LAND COVER CHANGE OF COASTAL MARINE ECOSYSTEMS: A CASE STUDY OF ZANZIBAR

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ABSTRACT

Over the past three decades, coastal marine ecosystems of Tanzania have experienced a notable decline in the state of their environment through loss of natural habitats and biodiversity. Much of this change is attributable to human activities. This study investigated changes that have occurred as a result of human activities and climate change/variability, for the period between 2001 and 2011. Two demographically different locations in Zanzibar, namely Kisakasaka and Bumbwini were selected for the study. Landsat ETM+ images were used to locate and quantify the changes for which the intensity analysis method was employed. The study revealed that between 2001 and 2011, the mangrove, cultivated land/shrubs and bare land covers declined by 127.4 ha (33.9%), 46.0 ha (7.4%) and 10.2 ha (22.6%) respectively while mixed trees, "*Jangwa la bahari*" and water covers increased by 147.2 ha (11.1%), 35.8 ha (119.7%) and 0.6 ha (0.02%) respectively for Kisakasaka location. During the same period, cultivated land/shrubs, mangrove and mixed trees covers declined by 262.2 ha (8.8%), 86.3 ha (12.6%) and 49.4 ha (1.3%) respectively while paddy, bare lands, "*Jangwa la bahari*" and water covers increased by 165.6 ha (37.6%), 109.7 ha (837.4%), 103.9 ha (151.5%) and 18.7 ha (0.8%) respectively for Bumbwini location. The study also revealed significant increases of population from 6 034 and 23 212 to 15 400 (155.2%) and 34 638 (49.2%) from 1988 to 2012 for Kisakasaka and Bumbwini locations respectively. Although long term rainfall data analysis for Zanzibar revealed no significant trend in amount, length of growing season and number of wet days indicated significant negative trends while both mean and minimum temperatures showed significant positive trends. It is concluded that changes in climate together with population pressure have mainly contributed significant changes in land cover observed over the respective study areas. Hence concerted actions are required to reverse the observed/perceived changes.

DECLARATION

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

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DEDICATION

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LIST OF ABBREVIATIONS AND ACRONYMS

AOI	Area of interest
Bugwood	A network of closely related websites focused in the areas of forestry, entomology, invasive species and integrated pest management
CCIAM	Climate change impacts, adaptation and mitigation
CLUE	Conversion of Land Use and its Effects
CMEBM	Coastal marine ecosystems based management
COLE	Commission for lands and environment
CPUE	Catch per unit effort
ECF	East coast fever
ENSO	El-Niño Southern Oscillation
ERDAS	Earth Resources Data Analysis System
ETM+	Enhanced Thematic Mapper plus
ESRI	Earth Sciences Research Institute
FAO	Food and Agriculture Organization of the United Nations
FMI	Finish Meteorological Institute
GIS	Geographical information system
GPS	Global positioning system
H_0	Null hypothesis
H_1	Alternative hypothesis
IOD	Indian Ocean Dipole
IPCC	Intergovernmental Pannel for Climate Change
LULCC	Land use land cover change
MAM	March – April - May

MUIENR	Makerere University Institute of Environment and Natural Resources
NAPA	National Adaptation Program of Action
NEMC	National Environmental Management Council
OND	October – November – December
PRA	Participatory rural appraisal
RGZ	Revolutionary Government of Zanzibar
SPCCSP	Strategic Plan for the Climate Change Science Programme
SPSS	Statistical Package for Social Sciences
SSC	Statistical Services Centre
SSTs	Sea surface temperatures
T1	Initial time
T2	Final time
TMA	Tanzania Meteorological Agency
UNDP	United Nations Development Programme
UNEP	United Nations Environmental Programme
URT	United Republic of Tanzania
USA	United States of America

CHAPTER ONE

1.0 INTRODUCTION

1.1 Problem Overview and Justification

Marine ecosystems are among the largest of the Earth's aquatic ecosystems. They include oceans, salt marshes and intertidal ecology, estuaries and lagoons, mangroves and coral reefs, the deep sea and the sea floor. Marine ecosystems cover approximately 71% of the Earth's surface and contain approximately 97% of the planet's water (Kennedy *et al*., 2002). According to Srinivas (1998), coastal habitats alone accounting for approximately one-third of all marine biological productivity and estuarine ecosystems (i.e., salt marshes, sea grasses, and mangrove forests) are among the most productive regions on the planet. Coastal areas are amongst the most heavily populated areas throughout the world, with about 60% of the world's population living along estuaries and the coast (Nicholls *et al*., 2007)**.**

These habitats provide valuable socio-economic and ecological services, including protection from storm surges. However, over the past three decades, Tanzania has experienced a notable decline in the state of its environment through loss of natural habitats and biodiversity (Leon *et al*., 2004). Much of this change is due to the changes in land use and land cover caused by increasing human population, industrial activities and poorly planned developments (Kabanza *et al*., 2013; Kashaigili *et al*., 2006).

The coast is a uniquely productive and fragile part of the environment; the place where land meets with sea, where multiplicities of human activities occur and where integrated decision making is essential. According to UNDP (2012), the continued degradation of coastal marine ecosystems through increased anthropogenic activities may lead to serious socio-economic problems as well as contribute to vulnerability to climate change. Land degradation can be inferred from land cover changes. Though humans have been modifying land to obtain food and other essentials for thousands of years, current rates, extents and intensities of land use/land cover change are far greater than ever in history, driving unprecedented changes in ecosystems and environmental processes at local, regional and global scales (Zhou and Yang, 2008). These changes encompass the greatest environmental concerns of human populations today, including climate change, biodiversity loss and the pollution of water, soils and air.

Like any other land, the coastal lands have come under increasing pressures from a wide variety of factors, including encroachment, unsustainable harvesting of forest products, invertebrates and fish resources, indiscriminate harvesting of mangroves and conversion of mangrove areas into cultivation, as well as the use of the coastal forests and woodlands for fuel (Leon *et al*., 2004). Coastal ecosystems which include mangroves, floodplains and wetlands are also threatened by developments like house construction and improvement of the road network which makes accessibility to these areas much easier; mining exploration activities as well as urbanization.

Mangroves form one of nature's best ways of combating global warming because of their high capacity for sequestering carbon. Being primary producers, mangroves utilize solar energy and carbon dioxide to produce organic carbon. Much of the carbon fixed by mangroves is retained as standing biomass (Alongi, 2002). Given these characteristics, mangroves are recognized as being more effective "carbon sinks" than terrestrial forests (Alongi *et al*., 2005). If not properly planned and managed, mangrove deforestation and degradation will not only lead to reduced carbon sequestration, but will also result in the release of carbon stored in the trees and sediments to the atmosphere, further contributing to global warming.

Historically land cover change has occurred primarily in response to population growth, technological advances, economic opportunity and public policies (SPCCSP, 2003). Most land cover modification and conversion is nowadays driven by human use rather than natural change (Turner *et al*., 1993). Overpopulation leads to over-utilisation of the land resources, excessive deforestation, and water related problems hence land degradation (Edwards *et al*., 1990).

Unsustainable fishing practices and mangrove forests degradation are the major threats to the sustainability of the coastal marine ecosystems. According to NEMC (2009), over-fishing and increased use of illegal fishing methods have resulted in declining Catch Per Unit Effort (CPUE). The trends of marine fisheries production have declined from 52 935 metric tonnes in 2001 (URT, 2004) to about 43 000 in 2008 (URT, 2008). In addition to the increased fishing pressure in traditional fishing grounds, destructive fishing methods have contributed greatly to undermining the marine ecology and fish habitats through dynamiting the coral reefs and clear cutting of the mangroves. Similarly shallow water trawling for prawns, beach seining and dynamite fishing destroy seaweeds both by uprooting and smothering those which are attached as they put sediments into suspension which ultimately settle on seaweeds (NEMC, 2009).

The mangrove ecosystem plays a crucial part in coastal biodiversity. They include and often host a number of other organisms such as algae, lichens, terrestrial mammals, birds, reptiles, insects, and marine fauna that live in the mud, crawl on the bottom, attach to the roots, stems and branches of mangrove trees or swim in the tidal water.

Owing to their indispensable use by coastal communities in the provision of goods and services and the influence imposed on them through human activities, the mangrove forests have continued to change through time in terms of area coverage, plant community structure, species diversity and density. Such changes do influence other important marine ecosystems such as sea grasses and coral reefs. Data collected recently on mangroves in the mainland coastal districts indicate that during the period 2003 to 2007 tree density, height and species changed and damaged areas increased (NEMC, 2009). Mangrove trees in Tanzania normally attain a height of 4 – 20 m depending on the species (Semesi and Mzava, 1991). Data that was gathered recently, indicate that the mangrove tree height ranges from less than 2 m comprising mostly seedlings to mature trees of about 10 m (NEMC, 2009).

Mangrove forests in the coastal areas of Tanzania are subject to a number of threats which consequently may lead to biodiversity loss and degradation of the whole coastal ecosystems. If not promptly checked, complete extinction of endemic animals or plants may occur. However, major causes or driving forces of biodiversity loss are those associated with the use of natural resources at the local level. Threats to mangrove forests and their habitats include: clearing, over-harvesting, destruction of coral reefs, pollution, climate change and climate variability (NEMC, 2009).

However, in Zanzibar the situation is somehow different from what is happening in Tanzania mainland; the coastal ecosystems have often been cleared to make room for agricultural land, human settlements, infrastructure and industrial activities. More recently, clearing for tourist developments, shrimp aquaculture, and salt farms has also taken place. This clearing is a major factor behind ecosystems loss along the coastal areas of Zanzibar. It is estimated that over 500 hectares of coral rag forest is cleared each year (FAO/UNEP, 1999) while hundreds of trees are cut in deep fertile western side of the island just for construction (e.g. on the east coast of Unguja island there are now 22 hotels compared to none in 1988 (RGZ, 2010)).

Rapid population growth in Zanzibar island over the last three decades has created a significant challenge to land use development in the island (RGZ, 1995). According to Masore (2011), it was estimated that the island at that time has a population of about 1.193 million people based on a population growth rate of 3.1% and a population density of 400 persons km^{-2}. The growing population has led to a higher demand for settlements, agriculture and other infrastructure developments which in turn has an impact on the resource base, threatening the productive and protective capacity of the marine resources (Kombo, 2010).

According to Makota (2011), effective and efficient land use and natural resources management highly depends upon adequate and accurate data and information. This study aimed to investigate land cover change and the driving factors in the coastal marine ecosystems of Zanzibar under the scenario of climate variability and change in order to provide information for coastal marine ecosystem based management (CMEBM) programmes. This knowledge is important for strengthening stakeholders so that they can be able to use and manage the land resources sustainably.

1.2 Objectives

1.2.1 Overall objective:

To quantify the magnitude of land cover change, both spatially and temporally, of coastal marine ecosystems for sustainable coastal marine ecosystems based management programmes.

1.2.2 Specific objectives:

i. To determine land cover changes along the coastal marine ecosystems of Zanzibar for the period 2001 to 2011.

ii. To evaluate factors influencing the dynamics of land cover along the coastal marine ecosystems of Zanzibar for the period 2001 to 2011

iii. To characterize climate parameters over Zanzibar for the past sixty years.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Definitions and Basic Concepts on Land Use/Cover

2.1.1 Land

Land is one of our most precious assets, and its use is multi-facetted. Land represents surface and space; it provides food, it filters and stores water; and it is a basis for urban and industrial development, leisure and a wide range of social activities. Land also stands for property, and is a production factor because of the vegetation and crops that can be grown on it. It even embodies a number of non-material dimensions, such as homeland, place of ancestry, a basis for survival or wealth. It is also an object that is taxed and desired by governments and interest groups.

Land is a delineable area of the earth's terrestrial surface, encompassing all attributes of the biosphere immediately above or below earth's surface, including those of the near-surface climate, the soil and landforms, the surface hydrology (shallow lakes, rivers, marshes, and swamps), the near surface sedimentary layers and associated ground water reserve, the plant and animal populations, the human settlement pattern and physical results of past and present human activities (FAO, 1995).

2.1.2 Land use and land cover

There is a close relationship between land cover and land use. However, land cover observation does not automatically mean land use, because land cover and land use, though interrelated, are not identical. The land use connotation entails interference by humans and an underlying intention to turn the natural land resources into a beneficial output. It entails both the manner in which the biophysical attributes of the land are manipulated, and the intent underlying that manipulation, namely, the purpose for which the land is used.

According to the FAO (1976), land use defines the human activities which are directly related to land, making use of its resources, or having an impact on them. In that context the emphasis is on the function or purpose for which the land is used and particular reference is made to the management of land to meet human needs.

Land use is the total of arrangements, activities and inputs that people undertake in a certain land cover type to produce, change or maintain it (FAO/UNEP, 1999). The land use choices made will vary in space and time and so will result in land cover (Cihlar and Jansen, 2001).

Land cover refers to the observed physical and biological cover over the surface of land, including water, vegetation, bare soil, and/or man-made features (FAO, 1997; FAO/UNEP, 1999; Zhou and Yang, 2008**).** Studies by Meyer and Turner (1996) showed that land use (both deliberately and inadvertently) alters land cover by converting the land cover, or changing it to a qualitatively different state; modifying it, or quantitatively changing its condition without full conversion; and/or maintaining it in its condition against natural agents of change. Many studies (Ngalande, 2002; Rugenga, 2002; Vanacker, 2002; Mbilinyi, 2000) have revealed the effect of human activities or arrangements (land use) on land cover.

2.1.3 Land use and land cover changes

Land cover change is a general term for the human modification of Earth's terrestrial surface. It has been defined as quantitative change in areal extent (increase or decrease) of a given type of land use or land cover (Briassoulis, 2000). Such changes have been occurring rapidly and involve large areas, especially in developing countries, and their influence on environmental conditions may easily be as large as the effects of climatic change (Vanacker, 2002).

Most of the land use/cover changes of the present and the recent past are due to human actions resulting from uses of land for production or settlement (Veldkamp and Fresco, 1995). Land use and land cover change is largely driven by the need to meet the increasing resource consumption (energy and food) of the expanding human population (Houghton *et al*., 1991).

