IMPACTS OF LAND USE AND LAND COVER CHANGES ON THE ECOSYSTEM SERVICES OF THE LITTLE RUAHA RIVER CATCHMENT, TANZANIA

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ABSTRACT

A study was carried out to evaluate spatial and temporal changes that have occurred over a period of 25 years in land use and land cover and their impacts on ecosystem services with strong focus in water and sediments yield in the Little Ruaha River Catchment (LRRC), in Rufiji River Basin. The objectives of the study were to analyze the spatial and temporal changes of land use/cover, assess the impacts of land use/cover changes on water and sediment yields and predict the future change in land use/cover and how it is likely to affect water and sediment yields in the LRRC. In this study, field survey, remote sensing and GIS techniques were employed to assess spatiotemporal dynamic of land use/cover. CA-Markov model was used to simulate the expected changes in land use/cover in the future. SWAT model was employed to simulate the potential impacts of land use and land cover changes in water and sediment yield in the catchment. Results have revealed that there has been a significant land use and vegetation cover transformation from one class to another for the period between 1990 and 2015. Natural forest, riverine forest, water, wetland and woodland decreased by 3.76%, 0.75%, 0.17%, 2.12%, and 8.03% respectively, while plantation, grassland, bushland, cultivated land and built up area increased by 0.57%, 4.71%, 6.02%, 5.76% and 0.73% respectively between 1990 and 2015. Moreover, the study has revealed that there have been notable impacts caused by land use/cover changes in water and sediment yield. The average annual surface runoff increased by 3.53 mm, sediment yields increased by 1.2 t/ha, long-term average annual river flow has increased with the annual values of 7.3mm, while base flow decreased by 2.86 mm. The future prediction scenario indicates that by the year 2040, the average surface runoff, annual river flow and sediment yield are expected to be 154.28 mm, 22.6mm, 11.35 t/ha respectively. The study recommends a proper enforcement of laws and regulations relating to natural resource and suitable land use planning and management in order to ensure sustainability of the catchment.

DECLARATION

I, CHILAGANE NYEMO, 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 to any other institution.

9/08/2017

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DEDICATION

This work is dedicated to my parents, relatives and friends.

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LIST OF ABREVIATIONS AND SYMBOLS

CLUE	Conversion of Land use
DEM	Digital Elevation Model
FAO	Food and Agriculture Organization
GIS	Geographical Information System
GLOVIS	Global Visualization Viewer
GRR	Great Ruaha River
HRU	Hydrological Response Unit
LRRC	Little Ruaha River Catchment
LULC	Land use and Land cover
LULCC	Land Use and Land Cover Change
MUSLE	Modified Universal Soil Loss Equation
QGIS	Quantum GIS
ROI	Region of Interesting
RS	Remote Sensing
SAGA	System for Automated Geoscientific Analyses
SAGCOT	Southern Agriculture Growth Corridor
SCP	Semi-automatic Classification Plugin
SWAP	Effects and Soil Water Atmosphere Plant
SWAT	Soil and Water Analysis Tool
TNBS	Tanzania National Bureau of Statistics
UNEP	United Nation Environment Programme
USGS	United States Geological Survey

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background Information

Ecosystems are the planet's life-support systems for the human species and all other forms of life (Schröter *et al.,* 2005). Ecosystem services are the direct and indirect contributions of ecosystems to human well-being that support directly or indirectly our survival and quality of life (BISE, 2010), which are provisioning services, regulating services, supporting services and cultural services (MEA, 2005). Despite the greater importance of these ecosystems, their productivity has been threatened due to unsustainable management practices as well as the increasing demand exceeding the ability of the ecosystem to supply (Devisscher, 2010).

There is worldwide evidence that river ecosystems have changed (Postel and Richter, 2003). Also, the increased competition for water and alterations in land use in the upstream of many rivers, are argued to have contributed to change in hydrological regimes of many rivers and wetlands. Little Ruaha River catchment in Tanzania, is one of the country's most significant waterways (Kadigi *et al.,* 2004). Furthermore, it is the main source of water during the dry season, and so is vital for the ecology of the Ruaha National Park. Regardless of its ecological and economical value, the sustainability of the catchment to supply ecosystem services is at risk due to land uses alteration (Hart and Buck, 2013) and the competing demands for the Ruaha's water abound with a large regional population, important wildlife areas and irrigated agriculture.

Land use and land cover changes have become a major challenge on the sustainability of the Little Ruaha River catchment (Milder *et al.*, 2013). Land cover change is expected to alter regional hydrologic conditions and results in varieties of impacts on ecosystem functioning (Li *et al*., 2007) especially water. Hydrological alteration of Little Ruaha River catchment is believed to have negative impact, not only on the livelihood of people through decreased crop and livestock production (Milder *et al.*, 2013) , but also on national economy through impact on the biological diversity of Ruaha National Park as well as sedimentation of Mtera dam (Milder *et al*., 2012). Therefore, this study was conducted to investigate the impacts of land use land cover change on river ecosystem with a strong focus on water and sediment yields in the Little Ruaha River Catchment area.

1.2 Statement of the problem

The Ihemi Cluster lies in an area where almost 80% of the population derives their livelihoods directly from agriculture through crop cultivation and livestock keeping (Mwinuka *et al.,* 2015) as well as high dependence on the natural resources for fuel wood and other off-farm activities such as charcoal making and bee keeping. Agricultural practices and resources uses in the cluster are unsustainable resulting not only in low crop yields, but also ecosystems degradation and limit their ability to function properly thereby affecting provision of essential services such as water, energy, food, and wildlife habitat (Milder *et al.*, 2012). Water resources have become a global crisis due to mismanagement (Kashaigili and Majaliwa, 2013). The increased land uses and land cover changes are said to have detrimental effects to water resource (Liu *et al*., 2009).

However, there is general understanding as regarding to the effects of land use and land cover change on water resources. Kashaigili (2008) found that, the modification of land use and cover has resulted in changes in temporal distribution of runoff and flow regimes of Great Ruaha River, where by Q_{50} flow progressively decline from 19.23 m^3s^{-1} in pre 1974 to 9.04 m^3s^{-1} in post 1985, there is still a gap on current understanding with regard to effects of land use and land cover change on river ecosystem. It is not clear how the

LULC change in the Little Ruaha River catchment has impacted on water yield and sediment loading, and the propagation of the changes in the future. It is also important noting that much of the planned agriculture development in the Ihemi Cluster depends on the Little Ruaha River, however it is not clear whether there will be sufficient flows to meet the various water needs in the future. Therefore, this study was conducted to improve understanding of the influence of land use and land cover change on water and sediment yields in Little Ruaha River catchment.

1.3 Significance of the Study

This study assessed and quantified the land use and land cover changes that have taken place and their impacts on the water resources and the future potential impacts of these land use land cover changes. The study provides useful data and information to stakeholders of various professions such as foresters, farmers, Natural Resource managers, conservationist, students and researchers about the impacts of land use and land cover changes on ecosystem services in Little Ruaha River Catchment area with strong focus on water resource and sediment yield.

It also addressed the current state of surface water resource and sediment yield within a cluster and predicts the future changes in Land use and Land cover in Little Ruaha River Catchment. Information gathered from this study is useful for conservation and management of Ihemi Agricultural Development Cluster as well as provision of basic information to different resource users for resource use decision making.

1.4 Objectives of the Study

1.4.1 Overall objective

The main objective of the study was to investigate the impact of land use and land cover change on ecosystem services (water and sediment yields) in the Little Ruaha River catchment.

1.4.2 Specific objectives

The specific objectives of the study were:

i. To analyze the spatial and temporal changes in land use and land cover in Little Ruaha River Catchment for period 1990's – 2015.

ii. To assess the impact of land use and land cover change on water resource and sediment yields in the Little Ruaha River catchment for the period 1990's – 2015.

iii. To predict the future changes in land cover, water and sediment yields in Little Ruaha River Catchment

1.5 Research Questions

i. What changes in land use and land cover occurred in the Little Ruaha River Catchment for the period between 1990 to 2015

ii. What are the impacts of land use and land cover changes on surface runoff, sediment yield and river flow of Little Ruaha River Catchment?

iii. What are expected future changes in land use and land cover in Little Ruaha River Catchment?

iv. What are expected future changes in surface runoff, sediment yield and river flows due to modification of land use and land cover in Little Ruaha River Catchment?

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Definitions of Terms

Land cover refers to the physical and biological cover over the surface of land (Earth's surface), including water, vegetation, and/or artificial structures (Mayer *et al.,* 2000). When considering land cover in a very pure and strict sense it should be confined to describe vegetation and man-made features. Consequently, areas where the surface consists of bare rock or bare soil are describing *land* itself rather than land *cover*. Land use and Land cover change (**LULCC**); also known as **land change**) is a general term for the human modification of Earth's terrestrial surface (DiGiano *et al.,* 2013).

Land use as defined by FAO/UNEP (1999), cited by Foley *et al.,* 2005., means arrangements of activities and inputs that people undertake in a certain land cover type to produce, change or maintain it. 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. Examples include categories such as forest reserves, settlements (e.g. urban and rural settlements), agriculture (irrigated and rain-fed fields), national parks, and transportation and other infrastructure.

Ecosystem services are the direct and indirect contributions of ecosystems to human well-being that support directly or indirectly our survival and quality of life (BISE, 2010). Millennium Ecosystem Assessment (2005) groups ecosystem services into four main categories, which are;

- **Provisioning services**; are the products obtained from ecosystems such as food, fresh water, wood, fiber, genetic resources and medicines.

- **Regulating services;** the benefits obtained from the regulation of ecosystem processes such as climate regulation, natural hazard regulation, water purification and waste management, pollination or pest control.
- **Supporting services;** highlight the importance of ecosystems to provide and to maintain the three other categories of ecosystem services such as water cycle, nutrient cycling, production of atmospheric oxygen and soil formation.
- **Cultural services**; include non-material benefits that people obtain from ecosystems such as spiritual enrichment, intellectual development, recreation and aesthetic values.

A **catchment** is an area that catches rainfall and directs it to a stream, river, reservoir or in builtup areas (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).

2.2 Land use and Land Cover Change (LULCC)

LULCC calls for special attention since humans have been modifying land to obtain food and other essentials for thousands of years, but current rates, extents and intensities of LULC changes are far greater than ever in history (Ruddiman, 2003), driving unprecedented changes in ecosystems and environmental processes at local, regional and global scales. LULCC can occur through the direct and indirect consequences of anthropogenic activities to secure their economic and social needs. Burning of areas to create the availability of wild game as well as cultivated land, resulting in extensive clearing such as deforestation and earth's terrestrial surface management that takes place today (Ellis and Pontius 2006).

LUCC is a complex process which is influenced by the jointly interactions between environmental and other social factors at different spatial and temporal scales (Valbuena *et al.*, 2008; Rindfuss *et al.*, 2004). More recently, industrial activities and developments have encouraged the concentration of population within urban areas. Urbanization and current growth rate drives intensive farming in the most productive lands and the abandonment of marginal lands (Ellis and Pontius 2006). These conversions and their consequences are obvious around the world and it is becoming a disaster around the metropolitan areas in developing countries. These changes encompass the greatest environmental concerns of human populations today (Foley *et al.,* 2005), including climate change, biodiversity loss and the pollution of water, soils and air. Monitoring and mediating the negative consequences of LULCC while sustaining the production of essential resources has therefore become a major priority for researchers and policymakers around the world.

2.3 Impacts of Land Use and Land Cover Change on Ecosystem Services

LUCC can greatly alter the provision of ecosystem services. Land Conversion to human utilization introduces the risk of undermining human wellbeing and long term sustainability (Rockstrom *et al*, 2009). Particularly, it is considered to be one of the drivers of global environmental change (Shao *et al.,* 2005).

Transformation of ecosystems into other land use categories, primarily the conversion of various vegetation covers to agricultural land and urban areas, impacts water flows and the biogeochemical cycle, and is closely linked to climate change (Milad *et al*., 2011; Schulp *et al*., 2008). The joint effects of land use and climate change are perceived as the most important driver of biodiversity loss (Chappin *et al.,* 2000). Because biodiversity is known to represent a key prerequisite for the functioning of an ecosystem and delivery of bundles of ecosystem services (MEA, 2005), land use change may undermine regulatory capacities of the ecosystems, e.g. in terms of the ability to avoid and minimize hazards (Rockstrom *et al.,* 2009; Measham *et al.,* 2011). A number of risks initiated by land use change or its consequences originate in diminished land productivity, land degradation, disruption of water regime, water contamination, or extra losses of biodiversity (Shao *et al.,* 2005).

Biodiversity has been diminishing considerably by land change. While lands change from a primary forested land to a farming type, the loss of forest species within deforested areas is immediate and huge (Ellis and Pontius 2006). According to Ellis and Pontius (2006), the habitat suitability of forests and other ecosystems surrounding those under intensive use are also impacted by the fragmenting of existing habitat into smaller pieces, which exposes forest edges to external influences and decreases core habitat area.

The conversion of tropical forest to grassland disrupts the hydrological cycle of a drainage basin, by altering the water yield of the area (Kashaigili *et al*., 2003). The conversion of vegetation such as tropical forest or savanna to grassland disrupts the hydrological cycle of a drainage basin by altering the balance between rainfall and evaporation and, consequently, the runoff response of the area. The higher surface albedo, the lower surface aerodynamic roughness, the lower leaf area and the shallower rooting depth of pasture compared with forest/cerrado all contribute to reduced evapo-transpiration (ET) and increase the long-term discharge (Li *et al*., 2007; Costa *et al*., 2003).

LUCC, particularly natural forest alteration makes soils vulnerable to a massive increase in windy and water soil erosion forms, particularly on steep topography. When accompanied by fire, also pollutants to the atmosphere are released. Soil fertility degradation within time is not the only negative impact; it does not only cause damage to the land suitability for future farming, but also releases a huge amount of phosphorus, nitrogen, and sediments to aquatic ecosystems, causing multiple harmful impacts of sedimentation and eutrophication.

2.4 Application of Remote Sensing on Land Use/Land Cover Detection

Remote sensing is an essential tool for land-change science because it facilitates observations across larger extents of earth's surface than is possible by ground-based observations. Many studies have been done by various natural resources experts, Slayback (2003) studied land cover change in the Takamanda forest reserve in Cameroon. The study revealed that most of the areas of forest conversion into other land uses were located on the periphery of existing villages and areas of pre-existing secondary forest and the rates of forest clearing increased as the expanding patterns of forest conversion indicated. Mulongo (1993) used remote sensing to assess the rate of natural resources exploitation and the implication of existing land policy in the reserved lands of Mboele-Muyonzi in Zambia.

Shreier *et al.* (1994) used remotely sensed data and historic land use/land cover dynamics to study resources status in the Himalaya, Nepal watershed using geographical information system. In this study forest, cropping system and socio-economic factors were investigated. Observations showed that between 1947 and 1990, forest, shrubs and agriculture were the only land uses. Deforestation was significant from years 1972 to

1990 and was more critical in the middle mountains of Nepal. It was reported that geographical information systems when integrated with remotely sensed data could be useful in identifying impact of deforestation due to increased agricultural activities and grazing.

Remote sensing has also been used in several studies in Tanzania. Luoga *et al.*, (2005) used remote sensing to investigate the potentials of local communities to sustainably manage miombo woodland resources. Results revealed that woodlands of Kitulanghalo Forest Reserve and surrounding public land covered 82.3% in 1964. However, woodland declined by 50% representing a decline of an overall mean of 1.6% per year for the period between 1964 and 1996.

Rugenga (2002) used remote sensing to study land use changes due to traditional irrigation activities for the periods 1955 to 1999 in Ruaha River, Tanzania. The study identified seven main land use classes including riverside vegetation, forest woodland, scrub, settlements and abandoned fields. The land use change was mainly observed along the Great Ruaha River and its distributaries. It was found that overpopulation, grazing and charcoal making were among socio-economic factors leading to land use/land cover changes.

Kashaigili (2008) used Remote Sensing technique to investigate the hydrological impacts of land-use and land-cover changes on flow regimes of the Great Ruaha River. Remote sensing and GIS techniques were used to inventory temporal changes of land-use and land-cover changes in the watershed. In this study hydrological data were analyzed to disclose the alterations and trends for three-time periods; pre-1974, 1974–75, and post-1985. Results revealed that there was a steady increase in cultivated area, from 121.2 km^2

to 874.3 km^2 between 1973 and 2000 while the woodland area decreased significantly over years. The minimum dry season area of the wetland declined significantly, with major changes occurring between 1984 and 2000. River flows were found to be highly variable within and between the years, and sensitive to land-use and land cover changes.

2.5 Predicting Future Land Use Change

Forecasting, and evaluating future land change is a complex set of tasks and, hence, it has to be performed after a deep scientific knowledge of the extent individuals, characters, as well as consequences of land transformation have been gathered (Meyer and Turner, 1994). A typical land use planning process requires the landscape planners to realize, classify, and investigate the current circumstances in order to project future probable development patterns, and propose plans based on available information (Brail and Klosterman, 2001).

According to Brail and Klosterman (2001), planners usually approach this task in two ways, a predominant or traditional approach and an analytical approach. The traditional approach foresees a future land use outcome and then prioritizes present-day policies required to achieve that outcome. The analytical approach simulates alternate current strategies and compares their consequences. A recent pervasive approach to consider and simulate human decisions in LULC change is the use of multi-agent systems (MAS) (Robinson *et al*. 2007; Valbuena *et al*. 2008). MAS are defined as modeling tools that allow entities to make decisions according to the predefined agents, and the environment also has a spatial explicit pattern. In fact, agents in the system might represent groups of people or individuals, etc. (Valbuena *et al.*, 2008; Bonabeau, 2002;).

2.6 Land Use and Land Cover Prediction Models

Several methods have been developed for forecasting land use change, with varying degrees of sensitivity to the influence of transportation networks. The simplest types of models for forecasting land use change are Markovian models (such as Markov chain models) and Cellular and agent based models (Brown, 2000; Levinson, 2002; Weng, 2002).

