwakalila, S. and Masolwa, P. (2011). Climate change impacts, local knowledge and coping strategies in the great Ruaha River Catchment Area, Tanzania. *Natural Resources*2: 212 – 223.

Kashaigili, J. J. and Majaliwa, A. M. (2013). Implications of land use and land cover changes on hydrological regimes of the Malagarasi River, Tanzania. *Journal of Agricultural Science and Application* 2(1): 45 – 50.

Kashaigili, J. J. and Majaliwa, A. M. (2010). Integrated assessment of land use and cover changes in the Malagarasi river catchment in Tanzania. *Journal of Physics and Chemistry of Earth* 35: 730 – 741

Kashaigili, J. J. (2006). Land covers dynamics and hydrological functioning of wetlands in the Usangu Plains, Tanzania. Thesis for Award of PhD Degree at Sokoine University of Agriculture, Morogoro, Tanzania, 299pp.

Kashaigili, J. J., Mahoo, H. F., Mccartney, M., Lankford, B. A., Boniface, P. and Mwanuzi, F. L. (2003). *Integrated Hydrological Modelling of Wetlands for Environmental Management: The Case of the Usangu Wetlands in the Great Ruaha Catchment.* International Water Management Institute, South Africa. 3pp.

Khairy, W. M., Climatology, S. and Sensing, R. (2000). *Assessing and Modeling Flood Event and Climate.* Centre for hydrology, soil climatology, and remote sensing. Alabama University, Alabama. 20pp.

Li, L., Zhang, L., Wang, H., Wang, J., Yang, J., Jiang, D. and Li, J. (2007). Assessing the impact of climate variability and human activities on streamflow from the Wuding River basin in China. *Journal of Hydrology and Earth Sciences* 10: 3485 – 3491.

Li, Z., Liu, W., Zhang, X. and Zheng, F. (2009). Impacts of land use change and ciimate variability on hydrology in an agricultural catchment on the Loess Plateau of China. *Journal of Hydrology* 377(2): 35 – 42.

Lin, Y. P., Hong, N. M., Chiang, L. C., Liu, Y. L. and Chu, H. J. (2012). Adaptation of land-use demands to the impact of climate change on the hydrological processes of an urbanized watershed. *International Journal of Environmental Research and Public Health* 9(11): 4083 – 102.

Moglen, G. E., Eltahir, E. A. B. and Bras, R. L. (1998). On the sensitivity of drainage density to climate change. *Water Resources Research* 34: 855 – 862.

Ndomba, P. M., Mtalo, F. and Killingtveit, A. (2005). The suitability of SWAT model insediment yield modelling for Ungauged Catchments. A Case of SimiyuSubcatchment, Tanzania. *Proceedings of the 3rd International Soil and Water Assessment Tool Conference, EAWAG*-Zurich, Switzerland, 11 –15 July 2005. pp. 61– 69.

Nzunda, N.,Munishi, P. K. T., Kashaigili, J. J., Geofrey, E. S. and Joel, F. M. (2013). Land use and vegetation cover dynamics in and around Kagoma Forest Reserve in Tanzania. *Journal of Ecology and the Natural Environment* 5(8): 206 – 216.

Ngalande, H. (2002). Spatial environmental assessment of the impact of land use on land resources in Lusitu Area, Siabonga District, Zambia. Dissertation for Award of MSc Degree at Sokoine University of Agriculture, Morogoro, Tanzania, 94pp.

Palamuleni, L. G. and Annegarn, H. J. (2011). Hydrological response to predicted land cover change in the upper shire river catchment, Malawi. *International Journal of Environmental Research and Public Health* 36(1): 43 – 52.

Rientjes, T. H. M., Haile, A. T., Kebede, E., Mannaerts, C. M. M., Habib, E. and Steenhuis, T. S. (2011). Changes in land cover, rainfall and stream flow in Upper Gilgel Abbay catchment, Blue Nile basin – Ethiopia. *Hydrology and Earth System Sciences*15(6): 1979 – 1989.

Roberts, G. (1998). The effects of possible future climate change on evaporation losses from four contrasting UK water catchment areas. *Hydrological Processes* 12: 727– 739 .

Salehe, F. S., Mtambo, M. M. A., Tarimo, A. K. P. R., Mattee, A. Z. and Hassan, S. N. (2012). Schistosomiasis: A comparative study of its socio- economic consequences in different types of irrigation schemes in Tanzania. *Journal of Agricultural Sciences* 1(8): 240 – 249.

Sanders, H. and Fitts, J. (2011). Assessing the sustainability of rural water supply programs: A Case Study of Pawaga, Tanzania. [http://dukespace.l ib.duke.edu /dspace/handle/1 0161/3649] site visited on 9/ 7/2013.

Sefton, C. E. M. and Boorman, D. B. (1997). A regional investigation of climate change impacts on UK stream flows. *Journal of Hydrology* 195: 26 – 44.

Tadele, K. and Förch, G. (2007). *Impact of Land Use/Cover Change on Streamflow:* The Case of Hare River Watershed, Ethiopia. 236pp.

Tracy J. B. and Scott N. M. (2013). Using the Soil and Water Assessment Tool to assess land use impact on water resources in an East African watershed. *Journal of Hydrology* 486: 100 –111.

