IMPACTS OF LAND USE CHANGES ON WATER BALANCE IN THE RUVU RIVER SUB-BASIN: THE CASE ON MVUHA RIVER SUB-CATCHMENT

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ABSTRACT

This study was carried out to assess spatial and temporal land use changes that have occurred over a period of 40 years in Mvuha River sub-catchment and its impacts to the water balance. The specific objectives of this study were i) to determine the spatial and temporal changes on land use and land cover in Mvuha River sub-catchment for the past forty years, ii) carry out statistical and trend analysis of temporal rainfall and river discharge and iii) to determine runoff hydrologic response and water quality response to land use in the sub-catchment. Land use and land cover change detection was conducted using Remote sensing and GIS techniques, trend analysis of temporal rainfall and river discharge was evaluated using statistical methods and lastly rainfall simulation experiments were used to determine runoff, hydrologic and water quality response to land use. Results showed that there were significant land use changes and/or conversions. For example forest, bushland and swamps decreased while woodland, grassland, settlement and agriculture increased. Analysis of temporal rainfall data showed that rainfall trend is almost constant and analysis of river discharge data showed a decreasing discharge rate. Correlation of longterm rainfall data and discharge rate showed a weak positive correlation which imply weak association. Rainfall simulation experiments revealed significant difference on runoff, hydrologic response and water quality response with land use. Grazing showed the highest runoff rate followed by cultivation and lastly forested land use. In terms of water quality, grazing lands had the highest insoluble suspended solids followed by agricultural land use and lastly forested land use which had the least insoluble suspended solids. The study recommends that Wamii-Ruvu water Basin office (WRBO) to have clear strategies to protect forests from encroachers and reduced livestock grazing activities in the catchment. In addition, suitable land use planning and management strategies are needed in order to avoid catchment degradation.

DECLARATION

I, Masaro, Samuel David, 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 for degree award in any other institution.

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The above declaration is confirmed by supervisors:

Prof. B.P. Mbilinyi. Date

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Prof. H. F. Mahoo Date

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DEDICATION

This work is dedicated to my God the father of my Lord Jesus Christ whom by his grace granted me this opportunity to achieve this goal. Also I dedicate this work to my beloved parents Mr. & Mrs Masaro for their financial support and encouragement.

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LIST OF ABBREVIATIONS AND ACCRONYMS

FAO	Food and Agriculture Organization
G/cm^2	Grams per centimeter cubic
G/l	Grams per litre
GIS	Geographical Information System
GLOVIS	Global Visualization Viewer
LULC	Land use and Land cover
LULCC	Land Use and Land Cover Change
MSS	Multispectral Scanner System
QGIS	Quantum GIS
SAGA	System for Automated Geoscientific Analyses
TM	Thematic Mapper
USGS	United States Geological Survey
UTM	Universal Transeverse Mercator
WRBWO	Wami-Ruvu Basin Water Office

CHAPTER ONE

INTRODUCTION

1.1 Background Information

Land use describes the exploitation and utilization of land resources by humans, e.g. through agriculture and urbanization (Pielke *et al.,* 2002). Land use can disrupt the surface water balance and the partitioning of precipitation into evapotranspiration, runoff, and ground- water flow (Foley *et al*., 2005). Land use also affects the transpiration rates on the catchment. Bradford *et al.* (2001) reported that a number of studies have shown that evapotranspiration from a forested catchment is generally greater than that from a grassed catchment with the same climatic conditions (Holmes and Sinclair, 1986; Turner, 1991; Zhang *et al.*, 2001).

Land use change has been accelerated by population increases and migration as food, shelter, and materials are sought and acquired (Smith *et al.,* 2015). Land use is undergoing major changes due not only to pressures for more efficient food, feed, and fiber production to support growing populations but also due to policy shifts that are creating markets for biofuel and agricultural carbon sequestration (Stonestrom *et al.*, 2009).

The changes in land use have occurred both locally, regionally and globally over the last few decades and will continue in the future as well (Mishra *et al.*, 2014). It is estimated that humans have directly modified at least 70 million km^2, (or more than 50 percent) of Earth's ice-free land area (Hooke *et al.,* 2012). Land use changes have potentially large impacts on water resources, yet quantifying these impacts remains among the more challenging problems in hydrology (Stonestrom *et al.,* 2009). Land use changes are altering the hydrologic system and have potentially large impacts on water resources. Similarly, rapid socio-economic development drives land use changes which include changes of land use classes, e.g. conversion of natural forest to cropland or conversion of cropland to urban area due to urbanization, as well as changes within classes such as a change of crops or crop rotations (Wagner, 2013). Most of the empirical evidences indicate that land use and land cover changes and socio-economic dynamics have a strong relationship. For example, as population increases the need for cultivated land, grazing land, fuel wood increases; settlement areas also increase to meet the growing demand for food and energy, and livestock population (Mengistu, 2009). Land-cover changes also affect regional climates through changes in surface energy and water balance (Pielke *et al.,* 2002). Land use change influences the local water balance (Fohrer *et al.,* 2001). Thus, land-use management strategies will have an impact on catchment water balance (Bradford *et al.,* 2001).

Studies by Kashaigili (2006) and Majaliwa (2009) show that the population is rapidly growing, which lead to rapid land use change and resource degradation whereby conversion of land use mainly from natural vegetation to other land use type lead to the decrease in the area under natural vegetation and forest cover.

Currently, water quality management in the Wami-Ruvu River basin is facing challenges related to land use and human activities as a result of rapid population increase. The Morogoro District Council that occupies the Upper Ruvu catchment had a population of about 304,019 in 2011 with an average population density of 25 people/km^2 in 2000 at the Upper Ruvu catchment (Mt. Uluguru); In 2009, the catchment accommodated 60% of the total population with a population density of 250–300 people/km^2 (URT 2011) cited by Msaghaa *et al.* (2014).

Deforestation on the other hand is another major problem facing Uluguru, Ukaguru, Nguru, and Mgeta mountain forests in the Wami-Ruvu River sub basin. This is driven by demand for timber, collection of firewood and land for agricultural purposes. However, the forests and woodland cover in the Uluguru Mountains has decreased by 12.7 and 59% in 1995 and 2000, respectively (Yanda and Munishi, 2007). There has also been a high influx of pastoralists in the area, an activity which is believed to contribute towards land degradation especially in wetlands thus negatively impacting to water resources in the area (Ngana *et al.*, 2010).

1.2 Justification

Land use and land cover change affect the different hydrological components like interception, infiltration and evaporation thereby influencing runoff generation and streamflow regimes (Gumindoga, 2010). Additionally, impacts of land-use change on hydrology have shown to vary from place to place, hence the need for local scale studies to be conducted (Wang *et al.*, 2012).

Earlier studies conducted by Yanda and Munishi (2007) in the Ruvu river sub-basin revealed that vegetation cover changed considerably between 1995 and 2000; the disappearance of vegetation cover led to increased surface runoff, flash floods and reduced infiltration ultimately resulting in reduced base flows in rivers. This contradicts earlier claims which suggest that for the existing high rainfall and low evaporation regime of the Uluguru Mountains, there is a more likehood of an increase in runoff, which will maintain the flow in the rivers for the next 50 years (Norconsult *et al.*, 2007).

These contradictions led Ngana *et al.* (2010) to recommend that for the future water resources management, WRBWO needs to undertake some further research to establish different scenarios anticipated in the Ruvu river sub-basins.

Studies on land use/land cover change effects on hydrology by Yanda and Munishi (2007), Norconsult *et al.* (2007), Ngana *et al.* (2010) Msaghaa *et al.* (2014), Norbert *et al.* (2012) in the Ruvu river sub basin at different times didn't attempt to quantify the effect of land use and land cover change on water balance through field experiment data instead they used modelling. Since modeling studies can predict the key mechanisms of impacts of land use change on water balances, field data and experiments provide more accurate information on the consequences of land use changes (Li *et al.*, 2007). Therefore this study on land use and land cover change effects on the water balance in the Mvuha River sub-catchment was carried out in order to quantify the effect of land use and land cover change on water balance through field experiments.

The aim of this study was to assess quantitatively the effects of land use and cover change on the stream flows for Mvuha river sub-catchment through field rainfall simulation experiments together with land use and land cover dynamics. Statistical and trend analysis of temporal rainfall and river discharge were also performed to reveal the impacts of land use and land cover change on water balance in the sub-catchment.

1.3 Objectives

1.3.1 Overall objective

The main objective of the study was to assess the impacts of land use changes on water balance in Mvuha river sub-cathment.

1.3.2 Specific objectives

The specific objectives include the following:-

i) To determine the spatial and temporal changes on land use and land cover in Mvuha River sub-catchment for the past 40 years (1975 – 2015).

ii) Carry out statistical and trend analysis of temporal rainfall and river discharge and

iii) To determine runoff, hydrologic response and water quality responses to land use in the sub-catchment.

CHAPTER TWO

LITERATURE REVIEW

2.1 Definitions of key Terms

Land use involves the management and modification of natural environment or wilderness into built environment such as settlements and semi-natural habitats such as arable fields, pastures, and managed woods. It also has been defined as "the arrangements, activities and inputs people undertake in a certain land cover type to produce, change or maintain it" (FAO, 1997; FAO/UNEP, 1999).

Land cover describes the physical states of the land surface including cropland, forest, wetlands, pastures roads and urban areas (Cihlar and Jansen, 2001).

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 (Ellis, 2011). Scientists and the public alike now understand that contemporary change in many realms of the biosphere is largely the product of human activities (Turner *et al.*, 1994).

Water balance is defined as the net change in water, taking into account all the inflows to and outflows from a hydrologic system (Latha *et al.*, 2010).

2.2 Land Use Dynamics/Change Detection

Change detection is an important process in monitoring and managing natural resources and assessing environmental impacts because it provides quantitative analysis of the spatial distribution of changes (Macleod and Congation, 1998). Past and present studies conducted by organizations and institutions around the world, mostly, has concentrated on the application of land use and land cover (LULC) changes (Reis, 2008).

Change detection is a technique which is also used for the assessment of resources, where multi-date images are compared to find out the type and amount of changes which have occurred (Yacouba *et al.,* 2009). Sigh (1989) defined change detection as the process of identifying differences in the state of an object or phenomenon by observing it at different times (Hussain *et al.,* 2013). Timely and accurate change detection of earth's surface features provides the foundation for a better understanding of the relationships and interactions between human and natural phenomena in order to better manage and use resources (Lu *et al.,* 2010). The objective of change detection is to compare spatial representation of two points in time by controlling all variances caused by differences in variables that are not of interest and to measure changes caused by differences in the variables of interest (Green *et al.,* 1994). When one is interested in knowing the changes over large areas and at frequent intervals satellite data are commonly used. Results of the digital analysis to a large extent depend on the algorithms used (Minu and Shetty, 2015).

Good change detection research should provide the following information: area change and rate of change, spatial distribution of changed types, change trajectories of land-cover types, and accuracy assessment of change detection results (Lu *et al.,* 2004). Remotely sensed data have been used to characterize patterns of land cover change at scales from a few meters to a few degrees in latitude and longitude depending on the sensor (NRC, 2008). The wider availability of large archives of historical images makes long-term change detection possible. It has been generally agreed that change detection is a complicated and integrated process. No existing approach is optimal and applicable to all cases (Jianya *et al.,* 2008). The simple detection of change is rarely sufficient in itself:

information is generally required about the initial and final land cover or types or land uses, the "from-to" analysis (Khorram *et al*., 1999).

Maximum Likelihood Classification has been found to be the most accurate and commonly used classifier, when data distributional assumptions are met; Wu and Shao (2002) and McIver and Friedl (2002) reported that the Maximum Likelihood decision rule is still one of the most widely used supervised classification algorithms (Yacouba *et al.*, 2009).

Change map using post classification technique of two images will only be generally as accurate as the product of the accuracies of each individual classification (Pathak, 2014). As opined by Lambin *et al.,* (2003), remote sensing has an important contribution to make in documenting the actual change in land use/land cover on regional and global scales (Adeoye, 2012).

2.3 Image Classification

Land use and land cover classification is the practical way to analyze land cover particularly for large areas (Zegre *et al.*, 2013). Image classification, in the field of remote sensing is the process of assigning pixels or the basic units of an image to classes; It is likely to assemble groups of identical pixels found in remotely sensed data into classes that match the informational categories of user interest by comparing pixels to one another and to those of known identity (Perumal and Bhaskaran, 2010). The classification may be one that seeks to group together cases by their relative spectral similarity (unsupervised) or that aims to allocate cases on the basis of their similarity to a set of predefined classes that have been characterized spectrally (supervised) (Foody, 2002).