2.6.1 Markov model

The Markov model is a theory based on the process of the formation of Markov random process systems for the prediction and optimal control theory method (Jiang *et al.*, 2009). It tends to treat land use change as a stochastic process by assuming that rates of change between land use types are more or less constant from one period to the next. The Markov model not only explains the quantification of conversion states between the land use types, but can also reveal the transfer rate among different land use types (Xiyong *et al.*, 2004). The Markov model projects land use transitions forward to any given future date, eventually reaching an equilibrium distribution of land uses. These models tend to have a limited ability to incorporate transportation networks and other spatial features, except as states (e.g., land use types) in the model (Yang *et al.*, 2007). It is commonly used in the prediction of geographical characteristics with no aftereffect event which has now become an important predicting method in geographic research (Jiang *et al.*, 2009). Based on the conditional probability, the prediction of land use changes is calculated by the following equation (1)

$$S(t+1) = Pij \times S(t) \qquad (1)$$

Where;

S (t);   is the system status when there is no change at the time (t)

S (t+1); is the system status when there is a change at time (t+1)

Pij;   is the probability of movement (transition) from one state *i* to state *j*

2.6.2 Cellular Automata Model

The behavior of CA models is affected by uncertainties arising from the interaction between model elements, structures, and the quality of data sources used as the model input (Batty *el al*., 1999; Peterson *et al.*, 2009). It focuses mainly on the local interactions of cells with distinct temporal and spatial coupling features and the powerful computing capability of space, which is especially suitable for dynamic simulation and display with self-organizing feature systems. Advances in computational power and data storage have facilitated the development of models that disaggregate urban space to a greater degree and can operate with individuals or land parcels as the units of analysis, rather than zones. These include microsimulation models of urban development (Waddell *et al.*, 2003) as well as models based on a cellular automata framework (Yeh, 2002). Cellular automata models emphasize neighbour effects and dynamic interactions between agents (with land use cells as agents), while microsimulation models treat individual households and firms as agents and attempt to simulate their behaviour in terms of location and travel choices. The use of geographic cellular automata for land use change simulations not only takes into account comprehensive consideration soil conditions, climatic conditions, topography and other natural factors, but also considers a comprehensive policy, economy, technology and other human factors, and takes into account the historical trends of land use with strong applicability. The CA model can be expressed as follows, equation (3)

$$S(t, t+1) = f(S(t), N) \qquad (3)$$

Where; S is states of discrete cellular, t is the time instant, t +1 is the coming future time instant respectively, N is the cellular field and f is the transition rule of cellular states in local space.

2.6.3 CA Markov model

CA–Markov is a combined Cellular Automata/Markov Chain/Multi-Criteria/Multi-Objective Land Allocation (MOLA) land cover prediction method that adds an element of spatial contiguity as well as knowledge of the likely spatial distribution of transitions to Markov chain analysis.

The Markov model focuses on the quantity in predictions for land use changes. For this model, the spatial parameters are weak and do not recognize the various types of land use changes in the spatial extents (Wickramasuriya *et al.*, 2009). The CA model has a strong space conception, which is a strong capability of space-time dynamic evolution with complex space systems. The CA–Markov model, which incorporates the theories of Markov and Cellular Automata, is about the time series and space for the advantages of forecasting. It can achieve better simulation for temporal and spatial patterns of land use changes in quantity and space (Wang *et al.*, 2009). The CA–Markov module in IDRISI32 integrates the functions of cellular automation filter and Markov processes, using conversion tables and conditional probability of the conversion map to predict the states of land use changes, and it may be better to carry out land use change simulations.

2.7 Water and Sediment yield modeling in watersheds

2.7.1 Soil and Water Assessment Tool Model (SWAT)

SWAT model operates on a daily time step and is designed to predict the impact of land use and management on water, sediment, and agricultural chemical yields in ungauged watersheds (Neitsch, 2001). It was developed by Agricultural Research Services of United States Department of Agriculture to predict the impact of land management practices on water, sediment, and agriculture chemical yields in large and complex watersheds with varying soil, land use, and management conditions over long periods of time (Arnold *et al*., 1998).

Currently it operates as an extension within several GIS softwares including ArcView GIS, ArcGIS and Quantum GIS (QGIS). 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*., 2012). SWAT model is very useful because it has weather engine to generate the precipitation within an un-gauged watershed based on stochastic and probabilistic methods (Arnold *et al*., 2012). The model consists of two parts: a GIS-based module used for model data input and preparation, and the rainfall-runoff processing module. Geographic information system (GIS) data for topography, soils and land-cover are used in calibrating and validating the model, where the AVSWAT, an ArcView-GIS interface for the SWAT model (Cau and Paniconi, 2007) or QSWAT, a QGIS interface for the SWAT model being used.

2.7.2 Suitability of SWAT for modeling water balance

In SWAT, a watershed is divided into multiple subwatersheds, which are then further subdivided into hydrologic response units (HRUs) that consist of homogeneous land use, management, topographical, and soil characteristics. An HRU is the fundamental spatial unit upon which SWAT simulates the water balance. Alternatively, a watershed can be subdivided into only sub-watersheds that are characterized by dominant land use, soil type, and management. Water balance is the driving force behind all the processes in SWAT because it impacts plant growth and the movement of sediments, nutrients, pesticides, and pathogens. Simulation of watershed hydrology is separated into the land phase, which controls the amount of water, sediment, nutrient, and pesticide loadings to the main channel in each sub-basin, and the in-stream or routing phase, which is the movement of water, sediments, etc., through the channel network of the watershed to the outlet. Below is a brief description of the processes simulated by SWAT. The land phase of the hydrologic cycle is modeled in SWAT based on the water balance equation:

$$SWt = SWo + \sum_{i=1}^{n} (Rday - Q_{surf} - Ea - Wseep - Q_{gw}) \quad \text{.................................... (4)}$$

Where; SWt is the final soil water content (in mm), SW_0 is the initial soil water content (mm), t is the time (days), Rday is the amount of precipitation on day i (mm), Qsurf is the amount of surface runoff on day i (mm), Ea is the amount of evapotranspiration on day i (mm), Wseep is the amount of percolation and bypass flow exiting the soil profile bottom on day i (mm), and Q_{gw} is the amount of return flow on day i (mm). Many studies like (Shimelies and Makonnen, 2013; Githui, 2008; Ndulue *et al*, 2014; Palamuleni and Annegarn, 2011) have applied SWAT model to simulate of the impacts of land use/cover changes on hydrological ecosystem. All of mentioned studies shown successfully results.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Materials

3.1.1 Description of Study Area

Little Ruaha River Catchment (Fig. 1) is a tributary of the Great Ruaha River (GRR) that joins GRR just after the Ruaha National Park (Kashaigili *et al.*, 2003). Geographically, it is located in the Southern Highlands of Tanzania, within the Iringa Region and it lies between latitudes 7.2° to 8.6° south of equator and longitudes 34.9° to 35.9° East. The catchment has an estimated area of 6370 km^2, and serves many uses, including irrigation, livestock, and domestic uses, fisheries and the aquatic flora and fauna (Milder *et al.*, 2012).

The Little Ruaha River Catchment is found within Ihemi Cluster, one of the six clusters forming the Southern Agricultural Growth Corridor of Tanzania (SAGCOT) which covers a larger part of Iringa and Njombe regions. A cluster has an approximate population around 501, 204 with growth rate of 1.5% (Mwinuka *et al., 2015).*

The region's climate is unique in its heterogeneity, varying between the bimodal and unimodal rainfall patterns in southern highlands and northern lowland respectively, with annual rainfall range from 600 mm in low land to 1,600 mm in the highlands which in turn results in diverse land uses (Milder *et al.*, 2013). The mean annual temperature varies from about 18°C at higher altitudes to about 28°C. The elevation ranges from 698 m to above 2300m above mean sea level. Dominant soils in the area include Cambisols, Fluvisols, Leptosols, Lixisols, Nitisols and Solonetz.

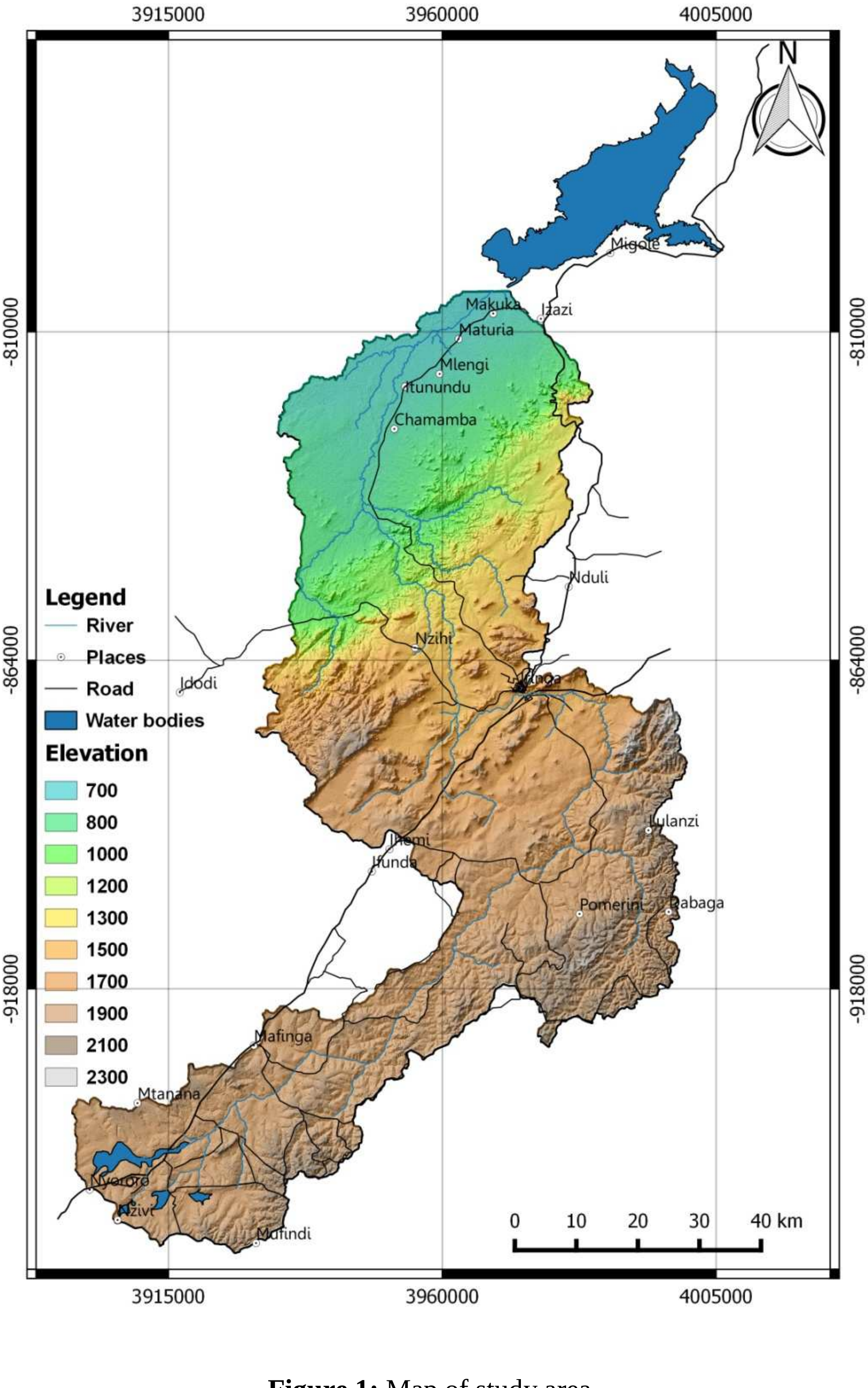


Figure 1: Map of study area

3.2 Methods

3.2.1 Data Collection, Tools and Techniques

Data collected included spatial data, Hydrological data and Meteorological data.

(i) Spatial data

Includes satellite images and 30 m resolution digital elevation model (DEM) downloaded from USGS – GLOVIS (www.glovis.usgs.gov) and NASA reverb (https://reverb.echo.nasa.gov) respectively.

(ii) Meteorological data

Meteorological data comprised rainfall, relative humidity, solar radiation, wind speed and minimum and maximum temperature data, were obtained from Tanzania Meteorological Agency and Rufiji Basin Water Office, Iringa.

Table 1: Summary of Meteorological data for Little Ruaha River Catchment

Station id	Name	Latitude	Longitude	Elevation (m)
9735011	Iringa Met	-7.78	35.69	1656
9735011	Mtera met	-7.08	35.91	683
9734001	Msembe	-7.73	35.94	793

(iii) Hydrological data

The data included water discharge, recorded from two different flow gauging stations, one located at the upper part of the catchment (Makalala) and other at the lower part of the catchment (Mawande). Data were available at Rufiji Basin Water Office in Iringa.

Table 2: Stream flow gauging stations in LRRC used in this study

Std ID	Stn Name	Geographical location		Year of record		No. Years	No. Missing data	Missing (%)
		Lat	Long	Start	End			
IKA32A	Makalala	-8.33	35.33	1957	2014	58	1957	9.24
IKA31	Mawande	-7.5	35.5	1957	2015	59	4491	20.8

3.2.2 Data analysis

To analyse spatial and temporal changes in land use and land cover in Little Ruaha River Catchment for period 1990's – 2015.

3.2.2.1 Cover change detection analysis

The land cover change detection analysis was conducted based on the following steps:

i. Satellite Image selection and acquisition

Appropriate satellite imagery acquisition was done with highly consideration of cloud cover, the seasonality and phenological effects (Kashaigili, 2006). Clouds free satellite images with the interval not less than five years from 1990 to 2015 (Table 1) were used in assessing temporal and spatial variation of land use/cover change in the study area.

Table 3: Satellite Imagery Data

Satellite	Sensor	Path/Row	Acquisition date	Season	Cloud cover (%)
Landsat 5	TM	168/65	11 July, 1990	Dry	0
Landsat 5	TM	168/66	11 July, 1990	Dry	0
Landsat 5	TM	168/65	20 July, 2005	Dry	6
Landsat 5	TM	168/66	7 July, 2005	Dry	6
Landsat 8	OLI-TIRS	168/65	4 October, 2015	Dry	9.78
Landsat 8	OLI-TIRS	168/66	21 October, 2015	Dry	0.03

i. Image Pre-processing

To ensure accurate identification of temporal changes and geometric compatibility with other sources of information, images were pre-processed whereby geo-correction was conducted to rectify precisely matching of images. Band stacking and Images enhancement was performed using different color composite band combination and its contrast was stretched from minimum to maximum to reinforce the visual interpretability of images. Images were registered to the UTM map coordinate system, Zone 36 South, Datum Arc 1960. Image Mosaic (Fig. 2) was conducted to merge together images of the same year with same path and different row so as to create a single image that covers the entire catchment.

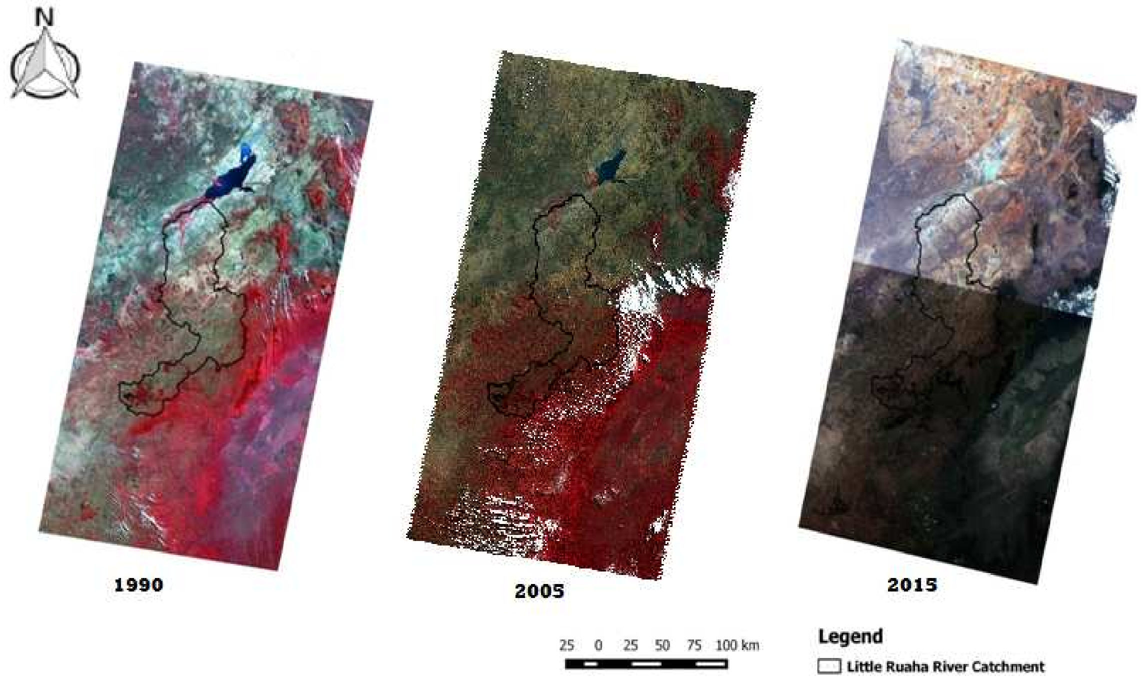


Figure 2: Mosaic images of study area for the year 1990, 2005 and 2015

ii. Preliminary image classification and ground truthing

Supervised image classification using Maximum Likelihood Classifier (MLC) was conducted to create base map. Data from ground truth were used to formulate and confirm different cover classes existing in the study area. Training sites were identified by inspecting an enhanced color composite imagery. Areas with similar spectral characteristics were trained and classified.

Supervised classification by using Semi-automatic Classification Plugin (SCP) available in QGIS 2.12.1 was conducted. The process involved selection of regions of interest (ROI) on the image, which represent specific land classes to be mapped. During

Supervised Classification, maximum of twelve distinct land cover classes were identified (Table 4) which are; Natural forest (NF), Plantation (PL), Riverine forest (RF), Water (WTR), Wetland (WET), Woodland (WD), Wooded rock (WR), Cultivated woodland (CW), Grassland (GR), Bushland (BS), Cultivated land (CLT) and Built up area (BLT).

iii. Final Image Classification and Accuracy Assessment

Kappa coefficient statistics was used to assess the accuracy of final image classification

$$K = \frac{N \sum_{i=1}^{r} x_{ii} - \sum_{i=1}^{r} (x_{i+} \times x_{+i})}{N^2 - \sum_{i=1}^{r} (x_{i+} \times x_{+i})} \quad (5)$$

Where N is the total number of sites in the matrix, r is the number of rows in the matrix, xii is the number in row i and column i, x_{+i} is the total for row i, and x_{i+} is the total for column.

The classified maps show good agreement with the real world as indicated by overall classification accuracies of 99.7%, 99.8%, and 99.5% respectively, for 1990, 2005 and 2015 with their corresponding Kappa statistics of 0.99, 0.98 and 0.99 respectively. Producer accuracies and user accuracies for each land use class presented in Appendix 1.