UNFCCC (2012). Climate change definitions. [https://www.google.co.tz/sear ch?q= UNFCCC%2C2012+Climate+change+definitionsaq=f&oq=UNFCCC%2C2012+Cl imate+chang] site visited on 8/4/2013.

URT (2007). *Iringa Regional Socio-economic Profile.* (2nd Edn.), Ministry of Planning, Economy and Empowerment, Dar es Salaam, Tanzania. 264pp.

URT (2013). *Tanzania Population and Housing Census 2012.Population Distribution by Administrative Areas.* National Bureau of Statistic, Dar es Salaam, Tanzania. 244pp.

Yesserie, A. G. (2009). Spatio temporal land use/land cover changes analysis and monitoring In the Valencia Municipality, Spain. Dissertation for Award of MSc Degree at Universitat Jaume I, Castellón, Spain, 69pp.

Zeray, L. A., Jackson, R. and Dilnesaw, A. C. (2007). Calibration and validation of soil and water assessment tool hydrologic model for meki water shed, Ethiopia. *Conference on International Agricultural Research for Development*. Tropentag, 9 - 11 October 2007. pp. 2 – 4.

Zhang, X., Srinivasan, R. and Hao, F. (2007). Predicting hydrologic response to climate change in Luohe River Basin using the soil and water assessment tool model. *Journal of American Society of Agricultural and Biological Engineering* 50(3): 901 – 910.

Zhi, L., Wenzhou, L., Xun-chang, Z. and Fen-li, Z. (2009). Impacts of land use change and climate variability on hydrology in an agricultural catchment on the loess plateau of China. *Journal of Hydrology* 377: 35 – 42.

APPENDICES

Appendix 1: Monthly Flows (m^3/s) at Makalala station

Year	Nov	Dec	Jan	Feb		Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
1980/1981	26.82	103.322	235.132	299.113	637.567	241.467	278.393	179.575	133.604	101.97	69.961	36.992	20.542
1981/1982	13.894	52.518	81.411	140.574	274.503	271.209	253.588	182.152					
1982/1983		181.285	317.921	313.089	812.295	429.504	329.418	246.217	172.012	127.853	86.206	48.123	30.215
1983/1984													
1984/1985													
1985/1986													
1986/1987													
1987/1988	25.403	87.546	119.919	226.541	434.006	386.35	362.949	230.094	170.882	128.11	89.596	56.626	33.735
1988/1989	33.322	50.883	91.323	139.231	281.437	206.117	254.375	191.604	153.861	107.056	89.471	68.053	28.616
1989/1990	23.334	84.867	74.317	192.867	352.051	272.142	280.017	256.37	165.012	120.756	95.94	63.853	43.152
1990/1991	32.484	61.627	114.083	198.091	373.801	203.252	274.856	175.68	117.935	82.613	58.002	34.545	24.749
1991/1992	11.52	14.949	76.59	127.007	218.546	188.611	132.281	118.111	78.625	53.382	33.453	16.588	7.615
1992/1993	22.51	62.165	107.038	218.705	387.908	291.971	327.895	227.345	145.811	100.52	65.945	45.628	20.072
1993/1994	10.657	6.855	46.738	111.661	165.254	302.57	254.739	166.826	102.104	67.083	42.749	23.131	12.228
1994/1995	4.2	4.927	55.602	116.059	176.588	307.549	207.594	144.877	106.986	63.972	43.932	20.454	8.457
1995/1996	2.826	9.421	42.26	93.943	145.624	205.914	228.463	142.217	99.882	67.741	45.217	27.662	17.049
1996/1997	8.752	24.082	77.015	99.937	201.034	170.234	229.43	129.17	88.89	62.859	33.841	18.422	10.737
1997/1998	16.252	157.575	289.186	317.737	764.498	346.164	323.339	215.091	136.685	92.647	69.469	47.218	25.997
1998/1999	20.005	24.953	38.099	43.107	106.159	151.004	113.274	75.192	50.939	31.794	22.838	12.769	5.91
1999/2000	5.696	10.273	34.037	50.84	95.15	99.134	94.353	43.634	21.799	15.092	10.713	4.053	0.335
2000/2001	2.539	44.63	84.71	143.575	272.915	232.953	181.515	115.477	73.445	50.944	32.778	18.116	7.958
2001/2002	2.161	25.289	115.845	220.668	361.802	344.083	249.126	150.711	92.067	63.28	40.246	26.909	16.075
2002/2003	10.849	25.101	74.956	58.813	158.87	64.556	208.495	67.675	48.397	30.354	19.347	10.298	5.737
2003/2004	3.589	15.917	79.794	51.057	146.768	104.285	176.887	82.79	49.76	37.074	26.185	18.163	9.004
2004/2005	3.8	40.22	99.879	70.815	210.914	169.875	164.719	89.147	55.167	40.344	27.032	13.527	6.816
2005/2006	4.829	3.065	26.625	61.299	90.989	87.736	118.183	100.296	64.529	43.506	29.524	15.791	6.875
2006/2007	2.162	94.505	169.558	225.499	489.562	262.37	198.963	135.714	91.91	60.355	49.356	31.35	14.302
2007/2008	9.987	29.547	144.722	261.931	436.2	334.136	311.014	229.313	152.852	101.432	70.741	41.648	24.579
2008/2009	20.233	98.374	207.578	282.313	588.265		376.302	250.912	170.99	119.922	77.975	48.341	27.048
2009/2010	58.58	87.335	223.476	281.051	591.862	403.791	284.736	215.607	136.123	96.942	67.283	44.734	27.779
2010/2011	17.029	15.037	68.498	110.874	194.409	170.288		122.192	70.307	49.741	34.481	22.064	16.138
2011/2012	10.093	45.123	62.582	109	216.705	191.186	201.85	118.335	74.326	52.823	37.571	23.352	12.962