According to Ellis and Pontius (2010), changes in land use and land cover dating to prehistoric era are the direct and indirect consequence of human actions to secure essential resources. Though humans have been modifying land to obtain food and other essentials for thousands of years, current rates, extents and intensities of land use and land cover changes are far greater than ever in history, driving unprecedented changes in ecosystems and environmental processes at local, regional and global scales. These changes encompass the greatest environmental concerns of human populations today, among others including climate change and biodiversity. Monitoring and mitigating the negative consequences of land use/land cover changes while sustaining the production of essential resources has therefore become a major priority of researchers and policymakers around the world (Ellis and Pontius, 2010).

2.2 Land use/cover change

2.2.1 Accuracy assessment

Accuracy assessment or validation has become a standard component of any land cover or vegetation map derived from remotely sensed data (Congalton, 2005). When generating thematic map from remotely sensed data, errors are inevitable. Congalton and Green (1993) provide a good number of sources of error that can be accumulated from the beginning of a mapping exercise through to the end. Ground or reference data collection is important and must be taken very carefully, though no reference data set may be completely accurate (Congalton, 2005; Liwa, 2006).

In statistical context, accuracy comprises bias and precision and the distinction between the two is sometimes important as one may be traded for the other (Foody, 2002). In thematic mapping from remotely sensed data, the term classification accuracy is typically taken to mean the degree of 'correctness' of a map or a classification. Many methods of accuracy assessment have been discussed and used in remote sensing (Foody, 2002; Jenssen and Van der Wel, 1994; Aronoff, 1982). The method that is used in this study is derived from an error matrix or confusion matrix. Error matrix is a comparison between sampled areas on the map generated from remote sensing data and those same areas as determined by reference data (Congalton, 1991; Congalton and Green, 1993). According to Liwa (2006) the error matrix is a cross tabulation of the classified class labels against those observed on the ground for a sample of cases at specified locations.

Many measures of the classification accuracy may be derived from the error matrix. One of the most popular is the percentage of cases correctly allocated. This is an easily interpretable guide to the overall accuracy of the classification. When attention focuses on the accuracy of the individual classes, then the percentage of cases correctly allocated may be derived from the error matrix by relating the number of cases correctly allocated to the class to the number of cases of that class. This is achieved from two stand points, giving rise to terms 'user's accuracy' and 'producer's accuracy', depending on whether the calculations are based upon the matrix's rows or columns marginal. The producer's accuracy shows the proportion of pixels in the reference data set that are correctly recognized by the classifier. The user's accuracy measures the proportion of pixels identified by the classifier as belonging to the class that agree with the reference data (Liwa, 2006).

2.2.2 Land use/cover change detection

Change detection is a very common and powerful application of satellite based remote sensing. Change detection analysis entails finding the type; extent and location of changes in land use and/or land cover (Yeh *et al.*, 1996). According to Lambin (1997), land use and land cover change analysis is an important tool to assess global change at various spatial–temporal scales. According to MacLeod and Congalton (1998), change detection on land cover focuses mainly on four aspects, namely; (a) detecting if a change has occurred, (b) identifying the nature of the change, (c) measuring the areal extent of the change, and (d) assessing the spatial pattern of the change. With the growing use of remote sensing, some studies have embarked on assessing and improving the methods for change detection (e.g. Fraser *et al*., 2009, 2005), while others are looking at the accuracy (e.g. Stehman *et al*., 2009; Foody, 2002; Zhang and Foody, 2009) and intensity analysis (Aldawik and Pontius, 2012). The assessment of spatial patterns of land cover changes over a long period using images of multi-temporal coverage is now possible considering the accumulation of remotely sensed images over the past decades; as such making it possible to generate an understanding of the drivers for the changes.

Many studies have been done in detecting land use/cover changes. For example, Kabanza *et al.* (2013) detected changes and identified local and global drivers of land-use/cover changes over south eastern Tanzania. Dewan and Yamaguchi (2009) quantified the patterns of land use and land cover change for the last 45 years for Dhaka Metropolitan that formed valuable resources for urban planners and decision makers to devise sustainable land use and environmental planning. Kashaigili *et al.* (2006) looked at the dynamics of Usangu plains wetlands using remote sensing and GIS as management decision tools.

2.2.3 Methods used for land use/cover change detection

Various algorithms are available for change detection analysis (ERDAS, 1999; Jensen, 1996; Singh, 1989) and they can be grouped into two categories namely (a) pixel-to-pixel comparison of multi-temporal images before image classification, and (b) post-classification comparison (Jensen, 1996). Different change detection algorithms have their own merits and no single approach is optimal and applicable to all cases. In practice, different algorithms are often compared to find the best change detection results for a specific application.

A post-classification comparison method is the most common approach (Mundia and Aniya, 2006; Jensen, 1996) for comparing data from different sources and dates. The approach identifies changes by comparing independently classified multi-date images on pixel-by-pixel basis using a change detection matrix (Yuan and Elvidge, 1998). The advantage of post-classification comparison is that it bypasses the difficulties associated with the analysis of images acquired at different times of the year and/or by different sensors (Yuan *et al*., 2005; Coppin *et al*., 2004; Alphan, 2003).

The post-classification method has been found to be the most suitable for detecting land cover changes (Wickware and Howarth, 1981) since it enables estimation of the amount, location, and nature of change. The matrix analysis produces a thematic layer that contains a separate class for every coincidence of classes in multi-date dataset. Although, the use of a change-detection matrix provides detailed information on the nature of changes, misclassification and misregistration may affect the accuracy of the results, since the accuracy of the change maps depends on the accuracy of individual classifications and subject to error propagation (Yuan *et al*., 2005; Zhang *et al.*, 2002).

The post classification method approach has been applied by a number of researchers; Ngalande (2002) used a similar approach to assess the impact of land use on land resources in Zambia. The author reported that the method was adequately used in area estimates and spatial assessment of environmental impacts particularly its ability to show the details of land use/cover transformations. Mbilinyi (2000) also used the method to assess land degradation in Iringa, Tanzania. The author reported that the method through the use of a change detection matrix provides advantage of giving detailed from-to information whereby land use/cover transformation becomes clearer. Kashaigili and Majaliwa (2010) used this method to assess the land use/cover change in Malagarasi River catchment while Namangaya (2011) used the method to evaluate resource use conflicts in protected coastal areas, their origin and management options in Mnazi Bay Ruvuma estuary. Kashaigili *et al.* (2006) also used the method to evaluate the dynamics of Usangu plains wetlands.

Aldwaik and Pontius, (2012) provide accounting methods to analyze land categories for three or more time points (which define two or more time intervals), and call the method as Intensity Analysis. The change analysis is carried out in terms of size and intensity at three levels, starting from general to more detailed levels, in order to extract three types of information, i.e.; at interval, category and transition levels. At interval level, the method examines how the size and annual rate of change vary across time intervals. At the category level, the method examines how the size and intensity of both gross losses and gross gains vary across categories for each time interval. And at transition level, the method analyzes how the size and intensity of a category’s transitions vary across the other categories that are available for that transition. At each level, the method tests for stationarity of patterns across time intervals.

2.3 Drivers of land use/cover changes

As mentioned by Lambin *et al*. (2003) and Geist and Lambin (2002) landuse/cover changes are driven by a complex of underlying causes, rather than by often claimed single factors such as 'shifting cultivation' or 'increasing population' pressure. Factors contributing to land cover changes are multi-directional. Land cover change in Zanzibar like other places of the world could have been attributed by a combination of factors which can be grouped in two; namely anthropogenic and biophysical (natural) factors. The main activities that contribute to land cover change includes expansion for agriculture (Wegner *et al.,* 2009; Hieronimo, 2007; Leopold, 2002), pole cutting and logging (Ahrends, 2005), charcoal production and fuel wood (Ahrends, 2005; Leopold, 2002), uncontrolled fires (Wegner *et al.,* 2009) and policy failure (Leopold, 2002).

The monitoring of land use/cover changes would be most relevant and useful when it is accompanied by the understanding of the forces driving change processes (Lambin *et al*., 1999). Demographic factors are the main drivers of land use/cover changes at all scales, whereas, the biophysical conditions merely act as constraints to where and what changes would take place in a certain area (Veldkamp and Fresco, 1995).

The driving forces of land use and land cover change are multifaceted. They may change in relative influence over time, and their impact will vary as the local context changes. In studying the nature of land use changes, Briassoulis (2000) distinguishes between three major types of changes: land use/cover conversions, corresponding to changes from one type to another; land cover/use modifications, which refer to alterations in the structure or function without a wholesale change from one type to another; and the maintenance of the land in its current conditions against agents of change (Briassoulis, 2000). In the case of agricultural land use, the changes may include intensification, extensification and marginalization.

2.3.1 Biophysical drivers

Land use may vary in nature and in intensity according to both the purpose it serves, whether it is food production, recreation, or mining, and the biophysical characteristics of the land itself. Hence, land use is shaped under the influence of two types of driving forces: human needs, and natural environmental features and processes. As found by Meyer (1995), land cover can be altered by forces other than anthropogenic. Natural events such as weather, flooding, fire, climate fluctuations, and ecosystem dynamics may also initiate modifications upon land cover. Rainfall as one of biophysical factors has been found to be a major factor that precludes changes in open spaces and sparsely vegetated areas into natural vegetation.

The study carried in Uganda by Mugisha (2002) has shown that shock events such as droughts, external factors, government policies, prevalence of disease, migration and landless people in societies that are a) overpopulated, b) willing to adopt new cultural and technological norms and c) capable of living in harmony with immigrants result in significant land cover/use changes. In addition, a research conducted by MUIENR (2002) revealed that knowledge of land cover/use changes is an indicator of societal conflicts, food insecurity and poverty.

2.3.2 Socio-economic drivers

2.3.2.1 Population growth

Globally, land cover today is altered principally by direct human use: by agriculture and livestock raising, forest harvesting and management and urban and suburban construction and development. There are also incidental impacts on land cover from other human activities such as forests and lakes damaged by acid rain from fossil fuel combustion and crops near cities damaged by tropospheric ozone resulting from automobile exhaust (Meyer, 1995). Hence, in order to use land optimally, it is not only necessary to have the information on existing land use/land cover but also the capability to monitor the dynamics of land use resulting out of both changing demands of increasing population and forces of nature acting to shape the landscape.

The consequences of population growth had been earmarked by many researchers on land use/cover change. As population increases; expanded growth begins to distort the environment, leaving what scientists call an ecological footprint since each person has certain basic needs such as land, water and energy use (Mohanty, 2009). According to Mishra (2002) population density has positive and significant impact on agricultural intensification over the decade in India. The massive population in developing countries is living below poverty line, in which mostly depend on non-sustainable agricultural practices and relatively small scope for further expansion of agricultural land which leads in environmental degradation and hence land use/cover change. (Mohanty, 2009).

According to Lompo *et al*. (2000), population growth from the 1960s onwards in Burkina Faso has had a major impact on the production and land management in Kirsi. In the past, vegetation was abundant and this helped to maintain high fertility as leaves fell and decomposed in the soil.

Studies conducted in Uyui district, Tabora region, Tanzania, revealed that from 1988 to 2002, the average household size increased by 2-fold which resulted in increased pressure on limited land resources including fuel wood for tobacco curing, charcoal, timber and agricultural land. This trend resulted in massive clearance of miombo woodland which was decreasing at a rate 8.5% and 5.4% per year for the period between 1970 to 1980 and between 1980 and 1997 respectively (Mbilinyi *et al*., 2004).

In the Uluguru Mountains, Tanzania, population has been increasing since the Waluguru people arrived in the area more than 300 years ago (Temple and Rapp, 1972), from the Ubena Plains, where they were pastoralists. Due to the fact that their cattle were subsequently decimated by the East Coast Fever (ECF), they resorted to farming with massive clearance of forests for agriculture. Since then, population density on the slopes of the Uluguru Mountains has been reported to be on the increase (>150 persons/km^2 in many areas) with an annual rate of 2.8% and more than 6.5% in some places (Lyamuya *et al*., 1994). As a result of this trend, agricultural area has been fragmented to small farm plots of about 0.8 ha to 0.9 ha as observed by Senkondo (1993).

2.3.2.2 Land tenure

Land acquisition is one of the factors that has been and is believed to be a root cause of accelerated natural resources degradation in many areas (Bugwood, 2002). In Machakos, Kenya, it was observed that customary land tenure system allowed private rights in land and hence free conversion of uncultivated land to arable use (Tiffen *et al*., 1994). It was further observed that this type of land tenure system encouraged conversion of grazing land to arable use and increased investments in arable land thus reducing land degradation. The study by Mbilinyi *et al*. (2004) showed that villagization programme in Tanzania had influence on household field plot sizes where individual households were allocated land ranging from 1 to 10 ha which overtime became fragmented as a result of increased population.

The study by Wilfred (2004) in some villages of the Uluguru Mountains, Tanzania, revealed that land acquisition by inheritance was 29% and purchase was 12%. Other acquisition modes involved borrowing 28%, renting 19%, and communal land 13%. From this study it was observed that inheritance was dominant in the area, but now it is losing its popularity because of land scarcity and has brought about fragmentation of land into small plots. The author also observed further that the changing land acquisition system from pure inheritance to a combination of inheritance, purchase, renting, borrowing and communal ownership has some conservation implications including agroforestry.

2.3.2.3 Farming practices

Productive land in Tanzania is becoming degraded due to inadequate attention given to appropriate farming practices resulting in slush and burn, shifting cultivation, cultivation along the slope especially in mountainous areas, and overgrazing (Mbegu, 1988). The Uluguru Mountain ranges of Tanzania, for example are dominated by farming practices whereby farmers cultivate along slopes and agricultural sustainability is at stake due to ever increasing soil erosion particularly landslides. It has been reported that agricultural land use in these mountains has changed drastically over the last 20 years (Kimaro, 2003). It has also been found that a common rotation was two to three years followed by a fallow period of three to four years and temperate vegetables were cultivated on a small scale.

According to Kimaro (2003), after 1980s the intensification of cropping systems increased due to population increase, land scarcity and expansion of the nearby Morogoro municipality and Dar es Salaam city. Due to this, fallow cultivation and crop rotation were discouraged and continuous cultivation intensified (Kilasara and Rutatora, 1993). The increase in demand of the vegetables especially in Morogoro municipality and Dar es Salaam markets has necessitated not only an increase in the area under cultivation on these slopes but also the use of improved methods of irrigation such as ditches and drag hose sprinkler irrigation system (Lulandala *et al*., 1995). Lompo *et al*. (2000) reported that as pressure on productive land grew due to population increase in Burkinafaso; farmers abandoned the practice of leaving fields for fallow as they could only survive by cultivating continuously even if this exhausted the soils.