Table 4: Land use/cover classification scheme

Land cover class	**Description**
Natural forest	Land covered with naturally regenerated native tree species with no clearly visible indications of human activities
Plantation	Artificially established forested area/cultivated land by planting or seeding (Plantation forest, tree farms, woodlots and Tea plantation)
Riverine forest	Forested area adjacent flowing bodies of water such as river, streams and dams
Water	Area within body of land, of variable size, filled with water, localized in a basin, which rivers flow into or out of them (Lake/Dam)
Wetland	Land area that is saturated with water either permanent or seasonally
Woodland	Area of land covered low density trees forming open habitat with plenty of sunlight and limited shade
Wooded rock	Area of land covered with low density trees in a visible exposed mineral rocks
Cultivated woodland	Area of land covered with low density and scattered trees with crop cultivation activities
Grassland	Land area dominated by grasses
Bushland	Area dominated with bushes and shrubs
Cultivated land	Farm with crops and harvested cropland
Built up area	Man-made infrastructure (roads and buildings) and settlement
Unclassified	Area with no input data or insufficient information which has been missed due to several reasons including clouds, clouds shadow, darkness, and sensor dysfunctioning

iv. Land use and Land covers Change Detection

Post classification comparison was used to quantify the extent of land cover changes over the period 1990 and 2015. Post classification comparison bypass 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). The estimation of the rate of change for the different land covers was computed based on the following formulas (Kashaigili and Majaliwa, 2013).

$$\%\ Cover\ change = \frac{Area_{i\ year\ x} - Area_{i\ year\ x+1}}{\sum_{i=1}^{n} Area_{i\ year\ x}} \times 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

$$Annual\ rate\ of\ change = \frac{Area_{i\ year\ x} - Area_{i\ year\ x+1}}{t_{years}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

$$\%\ Annual\ rate\ of\ change = \frac{Area_{i\ year\ x} - Area_{i\ year\ x+1}}{Area_{i\ year\ x} \times t_{years}} \times 100 \ldots\ldots\ldots\ldots\ldots (8)$$

$Area_{i\ year\ x}$ is the area of cover i at the first date,

$Area_{i\ year\ x+1}$ is the area of cover i at the second date,

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

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

Objective ii: To assess the impact of land use and land cover change on water and sediment yields in the Little Ruaha River catchment for the period 1990's – 2015

The study used Soil and Water Assessment Tool (SWAT) model to simulate the effects of land use and land cover change on water and sediments yields. SWAT model was chosen because unlike other models e.g. Conversion of Land use and its Effects (CLUE) and Soil Water Atmosphere Plant (SWAP), the model can delineate large catchment area and has a weather generator engine system which can simulate or fill in the missing data which is the case for many catchments in developing countries including Little Ruaha River Catchment.

3.2.2.2 SWAT Model set-up and simulation

The calibrated SWAT model was run with the input data including digital elevation model (DEM), soil map, land use map, rainfall, and stream flow. The following steps were conducted during SWAT model set up;

i. Watershed delineation

First step was watershed delineation which split the catchment into sub-basins according to the terrain model and river channels. The DEM was used to delineate the topographic characterisation of the watershed and to determine the hydrological parameters of the watershed namely the slope, flow accumulation, flow direction, and stream network. QSWAT 2012, a QGIS interface, was used to delineate the watershed. The watershed was subdivided into 31 sub-watersheds or sub basins.

ii. HRUs creation

HRUs were generated based on user-defined threshold percentages (Arnold *et al.*, 1998). Before defining the HRUs, the Land use data were reclassified to match with the SWAT land use classification (Table 5). Land use and soil data were required in SWAT model to determine the area and the hydrologic parameters of each land-soil categories simulated within each sub watershed (Fig. 4). Therefore, land use, slope and soil maps were overlaid. The study uses landuse, soil and slope filter to create the Hydrologic Response Unit (HRU) for each sub basin. Watershed was divided into 631 HRUs.

Table 5: SWAT Land use/cover reclassification scheme

Land use class	SWAT code
Natural forest	FRST
Plantation	FRSE
Riverine forest	WETF
Lake/Dam	WATR
Wetland	WETN
Woodland	FRSD
Wooded rock	SWRN
Cultivated woodland	AGRL
Grassland	PAST
Bushland	RNGB
Cultivated land	AGRC
Built up area	URML

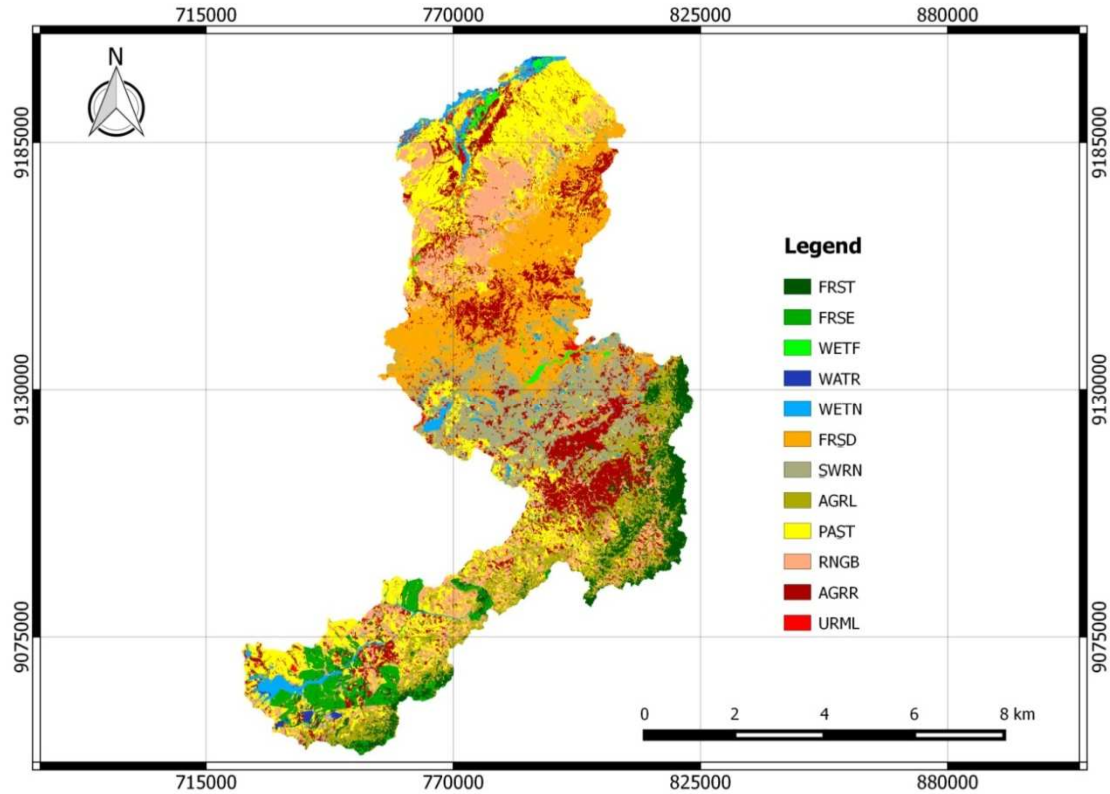


Figure 3: SWAT Land use

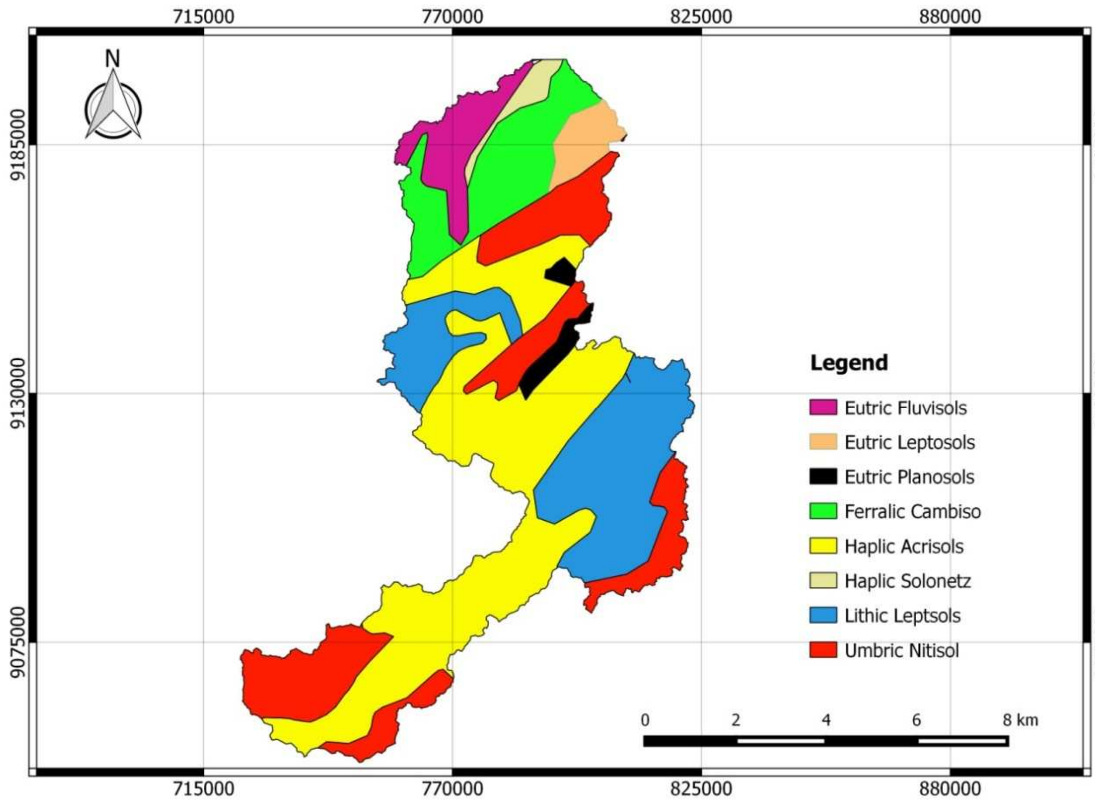


Figure 4: Little Ruaha River Catchment Soil Map

iii. Editing inputs and running SWAT

Input data (climatic data) were prepared, edited and saved into tab delimited format so that can be read in SWAT. SWAT Database was connected so as to link with SWAT reference database (QSWATRefmdb) and weather generator (WGEN_Iringa) was set up. Input data (Observed climatic data) which includes precipitation (pcp), temperature (tmp), relative humidity (rh), solar radiation and wind speed were loaded in the model and written under the Write SWAT Input Tables interface of the SWAT Model. Tables for observed weather data were created and after completing creating table, the model parameters were updated and the SWAT model was run.

3.2.2.3 SWAT model calibration and validation

SWAT input parameters are process based and must be held within a realistic uncertainty range. Model Calibration is to adjust a set of parameters so that the model agreement is maximized with respect to a set of experimental data. It is the process of turning model parameters based on checking results against observations to ensure the same response over time (Zeray *et al*., 2007). Validation is the process of determining the degree to which a model is an accurate representation of the real world from the perspective of the intended uses of the model (Trucano *et al.*, 2006). Calibration and Validation process in SWAT model involves three steps which are Sensitivity and Uncertainty Analysis, Model Calibration and Model Validation.

i. Sensitivity and Uncertainty Analysis

To understand how closely the model simulates the hydrological processes within a watershed, it is critical to examine the influence of different parameters. Sensitivity analysis is the computation of the most sensitive parameters for a given watershed. In this study a sensitivity analysis using the Sequential Uncertainty Fitting (SUFI-2) within the SWAT-CUP model (Abbaspour *et al.*, 2007) was used. The advantage of using SWAT-CUP relies on the possibility of using different kinds of parameters including those responsible for surface runoff, water quality parameters, crop, parameters, crop rotation and management parameters, and weather generator parameters (Arnold *et al.*, 2012).In total 10 parameters (Table 6) were found to be most sensitive for flow prediction in the model. It was found that the curve number (CN2) was the most sensitive parameter followed by the base flow alpha factor (ALPHA-BF), groundwater delay time (GW_DELAY), threshold water depth in the shallow aquifer (GWQMN), and groundwater “revap” coefficient (GW-REVAP).

Table 6: Most Sensitive Parameters and their fitted values

Rank	Parameter Code	Parameter definition	Fitted Value
1	CN2.mgt	Initial SCS CN II value	-0.641
2	ALPHA_BF.gw	Baseflow alpha factor	0.637
3	GW_DELAY.gw	Ground water delay	695.880
4	GWQMN.gw	Threshold water depth in the shallow aquifer	6.0758
5	GW_REVAP	Ground water “revap” coefficient	0.36
6	ESCO.hru	Soil evaporation compensation factor	0.8353
7	CH_N2.rte	Manning’s ‘n’ value for the main channel	0.046
8	CH_K2.rte	Channel effective hydraulic conductivity	69.770
9	ALPHA_BNK.rte	Baseflow alpha factor for bank storage	0.5199
10	SOL_AWC.sol	Available water capacity of soil layer	0.007

ii. Model Calibration and Validation

Calibration is an effort to better parameterize a model to a given set of local conditions, thereby reducing the prediction uncertainty. Model calibration is performed by carefully selecting values for model input parameters (within their respective uncertainty ranges) by comparing model predictions (output) for a given set of assumed conditions with observed data for the same conditions.

In this study calibration was conducted for daily and monthly simulations to improve model performance by using data from outlets of two sub-basins which are located in the upstream and downstream areas of the catchment. Calibration was done for 10 years from 1989 to 1998, 10 years prior to 1989 were used for warm up period which was intended to allow the model parameters to reach a steady state condition. Validation period was set for 7 years period from 1999 to 2005. The calibration and validation processes were carried out using the Sequential Uncertainty Fitting (SUFI-2).

3.2.2.4 Simulation analysis

The calibrated model was then used to simulate stream flows under changed land-use/cover condition for the year 1990/2015, while maintaining the same weather data. The influences of the land use land cover change on water resource were quantified by comparing SWAT outputs (Observed and Simulated) for the time period 1990/2015. The differences between observed and simulated discharge under changed land use land cover were represented the effects of land use and land cover changes on water resource in the catchment.

The SWAT model using the Modified Universal Soil Loss Equation (MUSLE) developed by Williams (1975) (Appendix 2) was used to simulate the sediment yield from the catchments (Neitsch *et al*., 2005). The simulated sediment yield results for the time period

1990 and 2015 were compared, the difference was deduced to reveal the impact of LULC change on sediment yields in Little Ruaha River Catchment.

Objective iii: To predict the future changes in land use/cover, water and sediment yields in Little Ruaha River Catchment

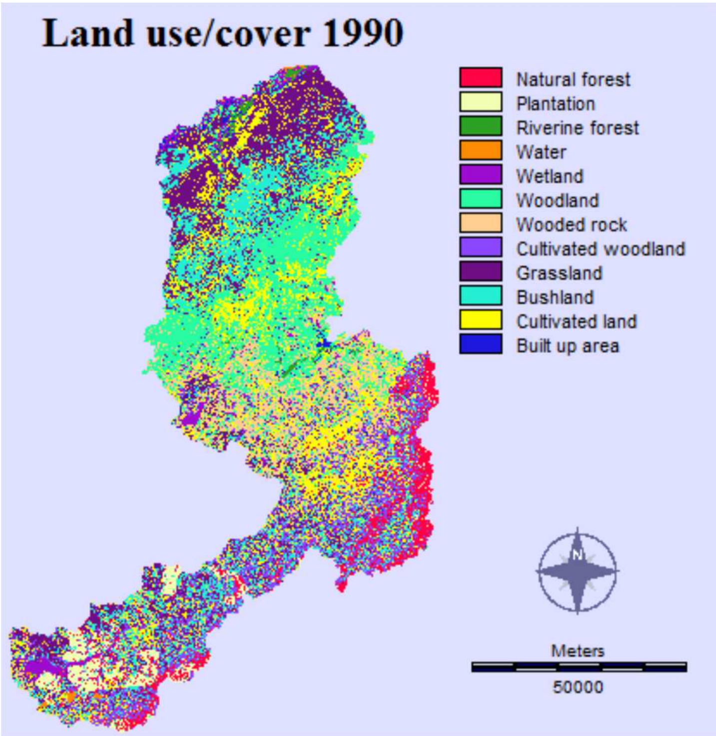
The present study utilized Markov Chain Analysis and Cellular Automata Analysis, jointly called CA–Markov, to predict and simulate the future change of land use and land cover in the Little Ruaha River Catchment. Future changes in water and sediment yields was assessed using a calibrated and validated SWAT model, by using a projected land use/cover map of the year 2040 while maintaining the same weather data.

3.2.2.5 CA – Markov chain analysis

Markov chain is a statistical tool that describes the probability of land use to change from one-time period to another by developing a transitional probability matrix between first period and second period based on the neighborhood effects (Al-Bakri *et al.,* 2013; Wang *et al.,* 2014; Araya and Kabral, 2010). This model was based on using and evaluating land use layers of previous years to predict the spatial distribution of land uses in the future (Wu *et al,* 2010). For the better simulation for temporal and spatial patterns of land use changes in quantity and space, the combination of Cellular automata and Markov chain (CA-Markov) were developed.

The simulated model was developed by using IDRISI Selva 17.0 software and it involved two main stages which are calculating conversion probability (conversion probability matrix, conversion area matrix and layers of conditional probability) done by using Markov chain analysis, and the second stage was spatial specification of land use coverage simulated based on CA spatial operator and multi criteria evaluation (MCE).

In the developing CA Markov model, the classified land use map of 1990 which represent past, and 2015 which represent present time were converted into IDRISI data format (Figure 6) and selected to be input data into the model, to calculate matrices of conversion probabilities and conversion areas (Transition area matrix and transition probability matrix).