2.4 Spatial and Temporal Rainfall Patterns

Spatial and temporal variability in precipitation directly influence surface runoff and groundwater infiltration in watersheds (Bloschl and Sivapalan, 1995). It has been long recognized that rainfall patterns play an important role in runoff generation and some studies have described these patterns (e.g. Goodrich *et al.*, 1995) and examine their effect on hydrological response (e.g. Singh, 1997) cited by Morin *et al.* (2005). Statistical analysis is commonly used to investigate rainfall patterns. Loukas and Quick (1996) used correlation coefficient for statistical association between the precipitation series at any two stations. Michaud *et al.* (1995) used regression model of local rainfall related to elevation, while Wotling *et al*. (2000) used rainfall intensity distribution and principal component analysis (PCA) to assess the complexity of the terrain in addition to the elevation (Manik and Sidle, 2003). In general, differences in rainfall pattern may involve a combination of two statistical outcomes; a shift in the mean and a change in the scale of the distribution functions, the gamma distribution is a popular choice for fitting probability distributions to rainfall totals because its shape is similar to that of the histogram of rainfall data (Ben-Gai *et al.*, 1998). Both precipitation volume and intensity can be used to examine the potential for surface runoff and erosion in a watershed (Tech, 2011).

2.5 Rainfall Simulation

Rainfall simulation is used extensively in field and laboratory research for understanding and assessing the factors governing the soil erosion process including both the runoff and the soil loss or sediment transport processes. Among the main advantages are (a) the ability to take many measurements quickly without having to wait for natural rain and (b) to be able to work with controlled rain thereby eliminating the erratic and unpredictable variability of natural rain (Gabriels, 2011).

Rainfall simulators represent a widespread tool for studying hydrologic processes involving interactions of rainwater with soils, such as soil erosion, overland flow generation, and infiltration (Lora *et al.,* 2016). On a small spatial scale, rainfall simulators can be useful tools to help quantify the amount of infiltration or excess runoff (Hortonian overland flow) and erosion generated by different rainfall intensities, considering factors such as slope, soil type, burn severity condition, and the type of forest floor (Covert and Jordan, 2009).

The earliest rainfall simulators used drop-forming mechanisms such as hypodermic needles and string to generate drops (Mutchler and Hermsmeier 1965). With no pressure in the system, the raindrops had to be released at heights as high as 30 ft (9 m) to ensure that drops reached speeds near terminal velocity which were highly susceptible to environmental conditions such as high winds but during the 1960's, pressurized rainfall simulation systems became more popular they rely on nozzles or sprinkler heads to produce rain-like drops (Horne, 2017).

The nozzle design rainfall simulator uses a water source that feeds one or more nozzles at a constant specified pressure. This has several advantages in that it is more portable, can produce greater and different intensities, and can create a more random drop pattern similar to natural rain (Kinner and Moody, 2007). Most rainfall simulator experiments have used a constant rainfall intensity in their experimental design; in situations when multiple intensities are used, the steady state infiltration rate tends to increase with increasing rainfall rate, indicating that runoff contributing area is a function of rainfall intensity (Stone and Paige, 2003). Some of the possible variables are the rainfall characteristics such as intensity, kinetic energy, and hydrologic thresholds that must be exceeded to generate a runoff response (Kinner and Moody, 2007).

2.6 River Discharge and Runoff

River discharge is known to reflect an integrated response of the entire river basin while rainfall serves as one of the major inputs into the runoff processes (Githui *et al.,* 2005). Runoff coefficient has been an important index to reflect the runoff yield (Xiaoming *et al.,* 2007).

Coverage and land use have large effects on runoff yield, and different precipitation conditions also have different impacts on runoff yield (Xiaoming *et al.*, 2007). Dry land agriculture can have large effects on water resources, increasing recharge and flushing accumulated salts to rivers (Cook *et al.,* 2001). Surface runoff and river discharge generally increase when natural vegetation (especially forest) is cleared (Sahin *et al.*, 1996). For instance; the Tocantins River basin in Brazil showed 25% increase in river discharge between 1960 and 1995, coincident with expanding agriculture but no major change in precipitation (Costa *et al*., 2003). One form of impact resulting from land cover changes is disturbance in stream flow regimes of watersheds (Kashaigili, 2008; Bewket and Sterk, 2004) the underlying assumption being that, land under little vegetative cover is subject to high surface runoff, low infiltration rate and reduced groundwater recharge through sub-surface base flow. The reduced infiltration and groundwater recharge, eventually leads to lowering of water tables and intermittence of once perennial streams (Kashaigili, 2013).

Runoff start-time and runoff rate are two important parameters for runoff. Rainfall simulation results showed that two land cover types had different mean runoff and sediment yield (Zhao *et al.,* 2013). Variability in stream flow produced by complex interactions of land use, land management, and climate, combined with competing and increased demand, make management of water resources at watershed scales extremely challenging and requires a thorough understanding of these interactions. Given that impacts of Land Use and land Cover Changes on water resources are the result of complex interactions between diverse site specific factors and offsite conditions, standardized types of responses will rarely be adequate. General statements about land–water interactions need to be continuously questioned to determine whether they represent the best available information and whose interests they support in decision-making processes (FAO, 2002; Bewket and Sterk, 2004) cited by Mengistu (2009).

2.7 Hydrologic Response to Land Use

Hydrologic response can be defined as the translation of rainfall into runoff via watershed routing, storage and loss processes (Kult *et al.,* 2012). Land use and land cover influences watershed hydrological responses by partitioning rainfall between return flow to the atmosphere as evaporation and transpiration and flow to aquifers and rivers (Mengitsu, 2009). Hydrological response is an integrated indicator of watershed function, and significant changes in land cover may affect overall health and function of watershed (Hernandez *et al.,* 2000).

Land use change has a direct effect on hydrologic processes through its link with the evapotranspiration regime on one hand and on the other hand the degree and type of ground cover has an enormous impact on the initiation of surface runoff (Fohrer *et al.,* 2001). Land use is a major force that can alter hydrological processes over the range of temporal and spatial scales in arid regions, e.g. the partitioning of precipitation into evapotranspiration, runoff, and ground water flow (Foley *et al.,* 2005). Reduction in forest cover, through timber harvesting, for example, can increase stream flow in the short term. These increases in water yield are generally not sustained over the long-term, however; any increases in water yield are most likely to occur during high precipitation events and not likely to occur during drier times when water demand is high (Barten *et al.,* 2008). Bronstert *et al.,* (2002) systematically generalized some factors affecting the hydrological process of land and near-to-land uses, and the most significant land use changes included vegetation change, crops and their management. Some researchers have been conducted, and the general conclusion is that the runoff yield increased with the decrease in vegetation coverage.

Understanding how Land use and land cover changes influence stream flow will enable planners to formulate policies towards minimizing the undesirable effects of future land use changes on stream flow patterns (Mengistu, 2009).

2.8 Water Quality Response to Land Use

Land cover and land use are very important elements in relation to water quality, different types of land use and land cover affect the quality of water (Bowden *et al.,* 2015). Land use and land cover have long been known to have effects on surface and groundwater quality. Increased human activity raises the likelihood of increased contaminants in the water supply; rural land use, such as agriculture, can also affect water quality whereby agricultural runoff into streams and watersheds can actually make rural streams more toxic than those in urban areas (Henderson, 2014). Stonestrom *et al.* (2009) reported that land use changes can affect water quality, for example, by introduction of nitrogen compounds and other biologically active solutes (Schlesinger *et al.,* 2006; Schlesinger, 2009).

Land use changes can also affect water quality by large-scale alteration of sediment budgets (Hassan *et al.,* 2008; Valentin *et al.,* 2008); additional water quality impacts of land use change include salinization of soil water, groundwater, and surface water (Allison *et al.*, 1990; Schoups *et al*., 2005).

It is difficult to predict the specific effects of forest management on water quantity and quality in unmonitored basins, over long time periods, or in large watershed (Jones *et al.*, 2009). Demissie *et al.* (2004) studied the influence of land use change on the hydrology, erosion and sediment yield in the Legedad Reservoir watershed in Ethiopia and found that there was a considerable impact on water quantity, erosion and sediment yield. The authors stated that due to the intensification of agricultural land use, also water quality had decreased continuously (Koch *et al.*, 2012). Vegetation, particularly forests, intercepts precipitation, facilitates infiltration, and stabilizes soil, thereby reducing the rates of erosion and runoff (Ferrell, 2001). As land is developed, vegetative cover decreases and the amount of impervious surfaces increases (Ferrell, 2001).

2.9 Soil Structure, Soil Bulk Density and Soil Sealing

Bulk density is an indicator of soil compaction and soil health. It is the weight of dry soil per unit of volume typically expressed in grams/cm^3. It affects infiltration, rooting depth/restrictions, available water capacity, soil porosity, plant nutrient availability, and soil microorganism activity, which influence key soil processes and productivity (NRCS-USDA, 2009). Available water capacity is affected by soil texture, presence and abundance of rock fragments, soil depth and restrictive layers.

Soil sealing refers to the permanent covering of an area of land and its soil by impermeable artificial material (e.g. asphalt and concrete), for example through buildings and roads. The area actually sealed is only part of a settlement area, and gardens, urban parks and other green spaces are not covered by an impervious surface (Prokop *et al.*, 2011). Sealing by its nature has a major effect on soil, diminishing many of its benefits (Tóth *et al.*, 2007).

Land cover or land use change (e.g. from forest or natural grassland to pasture or cropland), removes biomass, changes vegetation and disturbs soils, leading to loss of soil carbon and other nutrients, changes in soil properties, and changes to above- and below-ground biodiversity (Smith *et al.*, 2015). Modification of soil physical properties by hoof action, in concert with reduced vegetation cover, often results in increased bulk density and penetration resistance of soils (Wood and Blackburn, 1981; Blackburn, 1984). Land use or land management that does not result in a change of cover (e.g. forest harvest and regrowth, increased grazing intensity and intensification of crop production), can potentially result in degradation of soil properties, depending on the characteristics of the management practices (Smith *et al.*, 2015).

2.10 Water Infiltration

When water is applied to the soil surface, water naturally seeps down by gravity provided no physical barriers (such as impermeable layers at the soil surface or within the soil profile) impede this process (Mudgal *et al.*, 2014). The seep down of water by gravity is called water infiltration. Surface soil conditions including the presence of macropores determine the amount of water entering the soil (Mukhtar *et al.,* 1985). Infiltration characteristics are closely related to soil structure and may be a good indicator of changes in soil physical and biological properties. Macropores can greatly increase infiltration and are created by soil fauna and old root channels, fracture planes caused by tillage, and soil cracks caused by drying and freezing (Mukhtar *et al.*, 1985; Radke and Berry, 1993) cited by Bharati *et al.* (2002). As the bulk density increased, infiltration decreased (Bharati *et al.*, 2002). The sealing process may limit performance of soil functions (retention, production, filtering, and biodiversity) and accelerate other soil threats such as decline in organic matter, contamination, floods, compaction (Stuczynski, 2007).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Materials

3.1.1 Description of the study area

Mvuha river sub-catchment is a tributary of Ruvu river sub-Basin. The Ruvu river is one of the major rivers in Tanzania that drain the Eastern Arc Mountains. The Ruvu river sub-Basin has an area of approximately 18 000 km^2. It lies between Latitudes 60° 05' and 70° 45' South and Longitudes 37° 15' and 39° 00' East (Fig. 1). The Mvuha river sub-catchment is located between Latitude 37^0 30' to 38^0 East and Longitude 7^0 to $7^0$30' South. It covers an area of 251.3 km^2 (Yanda *et al.*, 2010).