The study done by Kimaro (2003) revealed that most farmers in the northern slopes of Uluguru Mountains practised poor land husbandry without proper soil and water conservation measures and there has also been discouragement of fallow cultivation and crop rotation in the area. The adverse effect of poor land husbandry coupled with deforestation (for fuel wood, building material and land clearing for cultivation) are already being felt in the area for their contribution to the sedimentation of water courses and reduction of crop yields (UNEP/IISD, 2005; Kimaro, 2003; Munishi *et al*., 1998).

2.4 Climate Characteristics, Variability and Change

The evidence indicating significant changes in global climate over the past century has been presented in the Intergovernmental Panel on Climate change (IPCC) Fourth Assesment Report (2007a). Climate change is expected to challenge the adaptive capacities of many different communities, and overwhelm some, by interacting with and exacerbating existing problems of food security, water scarcity and the scant protection afforded by marginal lands (Brown, 2007). It has been pointed out that most probably extreme weather events (storms, floods, droughts) and changes in mean temperatures, precipitation and sea level rise will in many cases contribute to increasing levels of mobility. The average global surface temperature has warmed by 0.8°C in the past century and 0.6°C in the past three decades. According to National Research Council (2006, 2009), the last few decades of the 20th century were the warmest in the past 400 years. The Intergovernmental Panel on Climate Change has projected that if greenhouse gas emissions, the leading cause of climate change, continue to rise, the mean global temperatures will increase by 1.4 – 5.8°C by the end of the 21st century (IPCC, 2001a).

Recent scientific evidence suggests that the frequency and severity of climatic extremes is increasing, making adaptation an absolute necessity (IPCC, 2001b; UNEP, 2008). Though the occurrence of these events in most cases is beyond human control, opportunities exist to reduce the adverse effects of these events by formulating effective and efficient adaptation strategies.

Rainfall studies are of utmost utility for understanding nature and hence the behavior of climate changes (Maragatham, 2012). Changing precipitation pattern, and its impact on surface water resources, is an important climatic problem facing society today. Associated with global warming, there are strong indications that rainfall changes are already taking place on both the global and regional scales (India receives about 80% of its total rainfall during the summer monsoon season, from June to September (Sahai *et al.*, 2003)).

All regions of Tanzania and Zanzibar in particular are influenced by the El Niño-Southern Oscillation (ENSO) events and sea surface temperatures in the Indian Ocean (Indian Ocean Dipole) (Kijazi and Reason, 2005). Although differences exist between the exact effects of El Niño the broad pattern is increased rainfall during El Niño years and decreased rainfall during La Niña years, frequently leading to floods and droughts (Kijazi and Reason, 2005). Flooding is particularly severe when an El Niño year occurs in combination with the positive phase of Indian Ocean Dipole as was the case in 1997. In Zanzibar, extreme weather conditions have been experienced and recognized; recently winds have reportedly become stronger. Some villages have been flooded occasionally and the people report that rains have become less reliable in their life time.

2.5 Trend Analysis

A set of observations or data taken at specified a time usually at equal interval is called a time series. The time series analysis is helpful to compare the actual performance and analyze the cause of variations. By comparing different time series; important conclusion can be drawn (Maragatham, 2012). In this study, rainfall and temperature series represent the time series. There are four types of movements (components) of time series namely secular trends, seasonal variation, cyclical variations and irregular or random movement. In all four components ‘trend’ is a common terminology used. The variables are observed over a long period of time and any changes noted and calculated, and a trend of these changes is established (Maragatham, 2012).

Though there are several methods (techniques) have been developed in finding the trend and forecasting; the finding suitable method is an important task, because the rainfall trend is very crucial for the country in many sectors, particularly in agriculture, economic development and planning (Maragatham, 2012). Mann-Kendal test method has been used by many researchers to find statistical significance of trends. Ghalharia *et al.* (2012) have used the method in determining the seasonal and annual trend of temperature and rainfall in Iran. The results of their research indicate that the seasonal and annual precipitation do not have significant trends. Karmeshu (2012) conducted a study which focused on detecting trends in annual temperature and precipitation for the nine states in the North eastern United States using Mann-Kendal test. Results show that; the states of New Hampshire and Maine do not show statistically significant trends in precipitation.

Karabulut *et al.* (2008) used the method to find the trends in precipitation and temperature in Samsun. The results showed that there is no negative or positive statistically significant trend in their study area, despite of slight precipitation decrease in winter for the period of 1931 – 2006. Results of temperature trend analyses represent statistically significant trend for the period of 1974 – 2006. Results of this study do not deviate much from the findings of other studies such as those mentioned above.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Description of the Study Area

3.1.1 Selection and location of the study area

Zanzibar, which is part of the United Republic of Tanzania, consists of two main islands of Unguja and Pemba and about 50 other small islets. The islands are located 40 km off the mainland coast of East Africa in the Indian Ocean. The two main islands are 50 km apart separated by the 700 metre deep Pemba channel. The total surface area of Zanzibar is 2 654 km^2. The name Zanzibar refers to three different issues: the semi-autonomous state of Zanzibar, the island of Zanzibar (in Swahili Unguja) and finally the town of Zanzibar. This study uses the term Zanzibar referring to the island of Unguja, and therefore the data collected and analysed were based on Unguja, in Bumbwini and Kisakasaka (Fig. 1). It lies between latitudes 5° 40' and 6° 30' South; and longitude 39° and 40°East. It is about 85 km in length and 39 km in breadth at its broadest point. Its area is about 1 660 km^2. The study area was selected based on the fact that it is a pilot study area for the climate change, implication and mitigation (CCIAM).

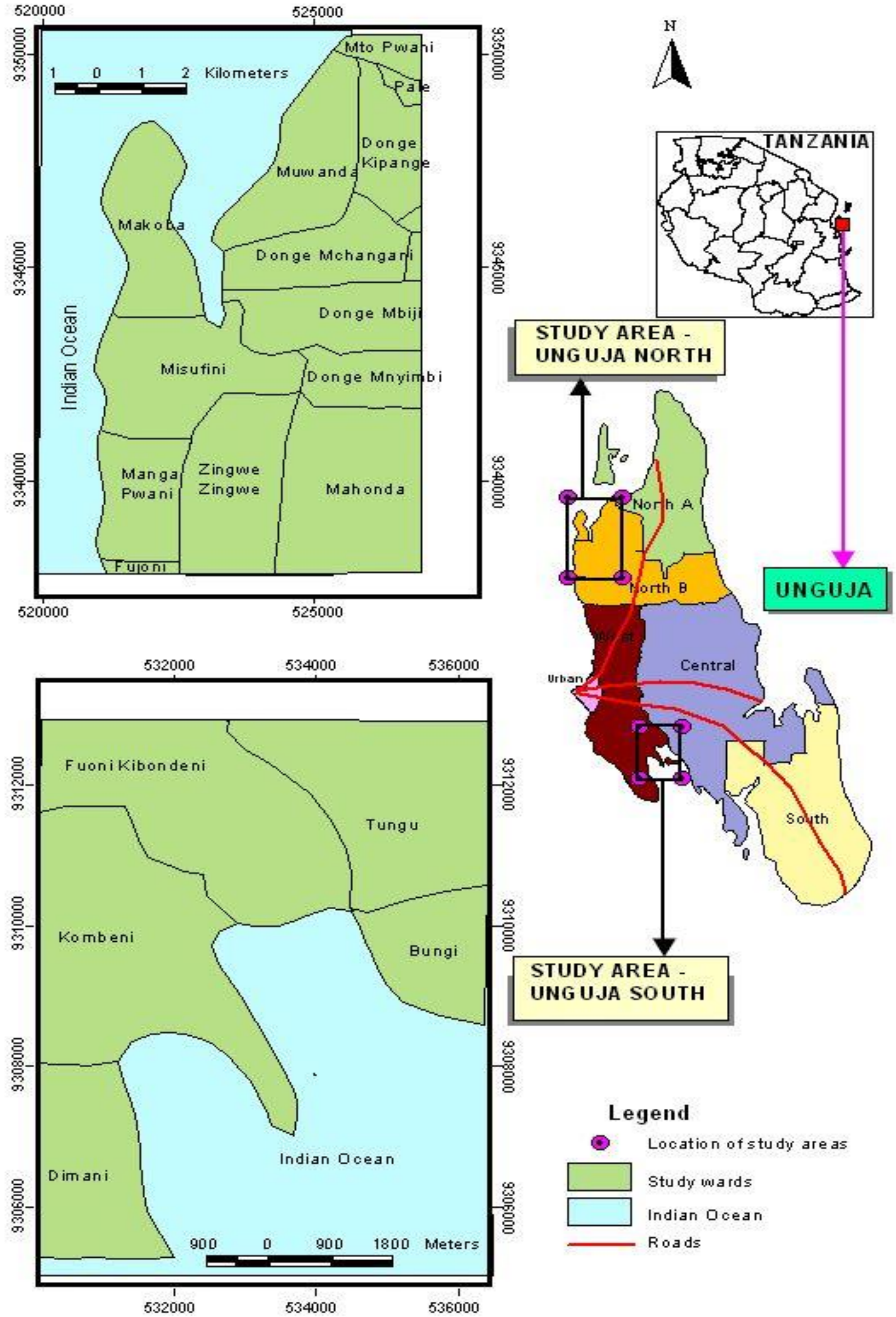

Figure 1: A map showing geographic location of the study area

3.1.2 Topography

Zanzibar is characterized by wide valley corridors, fault structures and residual hills reaching a maximum of about 117 meters above mean sea level in the central part, at Masingini. It is divided into two main geographical parts along a north-south division line: a fertile western part called "*Shamba"* with rich agricultural land and some hilly areas and unfertile land called "*Wanda"* on the eastern part (Scholz, 2008). The western part of Zanzibar is also characterized by elevated and undulating terrain (Kahyko, *et al*., 2008). Unguja Island is elongated and indented only sparsely with a stand of mangrove.

3.1.3 Population

According to the population census of 2012, Zanzibar (Pemba inclusive) had a population of 1 303 569 people at a growth rate of 2.8% and population density of 530 people per square kilometre (URT, 2013). This indicates that Zanzibar is one among the highly populated islands in the world. This has also a direct implication on resource demand for agriculture, forest products, tourism industry, as well as for settlement development.

3.1.4 Soils

Soils of Zanzibar can be categorised into upland soil types differentiated by geomorphology and lowland soils whose parent material forms the basis for classification. In general, soils of the western side of Zanzibar are deeper than those of the eastern side. Generally, the soils of the study area are well drained, moderately deep to deep red, yellowish red or orange sands and loamy sands with somewhat low natural fertility.

3.1.5 Climate

The climate of Zanzibar is characterized by four distinct seasons. The hot season (Kaskazi) is between December and February with little or no rains. "*Masika"* is the long rainy season from March – May. The relatively cool dry season with strong winds (Kipupwe) occurs between June and September, when light showers (Mchoo) may occur. "*Vuli"* is the short rainy season from October – December. Hence the rainfall regime can be described as bi-modal. The annual mean rainfall amount in Zanzibar is 1649.5 mm/yr. Temperatures are high during the short dry season of January to February, with maximum mean of 30.6°C, and low during the cool season lasting from May to September with mean minimum temperature of 21.8°C.

The relative humidity is high, with a monthly average ranging from 87% in April (Masika) to 76% in November (Vuli*)*, and a minimum of 60% during the dry season. Therefore, with humidity values in the range of 80%, daily temperatures can sometimes be as high as 40°C particularly in the night when the land is braced with hot breezes. Generally, the climate of Zanzibar is tropical and maritime, characterized by the monsoon trade winds.

3.1.6 Vegetation

The island was originally forested, but pressures such as population increase, human habitation and climate change and variability have resulted in widespread clearing, although a few isolated pockets of indigenous forests remain. Coastal vegetation has been cleared to allow development of beach-front properties in order to promote tourism. Therefore, there is a noticeable decrease in vegetation, especially in the west side of the island, which has experienced the greatest decrease in vegetation. There are only few places which are covered by dense green vegetation. Also economic dependence on agriculture has encouraged deforestation to increase the amount of land available for cultivation. The main crops in Zanzibar are coconuts and cloves. Bananas, citrus fruits and other spices are also grown commercially. Maize, cassava and other vegetables and cereals are grown for local consumption.

3.1.7 Land use and land tenure

The pattern of land uses in Zanzibar generally follows the distribution of different soil classes. The permanent, settled agricultural activities are carried out in the so called deep soil areas (western part of Zanzibar) while other activities such as tree felling, shifting cultivation and grazing are largely conducted in the coral-rag and mangrove areas (FAO, 1995). Over time the landscape of Zanzibar has modified into a predominantly agricultural landscape. Today cropland covers over 50 000 hectares or about a third of the area of Zanzibar (Klein, 2008). Land tenure system of Zanzibar is a complex combination of traditions and government legislation. Since the 1964 Revolution, all the land technically has been owned and controlled by the state. Although a number of Acts and pieces of legislation provide the officially recognized legal basis of the tenure system, traditions and community rules still play an important role.

Though the land was nationalized soon after the Zanzibar revolution in 1964, several tenure systems exist within the islands. With nationalization of land people had the right to own and sell only crops and structures located on a piece of land but could not sell land because it belongs to the State. In villages people still own land under customary law. There is also land "*wakf*" which is dedicated specifically for religious use and no one including the Government could use it for a different purpose.

3.1.8 Coastal marine resources

Mangrove forests located in various places on Zanzibar's coastline provide a means for livelihood for a large number of people. Direct harvesting for building materials and collection of firewood from the adjacent coastal thickets are common but according to forest protection laws in Zanzibar, such activities are mostly illegal since all the mangrove forests were declared forest reserves by Government. However, such laws are difficult to enforce and, strictly speaking, for some communities a life without encroaching the mangroves is next to impossible, since the only easy option is to use building materials from mangroves and clove trees. Beekeeping and crab gathering are also common activities in most mangrove forests of Zanzibar.