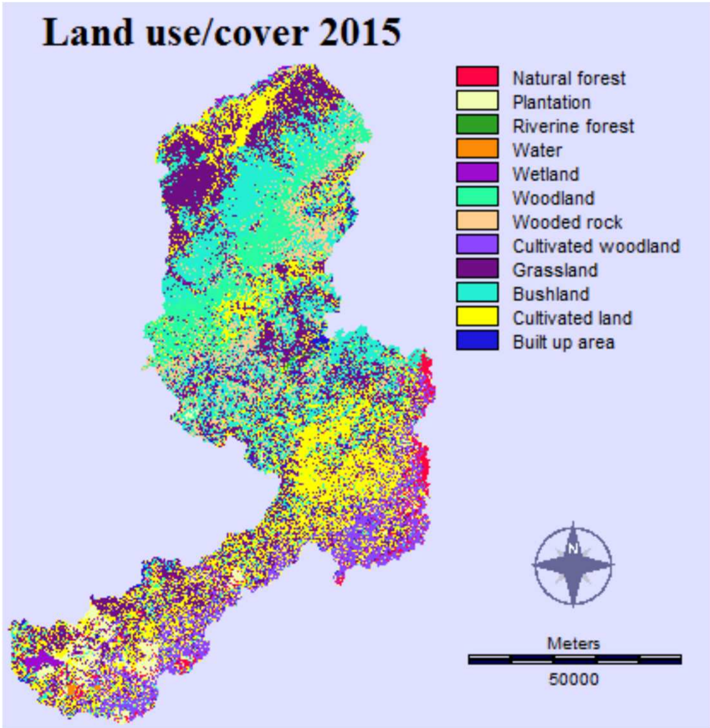


Figure 5: Land use/cover maps used in developing CA Markov model

The transition probability matrix (Table 7) expresses the likelihood (probability) that a pixel of a given class that will change to any other class (or stay the same) in the next time period

Table 7: Transitional probability matrix for land use/cover change 1990/2015

Given	Probability of a cell to change (transition) to;											
	NF	PL	RF	WTR	WET	WD	WR	CW	GR	BS	CLT	BLT
NF	0.1718	0.1248	0.0001	0.0001	0	0.0169	0.0031	0.4205	0.0703	0.0301	0.1571	0.0051
PL	0.1113	0.3571	0.0001	0.0001	0	0.0057	0.001	0.1464	0.1619	0.0251	0.1825	0.009
RF	0.0147	0.0046	0.0704	0.0008	0.0311	0.0858	0.0796	0.0153	0.2	0.1274	0.3372	0.0332
WTR	0.0017	0.0054	0.0006	0.292	0.2311	0.0332	0.0388	0.0001	0.0906	0.2089	0.0758	0.0216
WET	0.0134	0.0852	0.0006	0.002	0.1421	0.0786	0.0917	0.0458	0.1622	0.2277	0.1417	0.0093
WD	0.005	0.0039	0.0048	0.0001	0.0052	0.232	0.1841	0.0065	0.1879	0.2305	0.1116	0.0286
WR	0.0087	0.0072	0.0006	0	0.0003	0.0444	0.1381	0.032	0.2147	0.3533	0.1626	0.0381
CW	0.0345	0.0435	0	0	0.0001	0.0289	0.0166	0.2501	0.1603	0.1073	0.3354	0.0234
GR	0.007	0.0216	0	0	0.0061	0.0555	0.0388	0.0408	0.3625	0.1908	0.255	0.0217
BS	0.0117	0.0306	0	0	0.0008	0.1143	0.0373	0.0905	0.2273	0.2597	0.2189	0.0089
CLT	0.0086	0.012	0.0002	0	0.0033	0.0571	0.0418	0.0419	0.2712	0.2064	0.3344	0.0231
BLT	0.0051	0.005	0.0015	0	0.0285	0.0897	0.0357	0.0205	0.2543	0.1329	0.3151	0.1116

NF: Natural forest, **PL**: Plantation, **RF**: Riverine forest, **WTR**: Water, **WET**: Wetland, **WD**: Woodland, **GR**: Grassland, **WR**: Wooded rock, **CW**: Cultivated woodland, **BS:** Bushland **CLT**: Cultivated land **BLT**: Built up

The transition areas matrix (Table 8) expresses the total area (in cells) expected to change from the year 2015 to the year of 2040 according to those changes happened from 1990 to 2015.

Table 8: Transitional area matrix for land use/cover change between 1990/2015

Cell	Area in cells expected to change:											
in	NF	PL	RF	WTR	WET	WD	WR	CW	GR	BS	CLT	BLT
NF	30442	22126	12	26	3	2999	545	74534	12465	5337	27846	907
PL	30033	96362	21	26	4	1526	265	39509	43679	6769	49248	2426
RF	177	55	847	10	374	1033	958	184	2407	1534	4058	399
WTR	13	40	4	2132	1687	243	283	1	662	1526	554	158
WET	835	5323	35	122	8879	4911	5727	2858	10131	14225	8850	578
WD	3259	2531	3141	36	3406	150938	119760	4206	122233	149969	72599	18598
WR	4209	3489	312	1	123	21613	67174	15584	104434	171807	79069	18544
CW	21183	26753	27	6	49	17764	10174	153702	98476	65929	206090	14360
GR	11629	35770	49	0	10054	91847	64129	67501	599338	315549	421688	35914
BS	16350	42719	18	2	1094	159713	52099	126528	317696	362890	305895	12483
CLT	13756	19074	363	6	5293	90991	66651	66827	432309	329053	533105	36848
BLT	780	766	224	0	4366	13728	5463	3132	38892	20333	48204	17077

NF: Natural forest, **PL**: Plantation, **RF**: Riverine forest, **WTR**: Water, **WET**: Wetland, **WD**: Woodland, **GR**: Grassland, **WR**: Wooded rock, **CW**: Cultivated woodland, **BS:** Bushland **CLT**: Cultivated land **BLT**: Built up

In the final step of predicting and simulation the future change of land use and land cover, the land use map of 2015 was used as a base map, together with conditional probabilities data and matrix conversion probabilities were integrated using the CA spatial operator based on Markov chain analysis and MCE.

3.2.2.6. CA – Markov model validation

For model validation the simulated land use/cover map for 2015 was compared with the actual satellite derived land use/cover map based on the Kappa statistics. Then, standard Kappa index was used to check whether the model is valid or not (usually the Kappa Index for a valid model is >70%) (Wen, 2008). If the model has the Kappa Index less than 70% then the suitability map for the land covers and filter used should be repeated based on several considerations. Using VALADATE tool, IDRISI gave the standard Kappa of 0.83, Kappa for no information of 0.89, Kappa for grid-cell level location of 0.86 and Kappa for stratum-level location of 0.864 which are all more than 0.7.

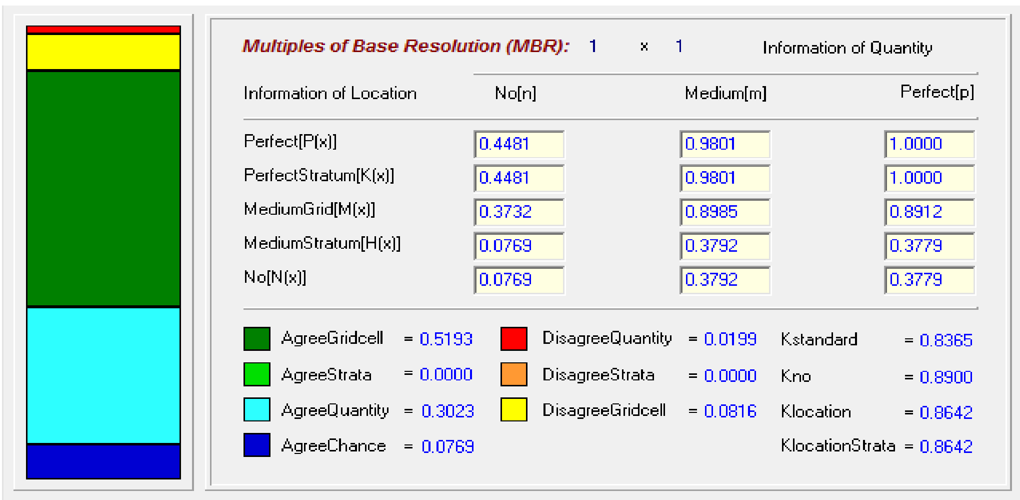


Figure 6: The spatio-statistical output generated in validation process

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Spatial and temporal changes in land use and land cover in Little Ruaha River Catchment for period 1990's – 2015

4.1.1 Land use and land cover assessment

The land use land cover maps for the year 1990, 2005 and 2015 are presented in Fig. 7, 8 and 9. Generally, the maps show variations in cover coverage between the two window periods under consideration. Table 9 represents the spatial distribution of land use/cover coverage for the period between 1990 and 2015.

Table 9: Land use/cover area distribution between 1990 and 2015

YEAR	1990		2005		2015	
	Ha	(%)	Ha	(%)	Ha	(%)
Natural forest	39 872	6.26	22 957	3.60	15 950	2.75
Plantation	20 632	3.24	34 068	5.35	24 285	1.81
Riverine forest	5 878	0.92	2 746	0.43	1 083	0.18
Water	1 752	0.28	1 202	0.19	657	0.10
Wetland	19 157	3.01	11 785	1.85	5 622	0.37
Woodland	109 692	17.22	72 809	11.43	58 554	9.48
Wooded rock	60 288	9.46	75 121	11.79	43 767	6.87
Cultivated woodland	57 368	9.01	54 517	8.56	55 300	10.37
Grassland	118 784	18.65	129 797	20.38	148 795	23.82
Bushland	87 394	13.72	111 277	17.47	125 759	20.65
Cultivated land	106 782	16.76	109 047	17.12	143 468	21.17
Built up area	9 408	1.48	11 674	1.83	13 765	2.43
Total	**637 007**	**100**	**637 009**	100	**637 005**	**100**

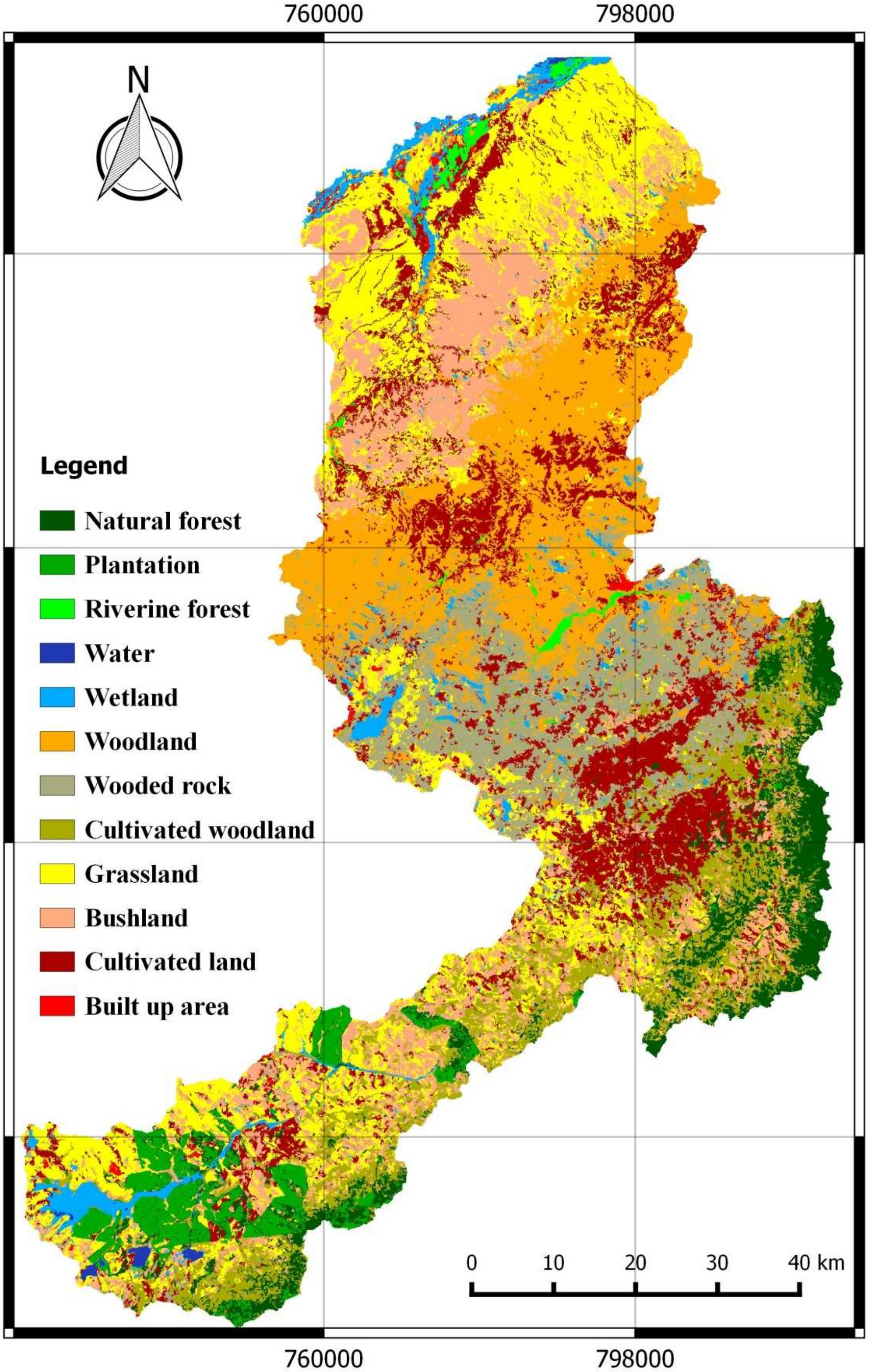


Figure 7: Land use/cover map for Little Ruaha River Catchment 1990

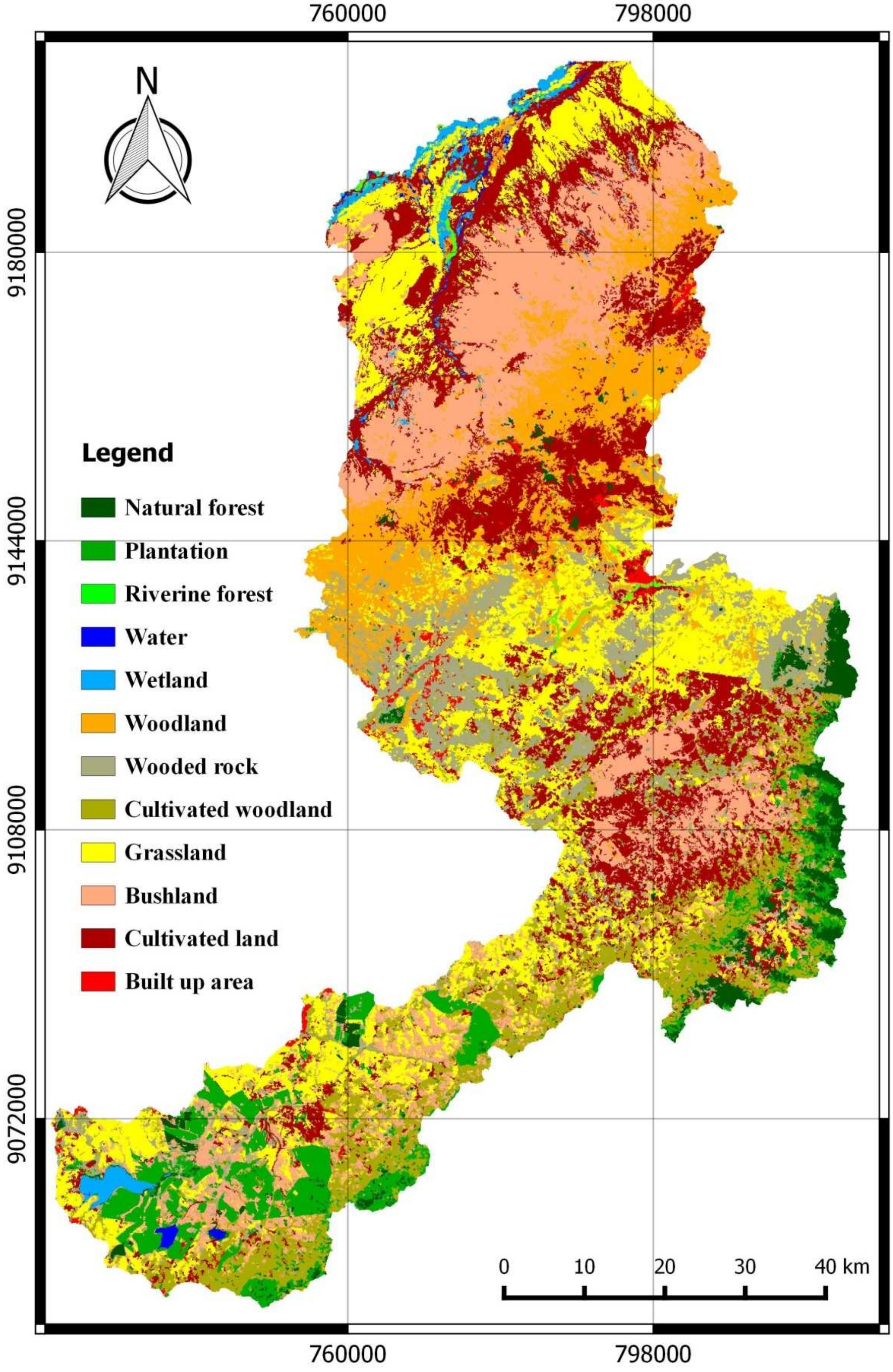


Figure 8: Land use/cover map for Little Ruaha River Catchment 2005

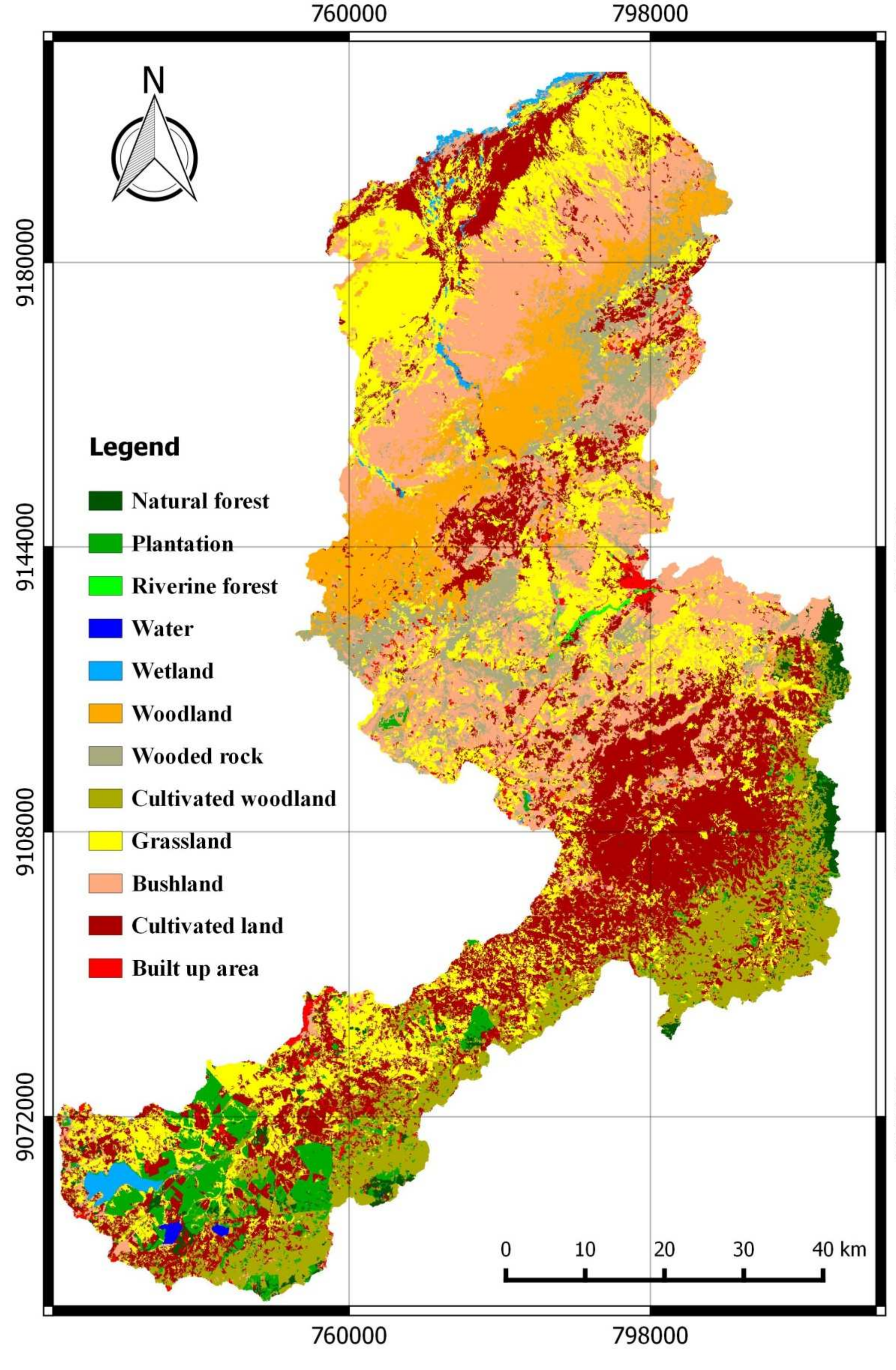


Figure 9: Land use/cover map for Little Ruaha River Catchment 2015

4.1.2 Land use/cover changes between 1990 and 2015

The extent of land use land cover change including area, percentage area change and percentage annual rate of change are summarised on Table 10. The increased and decreased amount is represented by positive signs (+) and (-) respectively.