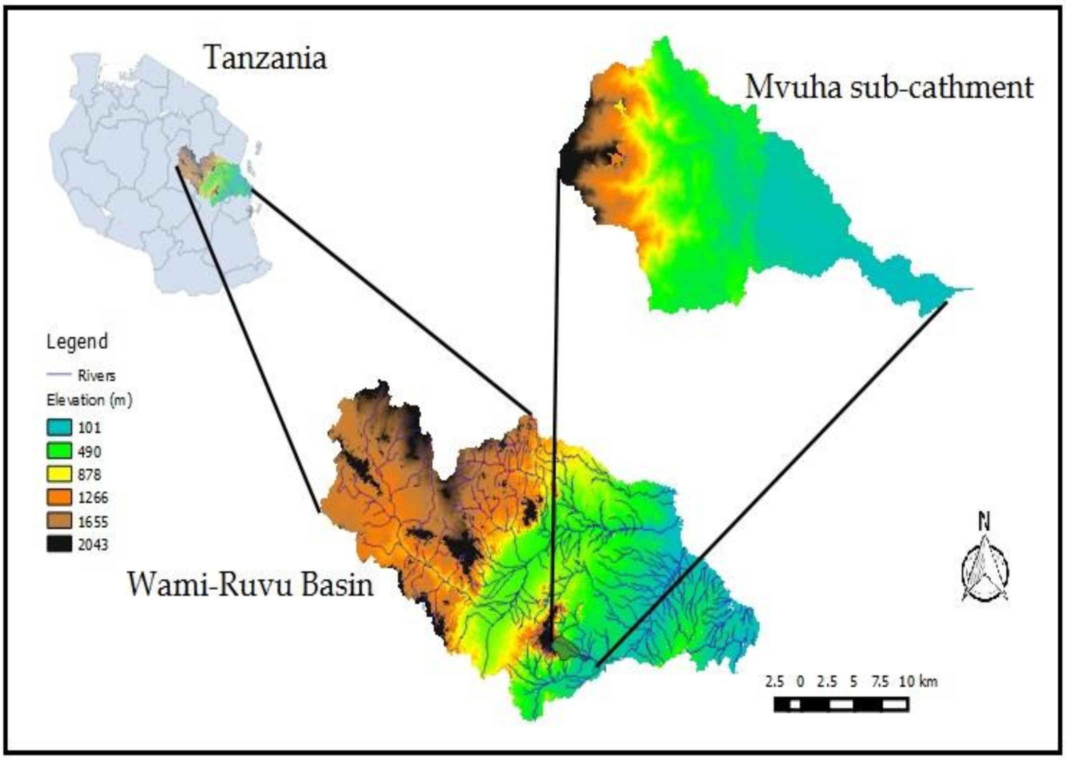


Figure 1: Map of the study area

The eastern slopes of the Uluguru Mountains have a mean annual rainfall in excess of 2500 mm while the western side of the mountains receives less than 2500 mm (WRBWO, 2008). Average monthly minimum and maximum temperatures are almost the same throughout the basin; the coldest month is August (about 18°C) and the hottest month is February (about 32°C). The annual average temperature is about 26°C (Msaghaa *et al.*, 2014). Mvuha River sub-catchment is composed mostly with four major soil types which are Ferralic Cambisol, Halpic Acrisol, Mollic Fluvisols and Umbric Acrisols (FAO, 2015). (Figure 2).

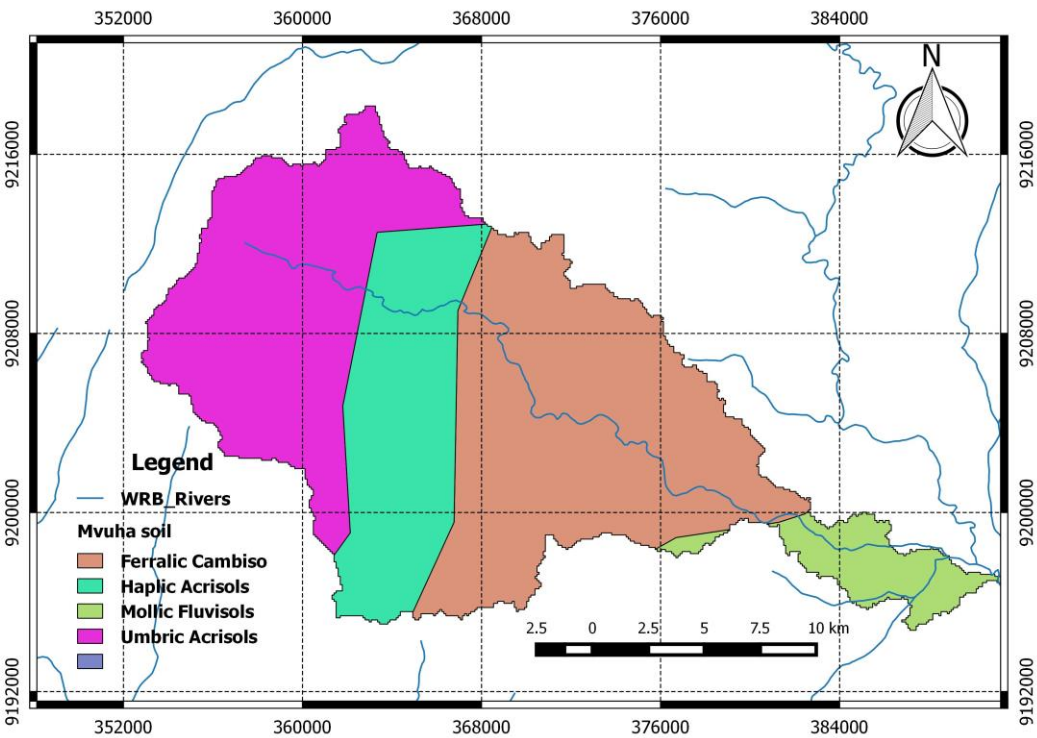


Figure 2: Soils of the study area (Mvuha catchment)

Source: Digital Soil Map of the World (FAO, 2015)

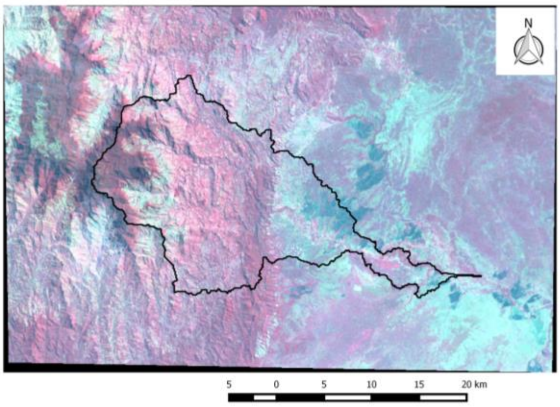
3.1.2 Data collection methods

3.1.2.1 Satellite data

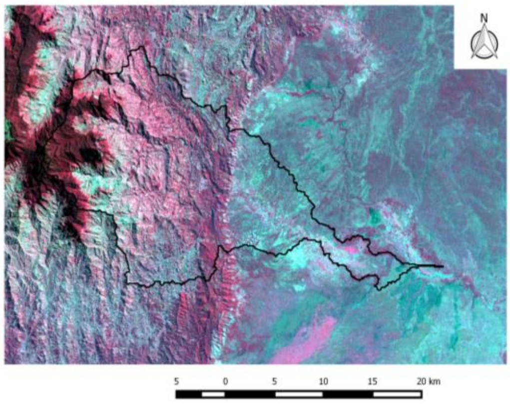
Landsat satellite images (Landsat 1975 MSS, 1995 TM and 2016 Landsat 8 images) with cloud cover less than or equal to fifteen percent (≤15%), were used in this study (Table 1 and Figure 3:a-c). These were obtained from United States Geological Survey (USGS) Data Interface from the Global Visualization Viewer (Glo Vis) (at http:glovis.usgs.gov.).

Table 1: Satellite Imagery Data

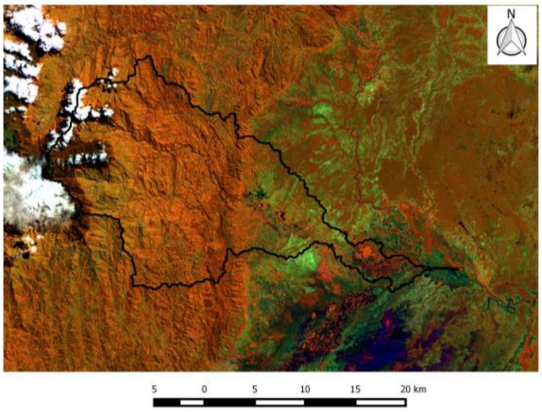
Satellite image	Path/row	Acquisition date	Season	Spatial Resolution	Cloud cover (%)
Landsat 2 MSS	179/65	26th July 1975	Dry	79 meters	0.0
Landsat 5 TM	167/65	1st July 1995	Dry	30 meters	1.0
Landsat 8	167/65	11th July 2015	Dry	30 meters	12.9



(a)



(b)



(c)

Figure 3: Sattelite images for July 1975, 1995 and 2015 over Mvuha sub-cathment

3.1.2.2 Rainfall data

Rainfall data of Matombo Mission station which is located within Ruvu river sub-basin approximately 8 km to Mvuha sub catchment and 70 km from Morogoro (WRBWO) were obtained from Wami-Ruvu Basin Water Office (WRBWO).

3.1.2.3 Hydrological data

Water discharge data of Mvuha river of 1954 to 1992 at Ngagama gauging station (1HC2) located at 0371605 and 9204285 UTM coordinates and water level data from 2007 to 2015 were available from Wami-Ruvu Basin Water Office (WRBWO).

3.1.2.4 Runoff, hydrologic response and water quality response to land use data

These data were collected by conducting field experiments at the study sites. Data were collected in three different land uses including: Forest land, grazing land and cultivated land use area. These three land uses were the major landuses in the area which occupies more than ninety five percent (95%) of the catchment area. Runoff yield, hydrologic response and water quality response data were obtained using rainfall simulators. Rainfall simulators were made of runoff plots with dimensions of 2 m long and 1.5 m wide which is the recommended dimensions for the rainfall simulators nozzles used in this research. The edges of the plots were made of steel metals to prevent water leakage into or out of the plots (Plate 1). They also consisted of a nozzle (2.5m in height) for water outlet.

Plate 1: Runoff collection plot at Mvuha sub-catchment

Five rain gauges to measure the amount of rainfall were installed, one at each corner and one at the center to measure rainfall quantity and distribution within the plot (Plate 2).

Plate 2: Runoff collection plot with rain gauge installed

A total of nine rainfall simulation experiments were performed in all three land uses; three at each landuse (Plate 3). A complete rainfall simulation experiment was run for a period of one and a half hours composed by three (3) parts of 30 minutes each. Water release (rainfall) in the plots lasted for 30 minutes because 30 minutes rainfall (I_{30}) is refeered to as the storm large enough to cause erosion when the soil was dry. The plots were then left undisturbed for the next 30 minutes to allow water to percolate into the soil. A second phase of water release was conducted for another 30 minutes (I_{30}) when the soils were wet. Data on soil moisture content was recorded by using soil moisture meter before starting the rainfall experiments because antecedent soil moisture content influences runoff start time and after completing rainfall experiment to know amount of moisture remain in soil after rainfall stops. Soil samples were also taken from the experimental plots before initiating the rainfall simulation; whereby undisturbed soil samples were taken at the soil surface of the experimental plot using soil core sampler. The samples were used for measuring bulky density because the soil bulky density affets water percolation into the soil; since bulky density is an indicator of soil compaction and soil health; it affects infiltration, rooting depth/restrictions, available water capacity, soil porosity, plant nutrient availability, and soil microorganism activity, which influence key soil processes and productivity (NRCS-USDA, 2009).

Other data collected included; run off starts time (time taken from initiation of rainfall experiment to the time when discharge started), discharge rate (volume of water collected as runoff yields at every five minutes interval) and when surface runoff stopped (time taken to end the discharge after rainfall stops). Water samples from runoff yields (discharged water) were taken for analysis of water quality; whereby water samples were taken after each 5min runoff yields collected.

The simulated rainfall intensity rate was recorded using a rainfall intensity meter that was installed at the experimental site. Similary, the distribution pattern was also recorded from the rain gauge measurements.

Plate 3: Performing a rainfall simulation experiment at Mvuha sub-catchment

3.2 Methods

3.2.1 Determination of spatial and temporal changes on land use and land cover

3.2.1.1 Digital Image processing

Remotely sensed data were processed using QGIS 2.12 software. The Landsat imageries were rectified to the UTM projection, zone 37 on Clarke 1880 spheroid and Arc 1960 datum. Image pre-processing and processing involved were layer stacking whereby all image bands were merged, re-projection whereby the images re-projected to ARC 1960/UTM zone 37S, geo-referencing and clipping the study area.

3.2.1.2 Image classification

Supervised classification was done using QGis 2.12 software whereby semi-automatic plugins was used to perfom this process. Supervised classification process involved selection of training sites on the image, which represent specific land classes to be mapped (Table 2). Then Maximum Likelihood Classifier (MLC) which is the classification algorithm was utilized to perform the classification of the image whereby all the classes are sorted apart and land use and land cover distribution maps was produced.

Table 2: Land use and land cover classification scheme (Source: **NAFORMA field manual, 2010)**

Land use	**Description**
Forest	All forested areas where both evergreen with deciduous trees growing and neither predominates.
Woodland	All areas with low density trees compared to forest
Bushland	All areas dominated by bushes and shrubs.
Grassland	All grasses dominated lands
Settlements and Agriculture	All built up areas, human habitats, institution, roads, play grounds and all other infrastructure, cultivated land with crops, fallowed and harvested cropland.
Swamps	Wetland area which are saturated with water temporaly (seasonaly or permanent and water bodies.

3.2.1.3 Change detection

Change detection were done using SAGA-GIS 2.1.2 software whereby the classified images were used to run and produce land use and land cover change detection maps. Change detection results enabled to observe significance differences on land use and land cover change patterns.

3.2.2 Statistical and trend analysis of temporal rainfall and river discharge

The long-term rainfall amount and temporal distribution from 1975 to 2015 were rearranged and analyzed by using INSTAT software and Microsoft excell, then the rainfall trend were assessed. River discharge data of 1975 to 1992 and water level data of 2007 to 2015 were also used. The discharge rate data were analyzed to assess the trend of discharge for the time from 1975 to 1992. Water level data were also analyzed and the trend were assessed from 2007 to 2015.