Other marine resources include coral reefs, seagrass beds, and sandy beaches. With more than 200 000 km^2 of coral reefs and plenty of seagrass beds, the undersea marine environment is one of the best in East Africa.

3.2 Pre-field Work

3.2.1 Collection of materials and relevant data

The collection and study of the following materials were done:

- Topographic map at the scale of 1:50 000 year 1985

- Satellite images- Landsat 2001, 2009 and 2011
- Aerial photographs of 2005 at a scale of 1:50 000
- Population data for 1988, 2002 and 2012
- Hand held Global Positioning Systems (GPS) receiver
- A digital camera

3.2.2 Interpretation of maps, aerial photographs and satellite imagery

In preparation for land cover mapping, stereoscopic examination of aerial photographs/satellite imagery of Zanzibar for the year 2001, 2009 and 2011, at a scale of 1:50 000, was carried out. Topographic map at a scale of 1:50 000 was also interpreted visually to complement the aerial photograph/satellite imagery interpretation. The elements land use/cover, vegetation cover, relief, drainage patterns, road networks and settlements were considered in the interpretation. Land cover and geomorphic features for 2001, 2005, 2009 and 2011 aerial photographs/satellite imagery were interpreted following procedures outlined by Dent and Young (1981) and Lillesand and Kiefer (2000). The georeferenced land cover maps obtained were imported into GIS environment using ERDAS software.

3.2.3 Image pre-processing and classification

Remotely sensed data from Landsat ETM+ were processed using ERDAS Imagine 9.1 software. These Landsat imageries were orthorectified using the UTM projection, zone 37 with Clarke 1880 spheroid and Arc 1960 datum. An area of interest (AOI) was selected based on a criterion that the mangrove forests of Kisakasaka and Bumbwini are included among other land covers along the coastal marine ecosystems. This AOI was used to subset the three Landsat ETM+ imageries of 2001, 2009 and 2011 using ERDAS Imagine for both study areas. Landsat imageries were processed (classified) to generate land cover types and also analysed to determine changes that have taken place within the study areas between years 2001 and 2011. Aerial photos of 2005 and topographic map of 1985, both at a scale 1:50 000 assisted in image interpretation and classification.

An ERDAS image processing system was used for all image data processing. The unsupervised image classification was used for all images followed by supervised classification. Seven classes for Bumbwini and six classes for Kisakasaka were formulated and confirmed through the use of ground-truth data and colour-composite images. Misclassified classes were interpreted visually and the results placed to the respective classes. The classes of interest included water, mangrove, jangwa la bahari/cleared mangrove, mixed trees (with settlements), paddy (for Bumbwini only), scrubs/crop (cultivated) land, and bare land. Mixed trees were interpreted together with settlement because houses in the area are mostly covered with palm trees, for which to separate the two covers based on landsat interpretation was very difficult. The spectral reflectance for jangwa la bahari and cleared mangrove, and cultivated (crop) land and scrubs were also difficult to differentiate, hence accounted in the same classes.

3.2.4 Images analysis

Recoding of classes was done in ERDAS Imagine, and then areas for each land cover category were calculated for the respective years. Change detection is a process of comparing any two datasets from the same area acquired at different times. In order to assess the land cover changes, comparison of maps of the same area at two different times (T1 and T2) say 2001 and 2011 for this case was done. This is a common technique in a GIS environment and interpretation of the comparison results would lead to the conclusion that the differences between the maps at T1 and T2 indicate land cover change (Campbell, 1997).

In this particular study, comparisons of 2001 – 09, 2009 – 11 and overall change of 2001 – 11 were done by performing matrix analysis in ERDAS software to determine the land cover changes in the study area. Therefore areas of changes were determined for each land cover category and the change detection matrix that shows the *"from-to"* change categories, persistence and gross gain and loss were generated.

3.2.5 Preparation of questionnaire for socio-economic survey

A semi-structured questionnaires was prepared (attached in Appendix 1) for socio-economic data collection. The questionnaire included important attributes on: demography, accessibility to urban markets, fallowing period, level of literacy, land tenure, people's involvement in various land uses including agriculture, urbanisation, industrialisation, fishing and climate change awareness.

3.3 Field Work

3.3.1 Land use/cover mapping

In the field, systematic free survey procedures as outlined by Dent and Young (1981) and Landon (1991) at semi-detailed level (scale 1:50 000) were conducted using the results of the aerial photographs/satellite images interpretation to select observation and sampling points. At each observation site data on terrain characteristics, and land cover types were collected. At the beginning of the survey, reconnaissance of the whole study area was done followed by the selection of representative transects to locate observation sites and sampling points. In each transect existing land cover types or classes were described (Dent and Young, 1981). Land cover classes were fully analysed, verified, described and georeferenced. Georeferencing was done using a hand held Global Positioning System (GPS) receiver. A total of 112 reference points were collected from Bumbwini area and 62 points from Kisakasaka based on the 2011 image. Historical land cover was verified in the field by interviewing farmers (Anderson *et al*., 1976).

3.3.2 Socio-economic survey

Socio-economic data was collected using a variety of participatory rural appraisal (PRA) techniques including focus group discussion, key informants and questionnaire survey. A cross-sectional study design was used to explore important information on demography, accessibility to urban markets, fallowing period, level of literacy, land tenure, people’s involvement in various land uses including agriculture, urbanisation, industrialisation, and fishing, uses of coastal marine ecosystems and climate change awareness. Purposive followed by random sampling technique was employed.

3.4 Post Field Work

Upon finishing the interpretation, accuracy assessment was conducted. The reference points collected during the field work was used for accuracy analysis. The 2011 imagery was selected for conducting accuracy assessment because it is the most recent image and close to ground observations. The overall accuracy is acceptable if it is greater than 80% (Turan *et al.,* 2010).

Land cover change detection was implemented through data integration procedures carried out in GIS environment using ERDAS computer software. The generated land cover maps for 2001, 2009 and 2011 were analysed using ERDAS following the map overlay method. Change detection flow matrix was produced by overlying land cover maps for year 2001, 2009 and 2011 in order to obtain class-to-class changes (ESRI, 1995).

Both biophysical as well as socio-economic factors were considered in this study. Those factors included climate, vegetation and farming practices. Climatic data were obtained from the Tanzania Meteorological Agency (TMA). Daily rainfall and temperature data for 60 and 54 years respectively were used to carry out trend analysis using Instat (Stern *et al.*, 2006) package and Mann-Kendal test (FMI, 2002).

3.4.1 Land cover change detection analysis

The change detection was done by post classification approach in ERDAS software. The approach identifies quantitative changes by comparing two independent classified images on a pixel by pixel basis using a change detection matrix (Aldwaik and Pontius, 2012; Mbilinyi, 2000).

Analysis of transition matrix and quantitative change was done based on the definition adopted from Pontius *et al.* (2004) and Alo and Pontius (2008). The persistence is an area (A_{ii}, given in a column for category i, or A_{jj}, given in a row for category *j*) which remained under the same land cover category over time, i.e. remained unchanged, which in a standard cross-tabulation matrix, is given in the diagonal.

The gross loss, L_i, is the area which experiences loss by category i between initial time and subsequent time, given as the difference between total area $(\sum A_{i+})$ and persistence in a column (equation 1). The gross gain, G_j, is the area which experiences gain by category *j* between initial time and subsequent time, given as the difference between total area $\left(\sum A_{+j}\right)$ and persistence in a row (equation 2).

$$L_i = \sum A_{i+} - A_{ii} \quad \text{.....1}$$

$$G_j = \sum A_{+j} - A_{jj} \quad \text{.....2}$$

Net quantity change is the absolute difference between the gross gain and the gross loss (equation 3), and overall change for each category is given as the sum of the gross gain and gross loss (equation 4).

$$Net\ quantity\ change = |Gross\ gain - Gross\ loss| \quad \text{.....3}$$

$$Overall\ change = Gross\ gain + Gross\ loss \quad \text{.....4}$$

When a land cover experiences gross gain and gross loss simultaneously, this kind of change is known as swap location change (Alo and Pontius, 2008), and is given by equation 5.

$$Swap\ location = Overall\ change - Net\ quantity\ change \ldots\ldots\ldots\ldots 5$$

3.4.2 Assessment of anthropogenic and biophysical factors considered to influence land use/cover changes

3.4.2.1 Assessment of anthropogenic factors

The socio-economic information collected through household survey was organized into manageable units. Relevant coded information was then subjected to content analysis using the Statistical Package for Social Sciences (SPSS) computer programme. Microsoft Excel computer software was used to develop a summary of quantitative information (frequencies) observed during the study period. Frequency and cross-tabulation results were used to study the socio-economic activities. The population information in spatial form for 1988, 2002 and 2012 in each study area was collected. This was mapped with land cover changes observed to find out their relationship.

3.4.2.2 Assessment of climate characteristics

Daily mean rainfall was computed and the cumulative mean daily curve was used to estimate possible early start and early end of growing season for both long and short rainy seasons (Kihupi *et al*., 2007; Kingamkono *et al*., 1994; Kingamkono, 1993; Kassase, 1992). Total annual rainfall, extreme events, number of wet days and 10-day dry spell within 30-day period in each season were computed for each year and simple linear trend analysis for each characteristic was carried out. Extreme events as defined by Stern *et al.* (2006) are those events which may cause damaging, such as heavy rainfall, high flood flows in rivers, high winds, or extreme temperatures, either hot or cold. Extreme events considered in this study are only those caused by rainfall. The dry spells were grouped into three temporal periods of twenty years each for early, mid and late years. Frequency analysis of monthly rainfall data was carried out to obtain probabilities of exceedance for the wet, normal and dry year (Kihupi *et al*., 2007; Kingamkono *et al*., 1994; Kingamkono, 1993; Kassase, 1992).

This climatic information was used to assess the temporal relationship with observed land cover change. However, missing records in daily observed rainfall and temperature data made it impossible to conduct spatial analysis within the area. Initially there were ten rain gauge stations selected for analysis, namely; Selem, Mkokotoni, Mahonda, Kisongoni and Donge kipande in Bumbwini, and Tunguu, Mwera, Hanyagwa, Bustani ya wananchi and Kisauni (Zanzibar airport) in Kisakasaka. All stations with missing data equivalent to 5 or more years (that is around 15% of the data) were rejected. As a result, all of them except Kisauni (Zanzibar airport), were rejected due to insufficient data.

3.4.3 Statistical significance trend test for climate characteristics

There are a lot of statistical tools for detecting trend in the time series data, but there are two mathematical tools which are said to be widely used (Karpouzos *et al.*, 2010); parametric and non-parametric (Hamed, 2008). The parametric tools are said to be more powerful but require independent and normally distributed data; and non-parametric tools which assume observations are dependent (Karpouzos *et al.*, 2010). Mann Kendall test is a statistical test widely used for the analysis of trend in climatologic and in hydrologic time series (Onoz and Bayazit, 2012). Statistical significance trending test using both Mann-Kendall and simple test was performed to find out the trend in climate parameters.

There are two advantages of using Mann Kendall test. First, it is a non-parametric test and does not require the data to be normally distributed. Second, the test has low sensitivity to abrupt breaks due to inhomogeneous time series (Tabari *et al*., 2011). According to this test, the null hypothesis H_0 assumes that there is no trend (the data is independent and randomly ordered) and this is tested against the alternative hypothesis H_1, which assumes that there is a trend (Tabari *et al.*, 2011). Mann-Kendall test is given by the following equation:

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sign(x_j - x_k) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 6$$

Where:

S = Mann-Kendall test value

x_j and x_k = Sequential data values in the years j and k

j, *k* and *n* = Length of the data

The presence of a statistically significant trend is evaluated using the Z value, which is given by equation 7:

$$Z = \begin{cases} S - 1/\sqrt{VAR(S)} & if\ S > 0 \\ 0 & if\ S = 0 \\ S + 1/\sqrt{VAR(S)} & if\ S < 0 \end{cases} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 7$$

Where: Z = Normalized test statistic

S = Mann-Kendall statistic value

VAR(S) = Mann-Kendall variance

A positive (negative) value of Z indicates an upward (downward) trend. To test for either an upward or downward monotone trend (a two-tailed test) at α level of significance, H_0 is rejected if the $|Z| > Z_{1-\alpha/2}$, If the p value is less than the significance level α (alpha) = 0.05, H_0 is rejected. Rejecting H_0 indicates that there is a trend in the time series, while accepting H_0 indicates no trend was detected. On rejecting the null hypothesis, the result is said to be statistically significant.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Land Cover Change

4.1.1 Classification accuracy assessment

The overall classification accuracy is given by percentage of the pixels that were considered to be correctly classified out of total referenced.

4.1.1.1 Accuracy assessment for Bumbwini image

Table 1 shows details of producer's and user's accuracy for Bumbwini. Mangrove had the highest producer's accuracy of 96.0% and thus it was assumed that this proportion had been correctly classified followed by mixed trees, cultivated land and paddy with 94.7%, 82.1% and 80.0% respectively. Classes of water, "*jangwa la bahari"* and bare land achieved less than 80% of the producer's accuracy, which indicates that a considerable number of pixels belonging to these classes had been classified erroneously into other classes or in other words, there was an omission error of greater than 20% for water, "*jangwa la bahari"* and bare land classes.

On the other hand, Water had the highest user's accuracy (100%) showing that all of the pixels labeled water on the classified image represented water. Although mixed trees had a higher producer's accuracy, only 78.3% of the area labeled mixed trees was actually covered by mixed trees on the ground. This means that 21.7% of pixels classified as mixed trees were actually other information classes. The class mixed trees, therefore, has a commission error of 21.7%. The same can be said for the cultivated land and paddy. The number of pixels which were considered to be correctly classified is 91 out of 112 which gives an overall accuracy of 81.3%.