Table 10: Land use/cover change between 1990 and 2005 and between 2005 and 2015

LULC	1990		2005		2015		1990-2005				2005-2015			
	Ha	%	Ha	%	Ha	%	Area change (Ha)	Change (%)	Annual Rate of Change (Ha/year)	%Annual Rate of change (%/year)	Area change (Ha)	Change (%)	Annual Rate of Change (Ha/year)	%Annual Rate of change (%/year)
NF	39872	6.26	22957	3.6	15950	2.50	-16915	-2.66	-1127.67	-2.83	-7007	-1.10	-700.70	-3.05
PL	20632	3.24	34068	5.35	24285	3.81	13436	2.11	895.73	4.34	-9783	-1.54	-978.30	-2.87
RF	5878	0.92	2746	0.43	1083	0.17	-3132	-0.49	-208.80	-3.55	-1663	-0.26	-166.30	-6.06
WTR	1752	0.28	1202	0.19	657	0.10	-550	-0.09	-36.67	-2.09	-545	-0.09	-54.50	-4.53
WET	19157	3.01	11785	1.85	5622	0.88	-7372	-1.16	-491.47	-2.57	-6163	-0.97	-616.30	-5.23
WD	109692	17.22	72809	11.43	58554	9.19	-36883	-5.79	-2458.87	-2.24	-14255	-2.24	-1425.50	-1.96
WR	60288	9.46	75121	11.79	43767	6.87	14833	2.33	988.87	1.64	-31354	-4.92	-3135.40	-4.17
CW	57368	9.01	54517	8.56	55300	8.68	-2851	-0.45	-190.07	-0.33	783	0.12	78.30	0.14
GR	118784	18.65	129797	20.38	148795	23.36	11013	1.73	734.20	0.62	18998	2.98	1899.80	1.46
BS	87394	13.72	111277	17.47	125759	19.74	23883	3.75	1592.20	1.82	14482	2.27	1448.20	1.30
CLT	106782	16.76	109047	17.12	143468	22.52	2265	0.36	151.00	0.14	34421	5.40	3442.10	3.16
BLT	9408	1.48	11674	1.83	13765	2.16	2266	0.36	151.07	1.61	2091	0.33	209.10	1.79
TOTAL	**637007**	**100**	**637000**	**100**	**637005**	**100**								

NF: Natural forest **PL:** Plantation **RF:** Riverine forest **WTR:** Water **WET:** Wetland WD**:** Woodland **WR:** Wooded rock

CW: Cultivated woodland GR**:** Grassland **BS:** Bushland **CLT:** Cultivated land **BLT:** Built up area

The results, indicate that for the period between 1990 and 2005 the area under natural forest which occupied 39872 ha (6.26%), decreased to 22957 ha (3.6%), indicating the decrease of about -2.66%. Likewise, riverine forest and woodland decreased from 5878 ha (0.92%) and 109692 ha (17.22%) to 2746 ha (0.43%) and 72809 ha (11.43%) respectively, a decrease of -0.49% and -5.79% for riverine forest and woodland respectively. Water and wetland decline from 1752 ha (0.28%) and 19157 ha (3.01%) to 1202 ha (0.19%) and 11785 ha (1.85%) indicating the loss of -0.09% for water and -1.16% for wetland. At the same time, cultivated land and built up area showed an increase from 106782 ha (16.76%) to 109047 ha (17.12%) and from 9408 ha (1.48%) to 11674 ha (1.83%) respectively, indicating the gain of about +0.36% and +0.36% respectively.

For the period between 2005 and 2015, the natural forest, riverine forest, woodland, water and wetland declined to 15950 ha (2.50%), 1083 ha (0.17%), 58554 ha (9.19%), 757 ha (0.1%) and 5622 ha (0.88%) respectively, indicating the percentage loss of -1.1%, -0.26%, -2.24%, 0.09%, and -0.97% respectively. For the same period of time, cultivated land and built up area increased to 143468 ha (22.52%) and 13765 ha (2.16%) respectively, a gain of +5.4% for cultivated land and +0.33% for built up area.

Natural forest decreased at a rate of -1127.67 ha/year (-2.83%/year) over a period of 15 year (1990 - 2005), and -700.70ha/year (-3.05%/year) over a period of 10 years (2005-2015), likewise, riverine forest, woodland showed a similar trend of decline. This rapid decrease in forest cover might be due human encroachments for timber, firewood and medicine, noticeable felling of trees for expansion of agricultural farms. This has also been emphasized by local people during baseline survey, where by respondent reported fire burning and cutting tree has been serious problem in recent years.

Water decreased at a rate of -36.67 ha/year (-2.09%/year) over a period of 15 year (1990 - 2005), and -54.50 ha/year (-4.53%/year) over a period of 10 years (2005-2015), likewise wetland decreased at a rate of -491.47 ha/year (-2.57%/year) and -616.30 ha/year (-5.23%/year) for the same period of time. The linear decrease of water resource is due to destruction of riparian zones. Tanzania Government has been restricting agricultural activities that are carried along rivers, in catchments and in all valley bottoms, but still many areas of this type are used for agricultural activities. Bottom valley cultivation (Vinyungu) is the most dominating traditional irrigation farming observed during field survey. Vinyungu, type of farming practiced in dry season play a great role in converting wetland into cultivated land which in turn threaten the sustainability of wetlands to supply vital ecosystem services especially water discharge. During survey more than 90% of farmers practice vinyungu cultivation in dry season. Other factors for the observed decrease of water resource are drying up of water bodies due to decrease in rainfall and increase in competitors' user.

The cultivated land and built up area increased at a rate of 151 ha/year (0.14%/year) and 151.07 ha/year (1.61%/years) over a period between 1990 and 2005, and increased at a rate of 3442ha/year (3.16%/year) and 2091 ha/year (2.09%/year) for cultivated land and built up area respectively for the period between 2005 and 2015. This rapid increase might be due to clear felling of trees mainly woodlands for firewood, and population increases (Figure 10) that leads to the expansion of farmlands and settlement to sustain the livelihood of local communities.

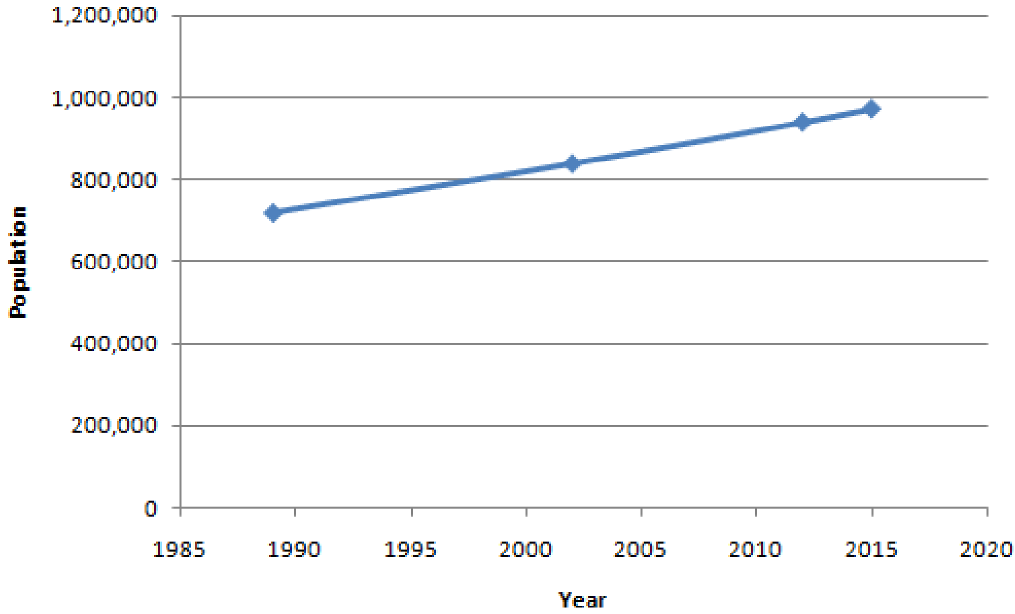


Figure 10: Population data for Iringa region (Source: TNBS)

4.1.3 Change detection of different land use/cover

The overall gain and loss of land use/cover between the period 1990 and 2015 are presented in Table 12 and illustrated in Figure 11. The net change of each land use/cover category is presented in Figure 12, and the change detection matrix for the different periods between 1990 and 2015 are presented in Table 11, 12 and 13 clearly reflecting on the land use transformation in the Little Ruaha River Catchment.

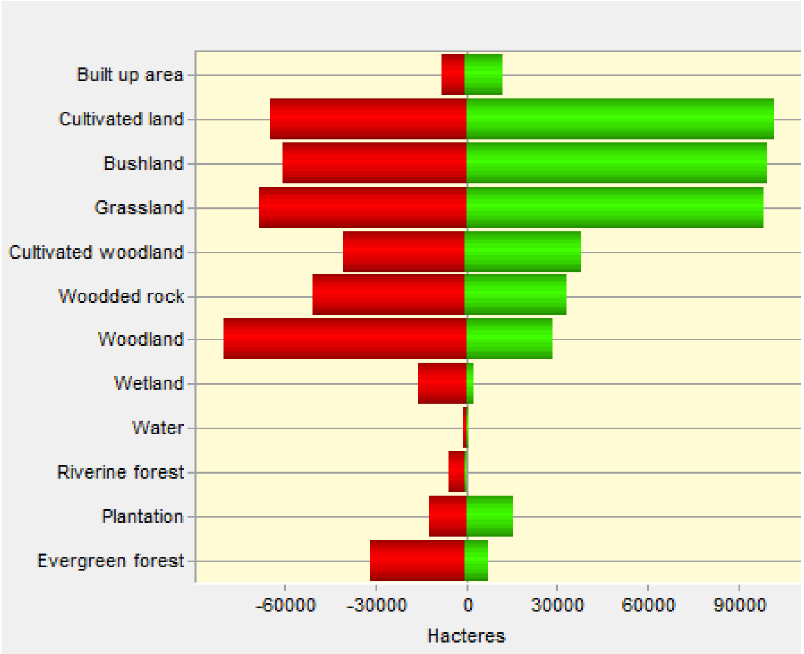


Figure 11: Gain and looses by each land use category between 1990 and 2015

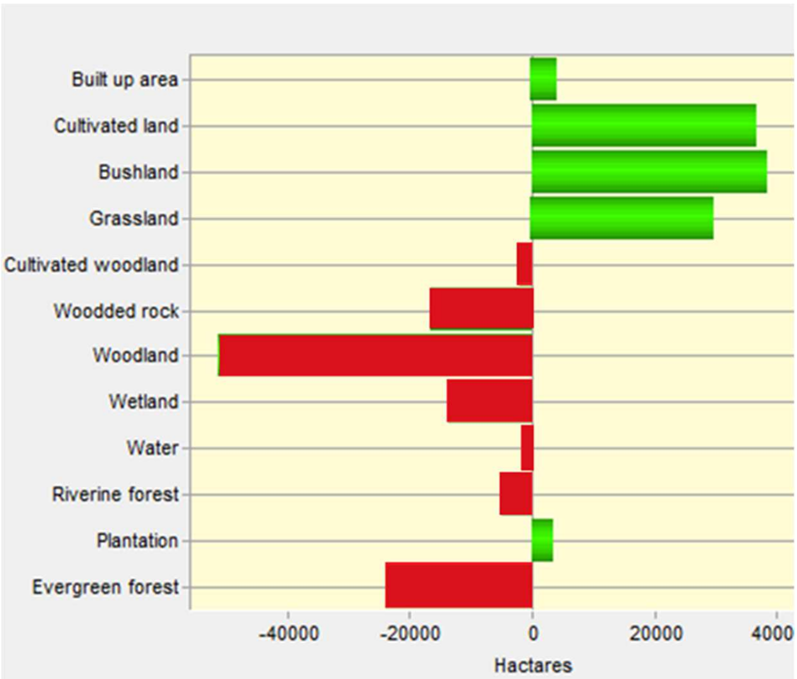


Figure 12: Net change of each land use category between 1990 and 2015

Table 11: Change detection matrix for the period of 1990 to 2005

Cover in 1990	Cover in 2005 (Ha)												
	NF	**PL**	**RF**	**WTR**	**WET**	**WD**	**WR**	**CW**	**GR**	**BS**	**CLT**	**BLT**	**TOTAL**
NF	(9238)	10 721	15	11	27	837	3 615	8 298	652	3 522	2 611	102	**39 648**
PL	2 333	(12020)	1	2	2	295	1 630	1 122	675	1 959	429	25	**20 494**
RF	517	111	(652)	21	658	1 371	419	177	623	35	1 044	190	**5 819**
WTR	88	50	135	(839)	245	49	44	1	40	3	100	17	**1 613**
WET	1 154	1 207	962	107	(4610)	1 882	5 084	818	460	1 149	955	133	**18 521**
WD	1 743	654	631	10	1560	(46048)	18 545	1 410	12 922	8 239	15 203	2 933	**109 398**
WR	519	391	27	0	10	4 752	(21414)	6 503	14 210	3 112	6 682	2 345	**59 966**
CW	3 043	3 484	7	1	9	1 067	8 440	(17282)	5 232	7 275	10 362	891	**57 092**
GR	847	1 953	47	28	1 045	7 105	6 351	6 359	(39609)	25 702	25 821	2 733	**117 600**
BS	1 458	1 841	5	2	1 147	3 503	6 593	7 278	12 270	(41197)	10 890	755	**86 937**
CLT	1 316	1 087	108	49	1 364	9 930	9 769	5 843	15 301	18 395	(40786)	2 346	**106 294**
BLT	306	36	195	25	1 223	1 273	681	258	1 238	857	1 880	(1212)	**9 183**
TOTAL	**22 563**	**33 553**	**2 786**	**1 095**	**11 898**	**78 113**	**82 584**	**55 350**	**103 230**	**111 447**	**116 263**	**13 681**	**637 065**

NF: Natural forest, **PL**: Plantation, **RF**: Riverine forest, **WTR**: Water, **WET**: Wetland, **WD**: Woodland, **GR**: Grassland, **WR**: Wooded rock, **CW**: Cultivated woodland, **BS:**Bushland **CLT**: Cultivated land **BLT**: Built up

Numbers in brackets indicate cover areas that remained unchanged between the two periods of 1990 and 2005.

Table 12: Change detection matrix for the period of 2005 to 2015

Cover in 2005	Cover in 2015 (Ha)												
	NF	**PL**	**RF**	**WTR**	**WET**	**WD**	**WR**	**CW**	**GR**	**BS**	**CLT**	**BLT**	**TOTAL**
NF	(4867)	2 105	72	14	373	970	439	6 344	2 425	1 415	3 587	353	**23 063**
PL	4 559	(10312)	14	14	50	390	265	8 043	2 970	1 103	5 524	308	**33 553**
RF	32	0	(362)	0	325	217	113	6	522	356	739	114	**2 786**
WTR	3	7	0	(615)	80	8	1	3	25	220	79	55	**1 095**
WET	7	62	2	8	(2855)	569	244	25	2 513	2 302	3 203	110	**11 898**
WD	398	296	433	1	142	(24969)	14 699	777	9 650	18 084	7 384	1 281	**78 113**
WR	1 532	2 508	118	5	120	6 639	(14356)	4 820	16 270	23 001	11 344	1 870	**82 584**
CW	1 851	2 717	1	0	2	1 636	1 286	(18830)	7 772	6 856	13 476	924	**55 350**
GR	560	1 439	40	0	303	1 982	3 218	2 850	(49946)	15 125	24 765	3 004	**103 230**
BS	1 053	3 356	1	0	62	15 262	6 828	7 758	17 436	(35204)	23 959	528	**111 447**
CLT	873	1 314	15	0	769	4 578	1 556	5 448	34 816	17 735	(46520)	2 138	**115 763**
BLT	41	35	19	0	105	951	573	241	3 364	3 241	2 350	(2762)	**13 681**
TOTAL	**15777**	**24150**	**1077**	**657**	**5186**	**58171**	**43578**	**55144**	**147707**	**124642**	**143029**	**13448**	**637065**

NF: Natural forest, **PL**: Plantation, **RF**: Riverine forest, **WTR**: Water, **WET**: Wetland, **WD**: Woodland, **GR**: Grassland, **WR**: Wooded rock, **CW**: Cultivated woodland, **BS:**Bushland **CLT**: Cultivated land **BLT**: Built up

Numbers in brackets indicate cover areas that remained unchanged between the two periods of 2005 and 2015.