Correlation of longterm rainfall data with discharge rate data were performed to assess their relationship.

$$\mathbf{r = s_{xy}/\sqrt{(s_x^2 * s_y^2)}}$$

Where: s_{xy} = Sample covariance of X and Y

s_x^2 = Sample variance of X

s_y^2 = Sample variance of Y.

3.2.3 Determination of runoff, hydrologic response and water quality response to land use

Data collected from three land uses which was forested, cultivated and grazing land use. Run off time (time taken from initiation of rainfall experiment time discharge starts), discharge rate (volume of water collected as runoff yields at every five minutes interval) and runoff stops (time taken to end the discharge after rainfall stops) and these data were re-arranged and analyzed using SPSS software to assess the significant difference in runoff, hydrologic response and water quality response of the different landuses.

3.2.3.1 Determination of effect of land use on hydrologic response

Hydrologic response data which are runoff start time, discharge rate, run off end time from forest, cultivated and grazing land where rainfall simulation were performed these data were analysed using SPSS software. Mean runoff start time, discharge rate and run off end time were assessed to identify significant difference across forest, cultivation and grazing land. This enabled to know which landuse have the quick runoff start time, what is the peak runoff of each land use, which landuse have the shortest and which one have the longest runoff end time and lastly to know which land use have highest water retention and water percolation. These enabled to know the water balance of the specific area whereby knowing the inflow of water through rainfall and the total outflow through runoff, retain and percolated water were calculated.

3.2.3.2 Determination of effect of land use on water quality

Runoff yields from forest, cultivation and grazing land were taken to laboratory for water quality assessment whereby only one water quality parameter was assessed which was presence of insoluble suspended solids. In the laboratory evaporation method was used to asses the amount of insoluble suspended solids in the runoff yields whereby the samples were evaporated then the remained solids were measured. Data collected after the process were analyzed statistically and the mean insoluble solids of the sample collected from forest, cultivation and grazing land were compared to assess significant differences across them to see if they were statistically different.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Spatial and Temporal Changes on Land Use and Land Cover

4.1.1 Land use and land cover distribution for the period 1975 - 2015

The land use and land cover distribution of 1975, 1995 and 2015 are presented in Figs. 3, 4 and 5 respectively. Generally, they show the variation in cover between the periods under consideration. Satellite images of 1975, 1995 and 2015 were used to produce land use and land cover distribution maps. Supervised classification by using Semi-automatic Classification Plugin (SCP) and Maximum Likelihood Classifier (MLC) which is the classification algorithm available in QGIS 2.12.1 was used to produce these land use and land cover distribution maps.

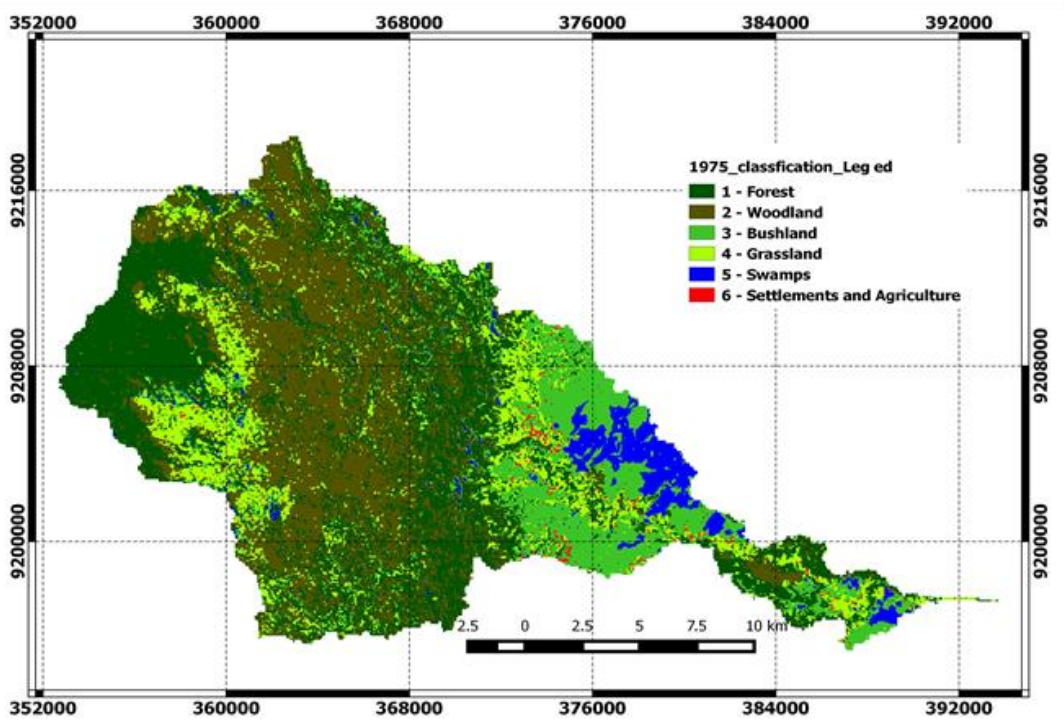


Figure 3: Land use and land cover distribution in Mvuha sub-catchment in 1975

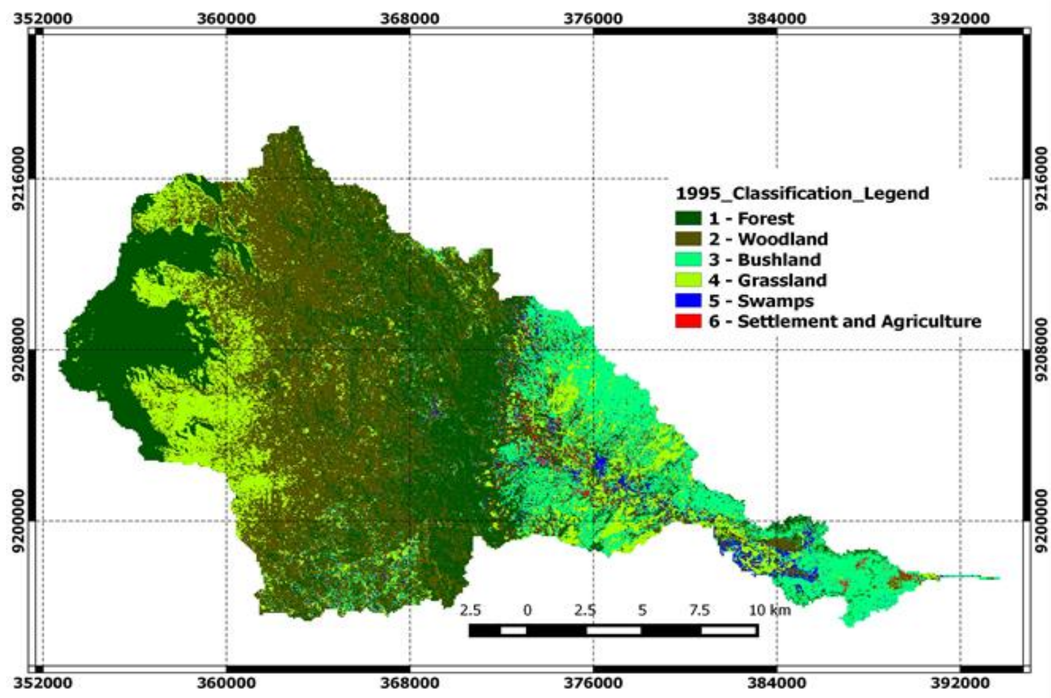


Figure 4: Land use and land cover distribution in Mvuha sub-catchment in 1995

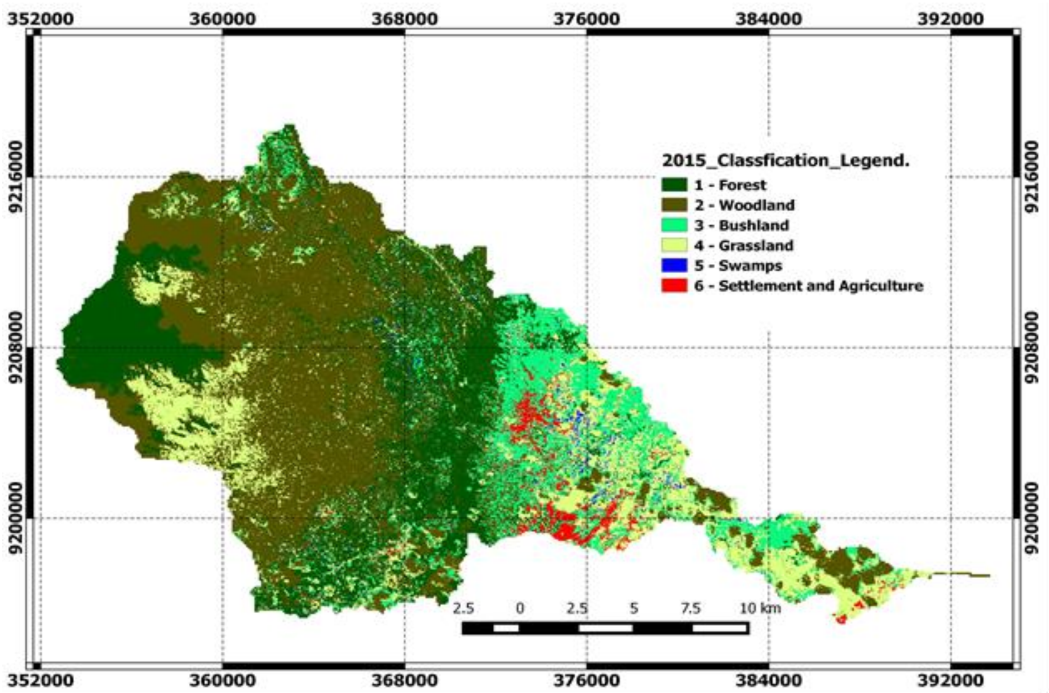


Figure 5: Land use and land cover distribution in Mvuha sub-catchment in 2015

Forested area was 132.74 km^2 in 1975 which was 34.21 percent of the all land cover in the catchment; in 1995 was 121.02 km^2 which was 31.2 percent and in 2015 was 94.54 km^2 which was 24.38 percent. In 1975 woodland area was 131.9km^2 which was 33.99 percent, in 1995 was 144.03 km^2 which was 37.14 percent and in of the all land cover. Bushland was 56.81km^2 which was 14.64 percent in 1975, in 1995 was 54.91 km^2 which was 14.16 percent and in 2015 was 47.06 km^2 which was 12.13 percent of the all land cover. In 1975 grassland was 47.7 km^2 which was 12.29 percent, 1995 was 58.18 km^2 which was 15 percent and in 2015 was 67.54 km^2 which was 17.41 percent of the all land cover. Swamps was 16.57km^2 which was 4.27 percent in 1975, in 1995 was 5.64 km^2 which was 1.45 percent and in 2015 was 2.92 km^2 which was0.75 percent of the all land cover in the catchment. 1975 settlement and agriculture was 2.11km^2 which was 0.6 percent, in 1995 was 4.05 km^2 which was 1.04 percnt and in 2015 was 8.74 km^2 which was 2.25 percent of the all land cover in the catchment.

4.1.2 Land use and land cover change

Land use and land cover change detections results were obtained from land use and land cover distributions maps which originated from satellite images of 1975, 1995 and 2015 through supervised image classification process. Change detection analysis was done in two pairs. The first pair was changes of the land use and land cover distribution of 1975 and 1995 which shows changes between 1975 to 1995; and the second pair was changes of the land use and land cover distribution of 1995 and 2015 which shows changes between 1995 to 2015. Land use and land cover distribution change detection results which shows land use and land cover conversion from one class to another is shown in Figures 6 and 7 below.