Table 1: Accuracy totals for Bumbwini

Class Name	Reference Totals	Classified Totals	Number Correct	Producers Accuracy %	Users Accuracy %
Water	9	5	5	55.6	100.0
Mangrove	25	25	24	96.0	96.0
Jangwa la bahari	10	12	6	60.0	50.0
Mixed trees	19	23	18	94.7	78.3
Paddy	10	12	8	80.0	66.7
Cultivated/shrubs	28	26	23	82.1	88.5
Bare land	11	9	7	63.6	77.8
Totals	**112**	**112**	**91**		
Overall Classification Accuracy					**81.3**

4.1.1.2 Accuracy assessment for Kisakasaka image

Table 2 shows details of producer's and user's accuracy for Kisakasaka. Water, "*jangwa la bahari"* and mixed trees had the highest producer's accuracy of 100.0% and thus it was assumed that this proportion had been correctly classified, followed by bare land with 83.3%. Classes of mangrove and cultivated land achieved only 68.8% and 60.0% of the producer's accuracy respectively, which indicates that a considerable number of pixels belonging to these classes had been classified erroneously into other classes or in other words, there was an omission error of 31.2% and 40% for mangrove and cultivated land classes respectively.

On the other hand, water, mangrove, cultivated land and bare land had the highest user's accuracy (100%) showing that all of the pixels labeled water, mangrove, cultivated land and bare land on the classified image were actually water, mangrove, cultivated land and bare land respectively. Although mixed trees and "*jangwa la bahari"* had the highest producer's accuracy of 100%, only 63.6% and 62.5% of the area labeled mixed trees and "*jangwa la bahari"* were actually covered by mixed trees and "*jangwa la bahari"* on the ground respectively. This means that 100% of mixed trees and 100% of "*jangwa la bahari"* visited were correctly interpreted but only 63.6% of mixed trees and 62.5% of "*jangwa la bahari"* interpreted were real. The classes mixed trees and "*jangwa la bahari"*, therefore, have commission errors of 36.4% and 37.5 respectively. The number of pixels that were considered to be correctly classified is 51 out of 62 which gives an overall accuracy of 82.3%.

Table 2: Accuracy totals for Kisakasaka

Class Name	**Reference Totals**	**Classified Totals**	**Number Correct**	**Producers Accuracy %**	**Users Accuracy %**
Water	5	5	5	100.0	100.0
Mangrove	16	11	11	68.8	100.0
Jangwa la bahari	5	8	5	100.0	62.5
Mixed trees	14	22	14	100.0	63.6
Cultivated land	10	6	6	60.0	100.0
Bare land	12	10	10	83.3	100.0
Totals	**62**	**62**	**51**		
Overall Classification Accuracy					**82.3**

4.1.2 Spatial distribution of land cover types in the study area

Figures 2 and 3 show total area covered in hectares by each land cover class (category) at each epoch for Kisakasaka and Bumbwini study areas respectively. Tables 3 and 4 show total area covered in percentage by each land cover class (category) at each epoch for Kisakasaka and Bumbwini respectively. The largest area is covered by water 2532.7 ha (51.4%), followed by mixed trees 1472.6 ha (29.9%), cultivated land 572.0 ha (11.6%), mangrove 252.1 ha (5.1%), "*jangwa la bahari"* 65.7 ha (1.3%) and bare land 34.5 Ha (0.7%) for Kisakasaka. At Bumbwini, the largest area is occupied by mixed trees 3780.4 ha (36.5%), followed by cultivated land/shrubs 2703.8 ha (26.1%), water 2374.7 ha (22.9%), mangrove 599.1 ha (5.8%), paddy 605.8 ha (5.8%), "*jangwa la bahari*" 172.4 ha (1.7%) and then bare land 122.9 ha (1.2%). Water occupies the largest area in Kisakasaka and third largest for Bumbwini because of geographical location of these areas. Mixed trees cover appears to have been mostly cleared during 2001 – 09 but restored during 2009 – 11 for both Bumbwini and Kisakasaka. This is because of awareness campaign and coastal conservation measures which have been implemented by society. Bare land shows drastic increase during 2001 – 09; largely to excessive deforestation done from 1995 to 2005 as reported by respondents. During this time both mangrove and upland open forest were highly exploited.

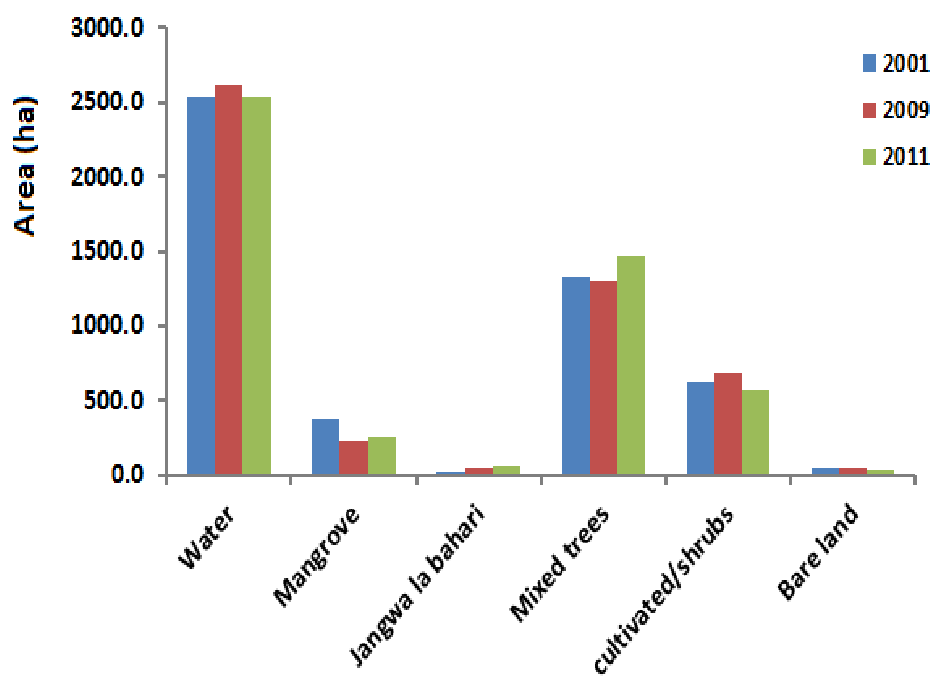

Figure 2: Distribution of land cover over Kisakasaka for 2001, 2009 and 2011

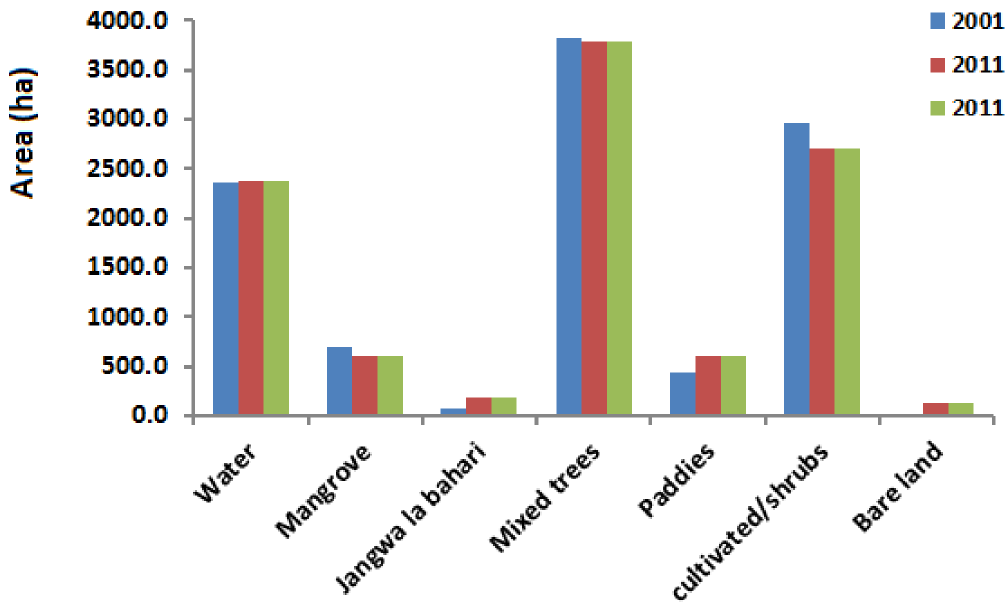

Figure 3: Distribution of land cover over Bumbwini for 2001, 2009 and 2011

Table 3: Land cover distribution for Kisakasaka in 2001, 2009 and 2011

Land cover classes	2001		2009		2011	
	Ha	%	Ha	%	Ha	%
Water	2532.1	51.4	2614.6	53	2532.7	51.4
Mangrove	379.6	7.7	231.6	4.7	252.1	5.1
Jangwa la bahari	29.9	0.6	52.2	1.1	65.7	1.3
Mixed trees	1325.5	26.9	1294.8	26.3	1472.6	29.9
Cultivated land/shrubs	617.9	12.5	687.1	13.9	572	11.6
Bare land	44.6	0.9	49.3	1	34.5	0.7
Total	**4929.6**	**100**	**4929.6**	**100**	**4929.6**	**100**

Table 4: Land cover distribution for Bumbwini in 2001, 2009 and 2011

Land cover classes	2001		2009		2011	
	Ha	%	Ha	%	Ha	%
Water	2355.9	22.7	2313.8	22.3	2374.7	22.9
Mangrove	685.4	6.6	551.4	5.3	599.1	5.8
Jangwa la bahari	68.6	0.7	214	2.1	172.4	1.7
Mixed trees	3829.7	37.1	3021.9	29.2	3780.4	36.5
Paddy	440.2	4.2	673.2	6.5	605.8	5.8
Cultivated/shrubs	2966	28.6	3357.4	32.4	2703.8	26.1
Bare land	13.1	0.1	227.3	2.2	122.9	1.2
Total	**10359**	**100**	**10359**	**100**	**10359**	**100**

Figures 4-6 and 7-9 show spatial distribution of land cover classes for Bumbwini and Kisasakasa respectively. It is clear that all cover classes are common in both Bumbwini and Kisakasaka except paddy, which is found in Bumbwini only. These land covers (category) are mixed trees, cultivated land/shrubs, water, mangrove, "*jangwa la bahari"* and bare land.