Table 13: Change detection matrix for the period of 1990 to 2015

Cover in 1990 (Km²)	Cover in 2015 (Ha)												
	NF	**PL**	**RF**	**WTR**	**WET**	**WD**	**WR**	**CW**	**GR**	**BS**	**CLT**	**BLT**	**TOTAL**
NF	(8058)	4796	3	6	1	650	118	16155	2702	1157	6035	197	**39876**
PL	2071	(8668)	1	2	0	105	18	2725	3012	467	3396	167	**20634**
RF	85	27	(487)	5	180	498	461	88	1160	739	1956	192	**5878**
WTR	3	9	1	(602)	375	54	63	0	147	339	123	35	**1752**
WET	248	1585	11	36	(3204)	1462	1705	851	3016	4235	2635	172	**19160**
WD	520	404	501	6	544	(29939)	19116	671	19510	23937	11588	2969	**109705**
WR	507	420	38	0	15	2604	(9797)	1877	12581	20697	9525	2234	**60295**
CW	1861	2351	2	1	4	1561	894	(16883)	8653	5793	18109	1262	**57375**
GR	752	2312	3	0	650	5937	4145	4363	(50660)	20397	27257	2321	**118798**
BS	959	2506	1	0	64	9371	3057	7424	18640	(26702)	17948	732	**87404**
CLT	840	1164	22	0	323	5555	4069	4080	26391	20088	(42013)	2249	**106795**
BLT	47	46	14	0	263	826	329	188	2339	1223	2899	(1236)	**9409**
TOTAL	**15952**	**24288**	**1083**	**657**	**5623**	**58561**	**43772**	**55306**	**148812**	**125774**	**143485**	**13767**	**637080**

EF: Natural forest, **PL**: Plantation, **RF**: Riverine forest, **WTR**: Water, **WET**: Wetland, **WD**: Woodland, **GR**: Grassland, **WR**: Wooded rock, **CW**: Cultivated woodland, **BS:**Bushland **CLT**: Cultivated land **BLT**: Built up

Numbers in brackets indicate cover areas that remained unchanged between the two periods of 1990 and 2015.

4.1.3 The impacts of land use/cover change on water and sediment yields in the Little Ruaha River catchment for the period 1990's – 2015

4.1.3.1 SWAT Model Calibration and Validation results

Calibration was conducted in two sub-basins located in upstream and downstream, for Makalala station and Mawande station respectively. The calibration process was done by comparing the simulated stream flows with the measured stream flows for each gauging station. Comparison of the results between the measured and calibrated stream flows show a good agreement with NSE, PBIAS and RSR statistical values falling within the range of good to very good models (Table 14). Calibration hydrograph are presented in Figure 13 and Figure 14, both are at monthly time step. The simulated mean monthly streamflow in Little Ruaha at Makalala station was 17.92 m^3/s while the observed was 21.58 m^3/s. The difference was not significant for the downstream gauging station as well, where the observed monthly stream flow was 3.08 m^3/s compared to the simulated 2.93 m^3/s.

Table 14: Calibration and Validation Results for the streamflow model output

Stations	**Evaluation Statistics**					
	NSE		**PBIAS**		**RSR**	
	CB	**VD**	**CB**	**VD**	**CB**	**VD**
Makalala	0.8 (vg)	0.65 (g)	-1.5 (g)	-27.5 (g)	0.45 (vg)	0.59 (g)
Mawande	0.75 (vg)	0.65 (g)	6.4(vg)	-28.2 (s)	0.5 (vg)	0.59 (g)

CB: Calibration **VD:** Validation vg; very good v; good s; satisfactory

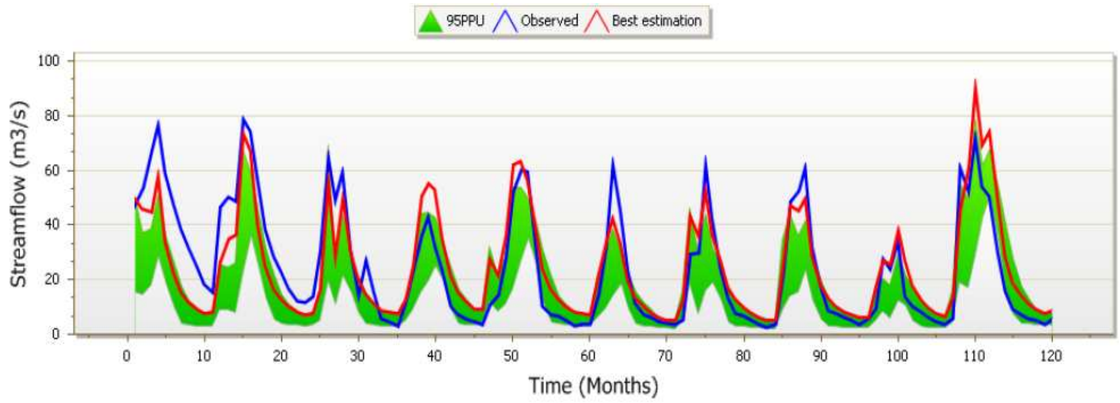


Figure 13: 95% Prediction Uncertainty calibration hydrograph at Mawande station

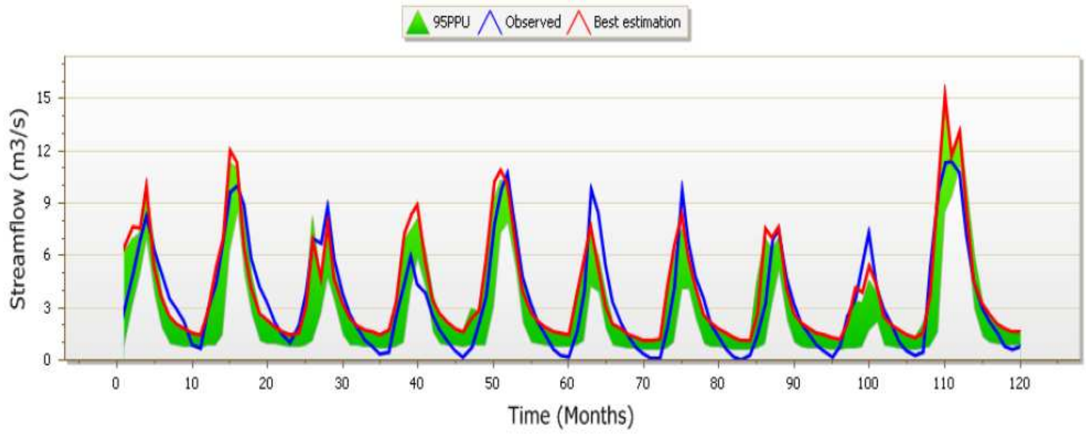


Figure 14: 95% Prediction Uncertainty calibration hydrograph at Makalala station

Graphical results for the validation period for the 7 years from 1999 to 2005 are shown in Figure 15 and Figure 16. Results further show that simulated mean daily stream flow was 17.52 m^3/s and observed mean daily flow was 23.06 m^3/s for Makalala gauging station and simulated mean daily stream flow of 2.89 m^3/s with observed mean daily stream flow of 3.21 m^3/s for Mawande gauging station.

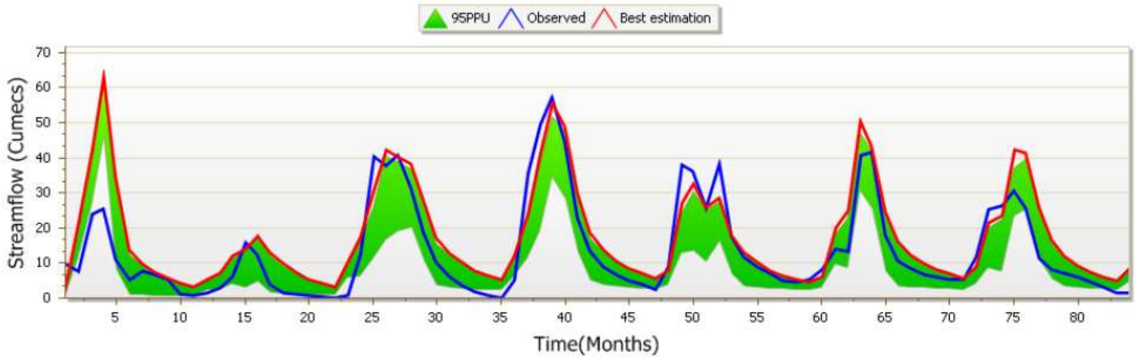


Figure 15: 95% Prediction Uncertainty validation hydrograph at Mawande station

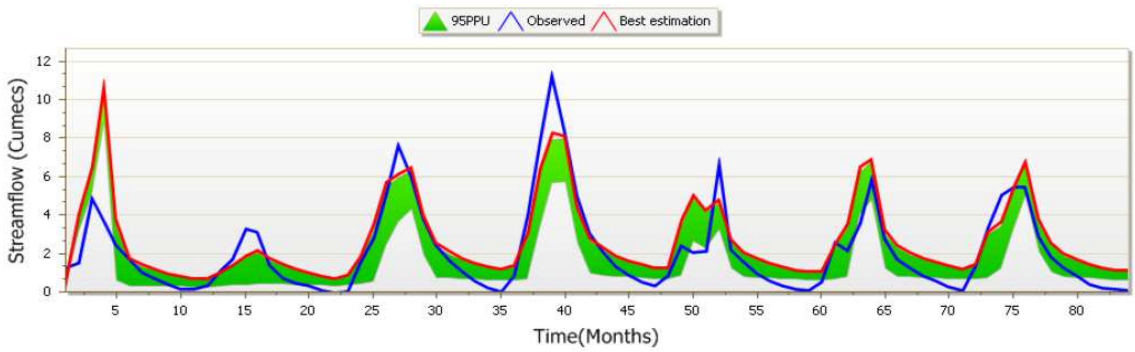


Figure 16: 95% Prediction Uncertainty validation hydrograph at Makalala station

4.1.3.2 Impacts of land use/cover change on water and sediment yields

Results (Table 15) indicate that land use and land cover change between 1990 and 2015 has contributed to the increase in annual surface runoff by 3.53mm and decrease in annual base flow by 2.86mm. Evapotranspiration and potential evapotranspiration decreased by 41.1mm and 232.1mm respectively. As explained by (Kashaigili 2008) that decrease in forest cover influence the increase in surface flow by decreasing opportunity of infiltration which in turn impact water yield and sediment yield. The annual water yield has increased from 134.35mm to 178.21mm and soil erosion increased by 1.2 ton/ha.

Table 15: Annual Hydrological summary for the watershed

Year	SURQ	ET	PET	GWQ	WATER YIELD (mm)	SEDIMENT YIELD (t/h)
1990	48.84	546.9	1814.9	8.94	134.35	2.214
2015	52.37	505.8	1582.8	6.08	178.21	3.420
Change	+3.53	-41.1	-232.1	-2.86	+43.86	+1.2

SURQ: Surface runoff contribution from stream flow from HRU (mm)
GWQ: Ground water contribution to stream in watershed on day, month, year (mm)
PET: Potential evapotransipiration in watershed (mm)
ET: Actual evapo-transpiration in watershed (mm)

The decreases in base flow and evapotransipiration have a potential effect on the change in annual river flow (Figure 17). Results from Land use and land cover change scenarios show, the mean annual flow has increased from 22.63mm to 29.69mm with respect to the change of land use and land cover from 1990 to 2015.

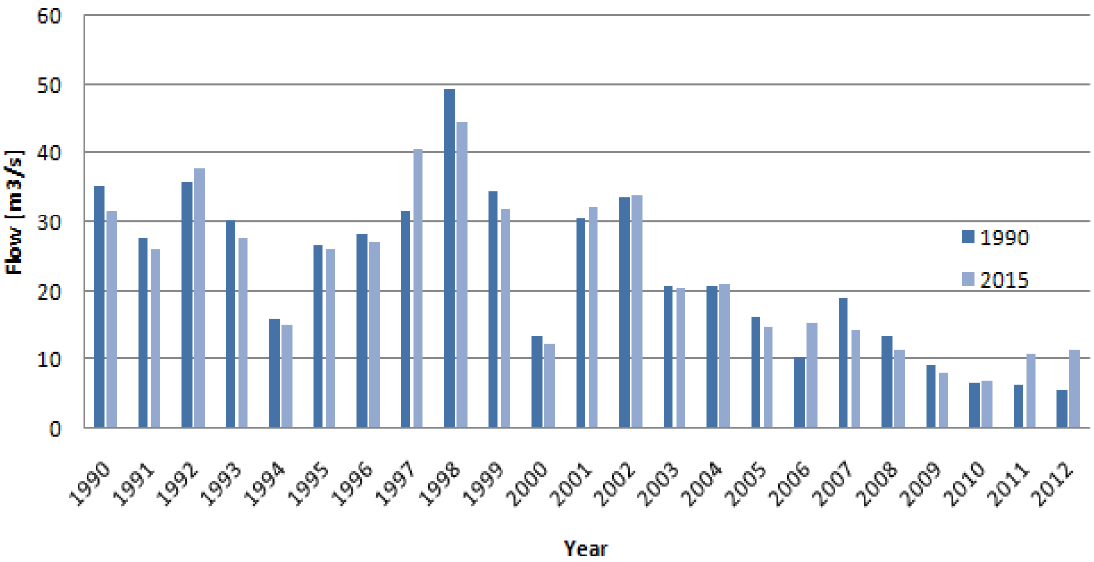


Figure 17: Annual mean flow with respect to LULC change scenario (1990 and 2015)

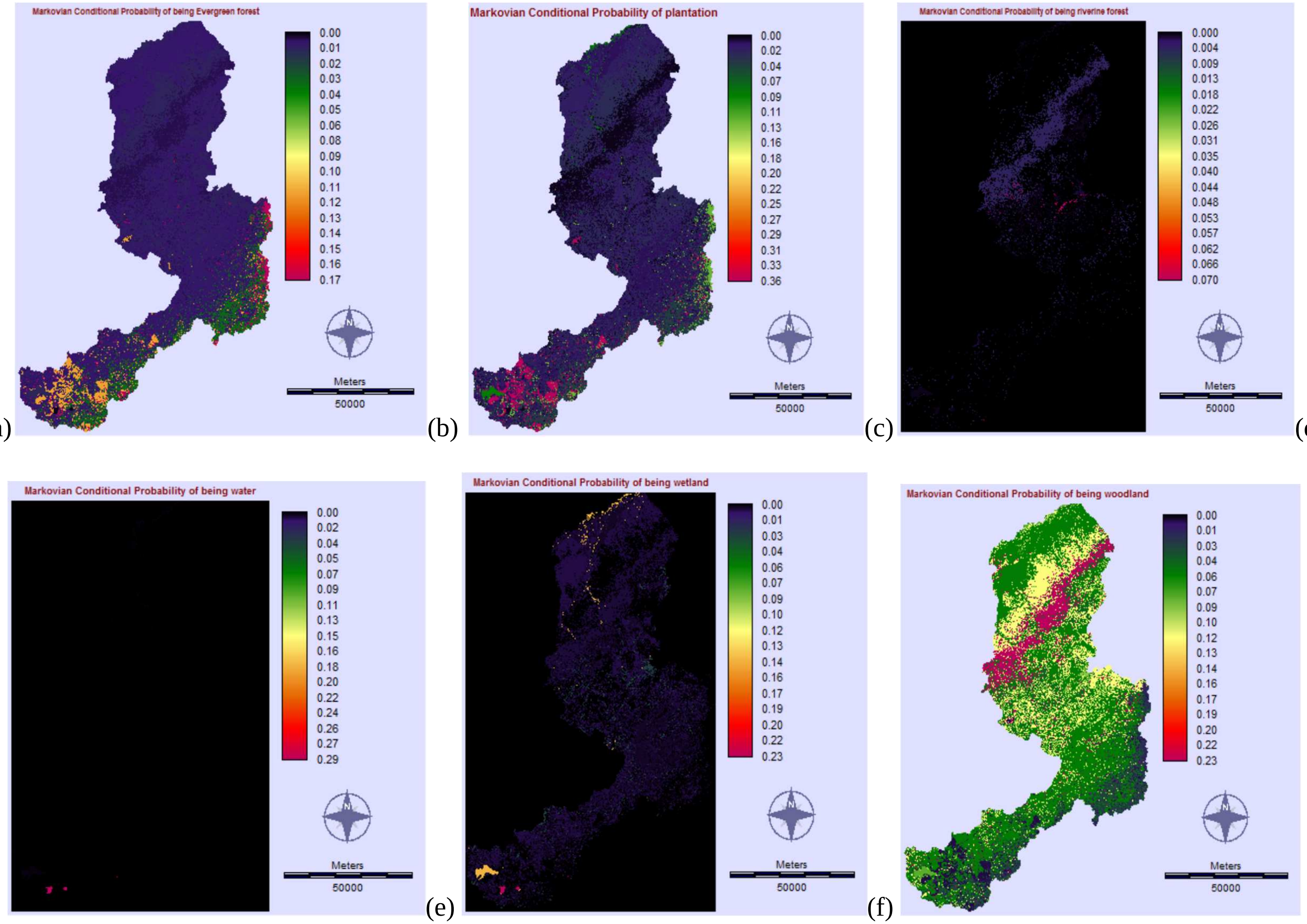
The study findings indicate that the change in the land use/covers has a significant impact to the hydrological response of Little Ruaha River Catchment. The expansions in agricultural activities and built up areas are direct linked with the increased water use for irrigation and domestic use. The land use changes, particularly, conversion of natural forest (Natural forest, woodland and riverine forest) between 1990 and 2015 are associated with the increased runoff generation process. Increase in storm runoff is mainly due to the reduced infiltration rate when forest is converted to other land uses (Kiersch, 2000; Allan, 2004). These changes in runoff generation are in agreement with the general knowledge that reducing forest cover leads into an increase in water yield (Kashaigili, 2008). Furthermore, the decrease in infiltration and evapotranspiration observed in the study is accompanied with the alteration of natural forest. This was highlighted in Bru-ijnzeel (1990), as cited in Kashaigili (2008) that forest cover removal decreases the opportunity of infiltration to the extent that surface flow exceeds the gain in base flow which results in diminished dry seasonal flow.