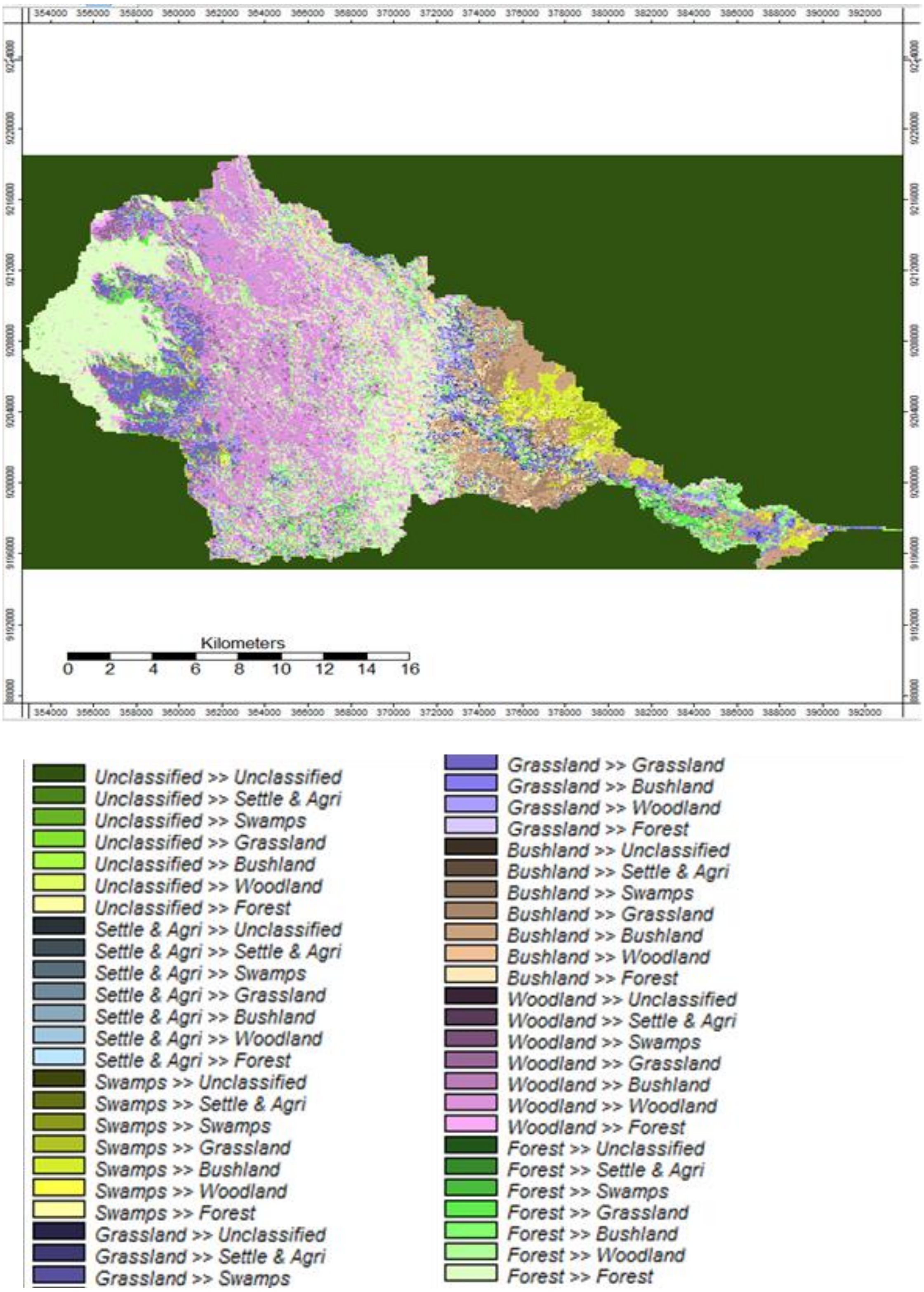


Figure 6: Land use and land cover change map of image scene, 1975 to 1995

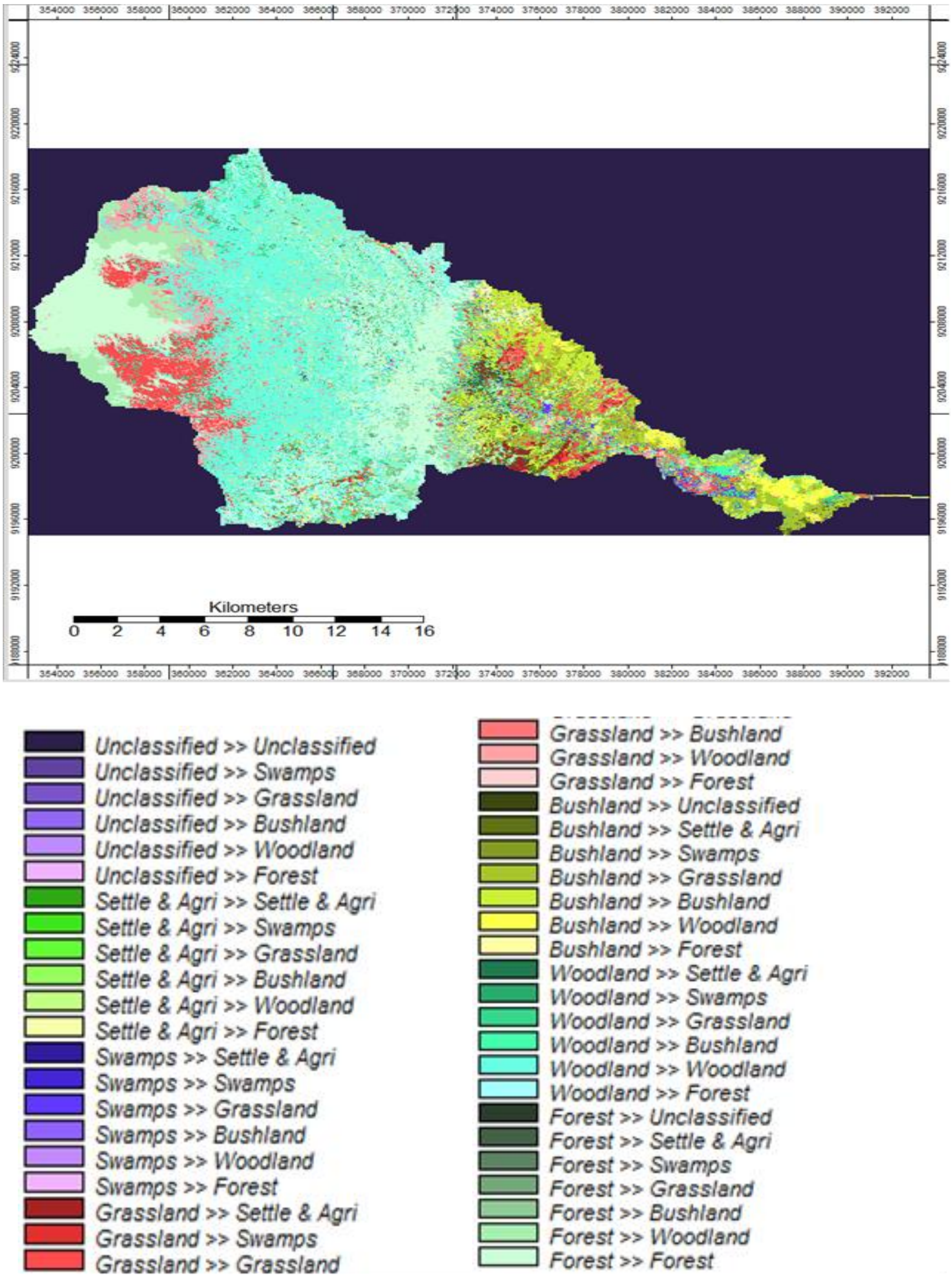


Figure 7: Land use and land cover change map of image scene, 1995 to 2015

Area changes, rate of changes and percentage change per year are presented in the Tables 3 and 4 below; whereby increased and decreased amount is represented by positive signs (+) and (-) respectively.

Table 3: Land use and land cover area, changed area and annual rate of change between 1975 and 1995

	1975		1995		Area changed	Cover change	Annual rate of change	Annual rate of change
Land use and land cover	Area (km^2)	Percent(%)	Area (km^2)	Percent(%)	Km^2	Percent(%)	(Km^2/Year)	(%/year)
Forest	132.74	34.21	121.02	31.2	-11.72	-8.83	-0.59	-0.44
Woodland	131.9	33.99	144.03	37.14	12.13	9.2	0.61	0.46
Bush land	56.81	14.64	54.91	14.16	-1.9	-3.34	-0.1	-0.17
Grassland	47.7	12.29	58.18	15	10.48	22	0.52	1.1
Swamps	16.57	4.27	5.64	1.45	-10.93	-66	-0.55	-3.3
Settlements and Agriculture	2.11	0.6	4.05	1.04	1.94	92	0.1	4.6
Total	387.83	100	387.83	100				

Table 4: Land use and land cover area, changed area and annual rate of change between 1995 and 2015

	1995		2015		Area changed	Cover change	Annual rate of change	Annual rate of change
Land use and land cover	Area (km^2)	Percent(%)	Area (km^2)	Percent(%)	Km^2	Percent(%)	(Km^2/Year)	(%/year)
Forest	121.02	31.2	94.54	24.38	-26.48	-21.88	-1.32	-1.09
Woodland	144.03	37.14	167.03	43.08	23	15.97	1.15	0.8
Bush land	54.91	14.16	47.06	12.13	-7.85	-14.3	-0.39	-0.71
Grassland	58.18	15	67.54	17.41	9.36	16.09	0.47	0.8
Swamps	5.64	1.45	2.92	0.75	-2.72	-48.22	-0.14	-2.41
Settlements and Agriculture	4.05	1.04	8.74	2.25	4.69	115.8	0.23	5.79
Total	387.83	100	387.83	100				

Results (Table 3 and 4) showed that there was variation in cover coverage between the two time intervals which was under consideration whereby all land cover categories changed but with varying magnitudes. Three land use and land cover have been expanding in area coverage all the time while the other three land use and land cover have been decreasing in area coverage. Land use and land covers which decreased in area coverage are forest, bushland and swamps. Forest decreased by 8.83 percent in the period of 1975 to 1995 with annual decreasing rate of 0.44 percent and in the period of 1995 to 2015 forest decreased by 21.48 percent with annual decreasing rate of 1.09 percent. Bushland decreased 3.34 percent in the period between 1975 to 1995 with annual decreasing rate of 0.17 percent and in the period between 1995 to 2015 was decreased by 14.3 percent with annual decreasing rate of 0.71 percent. Swamps decreased by 66 percent in the time between 1975 to 1995 with annual decreasing rate of 3.3 percent and in the period between 1995 to 2015 decreased by 48.22 percent with annual decreasing rate of 2.41 percent.

Land use and land cover which have been expanded in area coverage are woodland, grassland, settlements and agriculture. Woodland increased by 9.2 percent in between 1975 to 1995 with 0.46 percent annual increasing rate and between 1995 to 2015 increased by 15.97 percent with annual increasing rate of 0.8 percent. Grassland increased by 22 percent between 1975 to 1995 with annual increasing rate of 1.1 percent and between 1995 to 2015 increased by by 16.19 percent with annual increasing rate of 0.8 percent. Settlements and agriculture increased by 92 percent with annual increasing rate of 4.6 percent between 1975 to 1995 and in between 1995 to 2015 increased by 115.8 percent with annual increasing rate of 5.79 percent.

4.1.3 Change detection matrix of different land use and land cover (Confusion matrix)

The extent of land use land cover conversion from one land use to another is showed in the Table 5 and 6 below.

Table 5: Changes detection matrix in different land use coverage between 1975 and 1995

	Land use and land cover 1995(ha)						
Land use land cover 1975(ha)	Forest	Woodland	Bushland	Grassland	Swamps	Settlement and Agriculture	Total
Forest	6984.22	4096.44	783.45	1201.14	197.37	74.43	
	52.37%	30.71%	5.87%	9%	1.48%	0.56%	13337.05
Woodland	3231.45	7915.97	284.4	1554.84	82.44	23.58	
	24.68%	60.46%	2.17%	11.88%	0.63%	0.18%	13092.68
Bushland	1002.87	795.15	2621.54	1017.27	128.25	156.6	
	17.53%	13.9%	45.82%	17.78%	2.24%	2.74%	5721.68
Grassland	801.27	1470.69	653.31	1645.4	105.75	99.22	
	16.78%	30.8%	13.68%	34.45%	2.21%	2.08%	4775.64
Swamp	197.82	154.44	883.53	334.8	13.86	45.15	
	12.14%	9.48%	54.22%	20.5%	0.85%	2.78%	1629.6
Settlement and	41.85	25.29	84.96	47.34	12.51	14.4	
Agriculture	18.49%	11.17%	37.53%	20.91%	5.53%	6.36%	226.35
Total	12259.48	14457.98	5311.19	5800.79	540.18	413.38	38783

Table 6: Changes detection matrix in different land use coverage between 1995 and 2015

	Land use land cover 2015(ha)						
Land use land cover 1995(ha)	Forest	Woodland	Bushland	Grassland	Swamps	Settlement and Agriculture	Total
Forest	5756.67	4455.29	1105.92	595.44	57.6	123.84	
	47.6%	36.84%	9.14%	4.92%	0.48%	1.02%	12094.76
Woodland	2737.98	8972.82	998.55	1520.19	89.1	88.02	
	19%	62.28%	6.93%	10.55%	0.62%	0.61%	14406.66
Bushland	510.66	927	1825.56	1832.67	80.01	316.98	
	9.3%	18.88%	33.24%	33.36%	1.46%	5.77%	5492.88
Grassland	352.98	2192.49	492.48	2442.87	46.53	291.87	
	6.07%	37.68%	8.46%	41.98%	0.8%	5.02%	5819.22
Swamp	69.39	96.66	141.12	232.2	9.09	15.84	
	12.3%	17.13%	25.01%	41.15%	1.61%	2.81%	564.3
Settlement and	30.78	51.75	142.83	132.21	10.08	37.53	
Agriculture	7.6%	12.77%	35.25%	32.63%	2.49%	9.26%	405.18
Total	9458.46	16696.01	4706.46	6755.58	292.41	874.08	38783

Changes detection matrix results above (Table 6 and 7) explains how much, where, and what type of land cover change has occurred. The possible causes of the major different land use and land cover conversion that occurred in the catchment are explained below Forest have decreasing gradually whereby a large part of natural forest been converted to woodland (forest with low tree density). This majorly caused by forest poaching for production of timber for building, firewood and charcoal; which are the major source of energy in the catchment. Pastoralist also illegal use the forest and woodland for their grazing activities which lead to the destruction of forest especially reduction of tree density. Expansion farmland and settlement due to population growth also resulted to decreasing forest and woodland land cover in the catchment.