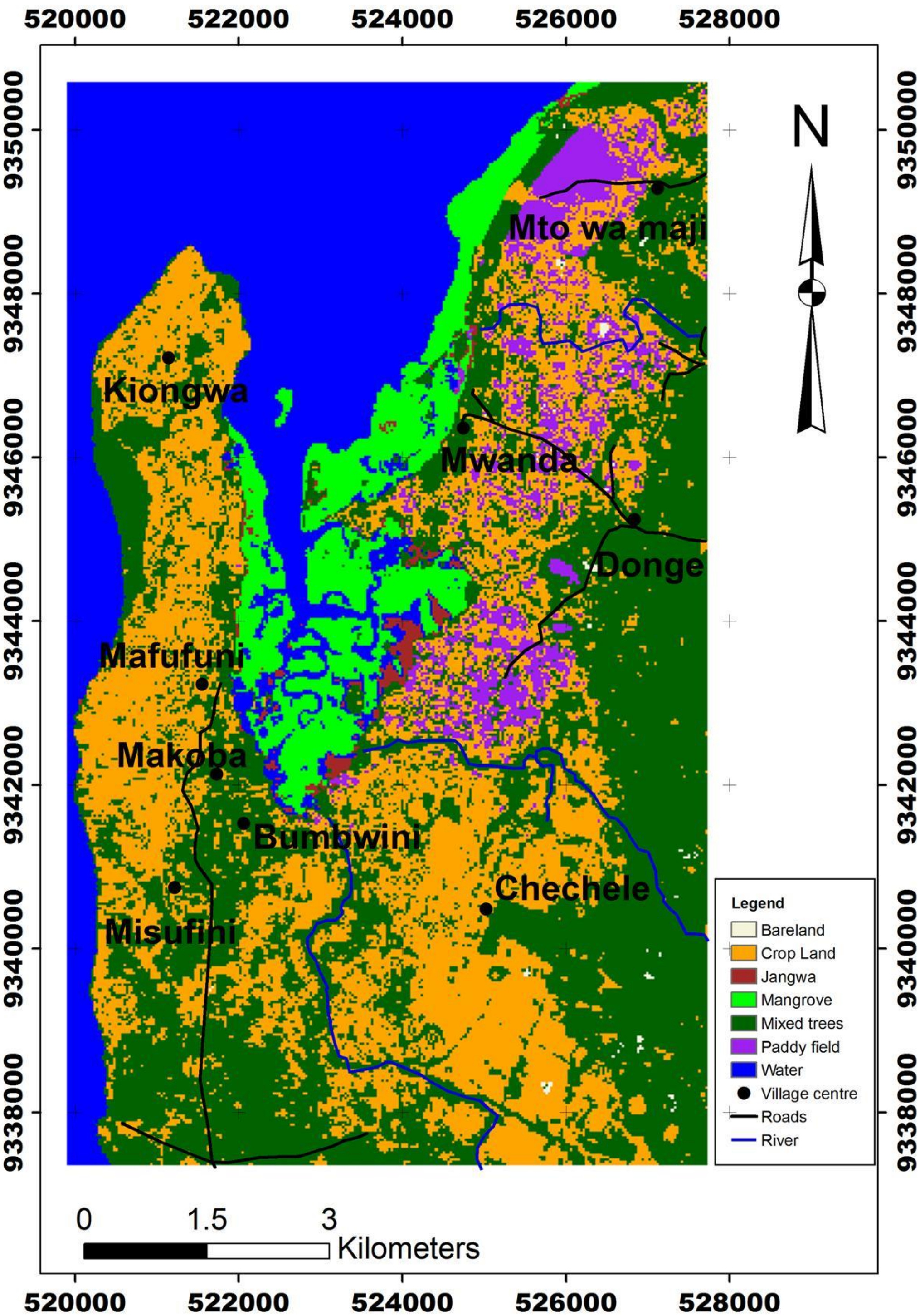

Figure 4: Land cover distribution in Bumbwini for 2001

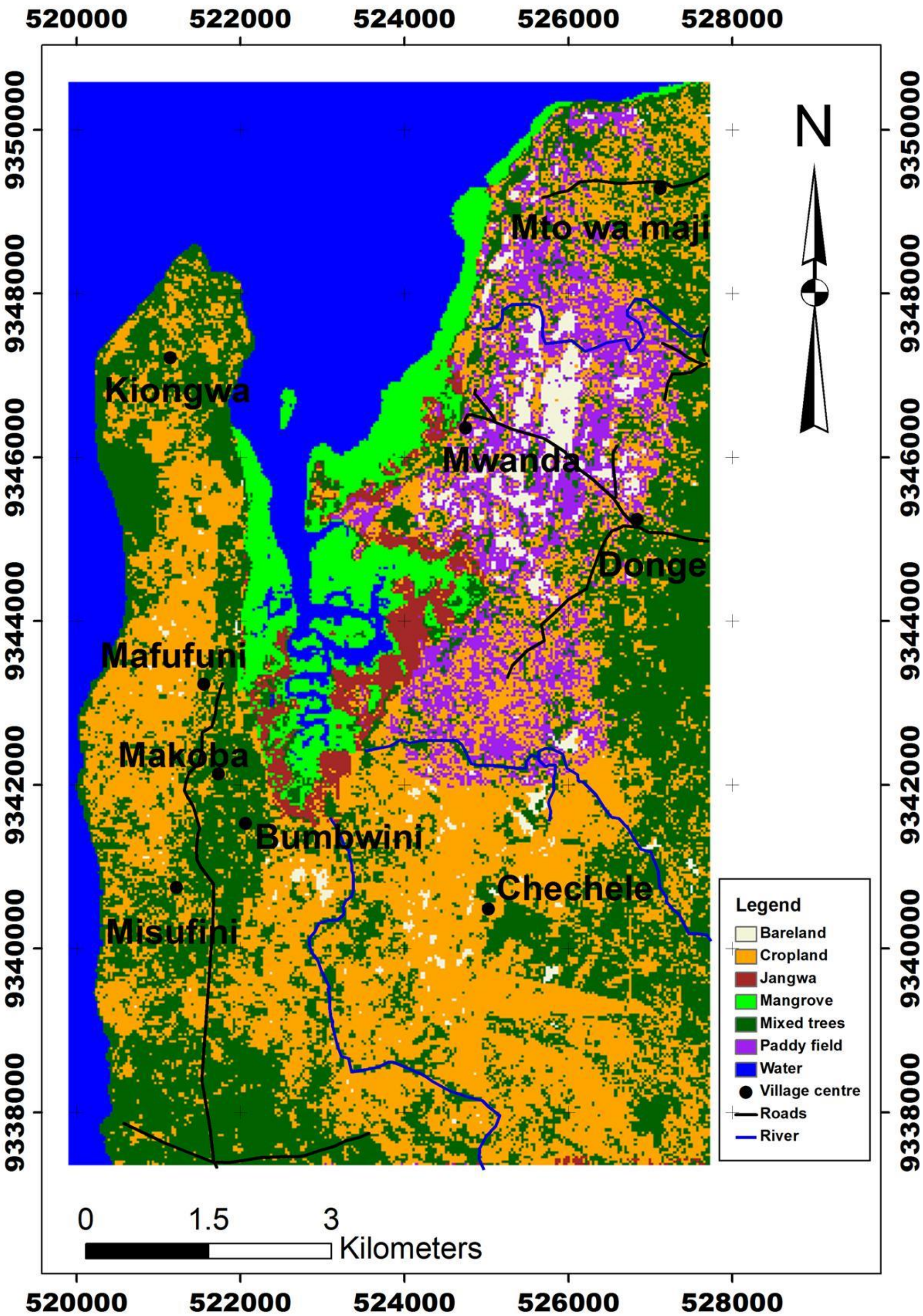

Figure 5: Land cover distribution in Bumbwini for 2009

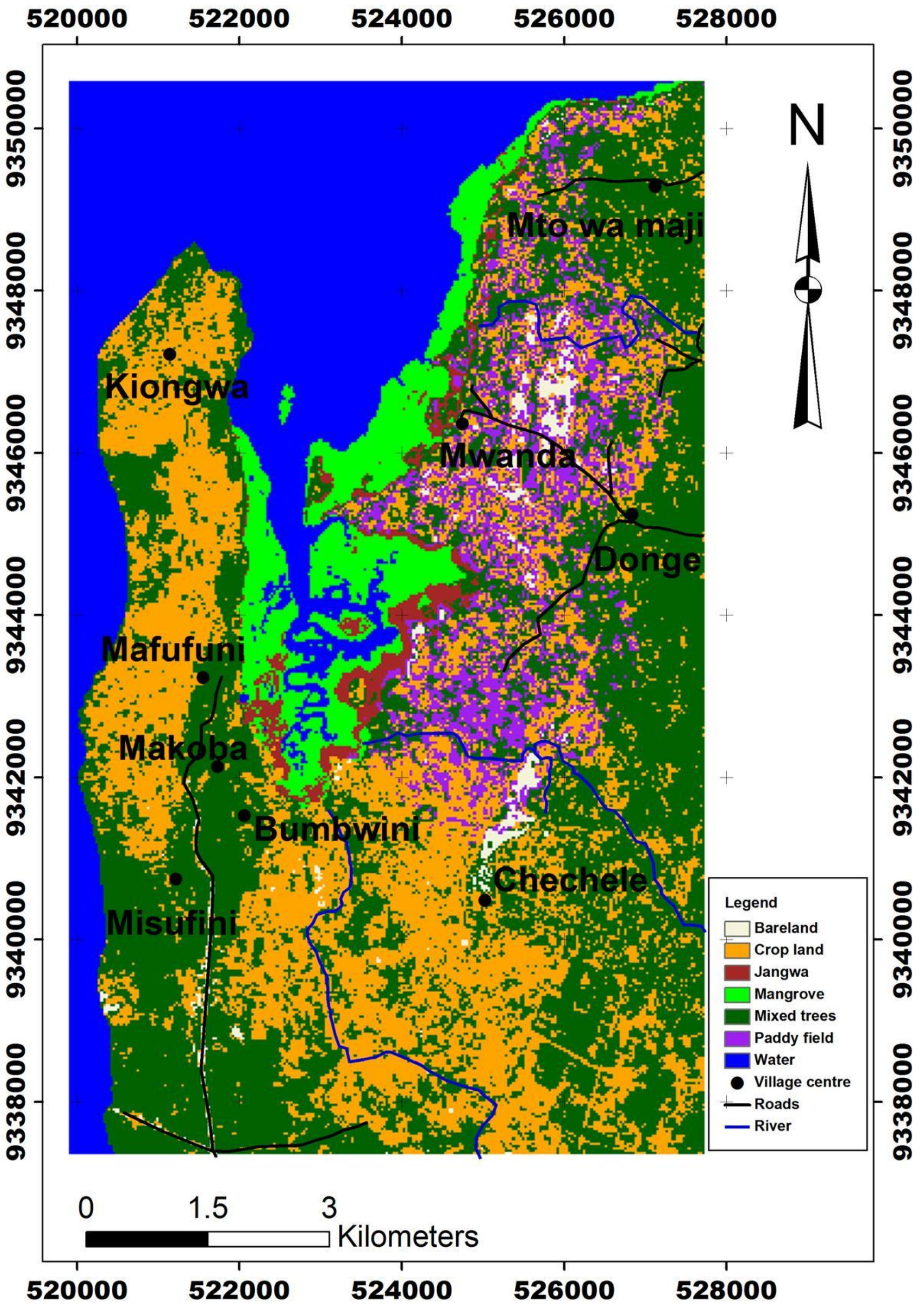

Figure 6: Land cover distribution in Bumbwini for 2011

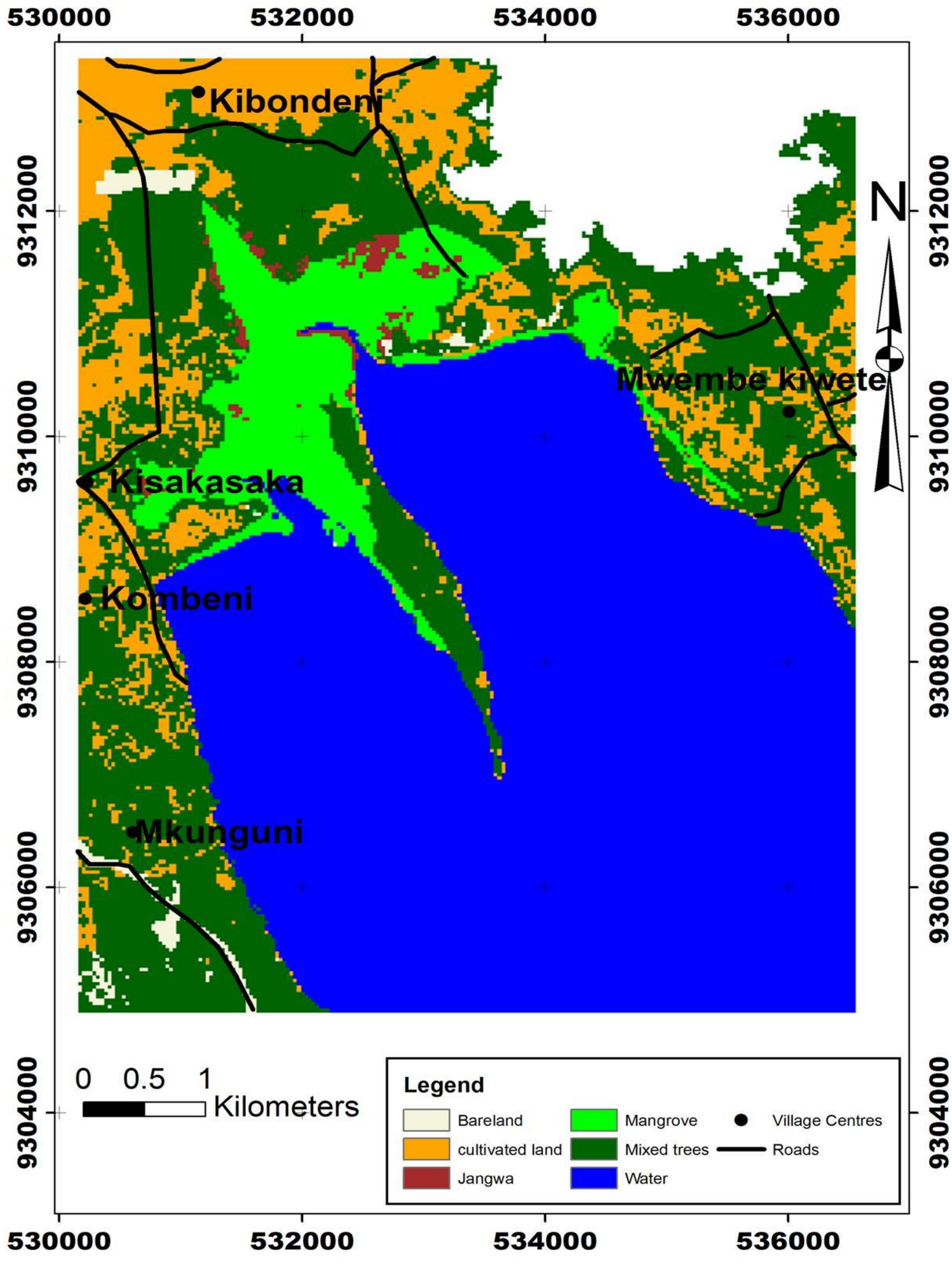

Figure 7: Land cover distribution in Kisakasaka for 2001

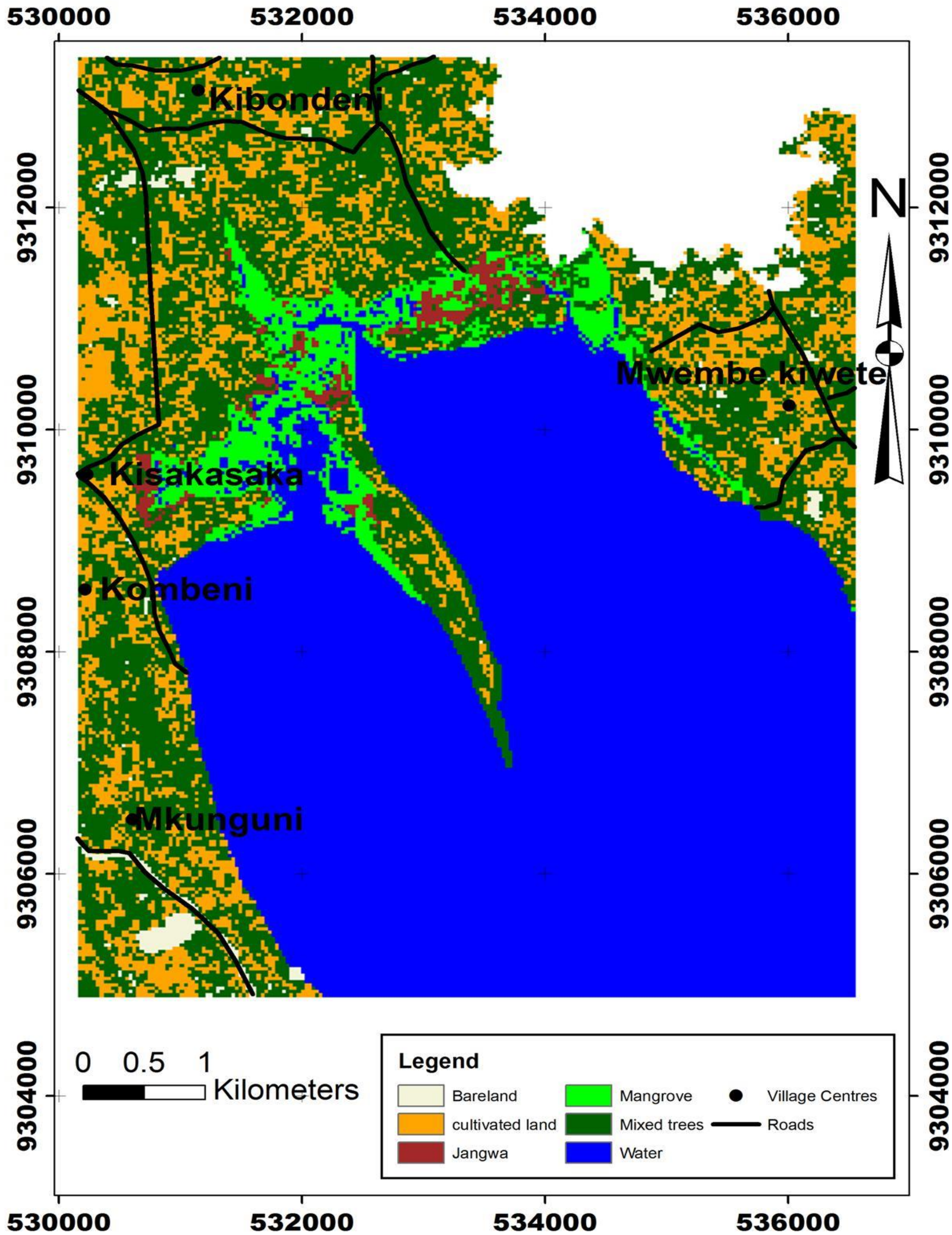

Figure 8: Land cover distribution in Kisakasaka for 2009

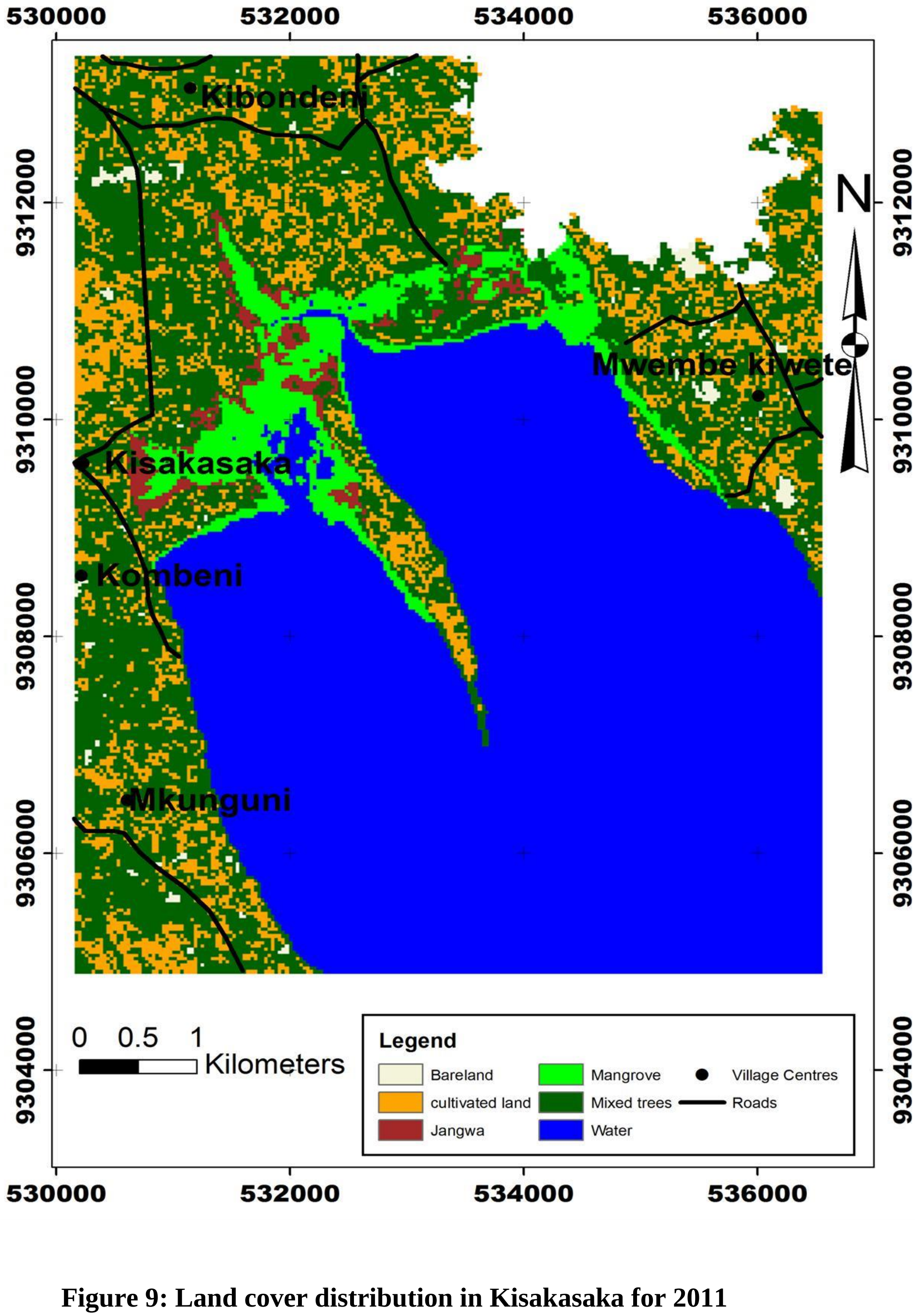

Figure 9: Land cover distribution in Kisakasaka for 2011

4.1.3 Spatial and temporal change of land covers

Persistence, gross gain and loss for each category are explained in Tables 5 and 6 for Kisakasaka and Tables 7 and 8 for Bumbwini between 2001 – 09 and 2009 – 11 respectively. Observed persistence is given in the main diagonal (bolded) while observed land cover changes are given off the main diagonal. The gross loss column shows the quantity of land cover that experienced a gross loss of land cover during 2001 – 09 and 2009 – 11 time intervals, and the gross gain column shows the quantity of land cover that experienced a gross gain of land cover during the same time intervals (Alo and Pontius, 2008). In order to budget the overall change for each category, the organized information is given in Tables 9 and 10 for Kisakasaka and Bumbwini respectively.

Table 5: Cross tabulation matrix of land cover change for Kisakasaka from 2001 to 2009

		2009							
		Water	**Mangrove**	**Jangwa/ cleared mangrove**	**Mixed trees**	**Crop land/ shrubs**	**Bare land**	**Total 2001**	**Gross Loss**
2001	**Water**	**2508.57**	4.32	0	15.66	3.33	0.18	2532.06	**23.49**
	Mangrove	72.36	**167.85**	28.71	85.86	24.75	0	379.53	**211.68**
	Jangwa/ cleared mangrove	1.71	5.49	**1.35**	15.03	6.3	0	29.88	**28.53**
	Mixed trees	23.76	39.78	15.21	**796.14**	421.38	29.25	1325.52	**529.38**
	Crop land/ shrubs	7.83	12.42	6.84	360.99	**223.83**	6.03	617.94	**394.11**
	Bare land	0.36	1.71	0.09	20.97	7.65	**13.86**	44.64	**30.78**
	Total 2009	2614.59	231.57	52.2	1294.65	687.24	49.32	**4929.57**	**1217.97**
	Gross Gain	**106.02**	**63.72**	**50.85**	**498.51**	**463.41**	**35.46**	**1217.97**	

Table 6: Cross tabulation matrix of land cover change for Kisakasaka from 2009 to 2011

		2011							
		Water	**Mangrove**	**Jangwa/ cleared mangrove**	**Mixed trees**	**Crop land/ shrubs**	**Bare land**	**Total 2009**	**Gross Loss**
2009	**Water**	**2521.35**	62.55	1.26	22.95	6.21	0.27	2614.59	**93.24**
	Mangrove	2.7	**173.25**	17.73	37.08	0.54	0.27	231.57	**58.32**
	Jangwa/ cleared mangrove	0	6.84	**29.34**	15.93	0.09	0	52.2	**22.86**
	Mixed trees	8.28	9.36	16.83	**977.13**	268.29	14.94	1294.83	**317.7**
	Crop land/ shrubs	0.36	0.09	0.54	388.26	**293.49**	4.32	687.06	**393.57**
	Bare land	0	0	0	31.5	3.15	**14.67**	49.32	**34.65**
	Total 2011	2532.69	252.09	65.7	1472.85	571.77	34.47	**4929.57**	**920.34**
	Gross Gain	**11.34**	**78.84**	**36.36**	**495.72**	**278.28**	**19.8**	**920.34**	

Table 7: Cross tabulation matrix of land cover change for Bumbwini from 2001 to 2009

		2009								
		Water	**Mangrove**	**Jangwa/ cleared mangrove**	**Mixed trees**	**Paddy**	**Crop land/ shrubs**	**Bare land**	**Total 2001**	**Gross Loss**
	Water	**2204.3**	58	61.4	19.9	2.5	9.9	0	2355.9	**151.7**
	Mangrove	61.4	**459.9**	65.6	66.9	4.9	26.8	0	685.4	**225.5**
	Jangwa/ cleared mangrove	2.5	7.7	**43.4**	8.8	0.6	5.5	0.1	68.6	**25.2**
	Mixed trees	43.4	24.9	28.2	**2180.8**	195.4	1314.3	42.9	3829.9	**1649.1**
2001	**Paddy**	0	0	3.7	73.6	**154.6**	165.2	43.1	440.2	**285.6**
	Crop land/ shrubs	2.3	1	11.8	667.4	312.7	**1830.5**	140.3	2965.9	**1135.4**
	Bare land	0	0	0	4.6	2.5	5.2	**0.8**	13.1	**12.3**
	Total 2009	2313.8	551.4	214	3021.9	673.2	3357.4	227.3	**10359**	**3484.7**
	Gross Gain	**109.5**	**91.5**	**170.6**	**841.1**	**518.6**	**1526.9**	**226.4**	**3484.7**	