Appendix 2: Monthly Flows (m^3/s) at Mawande station

Year	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
1988/1989			1489.946	1512.012	2091.415	2360.24	1833.107	1436.345	1196.543	990.542	749.429	581.307
1989/1990	482.001	1401.596	1527.059	1379.496	2407.514	0	1702.651	1161.189	864.269	691.549	516.487	379.825
1990/1991	361.877	414.36	870.471	1882.215	1524.898	1844.726	942.541	490.032	0	119.127	186.093	153.62
1991/1992	111.939	375.533	714.371	1056.07	1372.097	984.161	735.048	316.332	236.405	193.497	140.575	113.634
1992/1993	338.523	447.958	843.976	1461.928	1885.18	1794.066	1090.71			196.259	163.297	115.017
1993/1994	114.677		424.518	887.405	2016.588	1355.043	738.638	346.285	241.374	173.688	150.931	136.339
1994/1995	114.121	173.827	920.459	846.129	2031.842	1287.945	743.399	400.659	253.057	217.634	165.369	127.113
1995/1996	84.254	119.392	663.356	1418.126	1637.356	1892.3	999.248	527.341		247.363	191.607	163.747
1996/1997	114.428	190.67	299.568	806.808	758.048	1064.432	443.848	309.262	261.66	202.911	145.897	120.038
1997/1998	186.979	1949.231	1668.331	2021.445	1683.224	1529.346	938.643	487.063	301.303	228.355	47.962	
1998/1999			155.376	207.088	750.406	780.177	344.052	134.108				20.588
1999/2000	31.102	57.812	101.124	184.784	513.457	377.594	133.493	57.497	41.979	32.913	17.016	6.666
2000/2001	32.334	391.296	1266.029	1068.973	1277.762	941.814	588.33	318.698	192.111	117.773	62.675	34.124
2001/2002	12.075	160.405	1056.661	1387.967	1795.514	1329.966	717.995	413.842	285.064	212.855	158.358	132.174
2002/2003	88.165	283.516	1193.25	1020.825	819.067	1188.629	553.464	355.698	280.657	230.919	156.379	152.176
2003/2004	169.822	263.327	443.271	400.016	1268.702	1260.489	558.195	323.447	265.997	217.925	189.669	168.719
2004/2005	168.059	371.959	793.15	743.934	966.357	773.559	361.905	256.698	223.266	193.925	151.516	110.263
2005/2006	50.893	56.546	170.555	475.645	641.218	837.213	557.753	365.173	285.471	240.818	184.227	115.978
2006/2007	59.155	1194.147	1735.318	1630.23	1691.927	1165.345	764.84	506.187	363.237	300.402	237.579	195.686
2007/2008	145.796	463.939	913.998	1684.075	1670.417	1649.198	1029.178	627.141	411.857	293.919	171.977	112.653
2008/2009	114.68	448.314	750.399	797.401	1349.672	1416.391	660.603	373.201	280.77	212.677	866.648	159.112
2009/2010	196.871	236.884	896.734	865.64	1305.458	990.406	485.356	335.831	268.406	217.149	821.386	161.561
2010/2011	67.564	113.864	299.811	397.765	570.4	862.388	462.738	327.504	258.789	213.461	799.754	162.807
2011/2012	124.534	368.57	407.01	419.121	607.095	611.288	385.679	214.88	206.62	141.499	562.999	141.428