Studies from Tanzania and other different countries have also shown the influence of landuse changes on runoff generation (e.g. Kashaigili and Majaliwa 2013; Haile and Assefa, 2012; Balthazar et *al.,* 2014). According to this study, it is apparently clear that, land use and cover changes impact on the water yield and sediment yield and have implications on the sustenance flow regimes particularly dry season river flows which in turn cause adversely impacts to biotic component of ecosystem found within and outside the catchment.

4.1.4 Future changes in land use/cover, water and sediment yields in Little Ruaha River Catchment

4.1.4.1 Future change in land use and land cover in Little Ruaha River Catchment

The land use land cover map for the next 25 years is presented in Figure 19. The conditional probability maps that express the probability that each pixel will belong to designated class in the next 25 years are presented in Figure 18. They are called conditional probability maps since this probability is conditional on their current state. So these maps are a cartographical presentation of the transition probability matrix.


Markovian Conditional Probability of being Evergreen forest
0.00 0.01 0.02 0.03 0.04 0.05 0.06 0.08 0.09 0.10 0.11 0.12 0.13 0.14 0.15 0.16 0.17
Meters
50000
Markovian Conditional Probability of plantation
0.00 0.02 0.04 0.07 0.09 0.11 0.13 0.16 0.18 0.20 0.22 0.25 0.27 0.29 0.31 0.33 0.36
Meters
50000
Markovian Conditional Probability of being riverine forest
0.000 0.004 0.009 0.013 0.018 0.022 0.026 0.031 0.035 0.040 0.044 0.048 0.053 0.057 0.062 0.066 0.070
Meters
50000
Markovian Conditional Probability of being water
0.00 0.02 0.04 0.05 0.07 0.09 0.11 0.13 0.15 0.16 0.18 0.20 0.22 0.24 0.26 0.27 0.29
Meters
50000
Markovian Conditional Probability of being wetland
0.00 0.01 0.03 0.04 0.06 0.07 0.09 0.10 0.12 0.13 0.14 0.16 0.17 0.19 0.20 0.22 0.23
Meters
50000
Markovian Conditional Probability of being woodland
0.00 0.01 0.03 0.04 0.06 0.07 0.09 0.10 0.12 0.13 0.14 0.16 0.17 0.19 0.20 0.22 0.23
Meters
50000

(a) (b) (c) (d) (e) (f)

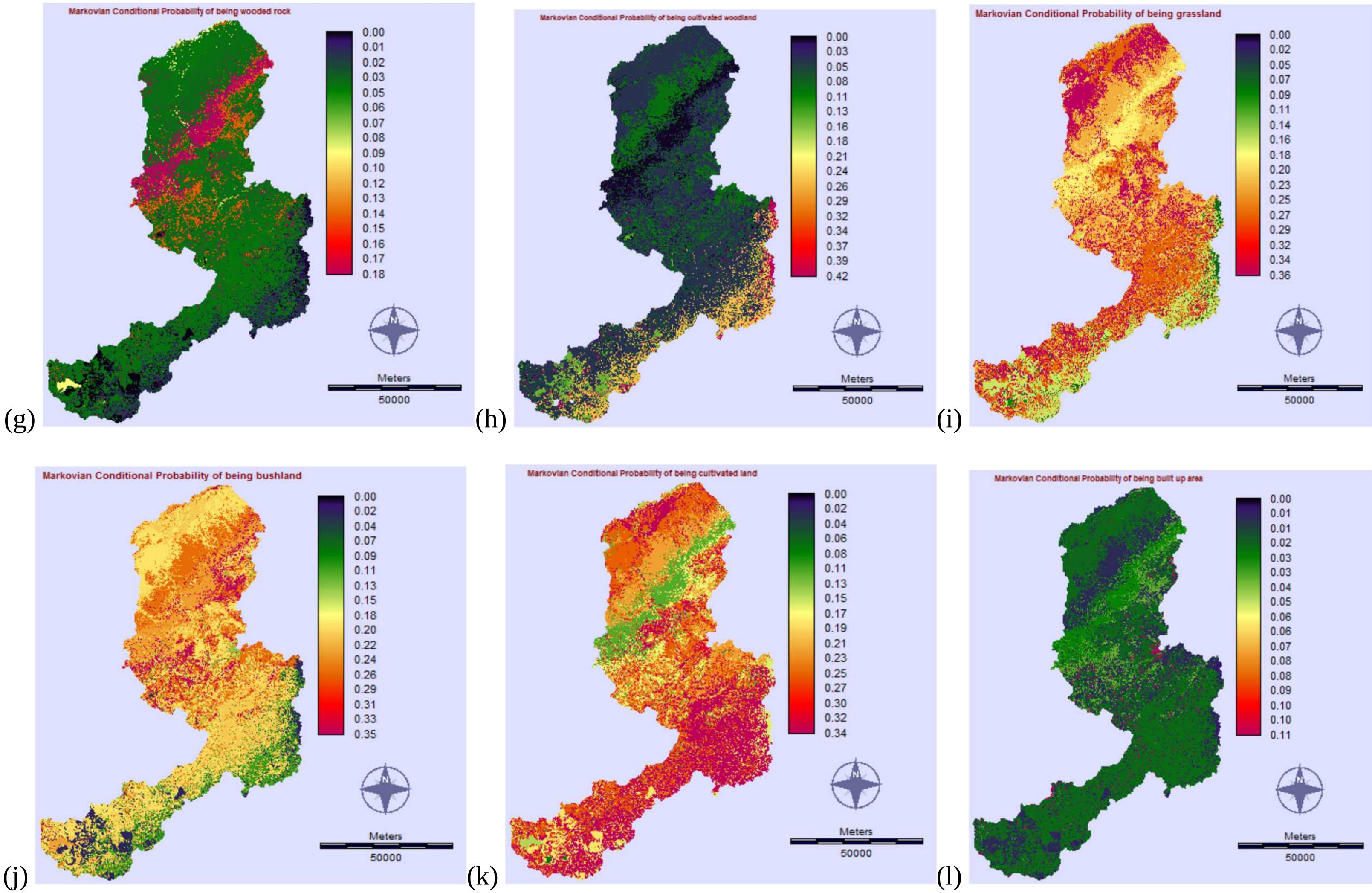


Figure 18: Conditional probability images for each land use/cover

Illustrations to Figure 18

(a) Markovia Conditional probability of being Natural forest

(b) Markovian Conditional probability of being plantation

(c) Markovian Conditional probability of being riverine forest

(d) Markovian Conditional probability of being water

(e) Markovian Conditional probability of being wetland

(f) Markovian Conditional probability of being woodland

(g) Markovian Conditional probability of being wooded rock

(h) Markovian Conditional probability of being cultivated woodland

(i) Markovian Conditional probability of being grassland

(j) Markovian Conditional probability of being bushland

(k) Markovian Conditional probability of being cultivated land

(l) Markovian Conditional probability of being built up area

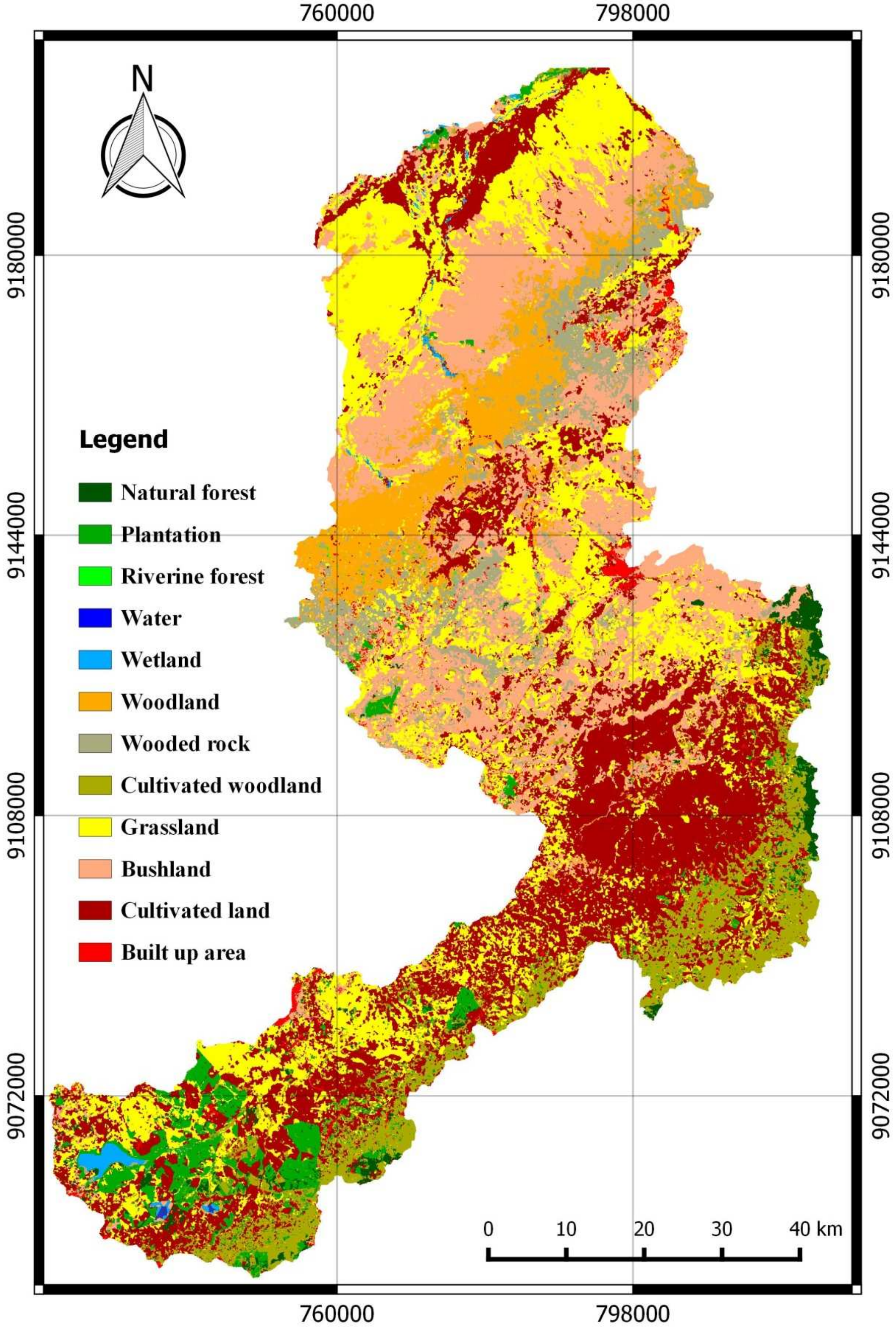


Figure 19: Land use/cover map for Little Ruaha River Catchment 2040

The statistical analysis of land use land cover for the predicted year 2040 is illustrated in Table.16. An overall change in land use and land cover in all the twenty five years of prediction revealed that, the grassland will dominate by occupying 25% which is equivalent to 160422 ha of the catchment followed by cultivated land which is expected to cover 24.82% equivalent to 158132 ha. Natural forest coverage will decrease from15950 ha (2.5%) existing in 2015 to 11936 ha (1.87%), riverine forest will decrease from 1083 ha (0.17%) experienced in 2015 to 461 ha (0.07%), woodland will decrease from 58554 ha (9.19%) existing in 2015 to 50158 ha (7.87%). As explained by Kashaigili (2008) that decrease in forest cover impact water resources, this has been revealed in this study due to projected decrease in water bodies and wetland whereby water bodies coverage and wetland expected to decrease to 211 ha (0.03%) and 3183 ha(0.5%), respectively.

Table 16: Percentage of predicted land use/cover based on CA-Markov model

LULC	2040	
	Area (Ha)	Coverage (%)
Natural forest	11 936	1.87
Plantation	22 950	3.60
Riverine forest	461	0.07
Water	211	0.03
Wetland	3 183	0.50
Woodland	50 158	7.87
Wooded rock	35 387	5.56
Cultivated woodland	49 901	7.83
Grassland	160 422	25.18
Bushland	130 023	20.41
Cultivated land	158 132	24.82
Built up	14 242	2.24
Total	637 007	**100**

4.1.4.2 Expected changes in water and sediment yields in Little Ruaha River Catchment

Table 17 presents SWAT simulations of the future scenarios. Results show that for the next 25 years the average annual surface runoff or overland flow will increase from 52.37 mm in 2015 to 154.28 mm in 2040, an increase of 101.91 mm. However, the average annual water yield will increase to 206.26 mm which will result to the increase of soil loss from 3.42 t/ha to 11.352 t/ha, the increase of 7.932 t/ha from 2015.

Table 17: Annual Hydrological summary for the watershed for the year 2040

Year	SURQ	ET	PET	GWQ	WATER YIELD (mm)	SEDIMENT YIELD (t/h)
2015	52.37	505.8	1582.8	6.08	178.21	3.420
2040	154.28	479.8	1814.6	7.98	206.26	11.352
Change	+101.91	-26	+232	+1.9	+28.05	7.932

SURQ: Surface runoff contribution from stream flow from HRU (mm)
GWQ: Ground water contribution to stream in watershed on day, month, year (mm)
PET: Potential evapotransipiration in watershed (mm)
ET: Actual evapo-transpiration in watershed (mm)

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

This study has examined the impact of land use and land cover changes on water and sediment yield in Little Ruaha River Catchment**.** The findings have revealed that the study area has undergone notable changes in terms of land use and land cover for the period between 1990 and 2015. Local knowledge disclosed various factors associated to land use and cover change that includes fire, cultivation along riparian zones, and deforestation. The results indicate that land use and land cover change has a significant impact to the hydrological response of the catchment. The greater increase of sediment yield and surface runoff with the decrease of base flow and lateral flow which has contribution to stream flow was directly associated with the transformation of land use and land cover in the catchment.

The study concludes that the modification of the land use and cover has resulted in changes in temporal distribution of runoff within the catchment. The study highlights the effects of landuse and land-cover changes on sediment yield and water resources for an informed decision on proper catchment planning and management.

Therefore, to ensure sustainability of the ecosystem services from Little Ruaha Rviver Catchment, the study recommends the following

i. A follow- up study is required to investigate appropriate interventions and alternative livelihood strategies in the area to ameliorate the current situation. According to the model results, it is necessary to prescribe appropriate soil and water conservation practices to control the stream flow and sedimentation problems in the catchment.

ii. The SWAT model is also capable of identifying areas within the basin with high water and sediment yield. This provides a useful guideline for formulating policies and developing plans to achieve sustainable land development. Based on the model output at the HRU level, high erosion areas may be easily identified within the basin. Subsequent land development should avoid such areas because of the need to adequately protect them with appropriate conservation strategies.

REFERENCES

Abbaspour, K. C., Yang, J., Maximov, I., Siber, R., Bogner, K., Mieleitner, J., & Srinivasan, R. (2007). Modelling hydrology and water quality in the pre-alpine/alpine Thur watershed using SWAT. *Journal of hydrology* 333(2): 413-430.

Al-Bakri, J. T., Duqqah, M., & Brewer, T. (2013). Application of remote sensing and GIS for modeling and assessment of land use/cover change in Amman/Jordan. *Journal of Geographic Information System* 5:509 – 519.

Allan, J. D. (2004). Landscapes and riverscapes: the influence of land use on stream ecosystems. *Annu. Rev. Ecol. Evol. Syst.* 35: 257-284.

Araya, Y. H., & Cabral, P. (2010). Analysis and modeling of urban land cover change in Setúbal and Sesimbra, Portugal. *Remote Sensing* 2(6): 1549-1563.

Arnold, J. G., Moriasi, D. N., Gassman, P. W., Abbaspour, K. C., White, M. J., Srinivasan, R., Santhi, C., Harmel, R. D., van Griensven, A., Van Liew, M. W. and Kannan, M. K. (2012). Model use, calibration, and validation. *American Society of Agricultural and Biological Engineers* 55(4): 1491 – 1508.

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

Balthazar, V., Vanacker, V., Molina, A., & Lambin, E. F. (2015). Impacts of forest cover change on ecosystem services in high Andean mountains. *Ecological indicators* 48: 63-75.

Batty M., Yichun X. and Zhanli S. (1999). *Modeling urban dynamics through GIS-based cellular automata*. Computers, Environment and Urban Systems, pp. 205–233.

BISE (2010). Ecosystem services — Biodiversity Information system for Europe. [http://biodiversity.europa.eu/topics/ecosystem-services] site visited on 29/7/2015.

Bonabeau, E. (2002). Agent-based modeling: Methods and techniques for simulating human systems. *Proceedings of the National Academy of Sciences* 99: 7280-7287.

Brail, R. K., & Klosterman, R. E. (2001). *Planning support systems: integrating geographic information systems, models, and visualization tools*. ESRI, Inc. 447pp.

Brown, D., Pijanowski B., and Duh .J. (2000). Modeling the relationships between land use and land cover on private lands in the Upper Midwest, USA. *Journal of Environmental Management* 59: 247–263.

Bruijnzeel, L. A. (1990). Hydrology of moist tropical forests and effects of conversion: a state of knowledge review. *Hydrology of moist tropical forests and effects of conversion: a state of knowledge review* 104(01): 185 – 288.

Buck, L. (2012). *SAGCOT Green Growth Leaders Workshop Report*, Government Printer, Dare es Salaam, Tanzania. 61pp.

Carlos, C., Simon, H. A. M. (2005). Ecosystems and Human Well – Being: wetlands and water - A report of Millenium Ecosystem, Assessment, *World Resource Institute, Washington, DC*. 2–47pp.

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.

Chapin Iii, F. S., Eviner, V. T., Naylor, R. L., Reynolds, H. L., Vitousek, P. M., Zavaleta, E. S., ... & Mack, M. C. (2000). Consequences of changing biodiversity. *Nature* 405: 234 - 242.

Costa, M. H., Botta, A., & 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(1): 206 - 217.

Devisscher, T. (2010). Ecosystem-based Adaptation in Tanzania; The role of ecosystem services for human well being and climate adaptation, pp 4 – 45.

DiGiano, M., Ellis, E., & Keys, E. (2013). Changing Landscapes for Forest Commons: Linking Land Tenure with Forest Cover Change Following Mexico's 1992 Agrarian Counter-Reforms. *Human ecology* 41(5): 707-723.

Ellis, E. and Pontius, R. G. (2006). Land-use and land-cover change-encyclopedia of earth. [http://www.eoearth.org/article/land-use_and_land-cover_change] site visited on 20/5/2016.