Table 8: Cross tabulation matrix of land cover change for Bumbwini from 2009 to 2011

		2011								
		Water	**Mangrove**	**Jangwa/ cleared mangrove**	**Mixed trees**	**Paddy**	**Crop land/ shrubs**	**Bare land**	**Total 2009**	**Gross Loss**
	Water	**2303**	10.3	0.4	0.2	0	0	0	2313.8	**10.8**
	Mangrove	38	**466.8**	29.3	14.7	0.5	2.2	0	551.4	**84.6**
	Jangwa/ cleared mangrove	1.1	61.7	**92.9**	20.8	16.2	17.1	4.2	214	**121.1**
	Mixed trees	31.3	43.6	31.5	**2279.5**	73.5	541.1	21.4	3021.9	**742.4**
2009	**Paddy**	0	2.1	3.1	168.2	**229.5**	265.5	4.9	673.2	**443.7**
	Crop land/ shrubs	1.3	14.7	15.3	1281.1	205.3	**1811.4**	28.4	3357.4	**1545.9**
	Bare land	0	0	0.1	15.9	80.7	66.5	**64**	227.3	**163.3**
	Total 2011	2374.7	599.1	172.4	3780.4	605.8	2703.8	122.9	**10359**	**3111.8**
	Gross Gain	**71.6**	**132.3**	**79.6**	**1500.8**	**376.3**	**892.4**	**58.9**	**3111.8**	

4.1.3.1 Land cover change for Kisakasaka

Table 9 shows that the largest gross loss in 2001 – 09 was experienced by mixed trees (529.4 ha), followed by cultivated land (394.1 ha) and mangrove (211.7 ha), while mangrove and mixed trees had a net quantity loss of 148 ha and 30.9 ha respectively. In 2009 – 11, the largest gross gain was for mixed trees (495.7 ha) followed by cultivated land (278.3 ha) and mangrove (78.8 ha) (Table 10).

The overall change i.e. 2001 – 11, in Kisakasaka (Table 11 and Fig. 10) shows that a total area of 127.4 ha (33.9%), 46.0 ha (7.4%) and 10.2 ha (22.6%) of mangrove, cultivated land and bare land respectively had declined, and 147.2 ha (11.1%) of mixed trees, 35.8 ha (119.7%) of "*jangwa la bahari*" and 0.6 ha (0.02%) of water had increased.

Table 9: Gain and loss of land cover for Kisakasaka between 2001 and 2009

Years	Land cover classes	Gross Gain	Gross Loss	Sum	Net Quantity change	Swap location
2001 – 2009	**Water**	106	23.5	129.5	82.5	47
	Mangrove	63.7	211.7	275.4	-148	127.4
	Jangwa la bahari	50.9	28.5	79.4	22.3	57.1
	Mixed trees	498.5	529.4	1027.9	-30.9	997
	Cultivated land/ shrubs	463.4	394.1	857.5	69.3	788.2
	Bare land	35.5	30.8	66.2	4.7	61.6

Table 10: Gain and loss of land cover for Kisakasaka between 2009 and 2011

Years	Land cover classes	Gross Gain	Gross Loss	Sum	Net Quantity change	Swap location
2009 – 2011	**Water**	11.3	93.2	104.6	-81.9	22.7
	Mangrove	78.8	58.3	137.2	20.5	116.6
	Jangwa la bahari	36.4	22.9	59.2	13.5	45.7
	Mixed trees	495.7	317.7	813.4	178	635.4
	Cultivated land/shrubs	278.3	393.6	671.9	-115.3	556.6
	Bare land	19.8	34.7	54.5	-14.9	39.6

Table 11: Overall gain and loss of land cover for Kisakasaka during 2001 - 2011

Years	Land cover classes	Gross Gain	Gross Loss	Sum	Net Quantity change	Swap location
2001 - 2011	**Water**	46.3	45.6	91.9	0.6	91.3
	Mangrove	70.7	198.2	268.9	-127.4	141.5
	Jangwa la bahari	63.8	28	91.8	35.8	56
	Mixed trees	580.3	433.2	1013.5	147.2	866.3
	Cultivated land/shrubs	395.5	441.5	836.9	-46	790.9
	Bare land	27.7	37.9	65.6	-10.2	55.4

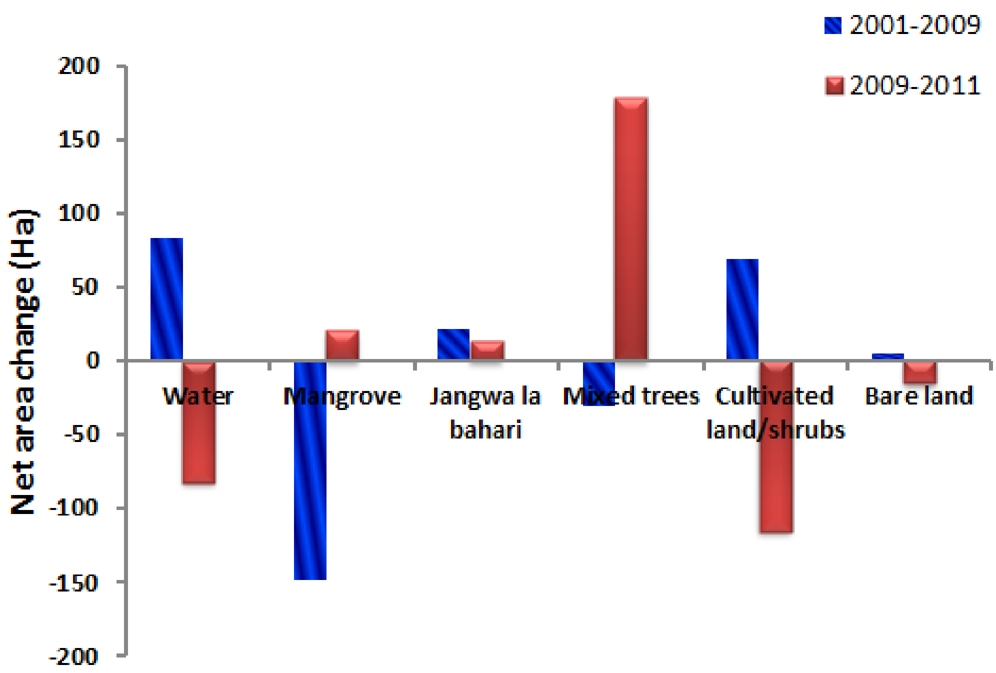

Figure 10: Net quantity change of land cover for Kisakasaka during 2001-2011

4.1.3.2 Land covers change for Bumbwini

Table 12 shows that the largest gross loss in 2001 – 09 in Bumbwini was experienced by mixed trees (1649.1 ha), followed by cultivated land (1135.4 ha), paddy (285.6 ha) and mangrove (225.5 ha), while mixed trees, mangrove and water showed a net quantity loss of 807.9 ha, 134.0 ha and 42.1 ha respectively. During 2009 – 11 (Table 13), the largest gross gain was for mixed trees (1500.8 ha) followed by cultivated land (892.4 ha) and mangrove (132.3 ha). The overall change, i.e. 2001 – 11 in Bumbwini (Table 14 and Fig. 11) shows that a total area of 262.2 ha (8.8%), 86.3 ha (12.6%) and 49.4 ha (1.3%) of cultivated land, mangrove and mixed trees respectively had declined, and 165.6 ha (37.6%) of paddy, 109.7 ha (837.4%) of bare land, 103.9 ha (151.5%) of "*jangwa la bahari*" and 18.7 ha (0.8%) of water had increased.