Bushland and grassland are mainly dominated by pastoralist with big herds of cattle, goats and sheeps who are using these areas for their grazing activities. Grazing activities in bushland lead to the destruction of small trees and shrubs which resulting reduced small trees and shrubs density automatically change the land use and land cover class whereby bushland changed to grassland. Changes detection matrix results (Table 6 and 7) shows the large part of bushland area have been converted to grassland. People and livestock demand drinking water and the main source of water in the area is the Mvuha river. This has significant contribution on the decreasing water quantity in Mvuha river.
The high decreasing rate of swamps (wetland) due to conversion to other land uses mainly grassland whereby grazing activities takes place and agriculture mainly used for paddy cultivation in the area. This have also resulted to increasing water demand from Mvuha river since it is the only reliable source of water in Mvuha sub-catchment. Almost all wetland have disappear the only remained wetland are few natural dams which are also disturbed by people who have vegetable production gardens sorounding them. Settlement and agriculture land have increasing gradually due to population growth where

by in 2012 general census Mvuha ward which is in the catchment had a population of 14 250 people who are entirely staying in the area doing their economic activities like crop farming and livestock keeping. Also according to Tanzania general census report of 2002 and 2012; in 2002 Morogoro district had a total population of 263 012 and in 2012 Morogoro district had total population of 286 248, an increase of a total of 23 236 people in the area. 2012 which is equivalent to 8% increase of the population, so this scenario is the major causes of increasing of settlement and agriculture landuse and the decrease of forest, woodland and bushland land uses.

4.2 Temporal Rainfall Trends, Water Discharge and Water Level Trends

4.2.1 Temporal rainfall trend

Rainfall data analysis of between 1979 to 2014 showed that rainfall was fluctuating year to year but the overall trend of rainfall increased at very low rate (Figure 8).

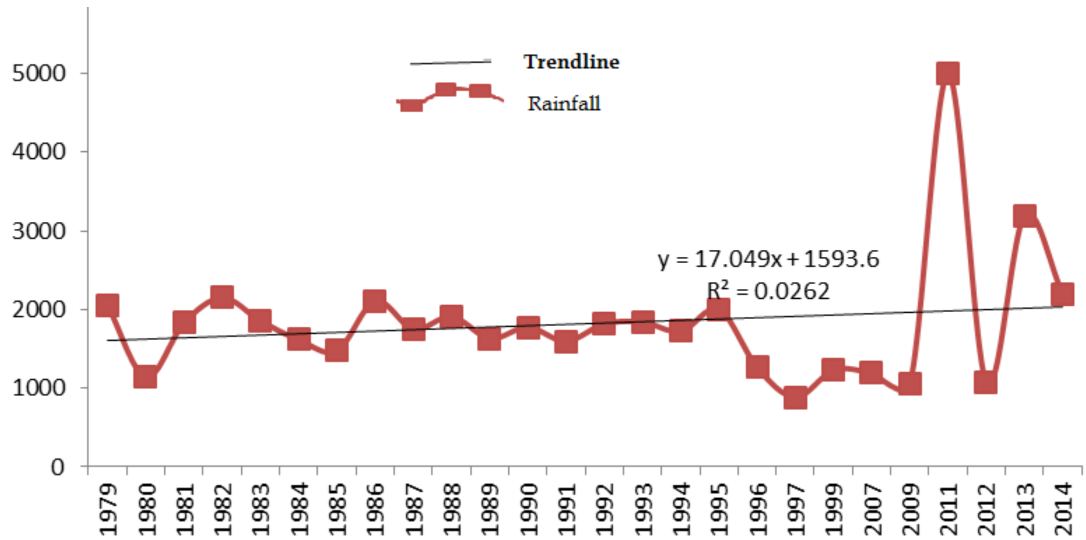


Figure 8: Rainfall annual trend of Matombo mission station from 1979 to 2014

Trendline (Figure 7) indicate that only 26 percent of the rainfall data showed that the trend is increasing at very low rate. From 1979 to 1995 rainfall was almost constant (the same) for all these years and from 1996 to 2014 there was high fluctuation of rainfall in the area may be was caused by climate change which was accelerated by environment destruction especially forest clearance since from the results of change detection above shows that forest have been decreased gradualy whereby between 1995 and 2015 about 21.88 percent of the forest cover disapper.

Rainfall trend in seasonal wise shows that rainfall trend is increasing in heavy/long rainfall season of March to May in a low rate but in low/short rainfall season the rainfall is decreasing at very low rate (Figure 9).

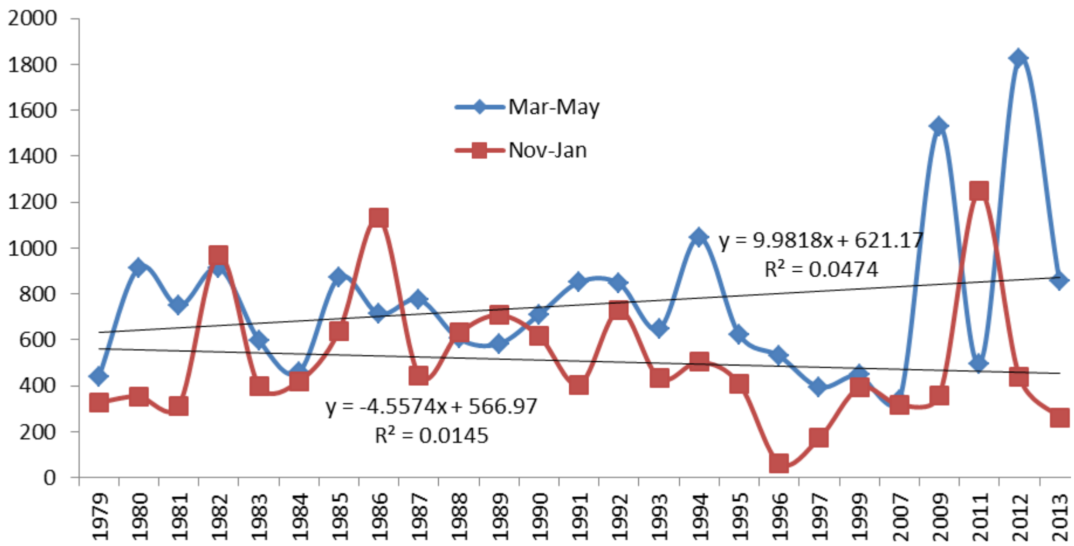


Figure 9: Rainfall trend on season base

Since rainfall in season bases fluctuation of rainfall in all season but overall trend shows long rains season of March, April and May rainfall is icreasing but short rain season of November, December and January rainfall is decreasing short rainall this reveal that if the future the short rain season will disappear completely if the causes of climate change aspecialy environmental destruction will be controlled.

4.2.2 River discharge trend

River discharge rate of Mvuha river at Ngagama gauging station from 1975 to 1992 were analysed and the discharge trend were computed (Figure 10)

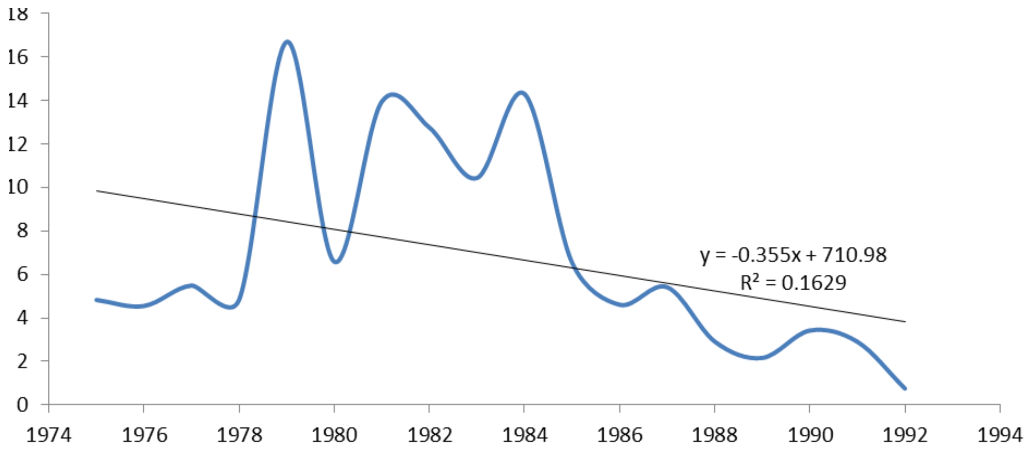


Figure 10: Discharge rate trend of Mvuha river from 1975 to 1992 at Ngagama gauging station

Discharge trend analysis show fluctuation and the decrease of the river discharge which was mainly may be caused by some factors like rainfall fluctuation, land use changes and diversion or trapping of water from the river above the gauging station. On the rainfall trend analysis show fluctuation and overall trend shows constant trend of rainfall up to 1995 which is opposite with discharge trend which is fluctuation and overall trend is decreasing, so rainfall is not the major causes of the decreasing trend. Land use changes and diversion or trapping of water from the river above the gauging station can be the major causes since change detection shows increasing of settlement and agriculture land uses which highly demand water.

Swamps which composed wetland area which are saturated with water temporaly (seasonaly or permanent and water bodies) have also gradually disappear may also being the cause of discharge rate trend decreasing since was also source of water for dometic use, livestock use and to the Mvuha river itself so when they disappear led the river discharge to decrease since one of its source of water collapse. River discharge trend analysis in season base showed that in all seasons,the discharge rate is decreasing slowly but at different rates, with a relatively higher rate in long rainy season of March to May as compared to the short rainy season of November to January.

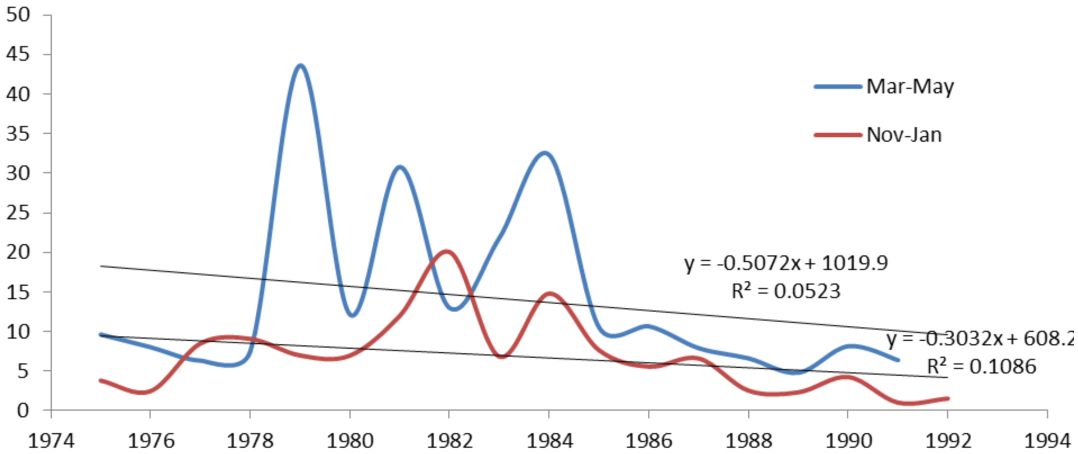


Figure 11: River discharge trend of Mvuha river from 1975 to 1992 at Ngagama gauging station in season base

In season bases also shows the same sceanario as the above river discharge trend but the short season of November to January the decreasing rate is high compared to long season of March to May this is reftection of the rainfall trend which shows the same in short season whereby the short season have low decreasing trend of rainfall.

4.2.3 Water level trend

Water level trend of Mvuha river at Ngagama gauging station from 2007 to 2015 analysis show that the water level trend is fluctuating year after year but the overall trend shows the water level increasing (Figure 12).