Appendix 3: Monthly Flows (m^3/s) at Ihimbu station

Year	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
1980/1981	165.93	361.46	558.06	921.9	881.34	1080.32	626.79	433.78	319.39	270.35	214.27	112.01
1981/1982	120.26	256.87	482.93	571	863.63	726.89	538.51	352.13	288.22	229.47	178.72	153.4
1982/1983	202.18	765.25	1113.2	978.17	1186.8	917.92	696.09					
1983/1984	172.62	355.94	711.6	244.6	432.17	848.94	657.54	482.03	352.56	269.43	184.68	147.76
1984/1985	186.94	607.69	722.68	861.8	944.23	1020.16	688.9	449.99	354.11	299.99	242.02	186.48
1985/1986	296.89		779.7	914.22	872.93			478.46	344.36	280.09	222.04	188.71
1986/1987	207.42	459.57	814.3	1055.52	1371.6	1242.9	840.76	582.45	448.43	347.24		
1987/1988					458.2	1103.23	663.42	491.49	378.03	303.72	230.91	181.62
1988/1989	175.74	261.41	498.67	608.5	764.53	877.49	634.7	465.62	300.37	281.1	218.55	179.35
1989/1990	159.55	362.32	219.41			1541		508.52	380.32	311.22	248.1	193.64
1990/1991	181.32	218.34	307.28					418.2	372.43	312.02	229.24	195.27
1991/1992	143.4	230.03	432.84	587.74	739.92	573.18	456.59	316.4	251.65	209.68	163.34	128.17
1992/1993	274.21	336.72	421.12	828.22	1218.8	1109.46	703.46	463.23	363.65	292.96	234.49	169.7
1993/1994	180.25	130.55	334.586	565.169	1503.41	885.787	617.47	368.958	298.221	250.424	191.84	162.302
1994/1995	125.958	180.56	380.977	499.978	1236.63	748.097	499.809	343.052	250.994	216.349	163.688	120.292
1995/1996	83.492	119.68	399.232	224.305	448.794	375.39	512.842	345.79	285.092	231.887	190.29	149.954
1996/1997	100.955	212.198	321.493	412.061	464.169	210.592	406.63	287.629	234.001	174.04	123.19	101.507
1997/1998	135.219	805.468			402.973	1405.07					167.865	252.974
1998/1999	180.45	177.769	163.254	150.014			87.727	232.006	263.612	249.655	184.626	143.307
1999/2000	119.829	160.956	236.004		721.313	628.567	347.553	230.388	190.724	165.687		
2000/2001	143.304	400.502	836.943	802.598	1067.47	857.315	560.956	383.91	295.509	236.875	177.924	132.535
2001/2002	234.866	541.615	892.162	1261.515	995.792	577.874	367.541	291.615	233.729			
2002/2003	127.61	3.613	538.886	415.265	428.567	851.906	402.1	282.271	219.779	158.63	108.295	91.949
2003/2004	73.146	408.272	166.4	473.615	625.087	851.039	409.228	273.901	219.157	167.541	139.456	105.656
2004/2005	83.501	308.222	725.575	742.323	756.117	784.104	418.299	280.719	237.443	190.788	132.961	
2005/2006	85.481	65.538	179.765	326.998	487.841	582.696	532.395	302.73	208.391	165.475	115.969	73.611
2006/2007	63.243	853.701	943.123	867.684	1146.58	781.496	522.664	373.191	268.546	242.529	152.459	117.396
2007/2008	92.176	218.412	773.941	1291.225	1313.41	1513.68	893.986	578.151	438.851	371.096	251.585	170.222
2008/2009	308.478	697.371	904.275	1113.081	1707.98	1812.06	855.383	541.071	432.589	329.994	241.856	201.293
2009/2010	560.288	1163.709	1506.699	1409.177	2233.4	1258.98	790.119	602.352	491.639	317.959	237.56	172.958

Appendix 4: Monthly Flows (m^3/s) at Ndiuka station

Year	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
1980/1981	440.773	636.552	988.223	981.793	1190.824	700.941					
1981/1982		589.511	640.235	977.067	416.524	518.563	443.268	379.169	303.282	218.136	194.8
1982/1983	382.591	768.364	761.03	908.088	960.339	757.321	531.691	455.471	371.762	252.918	
1983/1984	671.799	752.26	926.243	1017.21	1045.68	683.69	397.974	331.83	251.941	56.914	
1984/1985	572.328	789.267	973.699	1017.318	844.177	379.103	428.116	304.892	234.56		42.157
1985/1986	464.935	874.787	1092.445	1407.605	1256.691	814.646	502.275	369.692	280.175	192.596	131.53
1986/1987	228.085	324.08	621.248	705.298	1081.879	569.204	411.124	297.576	205.829		92.914
1987/1988	183.897	493.448	591.46	758.165	922.141	586.313	415.228	287.809	224.136	156.06	98.521
1988/1989	440.901	690.97	682.156	1138.574	1083.988	704.468	434.779	310.636	259.592	172.526	62.855
1989/1990	126.042	672.893	951.48	790.761	1198.756	664.757	394.163	302.101	241.908	149.277	111.47
1990/1991	155.693	410.791	592.175	854.322	1007.448	881.885	883.498	141.558			
1991/1992	271.217	407.995	898.968	1255.046	1210.118	727.979	420.274	339.718	254.215	61.275	
1992/1993		320.802	663.646	1447.682	959.296	574.401	405.701	286.722	161.644		
1993/1994	183.249	887.205	1011.84	1902.893	1347.904	1065.713	814.828				
1994/1995		851.083	1170.425	1554.334	1540.417	986.001	812.572	657.644	59.907		
1995/1996	440.178	234.85	892.594	933.125	1171.497	1027.706	853.079		777.348	145.076	
1996/1997	528.084					328.285	1505.999	887.26	938.933	746.068	237.9
1997/1998	229.213	638.447	1052.814	1329.786	1138.29	671.299	434.318	317.91	239.44	172.865	105.44
1998/1999	182.969	638.273	510.003	519.687	1039.831	561.117	339.812	250.418	174.249	130.749	76.437
1999/2000	472.286	570.16	640.813	837.907	915.06	504.723	315.984	242.894	169.032	135.06	91.264
2000/2001	182.969	638.273	510.003	519.687	1039.831	561.117	339.812	250.418	174.249	130.749	76.437
2001/2002	472.286	570.16	640.813	837.907	915.06	504.723	315.984	242.894	169.032	135.06	91.264
2002/2003	405.819	839.805	880.917	1014.436	964.832	512.154	349.17	269.424	209.736	134.96	90.952
2003/2004	167.2	454.428	341.894	565.172	805.421	623.897	386.328	245.899	187.904	119.93	67.28
2004/2005	894.689	1209.874	1154.222	1279.614	1026.38	664.906	456.436	322.623	291.973	180.846	111.57
2005/2006	334.962	1225.135	1175.785	1578.359	1117.129	857.355	544.302	418.996	331.532	239.645	160.56
2006/2007	624.919	925.18	1039.363	1459.37	1477.815	960.125	586.207	438.623	343.099	248.092	154.96
2007/2008	334.962	1225.135	1175.785	1578.359	1117.129	857.355	544.302	418.996	331.532	239.645	160.56
2008/2009	190.816	403.427	701.478	854.341	979.68	597.625	354.16	255.229	187.063	137.941	92.309
2009/2010	439.141	409.356	548.774	869.526	766.9	435.394	268.131	189.627	131.223	81.306	32.321