Foley, J. A., DeFries, R., Asner, G. P., Barford, C., Bonan, G., Carpenter, S. R., Snyder, P. K. (2005). Global consequences of land use. *Science* 309(5734): 570 - 574.

Food and Agriculture Organization (2005). Digital Soil Map of the World and Derived Soil Properties of the World; Food and Agricultural Organization of the United Nations: Rome, Italy.

Githui, F., Gitau, W., Mutua, F., & Bauwens, W. (2009). Climate change impact on SWAT simulated streamflow in western Kenya. *International Journal of Climatology* 29(12): 1823 - 1834.

Gupta, H.V., Sorooshian, S. and Yapo, P.O. (1999) Status of Automatic Calibration for Hydrologic Models: Comparison with Multilevel Expert Calibration. Journal of Hydrologic Engineering , 4, 135-143.

Gyamfi, C., Ndambuki, J. M., & Salim, R. W. (2016). Hydrological Responses to Land Use/Cover Changes in the Olifants Basin, South Africa. *Water*, *8*(12), 588.

Haile, G. E., & Assefa, M. M. (2012). The impact of land use change on the hydrology of the Angereb Watershed, Ethiopia. *International Journal of Water Sciences* 132: 53 - 62.

Han, J., Hayashi, Y., Cao, X., & Imura, H. (2009). Application of an integrated system dynamics and cellular automata model for urban growth assessment: A case study of Shanghai, China. *Landscape and Urban Planning* 91(3): 133 - 141.

Jantz, C. A., Goetz, S. J. and Shelley, M. K. (2004).Using the SLEUTH urban growth model to simulate the impacts of future policy scenarios on urban land in the Baltimore/Washington Metropolitan Area. *Environment and Planning B: Planning and Design* 31:251–271.

Jiang, G. H., Zhang, F. R. and Kong, X. B. (2009).Determining conversion direction of the rural residential land consolidation in Beijing mountainous areas. *Transactions of the Chinese Society of Agricultural Engineering* 25(2): 214 – 221.

Kadigi, R. M., Kashaigili, J. J., & Mdoe, N. S. (2004). The economics of irrigated paddy in Usangu Basin in Tanzania: water utilization, productivity, income and livelihood implications. *Physics and Chemistry of the Earth, Parts A/B/C* 29(15): 1091-1100.

Kashaigili, J. J. (2008). Impacts of land-use and land-cover changes on flow regimes of the Usangu wetland and the Great Ruaha River, Tanzania. *Physics and Chemistry of the Earth, Parts A/B/C*, *33*(8-13), 640-647.

Kashaigili, J. J. and Majaliwa, A. M. (2013). Intergrated assessment of land use land cover changes on hydrological regime of the malagarasi river catchment in Tanzania. *Journal of physics and Chemistry of the Earth* 35: 730 – 741.

Kashaigili, J. J., McCartney, M. P., Mahoo, H. F., Lankford, B. A., Mbilinyi, B. P., Yawson, D. K. and Tumbo, S. D. (2006). *Use of a Hydrological Model for Environmental Management of the Usangu Wetlands, Tanzania*. Research Report No. 104. International Water Management Institute, Colombo Sri Lanka, 48pp.

Kashaigili, J.J., Kadigi, R.M., Lankford, B.A., Mahoo, H.F. and Mashauri, D.A. (2005) Environmental Flows Allocation in River Basins: Exploring Allocation Challenges and Options in the Great Ruaha River Catchment in Tanzania. Physics and Chemistry of the Earth, Parts A /B/C, 30, 689-697.

Kiersch, B. (2000). Land use impacts on water resources: a literature review. *Land and Water Development Division, FAO, Rome*, 72pp.

Kimwaga, R. J., Mashauri, D. A., Bukirwa, F., Banadda, N., Wali, U. G., Nhapi, I., & Nansubuga, I. (2011). Modelling of non-point source pollution around lake victoria using swat model: a case of simiyu catchment tanzania. *Open Environ. Eng. J*, *4*, 112-123.

Legates, D. R., & McCabe, G. J. (1999). Evaluating the use of “goodness-of-fit” measures in hydrologic and hydroclimatic model validation. *Water resources research*, *35*(1), 233-241.

Levinson, D. M. and Chen W. (2002).A markov chain model of the change in transportation networks and land use. In: *Access to Destinations.* (Edited by Levinson, D. M. and Krizek, K. E.), Elsevier Science Publishers, Amsterdam, Netherlands. pp. 243–266.

Li, R. Q., Dong, M., Cui, J. Y., Zhang, L. L., Cui, Q. G. and He, W. M. (2007). Quantification of the impact of land-use changes on ecosystem services: a case study in Pingbian County, China. *Environmental Monitoring and Assessment* 128(3): 503 – 510.

Liu, W., Zhang, X. and Zheng, F. (2009). Impact of land use and climate variability on hydrology in an agriculture catchment on the loess Plateau of China. *Journal of hydrology* 377(2): 35 – 42.

Luoga, E. J., Witowski, E. T. F. and Balkwill, K. (2005). Land cover and use changes in relation to the institution framework and tenure of land and resources in Eastern Tanzania miombo woodland. *Environment, Development and Sustainability* 7: 7 – 93.

Mayer, R. J., Dale, V. H., Brown, S., Haeuber, R. A., Hobbs, N. T., Huntly, N., Naiman, and Valone, T. J. (2000). Ecological principles and guidelines for managing the use of land. *Ecological Applications* 10(3): 639 – 670.

Measham, T. G., Preston, B. L., Smith, T. F., Brooke, C., Gorddard, R., Withycombe, G., & Morrison, C. (2011). Adapting to climate change through local municipal planning: barriers and challenges. *Mitigation and Adaptation Strategies for Global Change*, 16(8): 889-909.

Meyer, W. B., & BL Turner, I. I. (1994). *Changes in land use and land cover: a global perspective* (Vol. 4). Cambridge University Press. 539pp.

Milad, M., Schaicha, H., Burgib, M. and Konolda, W. (2011). Climate change and nature conservation in Central European forests: A review of consequences, concepts and challenges. *Forest Ecology and Management* 261: 829 – 843.

Milder, J. C., Buck, L. E., Hart, A. K., & Scherr, S. (2012). The SAGCOT Greenprint: A Green Growth Investment Framework for the Southern Agricultural Growth Corridor of Tanzania, 87pp.

Milder, J. C., Buck, L. E., Hart, A. K., Scherr, S. J., & Shames, S. A. (2013). A framework for Agriculture Green Growth: Greenprint for the Southern Agricultural Growth Corridor of Tanzania (SAGCOT). *Dar es Salaam: SAGCOT Centre*, 120pp.

Millennium Ecosystem Assessment (2005).Ecosystems and human well-being: current state and trends. [http://www.millen iumassessment.org/en/Reports.aspx] site visited on 8/7/2015.

Moriasi, D.N., Arnold, J.G., Van Liew, M.W., Bingner, R.L., Harmel, R.D. and Veith, T.L. (2007) Model Evaluation Guidelines for Systematic Quantification of Accuracy in Watershed Simulations. Transactions of the ASABE, 50, 885-900.

Mulongo, M. C. (1993). Land use assessment of the reserved lands: A case study of MboleMuyonzo traditional land, Zambia. Dissertation for Award of MSc Degree at Sokoine University of Agriculture, Morogoro, Tanzania, 104pp.

Mwinuka, L., Schneider, I., Maeda, C., Mutabazi, K. D., Makindara, J., Graef, F., ... & Swamila, M. (2015). Comparing stakeholder views for mutual acceptable food value chain upgrading strategies in Tanzania. *African Journal of Agricultural Research*, 10(12): 1376-1385.

Nadia, H. S. (2010). Global water program. [http://www.globalwater.jhu.edu/mag azine/article/agriculturemeeting_the_water_challenge/] site visited on 22/7/2015.

Nash, J. E., & Sutcliffe, J. V. (1970). River flow forecasting through conceptual models part I—A discussion of principles. *Journal of hydrology*, *10*(3), 282-290.

Ndomba, P., Mtalo, F., & Killingtveit, A. (2008). SWAT model application in a data scarce tropical complex catchment in Tanzania. *Physics and Chemistry of the Earth, Parts A/B/C*, *33*(8-13), 626-632.

Ndulue, E. L., Mbajiorgu, C. C., Ugwu, S. N., Ogwo, V., & Ogbu, K. N. (2015). Assessment of land use/cover impacts on runoff and sediment yield using hydrologic models: A review. *Journal of Ecology and the Natural Environment 7*(2): 46-55.

Neitsch, S. L., Arnold, J. G., Kiniry, J. R. and Williams, J. R. (2005).*Soil and Water Assessment Tool Theoretical Documentation Version. Grassland, Soil and Water Research Laboratory*. Agricultural Research Service, USA. 26pp.

Neitsch, S. L., Arnold, J. G., Kiniry, J. R., & Williams, J. R. (2001). Soil and Water Assessment Tool-Version 2000-User's Manual. *Temple, Texas, USA*. 506pp.

NEMC., (2006). Integrated Ecosystems Assessment in Tanzania: Experiences in Ecosystems Management. National environment management council. [http:// www.unpei.org/PDF/TZ-Integrated-ecosystems-assessment.pdf] site visited on 18/7/2015.

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.

Peterson, L. K., Bergen, K. M. and Browna, D. G. (2009). Forested Land-Cover Patterns and Trends over Changing Forest Management Eras in the Siberian Baikal Region. *Forest Ecology and Management* 257(3): 911 – 922.

Postel, S. and Richter, B. (2003).*Rivers of Life: Managing Water for People and Nature.* Island Press, Washington. 74pp.

Rawat, J. S., & Manish, K. (2015). Monitoring land use/cover change using remote sensing and GIS techniques: A case study of Hawalbagh block, district Almora, Uttarakhand, India. National Authority for Remote Sensing and Space Sciences. The Egyptian Journal of Remote Sensing and Space Sciences, 18, 77–84.

Rindfuss, R. R., Walsh, S. J., Turner, B. L., Fox J. and Mishra, V. (2004). Developing a science of land change: challenges and methodological issues. *Proceeding National Academic Science* 101(39): 13976 – 13981

Rindfuss, R. R., Walsh, S. J., Turner, B. L., Fox, J., & Mishra, V. (2004). Developing a science of land change: challenges and methodological issues. *Proceedings of the National Academy of Sciences of the United States of America*, *101*(39): 13976 - 13981.

Robinson, D. T., Brown, D. G., Parker, D. C., Schreinemachers, P., Janssen, M. A., Huigen, M., & Berger, T. (2007). Comparison of empirical methods for building agent-based models in land use science. *Journal of Land Use Science 2*(1): 31-55.

Rockstorm, J., Makurira, H., and Savenije, H.S. (2009). Investigating water balance on farm techniques for improved crop productivity in rainfed system: A case of Makanya catchment, Tanzania. *Physics and Chemistry of the Earth* 34: 93 – 98.

Ruddiman, W. F. (2003). The anthropogenic greenhouse era began thousands of years ago. *Climatic Change* 61: 261 – 293.

Rugenga, E. (2002). Assessment of the land use changes due to traditional irrigation activities. The case study of four villages around Ruaha Mbuyuni, Iringa and Morogoro Tanzania.Dissertation for Award of MSc Degree at Sokoine University of Agriculture, Morogoro, Tanzania, 88pp.

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.

Salvini, P. and Miller E. J. (2005).An operational prototype of a comprehensive microsimulation model of urban systems. *Networks and Spatial Economics* 5: 217 – 234

Sander, H., Nelson, E., Hawthorne, P., Conte, M., Ennaanay, D. and Wolny, S. (2010). Projecting global land-use change and its effect on ecosystem service provision and biodiversity with simple models. *PLoS one* 5(12): 14327.

Schröter, D., Cramer, W., Leemans, R., Prentice, I. C., Araújo, M. B., Arnell, N. W., ... & Anne, C. (2005). Ecosystem service supply and vulnerability to global change in Europe. *Science* 310: 1333 - 1337.

Schulp, C. J. E., Nabuurs, G. J. and Verburg, P. H. (2008). Future carbon sequestration in europe – effects of land use change. *Agriculture, Ecosystems and Environment* 127: 251 – 264.

Shao, J., J., Wei Ch. and Xie D. (2005). Land use change and its corresponding ecological responses: A Review. *Journal of Geographical Sciences* 15(3): 305 – 328.

Shreier, H., Brown, S., Schimidt, M., Shah, P., Shrestha, B., Narkami, G., Subba and Wymann, S., (1994). Environmental auditing gaining forests but losing ground: A GIS evaluation in Himalayan Nepal watershed. *Environmental Management* 8(1): 139 – 150.

Slayback, D. (2003). Land cover changes in the Takamanda Forest Reserve, Cameroon: 1986-2000. Takamanda: *The Biodiversity of African Rainforest* 8: 173 – 179.

Sokile, C. S., Kashaigili, J. J., & Kadigi, R. M. (2003). Towards an integrated water resource management in Tanzania: the role of appropriate institutional framework in Rufiji Basin. *Physics and Chemistry of the Earth, Parts A/B/C, 28*(20-27), 1015-1023.

Tadesse, W., Whitaker, S., Crosson, W. and Wilson, C. (2015). Assessing the impact of land-use land-cover change on stream water and sediment yields at a watershed level using SWAT. *Open Journal of Modern Hydrology* 5: 68 – 85.

Trucano, T. G., Swiler, L. P., Igusa, T., Oberkampf, W. L. and Pilch, M. (2006). Calibration validation and sensitivity analysis. *Reliability Engineering & System Safety* 91(10): 1331 – 1357.

Trucano, T. G., Swiler, L. P., Igusa, T., Oberkampf, W. L. and Pilch, M. (2006). Calibration validation and sensitivity analysis. *Reliability Engineering & System Safety* 91(10): 1331 – 1357.

Valbuena, D., Verburg, P. H. and Bregt, A. K. (2008).A method to define a typology for agent-based analysis in regional land-use research. *Agricultural Ecosystem Environment* 128(2): 27 – 36.

Van Liew, M. W., J. G. Arnold, and J. D. Garbrecht. (2003). Hydrologic simulation on agricultural watersheds: Choosing between two models. Trans. ASAE 46(6): 1539-1551.

Waddell, P. A., Borning, A., Noth, M., Freier, N., Becke, M. and Ulfarsson, G. (2003).Microsimulation of urban development and location choices: Design and Implementation of Urban Sim. *Networks and Spatial Economics* 3: 43–67.

Wang, T., Wu, W., Xue, X., Han, Z., Zhang, W., & Sun, Q. (2004). Spatial-temporal changes of sandy desertified land during last 5 decades in northern China. *ACTA GEOGRAPHICA SINICA-CHINESE EDITION* 59(2): 203 – 212.

Welde, K., & Gebremariam, B. (2017). Effect of land use land cover dynamics on hydrological response of watershed: Case study of Tekeze Dam watershed, northern Ethiopia. *International Soil and Water Conservation Research, 5*(1), 1-16.

Wen, W. (2008). Wetland Change Prediction Using Markov Cellular Automata Model in Lore Lindu National Park Central Sulawesi Province. Dissertation of Awarding MSc Degree at Bogor Agricultural University, 90pp.

Weng, Q. (2002). Land use change analysis in the Zhujiang Delta of China Using Satellite Remote Sensing, GIS, and Stochastic Modeling. *Journal of Environmental Management* 64: 273 – 284.

Wickramasuriya, R. C., Bregt, A. K., Van Delden, H., & Hagen-Zanker, A. (2009). The dynamics of shifting cultivation captured in an extended Constrained Cellular Automata land use model. *Ecological Modelling* 220(18): 2302 – 2309.

Williams, J. R. (1975). "Sediment-yield prediction with universal equation using runoff energy factor." 244-252.

Willson, A. (2005). *Using Remote Sensing to Measure Forest Conversion and Land Use Changes in Xiaozhongdian Township, Northwest Yunnan Province.* Center for Biodiversity and Indigenous Knowledge. China. 15pp.

Wilson, E. H. and Sader, S. A. (2002). Detection of forest harvest type using multiple dates of Landsat TM imagery. *Journal of Remote Sensing of Environment* 80: 385 – 396.

Wu, N. and Silva, E. (2010). Artificial/intelligence solutions for urban land dynamics: A review. *CPL bibliography* 24(3): 246 – 265.

Xiyong, H., Bin, C., & Xinfang, Y. (2004). Land use change in Hexi corridor based on CA-Markov methods. *Transactions of The Chinese Society of Agricultural Engineering* 20(5): 286 – 065.

Yang, G. Q., Liu, Y. L. and Wu Z. F. (2007). Analysis and simulation of land use temporal and spatial pattern based on CA–Markov model. *Geomatics and Information Science* 32(5): 414 – 418.

Yeh, A. G. and Li, X. (2002). A Cellular Automata Model to Simulate Development Density for Urban Planning. *Environment and Planning B: Planning and Design* 29: 431 – 450.

Zeray, L. (2007, October). Calibration and Validation of SWAT Hydrologic Model for Meki Watershed. In *Ethiopia, Conference of Inter national Agricultural Research for Development.* 9 - 11 Oct, 2007 University of Kassel Wizenhausen and University of Göttingen, Germany. 5pp.

APPENDICES

Appendix 1: Classification accuracies (%)

	1990		2005		2015	
	PA	**UA**	**PA**	**UA**	**PA**	**UA**
Natural forest	99.65	99.76	100	94.85	99.10	99.10
Plantation	100	99.62	97.37	99.93	98.93	98.40
Riverine forest	99.61	100	91.66	98.50	100	100
Water	99.81	100	100	99.65	100	100
Wetland	100	99.95	99.18	99.81	99.76	100
Woodland	99.81	99.46	97.08	97.61	98.80	98.57
Wooded rock	98.53	99.01	97.11	96.34	99.84	99.69
Cultivated woodland	96.93	98.95	90.56	100	98.15	98.48
Grassland	99.47	99.47	100	99.47	99.62	99.89
Bushland	100	100	97.90	98.24	99.50	99.40
Cultivated land	99.80	99.42	99.04	97.52	99.48	98.33
Built up land	100	100	99.41	98.83	99.25	100
Overall accuracy	**99.79**		**98.43**		**99.25**	
Kappa statistic	**0.99**		**0.98**		**0.99**	

Appendix 2: Modified Soil Loss Equation (MUSLE)

$$\boldsymbol{Sed = (Q_{surf} \cdot q_{peak} \cdot area_{hru})^{0.56} K_{USLE} \cdot C_{USLE} \cdot P_{USLE} \cdot LS_{USLE} \cdot CFRG}$$

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