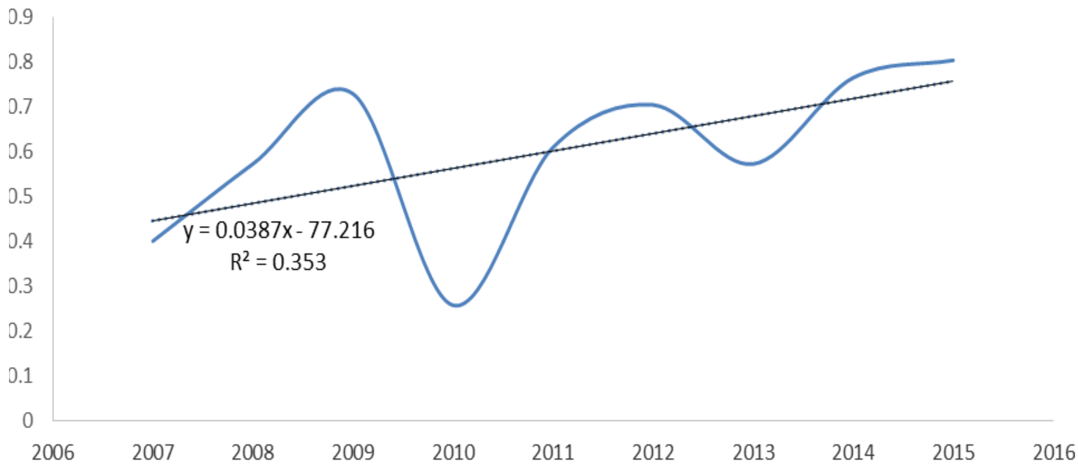


Figure 12: Water level trend of Mvuha river at Ngagama from 2007 to 2015

Annual water level trend from 2007 to 2015 at Ngagama gauging station shows that the overall trend is increasing; this scenario was not expected since in the previous years discharge trend shows gradual decrease so the water level also was expected to show the same scenario. The observed increase in water level trend may be due to siltation in the river since the rainfall trend was fluctuating but the overall trand was almost constant in all years. Siltation in the river may be caused by land use change especially from forest, woodland and bushalnd to grassland since there were increasing number of livestock especially cattle, goats and sheeps in the recent years whereby 9,377 cattle brought in Mvuha ward in 2012 which is in the catchment which are being fed around and along the river. These animals deposit their wastes as they are watered along river banks resulting in disturbace of river banks thus accelerating silt accumulation in the river.

Ngana *et al.,* (2010) reported that increasing livestock population will also add to the potential threat in the fishing stock due to increased soil erosion and heavy siltation. Also at the gauging station high siltation was observed whereby its affect the reading of the gauging meter. So siltation on river bed due to grazing activities in the catchment resulting to the gradual rise of water level of Mvuha river at Mvuha gauging station.

Plate 4: Cattle in Mvuha river crossing and drinking water

4.2.4 Integration of rainfall, water discharge and water level

The correlation coefficient between Rainfall and water discharge from 1975 to 1992 showed a weak positive correlation coefficient of 0.244. The weak positive correlation of rainfall and water discharge reveals that there is a weak association between these two variables. Since river discharge is known to reflect an integrated response of the entire river basin while rainfall serves as one of the major input into the runoff processes (Githui *et al.,* 2005), this shows that there are other factors which affect this relationship.

These may include landuse and land cover which may hinder the conversion of rainfall to runoff and finally to river discharge. The correlation coefficient of rainfall and water level from 2007 to 2014 is -0.071. This is a very poor negative relationship between rainfall and water level.

4.3 Runoff, Hydrologic Response and Water Quality Response to Land Use and Land Cover

4.3.1 Runoff and hydrologic response to land use

Runoff starts time, runoff rate and runoff ends time are the parameters which used to assess the hydrologic response to land use in the catchment. Data (Appendix 1) analyisis showed that runoff start time differed across forest, cultivation and grazing lands with ferralic cambisol soils at dry and wet soil condition status. When the soils were dry, mean shortest time to water runoff was observed in grazing area 1.7 minutes, followed by cultivation area 3.4 minutes and longest time was in forest area 6.38 minutes (Table 7).

Table 7: Runoff start time mean across forest, cultivation and grazing land uses under dry soil conditions

Landuse	Mean	N	Std. Deviation
Cultivation	3.4100	3	1.11772
Grazing	1.7167	3	1.07002
Forested	6.3767	3	7.19207
Total	3.8344	9	4.20750

When soils (ferralic cambisol) were wet mean average runoff start time were 1.01 minutes for cultivation area, 1.11 minutes for grazing area and 1.11 minutes for forested area land uses (Table 8).

Table 8: Runoff start time mean across forest, cultivation and grazing land uses under wet soil conditions

Landuse	**Mean**	N	Std. Deviation
Cultivation	1.0167	3	0.39627
Grazing	1.1133	3	0.04509
Forested	1.1133	3	0.07234
Total	1.0811	9	0.20835

Statistical comparisons of runoff start time from both simulations conditions of dry and wet soils showed that there is no significant difference in runoff start time across forested, cultivation and grazing land uses. Water discharge rate (runoff rate) whereby runoff yields volume was collected and measured after every five minutes for thirty (30) minutes rainfall simulation experiment to relate the storm of 30 minutes (I_{30}) Appendix 2) showed that there is significant differences in hydrologic response across forested area, cultivation area and grazing area when the rainfall simulation experiment was done on the dry soil. Forested land use showed the lowest mean average runoff rate (discharge rate), followed by cultivated land use and lastly grazing land use with the highest runoff rate which was signicantly different from cultivated and forested land uses (Figure 13).

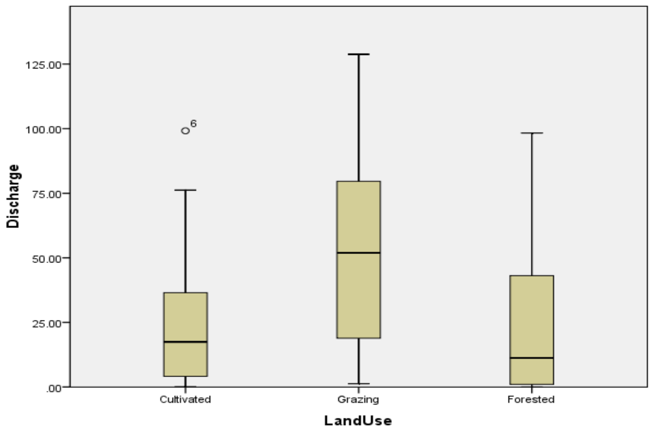


Figure 13: Box plot of the mean average runoff rate (discharge rate) of 30 minutes rainfall in cultivated, grazing and forested land uses when land was dry

Data analysis (Analysis of covariance and significance test) of the runoff rate (discharge rate) shows that there is significant difference of runoff rate (discharge rate) between the three land uses when rainfall simulation was done when the land was dry that runoff rate (discharge rate) of cultivation land, grazing land and forested land are statistical different at 5% level of significant (Table 9).

Table 9: Analysis of covariance (ANCOVA) table of discharge rate (runoff rate) in three landuses when rainfall simulation was perfomed on dry land

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Corrected Model	8847.421[a]	2	4423.711	4.436	.017
Intercept	64030.849	1	64030.849	64.203	.000
LandUse	8847.421	2	4423.711	4.436	.017
Error	50863.477	51	997.323		
Total	123741.748	54			
Corrected Total	59710.898	53			

a. R Squared = .148 (Adjusted R Squared = .115)

Water discharge (runoff yields volume) for 30 minutes storm (I_{30}) collected and measured after every five minutes (Appendix 2) data analysed (Analysis of covariance and significance test) and results showed that there is no significant difference of runoff rate (discharge rate) between the three land uses when rainfall simulation was done on the wet land that runoff rate (discharge rate) of cultivation area, grazing area and forested area are not statistical different at 5% level of significant (Figure 14 and Table 10).

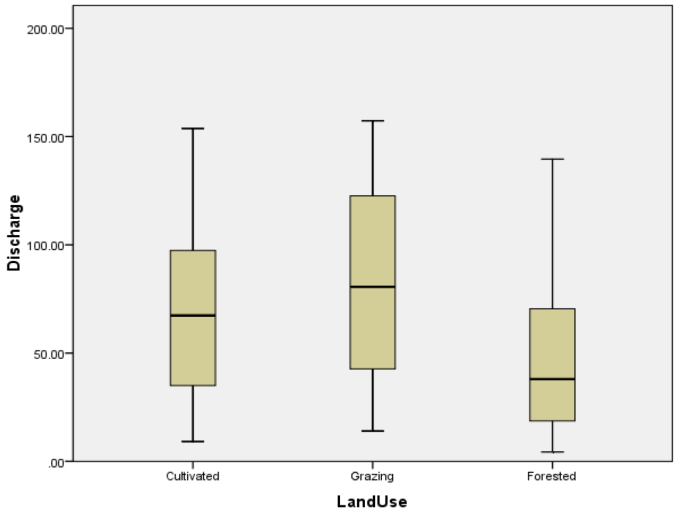


Figure 14: Box plot mean average runoff rate (discharge rate) of 30 minutes rainfall in cultivated, grazing and forested land uses when the land was wet

Table 10: Analysis of covariance (ANCOVA) table of discharge rate (runoff rate) in three landuses when rainfall simulation was perfomed on wet land

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Corrected Model	9907.478[a]	2	4953.739	2.829	.068
Intercept	232959.079	1	232959.079	133.051	.000
LandUse	9907.478	2	4953.739	2.829	.068
Error	89295.832	51	1750.899		
Total	332162.388	54			
Corrected Total	99203.310	53			

a. R Squared = .100 (Adjusted R Squared = .065)

Comparison of hydrologic response across forested, cultivated and grazing landuse when rainfall simulation were performed on dry soil was statistical different but when the soil was wet was not statistical different across the forested, cultivated and grazing landuse.

This reveal that land use have much effect the hydrologic response when there is little rainfall below 30 min (*I_{30}*) and the soil is total dry; if rainfall is low not enough to make the soil wet at the certain time so the hydrologic response will differ across different landuses. But when there is enough rainfall which can make soil wet in a short time land use has little effect or no effect at all in hydrologic response of the catchment.

When runoff started time taken to discharge one (1) litre runoff yields data was also collected (Appendix 1). When the land was dry average time taken to discharge one (1) litre runoff yields were 6.14 minutes on cultivation area, 2.94 minutes for grazing area and 9.68 minutes for forested area. Statistical analysis of these data showed that time taken to discharge one (1) litre runoff yields was not statistical different.

When the land was wet average time taken to discharge 1 litre were 1.62 minutes on cultivation area, 1.42 minutes on grazing area and 1.8 minutes on forested area. Also time taken to discharge one (1) litre runoff when the land was wet analysis shows there is no statistical significant differenc between cultivation, grazing and forested land uses. This reveal that time taken to discharge one litre of runoff is not much affected by the land use cause there is no statistical difference on this parameter when rainfall simulation was performed on dry and on wet soil conditions.

Time to end discharge (runoff stops) after rainfall stops was recorded (Appendix 1) whereby when simulation experiment was done on dry land forest area mean time taken to end dischsrge was 1.99 minutes, on grazing area was 4.06 minutes and on gultivation area was 2.31 minutes and when simulation experiment was done on wet land mean time taken to end runoff discharge 3.36 minutes on forest area, 4.28 minutes on grazing area and 2.52 minutes on cultivation area. Statistical analysis of these data (Time to end discharge (runoff stops) after rainfall stops) of simulation experiment on dry and wet land shows there is no significant differenc between cultivation, grazing and forested land uses.

Runoff yields collected after rainfall stops when rainfall simulation experiment was perfomed on the dry land (Appendix 1) showed that mean runoff yields volume collected on forest area was 2.34 litres, on grazing area was 4.03 litres and on cultivation area was 1.53 litres. Statistical data analysis showed that there was a significant difference in runoff yields collected after rainfall stops when rainfall simulation experiment was perfomed on dry land across forest, grazing and cultivation area. When rainfall simulation experiment was done on wet land runoff yields collected after rainfall stops on forest area volume collected was 2.12 litres, on grazing area was 4.6 litres and on cultivation area was 2.73 litres. Statistical data analysis showed that there is no statistical significant difference in runoff yields volume collected after rainfall stops on forest, grazing and cultivated area during rainfall simulation experiment.

As for runoff start time, runoff yields collected after rainfall stops on dry land was statistical different but on wet land was not statistical diferent this show resulted from runoff stat time since runoff start time which was influenced by land use so also runoff yields collected after rainfall stops affected by the land use.

4.3.2 Bulk density

Soil samples which were taken from the experimental plots where rainfall simulation were done they were analyes in laboratory and its bulky were determined (Appendix 1). Average bulky density of the soils taken on the areas where all rainfall simulation experiments were performed were as follows. From cultivation land use soil average bulky density was 1.18g/cm^3, grazing land uses soil average bulky density was 1.34 g/cm^3 and forest land use soil average bulky density was 1.19 g/cm^3.