Appendix 5: Annual rainfall (mm) at Iringa maji station

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
1980	144.5	78	92.8	89.4	4.1	0	0	0	0.6	0	28.8	196.2
1981	164.3	75.1	145	164.3	32.7	0	0	0	0	0	0	0
1982	133.5	108	69	96.6	11.85	0	0	0	0	3.1	108.4	182.2
1983	126.6	110.5	139.2	34.3	19.8	0	0	3	0.7	35.8	21.1	130.8
1984	169.9	108.1	107.4	124	0	0	0	0	0	8.7	28	189.1
1985	77	266	101.5	88.1	0	0	0	0	0	0	108.1	78.2
1986	127.3	15.7	108.5	29.7	24.9	2.3	0	0	0	2.1	42	236
1987	290.3	56.9	243.2	48.1	0	0	0	0	0	0	40.7	19
1988	131.9	93.6	330.9	83.7	0	3.5	0	0	0	0	33	151.6
1989	271.2	55.4	169.6	94.5	10.1	2.7	0	0	1	2.8	89.3	224.7
1990	115.1	144.2	191.4	114	1.4	0	0	0	0	0	6.2	64.1
1991	215.6	125.3	118.3	140.6	0	0	0	0	0	33.3	9	158.3
1992	116.4	220.1	148.5	103.5	10.9	0	0	0	0	31.5	172	112.2
1993	186.9	170.8	126.4	87.7	8.9	0	0	0	0	0	29.4	4.8
1994	179	137	119.5	22.1	0	0	0	0	0	3.5	36	179.4
1995	186	117.2	180	15.7	16.5	0	0	0	0	0	0	64.9
1996	186.5	226.1	113.7	89.2	1.4	0	0	0	0	18	0.5	48.8
1997	164.5	130.4	79.9	107.7	43.8	0	0	0	0	6.7	129.9	347.2
1998	268.9	191.7	50.6	105.2	22	0	0	0	0	0	8.2	78.7
1999	158.9	103.2	286.3	47.3	0	0	0	1.8	0	0	4.3	61.6
2000	84.4	101.7	88.6	75.2	0.1	0	0	1.2	0	0	138.8	149.5
2001	250.5	141.8	120.1	48.7	10.5	0	0	0	0	0	13.4	178.1
2002	189.9	136	235	27.4	0	0	0	0	0	0	0	132
2003	198.1	104.3	66	26	19.3	0	0	0	0	7.3	2.7	99.9
2004	163.6	105.9	225.1	72.4	0	0	0	0	15	3.5	20.1	130.2
2005	131.2	137	182.2	38	2.8	0.5	0	0	0	0	2.9	71.9
2006	39.7	127.2	110.2	115.2	16.2	0.3	0	2.5	0	0.9	61.7	296.2
2007	70.3	110.1	150.7	27.9	0	20.1	0.9	0	0	0.4	12.5	81.1
2008	143.2	148.4	146	58.9	1.4	2	0	0	0	18.3	17.3	134.1
2009	59.6	124.5	156.6	71.7	9.2	0	0	0	0	0	64.1	114.7
2010	94.1	74.7	161.5	26.9	0	0	0	0	0	16.2	70.1	68.1
2011	99	94.6	146.3	89.2	8.3	0	0	0	0	0	41.9	243.1
2012	86.3	90.4	68.6	89.1	1.4	0	0	0	0	24.4	73.3	189.9