Soil from grazing land use had the highest bulky density which could be explained by the modifications of soil physical properties by hoof action, thus reduced vegetation cover, often resulting in increased bulk density and penetration resistance of soils (Wood and Blackburn 1981; Blackburn 1984) cited by Donkor (2001). Due to the high bulky density, this results into poor infiltration rates thus accelerating high runoff rates in the grazing land use compared to other land uses (cultivated and forested land uses).

4.3.3 Water quality response to land use

Only one water quality parameter was measured from the runoff yields collected during rainfall simulation experments which was presence of suspended solids (sediments) in water. Runoff yields collected during rainfall simulation experments on forest area, grazing area and cultivation area were analysed in laboratory whereby total suspended solids were measured. Average suspended solids (sediments) founded in the runoff yields from cultivation area was 6.05 X 10^{-4} g/l, forest area was 3.25 X 10^{-4} g/l and grazing area was 9.15 X 10^{-4} g/l. Statistical data analysis of the total suspended solid (sediments) data from the runoff yields from rainfall simulation experiments showed that there were a significant difference across the differentland uses.

These sediments which are carried over by runoff and end up being deposited along the way to the river while other are carried into the river where they get deposited thus resulting into siltation. The siltation in the river may led to rise up of water level due to heavy siltation on the river bed. Changes in the land use and land covers observed in Mvuha sub-catchment have significant impact to the hydrological response of the area since the rainfall simulation experiments revealed significant differences between hydrological response on forested, cultivaton and grazing land uses. This implies that conversion of one land use to another results into changes in hydrological response of the catchment.

From rainfall simulation experiments, results showed that forested land use had the lowest runoff rate (discharge rate) compared to cultivatin ang grazing land uses.This revealed that conversion of forest to other land uses results into increased runoff rate (discharge rate). Also runoff start time when rainfall starts and runoff end time after rainfall stop were different in forested, cultivation and grazing land uses; and is thought to be influenced by changes in land use and land cover.

This has a negative effect on the water balance since the other land uses have high runoff yields during rainfall seasons. Therefore conversion of forest land use into other land uses will lead to increased runoff (flush floods) and river discharge during rainfall time but when rainfall stops there will be no more runoff because a lot of water were already expelled off. The high runoff in grazing land during rainfall is due to high bulky density of the soil on the grazing land that large livestock number lead to soil sealing compactness which results into lower infiltration capacity of water and high runoff. Tate *et al.* (2004) reported that several rangeland studies have shown that soil bulk density is negatively correlated with infiltration capacity and positively correlated with surface runoff (Packer, 1953; 1963; Liacos 1962, Rauzi and Hanson, 1966, Spaeth *et al.*, 1996).

Since forested land use show lowest sediments yields during rainfall simulation experments so conversion of forest to other land uses lead to high sediments yields. Grazing land use which is mainly bushland and grassland have the highest sediments yields and due to the increasing number of livestock in the catchment this leads to high production of sediments which are being deposited in low land and in water area resulting to high siltation in Mvuha river.

Heavy infestation by livestock has lead to the disappearance of the swamps whereby underground water recharge have been affected resulting to total wetland disappearance. Land use change, including urbanization, leads to soil sealing, increasing surface runoff and decreasing infiltration and evapotranspiration, and affects groundwater recharge (ENV/CIS/WG, 2015). Also the grazing activities together with other factors like expansion of human settlements and crop cultivation activities in the wetland areas have resulted to high rates of decreasing of swamps in the catchment.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

The study land use and land cover changes impacts on water balance in Mvuha sub-catchment results show that there are significant land use and land cover changes from 1975 to 2015 which had impacts on the hydrological responses of the catchment like increased runoff, poor infiltration and high sediments yields in runoff. Land use dynamics proceses shows there was high land use conversion is from one land uses to other land uses through different human activities like agriculture expansion, livestock keeping activities and deforestation. The extent of land use land cover conversion from one land use to another shows that forest cover have been reduced in tree density and conversion to other land uses which are woodland areas with low density trees compared to forest, bushland areas dominated by bushes and shrubs and grassland grasses dominated lands. Swamps (wetland) have been disappear year after year due to conversion to cultivated land and grassland. The large percent of earliest land cover have been converted to other land use and land cover.

Rainfall simulation experiments results on different land uses show significant differences of hydrological responses across forested, cultivation and grazing land uses whereby forested land uses had the lowest runoff rate compared to cultivated and grazing land uses. Total suspended solid in runoff yilds forested land uses had 3.25×10^{-4} g/l which is the minimum total suspended solids compared to 6.05×10^{-4} g/l of the cultivated land and 9.15×10^{-4} g/lof the grazing land uses. Since different land uses have diferrent hydrological response and the land uses have changed over time, there are changes in water balance over time due to land uses changes that previous the the large part of the catchment was forest since it have been converted to other land uses the water balance also changed.

High runoff and high sediment yields which experienced in grazing land, resulted to poor water quality and high siltation into the river. Also erosion in river banks results into deposition of sediments into river thus causing siltation in rivers. Since grazing activities are being expanded over time in the sub-catchment, precautions like controled number of animals to keep are needed in order to ensure sustainability of the catchment and good water quality since the river is dependable on supplying water to Ruvu river which is the major source of water to Dar es Saalam city.

The study recommends Wamii-Ruvu water Basin office (WRBO) and all community around the catchment to eradicate deforestation activities in all reserved natural forests and immediately to start afforestation practices in all natural forest cover up the forested area which have been destroyed and to start new forest especial around water sources in order to protects the water sources. All human activities around water bodies like natural dams and river should be stopped so that to ensure suistanability of the catchment. Effects climate change around the catchment water balance should be researched more since it have been not studied .

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APPENDICES

Appendix 1: Runoff start and end time (dry and wet), slope, bulky density, time to discharge 1Litre

Land use	Runoff start time Dry soil (Min)	Runoff start time Wet soil (Min)	Bulky density	Time to End discharge on Dry soil (Min)	Time to End discharge on Wet soil (Min)	Discharge collected after Rain stop on Dry soil (Lts)	Discharge collected after rain stop on Wet soil (Lts)	Time to Discharge 1 Litre on Dry soil (Min)	Time to Discharge 1 Litre on Wet soil (Min)	Slope (Percent)
Cultivation 1	2.12	0.56	1.41	2.58	2.30	2.39	2.32	3.00	1.22	16.00
Cultivation 2	4.02	1.27	1.25	2.11	3.07	0.80	3.47	9.02	2.11	19.00
Cultivation 3	4.09	1.22	0.89	2.25	2.19	1.40	2.40	6.40	1.52	13.50
Grazing 1	2.09	1.11	1.38	2.56	3.10	3.45	3.80	3.07	1.36	21.00
Grazing 2	2.55	1.07	1.24	3.40	3.33	3.55	3.80	4.42	1.37	16.00
Grazing 3	0.51	1.16	1.41	6.22	6.42	5.10	6.20	1.35	1.54	18.00
Forest 1	3.51	1.16	1.00	1.57	2.26	1.01	1.30	7.09	1.44	28.00
Forest 2	14.56	1.15	1.39	1.33	2.27	3.00	1.06	19.87	2.44	20.00
Forest 3	1.06	1.03	1.16	3.07	5.55	3.02	4.01	2.09	1.52	26.00

Appendix 2: Rainfall simulation data (hydrologic response data) discharge collected in every five minutes

	Dry soil rainfall simulation						Wet soil rainfall simulation					
Land use \ Time (Min)	**5**	**10**	**15**	**20**	**25**	**30**	**5**	**10**	**15**	**20**	**25**	**30**
Cultivation 1	4.8	12.7	19	19.59	19.72	23	18.7	26.35	27.4	27.1	27.6	26.56
Cultivation 2	0.01	1.1	2	7.6	6.7	6.6	9.15	17.9	18.6	16.6	12.5	13.2
Cultivation 3	0.21	3.9	9.5	10	9.3	10.4	11.7	23.3	20.7	20.9	20.89	20.3
Grazing 1	5.25	8.6	23.5	23.6	20.1	23.53	8.9	20.7	19.3	20.4	19.6	19.7
Grazing 2	1.3	15.1	20.25	18.7	20.12	19.6	14	24.16	23.91	23.96	22.8	21.23
Grazing 3	12.8	21.1	23.5	23.1	24.1	24.2	17.7	26.6	30.8	26.9	27.8	27.5
Forest 1	0.41	3.59	9.89	10.32	10.46	11.62	9.66	13.84	15.52	15.63	15.79	17
Forest 2	0	0	0.01 (10 ml)	1.01	2.27	2.75	4.34	7.07	7.24	9.13	9.1	9.75
Forest 3	8.6	15.5	19	18.5	18.1	18.6	11.4	22.2	25.3	25.1	25.7	29.9

Appendix 3: Mvuha river Discharge data of 1975-1992

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual total	Average
1975	4.800645	1.9575	6.427419	14.52867	7.939677	2.705	2.354194	-	1.938333	3.788387	2.108333	4.545161	53.09332	4.826665
1976	2.594839	-	-	10.49154	5.576452	5.978667	3.583226	0.364839	-	7.486129	2.351667	2.505806	40.93316	4.548129
1977	4.634516	2.9875	3.753226	9.085333	6.175806	2.377	2.184839	2.097419	9.363	2.388387	4.876	15.9704	65.89343	5.491119
1978	-	4.456429	11.03355	7.637667	3.67129	1.561333	2.047419	1.822903	1.402	1.38	4.270333	13.90871	53.19163	4.835603
1979	6.363871	16.36286	22.33806	64.87654	-	-	-	-	4.167667	4.847742	7.963	6.646129	133.5659	16.69573
1980	7.753871	9.548621	7.508387	20.685	8.33	3.370333	2.117742	2.159677	2.299667	2.117419	4.122333	9.02	79.03305	6.586088
1981	9.171	19.91536	-	30.7924	-	-	5.333871	14.4271	14.24333	4.845161	7.376333	19.38258	125.4871	13.94301
1982	17.52032	3.132143	6.918065	19.05414	-	4.129333	6.795806	5.053871	7.244	27.81355	25.267	17.38065	140.3089	12.75535
1983	13.04097	5.0275	16.65742	28.77433	20.03645	4.553333	10.11161	6.537586	9.568	3.373226	3.367	4.119032	125.1665	10.43054
1984	17.22871	15.04	6.472903	63.89433	26.57484	3.618333	3.01129	0.842581	0.771	6.870968	16.691	10.51452	171.5305	14.29421
1985	8.24871	2.132857	7.261613	16.75233	7.602258	-	2.714194	0.881613	1.221	10.49677	8.930333	5.744516	71.9862	6.5442
1986	8.37871	2.630714	5.653226	16.85733	9.496129	1.44	0.274194	0.817742	0.075	1.333548	3.839667	4.488065	55.28433	4.607027
1987	8.456923	2.907857	4.04	11.78033	-	-	-	-	0.073667	4.660323	7.893333	3.477097	43.28953	5.411192
1988	3.867097	2.584828	5.199677	13.804	0.849032	1.520667	0.478387	0.682581	1.468	0.785484	1.884333	1.868065	34.99215	2.916013
1989	4.969355	0.3375	2.459032	8.126	3.840645	0.438	0.028387	1.996452	0.252	1.42871	0.330333	1.704839	25.91125	2.159271
1990	2.205161	1.392143	8.154194	-	-	-	-	0.736452	0.864483	-	7.937037	2.648333	23.9378	3.419686
1991	2.091333	0.306	1.1975	10.53667	7.424839	-	0.692903	-	-	-	0.165556	0.815172	23.22997	2.903746
1992	-	0.676897	-	-	-	-	0.03871	-	-	-	-	1.540385	2.255991	0.751997

Appendix 4: Mvuha river water level of

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
2007	0.680161	0.384964	0.634138	0.81831	0.726267	0.434034	0.122258	0.32069	0.0816	0.040032	0.2843	0.281065	0.400652
2008	0.167581	0.111241	0.5034	2.653733	0.807387	0.363933	0.287419	0.045355	1.6972	0.109774	0.126233	0	0.572771
2009	0.144097	0.990179	1.870226	1.626167	1.990267	0.938667	0.566613	0.04	0	0	0.144733	0.434323	0.728772
2010	0.174645	0.623536	0.75929	0.836233	0.699129	0	0	0	0	0	0	0	0.257736
2011	0.506452	0	0	1.424167	1.549194	0.6535	0.104355	0	0.623	0.399355	0.257333	1.799032	0.609699
2012	1.153387	0.425172	1.264	1.187	2.358548	0.249167	0.020806	0.012097	0.091667	0.009677	0.1155	1.562742	0.704147
2013	0.514516	0.127679	1.692258	2.374167	0.844839	0.0505	0.018548	0.012903	0.033333	0.917258	0.066333	0.217419	0.572479
2014	0.303226	0.100893	0.881935	2.380167	2.251613	0.7805	0.14	0.35	0.133871	0.639839	0.559833	0.655645	0.764793
2015	0.784138	0	1.362708	1.5585	2.096452	0	0.14	0.35	0.133871	0.354839	2.475833	0.387097	0.80362