Appendix 6: Annual rainfall (mm) at Iringa Meteorological station

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1980	208.2	36.7	141.5	44	5.6	0	0	0	0	2.8	12.2	153.5
1981	128.3	85.8	133.9	131.4	6.5	0	0	0	0	0	40.1	46.9
1982	89.6	0	0	0	24.3	62.7	89.6	119.7	101.8	84.4	14.4	0.5
1983	0	0	0	0.6	61.9	2.8	0	0	0.6	61.9	245.8	115.6
1984	107.6	90.5	66.8	8.1	0	0	0	0.1	26.2	36.2	117.2	152.1
1985	80.7	57.2	110.3	1.6	0	0	0	0	0	27.5	143.1	52.4
1986	224	34.1	63.5	0	0	0	0	0	0	94.3	61.3	137.7
1987	32.1	76	26.3	16.6	0	0	0	0	1.2	26.6	227.8	108.8
1988	111.6	128.6	63.6	3.6	0	0	0	0	1.1	89.1	28	133.6
1989	66.7	257.5	19.1	0	0	0	0	0	4.1	19.7	60	255.4
1990	63.6	126.2	60.8	8.7	0	0	0	0	0	49.4	109.9	65.5
1991	106.7	164.2	111.9	4.8	0	0	0	0	0.3	23.5	41.6	160.4
1992	128.2	64.1	103.8	5.8	0	0	0	0	0.9	0	104.8	49.4
1993	184.6	94.9	37.7	9.6	0	0	0	0	13	29.7	32	188.1
1994	162.4	142.1	45	3.3	0	0	0	0	0	5.2	2.8	188.9
1995	117.2	233.7	11.3	0	0	0	0	0	14.7	1.2	50.6	102.8
1996	155.6	188.3	10.7	31.8	0	0	0	1.6	0	0	96.9	141.1
1997	265.2	89.9	56.2	0.6	0	0	0	0	1.6	0	32.1	72.8
1998	179.6	29.6	74.7	67.2	0.5	0	0	0	1.1	47.3	300.4	172.1
1999	197.5	89.9	109.2	98.9	0	0	0	0	0	0.5	18.9	109.5
2000	112.2	182	41.4	0	1	0	0	0	0	1	61.5	88.5
2001	76.4	85.8	52.7	47.8	10.3	0	0	0	0	199	70.4	184.2
2002	97.4	70.8	33.6	6	0	0	0	4.2	0	4.4	214.5	154
2003	121.4	173.2	24.9	3.8	0	0	0	0	0	4.4	125	173.3
2004	109.6	26	62.7	14.1	0.2	0	0	0	13.5	0	93.5	90.8
2005	165.1	126.2	140	0	0	0	0	0.7	0.3	22.8	127.3	183
2006	149.1	69.5	28.8	9.6	1	0	0	0	0	4	40.5	46.7
2007	121.4	70.6	85.8	26	0	0	0	0.2	0	32.2	327.1	148.3
2008	79.4	144.4	17	2	0	0	0	0	0.1	3.3	133.2	157.8
2009	207.6	130.6	58.4	0	0	0	0	0	7	10.8	115.2	47.4
2010	108.5	114.4	55.5	19.3	0	0	0	0	0	0	5.4	

Appendix 7: Annual rainfall (mm) at Mafinda Bomani station

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1980												190.3
1981	316	290.5	267.7	46.9	4.9	1	0	2	0	2.3	83.1	190.1
1982	127.7	197	281.3	118.8	2	0	0	0	0	17	104.8	405.3
1983	323.9	101.2	272.5	105.3	8	0	0	0	0	2.6	59.2	202.3
1984	240	146.8	220.1	120.1	3.3	0	0	0	0	0	105.3	252.3
1985	140.1	166.8	154.2	59	1.2	0	0	0	0	0.1	242.5	201.8
1986	206.9	130.1	122.9	48.8	0	0	0	0	0	35.6	53.3	254
1987	87	191.7	251.9	145.9	0	0	0	0	0	10.8	50.6	128
1988	173.2		411.5	15.7	0	0	0	0	0	3.1	83.2	122.9
1989	190	175.5	146.4	20.9	0	7.3	0	0	0	23.3	75.1	265
1990	188.4	318.4	143.4	161.6	41	0	0	0	0	1.4	140.9	179.8
1991	249	91.7	179.7	159.5	10.3	0	0	0	4.7	56.6	95.5	158.6
1992	202.4	215.2	247.5	61.7	9.6	0	0	0	0	1.2	310.9	148.3
1993	267.9	129.7	287.4	43	10.5	0	0	0	0	0	51.3	38.6
1994	264.6	169	258.5	49.9	4	0	0	0	0	1.3	26.5	141.7
1995	255.3	198.8	290.2	25.8	7	0	0	0	0	0	0	76.1
1996	127.2	195	235	40.5	0	0	0	0	17.5	0	0	0
1997	198.5	132	166.5	144	13	2	0	0	0	0	89.5	324.5
1998	316	165	188	178	69.5	0	0	0	0	0	91.5	131.5
1999	172.5	125	256.5	97	5.5	15.5	0.5	0	0	0	86.5	121.5
2000	188.5	215	202.5	86	1	0	0	0	0	20.5	125.5	285.6
2001	188	144	210	51	0	0	0	0	14	9.5	47.5	275.5
2002	202	198	346.5	43	1	0	0	0	10	1	43	141
2003	177	101	234	158	5	0	0	0	0	9	30	109
2004	156.5	223	202	188	0	0	0	0	19	0	75.3	203
2005	307	129.5	206.5	33	0	0	0	0	0	0	67	100
2006	309.2	226.1	190	95.6		0	0	0	0	27	162.2	329.5
2007	229.5	145.1	141	106	10.5	0	4	1	0	8	84.5	319.5
2008	145.5		2	56	0	0	0	0	0	0	104	212.5
2009	201	156	348	8	0	0	0	0	0	25	198.3	73.5
2010	182.5	136			0	0	0	0	0	0	54	0

Appendix 8: Annual rainfall (mm) at Mafinga National Service station

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1980			181.2	171.7	50	0	0	0	0.4	0		162.8
1981	66.6	145.5	237.4	42.7	0	0	0	0	0	3	71	147.8
1982	113.7	155.5	246.3	77	0	0	0	0	0	11.9	148.9	389.2
1983	204.6	148.7	226.2	57.5	0	0	0	0	0	0	45.8	144
1984	172.5	223.9	263.5	97.7	4.5	1.6	3.5	0	0	19.8	61.7	200
1985	187.1	161.3	246.8	65.3	0	0	0	0	0	0	179.8	295
1986	157.8	71.2	103.3	33.7	7.1	0	0	0	0	8.5	21	281.4
1987	155	166.3	300.5	69.6	0	0	0	0	0	0	42.7	217.1
1988	139.5	78.9	195	24	0	0	0	0	0	9	91.4	134
1989	145.1	158.8	153	28.9	0	0	0	0	0	4.5	59	303.5
1990	151.7	268.9	153	185.1	16.5	0	0	0	0	0	76	101.5
1991	181.1	83.8	147.8	174.8	7.1	0	0	0	0	45.5	9.7	139.3
1992	164.8	127.4	108.2	76.1	8.7	0	0	0	0	35	89.3	137
1993	237.5	93.6	233.4	81.4	0	0	0	0	0	0	33.5	
1994	252	117	222	12.2	0	0	0	0	0	0	29.3	89.3
1995	275	169.9	228.9	6.7	13.5	0	0	0	0	0	0	
1996	127.2	195	233	42.5	0	0	0	0	17.5	0	0	0
1997	198.5	132	166.5	144	13	2	0	0	0	0	89.5	324.5
1998	316	165	188	178	69.5	0	0	0	0	0	91.5	131.5
1999	172.5	125	256.5	97	5.5	15.5	0.5	0	0	0	86.5	121.5
2000	188.5	215	202.5	86	1	0	0	0	0	20.5	149.8	286.6
2001	207.7	144	210	51	0	0	0	0	14	9.5	47.5	275.5
2002	202	198	346.5	43	1	0	0	0	10	1	43	141
2003	173	41	221	227	5	0	0	0	0	13	26	92
2004	285	168	162	188	0	0	0	0	19	0	75.3	203
2005	307	129.5	206.5	33	0	0	0	0	0	0	67	100
2006	178	141	170	95.6	0	0	0	0	0	27	162.2	329.5
2007	177	120	119	51	16	0	0	0	0	0	34	281
2008	378	236		49.1	1	0	0	0	0	0	155	339.5
2009	157	241	378	220	17	0	0	0	0	0	247	73.5
2010	149	208	230	1	1	0	0	0	0	0	54	54

Appendix 9: Iringa Minimum temperature for year 1980 -2012

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1980	16.3	15.3	15.3	15.7	15	11.1	11.8	12.8	13.2	14 6	15.4	16.2
1981	15.4	15.5	15.3	15.1	13.9	12.1	11.4	12.4	12.9	14.6	15.2	16.4
1982	16	15.9	16.9	17.7	17.1	13.7	13.2	13.1	14.1	15.7	16.8	16.8
1983	16.5	16.1	16.3	15.7	14.9	13.8	12.7	12.8	13.4	15.3	15.6	16.4
1984	16.2	15.4	14.9	15.6	13.4	12.3	12.1	12	12.6	14.4	16	16.2
1985	15.2	15.7	13.2	14.8	14	12.7	12.3	12.3	12.9	14.3	15.9	16.7
1986	15	14.8	14.3	14.8	15.4	12.2	10.9	11.9	12.8	14.6	16.2	16.6
1987	16.2	15.8	15.6	15.9	14.6	12	11	12.4	13.3	15	16.1	16.6
1988	16.6	15.8	15.9	14.7	14.6	12.8	12.5	13.1	13.5	15.1	15.9	16.9
1989	16.4	15.5	15.5	14.7	14.3	12.2	12.1	11.3	13.1	13.8	15.4	16.8
1990	14.9	15.6	14.9	15.1	13.9	11.9	11.3	12.2	12.6	13.9	16.4	16.5
1991	16.4	15.5	14.6	14.1	13.8	11.7	11.2	11.4	11.9	14.5	15.5	16.4
1992	15.9	16.2	15.6	15.6	13.9	12.8	11.2	11.2	12.5	13.9	15.4	15.7
1993	16.1	15	15.1	15.2	13.7	12.5	11.2	11.7	11.8	13.9	15.3	16.1
1994	16.1	15.9	15	13.9	14.4	11.7	12	12	12.6	14.7	15.2	16.6
1995	16.3	15.4	15.1	14.9	14.7	12.3	11.6	12.2	13	14.1	15	16.1
1996	15.9	15.6	14.9	14.8	13.2	12.2	10.7	10.2	12	13.4	14.6	15.9
1997	16.1	15.4	15.8	14.9	13.2	11.6	12.2	12.4	12.9	15.6	17	17.1
1998	17.2	17.6	16.3	16.7	14.6	13.4	12.5	12.5	13.4	14.4	15.6	16.4
1999	17.3	16.2	16.6	15.7	14.3	12.8	12.8	12.5	13.3	14.2	15.7	16.6
2000	16.7	16.3	16	16	14.8	13.8	12.9	13.5	13.7	15.1	17	16.9
2001	17	16	15.7	15.7	15.1	12.9	12.2	12	13.3	14.8	15.5	16.8
2002	16.9	16.2	16	15	13.8	12.5	11.1	12.7	12.8	14.6	16.4	16.6
2003	16.5	15.5	15.8	15.8	15.5	13.6	12.8	12.6	13.7	14.8	16.2	17.2
2004	17	16.1	15.5	15.6	14.4	11.6	10.6	11	13.3	14.6	16.1	16.4
2005	16.3	16.3	16.1	15.5	14.5	13.2	14.5	12	13.4	14.5	15.4	16.3
2006	17.2	16.7	16.1	15.6	14.6	13.1	11.8	12.3	13.5	14.6	16.8	16.4
2007	16.4	16.2	15.3	14.7	14.9	13.2	12.6	12.7	13.6	14.7	15.9	16.3
2008	16.6	15.2	15.4	15.3	12.9	11.8	11.6	12.8	13.4	15.4	15.9	16
2009	15.9	16.1	15.5	16	14.3	13.3	12.7	13.4	14.5	15.5	16.7	16.6
2010	16.6	16.7	16.2	16.3	15.8	13.9	13.1	13.7	14.1	15.5	16.2	16.4
2011	16.5	17	15.7	15.8	14.8	13.4	12.6	14	15	16	17.3	17
2012	16.8	15.6	16.2	16.4	15.2	13.7	13	13.5	14.4	15.6	16.6	16.5

Appendix 10: Iringa Maximum temperature for year 1980 -2012

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1980				26.9	26.3	25.5	23.3	24.5	27.2	28.3	29.3	25.8
1981	26.3	26.1	27.6	25.5	25.4	25.4	24.6	25.7	27	28.7	29.6	27.3
1982	26.9	27.5	26.5	26.6	25.8	25.4	24.9	25.1	26.7	28.1	28.3	26
1983	26	27.7	27.7	27.3	26.6	25.7	25.2	26	27.5	28.5	29.6	28.6
1984	24.4	25.6	27.2	25.7	25.4	24	23.4	24.8	27.6	28.3	28.6	26.3
1985	27	24.2	26.5	25.9	26	25.7	24.7	24.5	26.6	27.8	26.8	26.9
1986	25	27.9	26.3	27	25.5	24.8	24.4	25.8	26.8	29.4	28.1	25.9
1987	25.1	25.5	26.6	27.1	26.5	27.1	26.5	25.5	25.6	25.7	27.8	29.2
1988	26.5	27.2	26.8	26.6	26	25	25.1	25.4	27.1	28.9	28.6	27.8
1989	23.8	25.6	25.9	24.6	24.5	24.3	23.7	24.3	26.7	28.3	29	26.3
1990	25.8	26.2	25.8	26.3	25.9	25.5	24.8	24.4	26.8	28.7	28.9	28.7
1991	26.1	27.6	27.8	25.8	25.8	26.1	23.8	25.6	27.3	28.3	29.4	27.4
1992	28.3	25.4	26.2	26.4	26.1	26.2	24.1	25.2	27.1	28.5	27.9	27.5
1993	26	25.6	26	26.3	26.5	24.9	23.3	24.6	26.5	28.3	29.6	30.7
1994	26.5	25.2	26.3	26.6	26.2	25.5	24.3	25	27	28.3	29.2	28.2
1995	26.3	26	26	26.8	25.7	26.5	24.8	25.7	27.4	29.2	29.8	28.4
1996	26.3	25.2	26.7	25.1	25.5	24.8	24.6	26.4	27.4	28	29.6	28.6
1997	28.2	25.5	27.6	26.1	25.5	24.9	24.2	26.5	27.7	28.2	28.5	25.4
1998	26.1	26.3	27.9	26.7	27	26	25	25.1	27	28.9	29.4	30.4
1999	27	28.3	25.6	25.7	25.7	24.8	23.4	24.8	26.6	28.2	29.3	28.1
2000	27.6	27.5	26.3	27.1	26.5	24.5	24.8	25.2	27.3	28.9	28	26.1
2001	24.8	26.3	27.3	26.4	26.1	24.9	24.7	26.2	28.1	28.9	29.9	27.7
2002	25.1	26.6	26.8	26.2	27.2	25.5	26	25	27.3	29	29.7	28.3
2003	26.7	27.5	28.7	27.5	26.8	25.8	24.8	26.9	27.5	29.2	30.7	28.8
2004	27.4	26.7	26.3	26.1	26.2	24.5	25.2	25.8	27.2	28.3	28.7	26.6
2005	26.9	28.3	27.2	27.1	26.4	25.7	24.1	25.5	27.6	28.3	30.3	30.9
2006	29.2	28.8	27	26.2	26.8	25.2	24.2	25.9	26.6	29	29	25.3
2007	26.3	26.4	26.5	27.1	26.5	25.1	24.7	25.8	27.9	28.2	29.7	26.8
2008	26	25.3	26.3	24.9	25.3	24.4	24.1	25.5	28	29.2	29.4	27.4
2009	28.1	25.7	26.4	26.2	27.2	25.8	24.4	25.5	28.2	28.7	28.3	27.8
2010	26.3	27.3	27.9	28	27.2	25.6	24.1	26	27.6	30	30.3	28.1
2011	27.5	26.9	27.1	26.8	26.6	26.7	26.2	26.4	27.8	29.9	29.9	27.9
2012	27.1	28.9	27.6	27	26.6	26.2	26.4	26.7	28.8	29.9	30	28.7