Table 12: Gain and loss of land cover for Bumbwini during 2001-2009

Years	Land Cover classes	Gross Gain	Gross Loss	Sum	Net Quantity change	Swap location
2001 - 2009	**Water**	109.5	151.7	261.2	-42.1	219.1
	Mangrove	91.5	225.5	317.1	-134	183.1
	Jangwa la bahari	170.6	25.2	195.8	145.4	50.4
	Mixed trees	841.1	1649.1	2490.2	-807.9	1682.3
	Paddy	518.6	285.6	804.2	233	571.1
	cultivated/ shrubs	1526.9	1135.4	2662.2	391.5	2270.7
	Bare land	226.4	12.3	238.8	214.1	24.7

Table 13: Gain and loss of land cover for Bumbwini during 2009-2011

Years	Land Cover classes	Gross Gain	Gross Loss	Sum	Net Quantity change	Swap location
2009 - 2011	**Water**	71.6	10.8	82.4	60.8	21.6
	Mangrove	132.3	84.6	216.9	47.7	169.2
	Jangwa la bahari	79.6	121.1	200.7	-41.6	159.1
	Mixed trees	1500.8	742.4	2243.3	758.4	1484.8
	Paddy	376.3	443.7	820	-67.4	752.6
	cultivated/ shrubs	892.4	1545.9	2438.3	-653.6	1784.7
	Bare land	58.9	163.3	222.1	-104.4	117.7

Table 14: Overall gain and loss of land cover for Bumbwini during 2001-2011

Years	Land Cover classes	Gross Gain	Gross Loss	Sum	Net Quantity change	Swap location
2001 - 2011	Water	161.9	143.2	305.1	18.7	286.4
	Mangrove	118.9	205.2	324.1	-86.3	237.8
	Jangwa la bahari	143	39.2	182.2	103.9	78.3
	Mixed trees	1261.3	1310.7	2571.9	-49.4	2522.5
	Paddy	475.4	309.8	785.2	165.6	619.6
	cultivated/ shrubs	1111.9	1374	2485.9	-262.2	2223.7
	Bare land	122.5	12.8	135.3	109.7	25.6

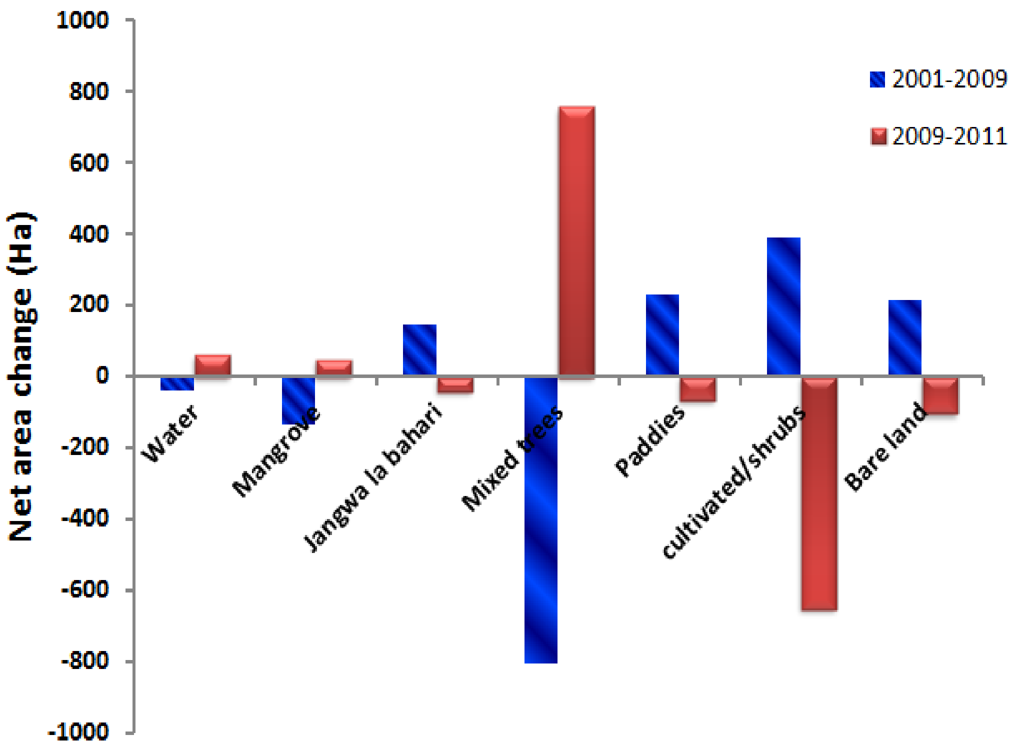

Figure 11: Net quantity change of land cover for Bumbwini during 2001-2011

There are several factors that have contributed to land cover changes in the study areas. These factors had different impacts on various land covers. For example, a large loss of mixed trees and mangrove forest during earlier years is attributed to cutting down of these trees for firewood as well as poles for construction of boats and houses. However after becoming aware of the impact of deforestation, conservation measures were introduced and encouraging results have been observed since. Deforestation has declined and mangrove trees are being replanted (Plate 1). Also there has been a net gain of mangrove through intrusion of salt water onto the cultivated land thus causing new regeneration of mangrove. This has been observed in Bumbwini as shown in Plate 2.

Plate 1: Replanting of mangrove trees in Bumbwini

The paddy cover that had been affected by salt water intrusion has now converted to grazing land. Residents in the area observed that a kind of vegetation called "*mashekeshu*" (mangrove fern or *acrostichum aureum*) used to exist previously and this was used to prevent inundation of the cultivated land by the salt water. However, with the removal of this vegetation overtime coupled with sea level rise, inundation of the area with salt water is the order of the day.

A number of studies (Kabanza, 2013; Makota, 2011; Kashaigili and Majaliwa, 2010; Kashaigili *et al.*, 2006) attribute change in land use/land cover to population growth. This study attributes changes in land use/cover not only to population growth, but also to urbanization with consequent loss of arable land to construction activities including houses and climatic variability and change.

Plate 2: Regeneration of mangrove trees due to salt water intrusion in Bumbwini

4.1.4 Intensity analysis

The kind of results given above explain only how much, where, and what type of land cover change has occurred. It gives the quantity of each category, but doesn't give any details concerning individual transitions, intensity and stationarity between categories. The results given in the following sections attempt to address the individual transitions, intensity and stationarity between categories (Aldwaik and Pontius, 2012).

4.1.4.1 Interval level analysis

Figures 12 (a) and (b) shows a graphical approach of intensity analysis to present results at interval level. The dashed line in the figures indicates uniform rate of change. To the left of the uniform line the rate of change is slow while to the right the rate is fast. The interval 2001 – 09 was identified to be slow in terms of overall annual change for both study areas (Figs.12 (a) and (b)), while 2009 – 11 was fast. The study also revealed that the uniform rate of change in Bumbwini (Fig. 12 (b)) was higher than in Kisakasaka (Fig. 12 (a)). This could be attributed to population differences, since Bumbwini is highly populated compared to Kisakasaka. A similar method was used by Aldwaik and Pontius (2012) who obtained different results for a site in northern Massachusetts, USA where they found the rate of overall change to be slower in the second time interval.

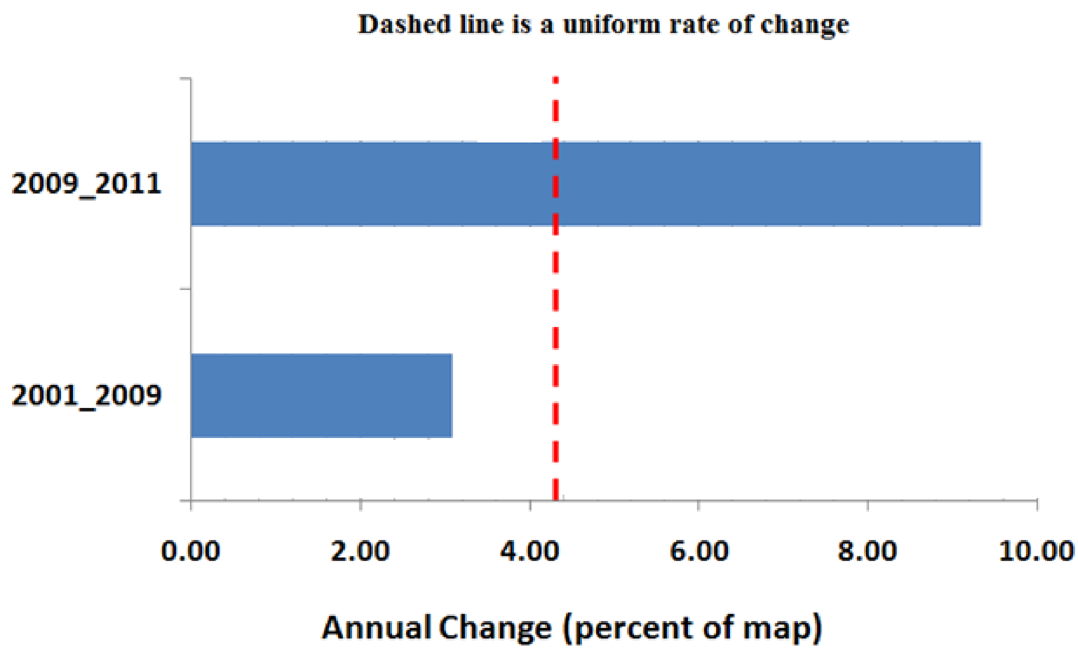

Figure 12 (a): Comparison of land cover intensity analysis between 2001-2009 and 2009-2011 time intervals for Kisakasaka

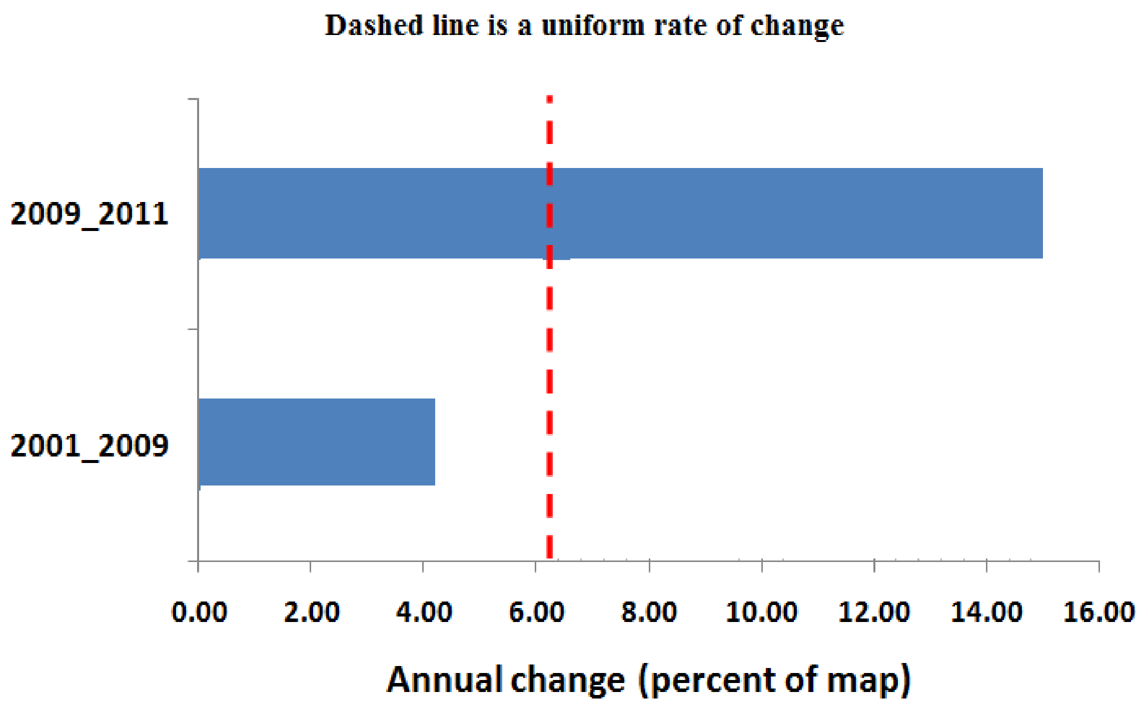

Figure 12(b): Comparison of land cover intensity analysis between 2001-2009 and 2009-2011 time intervals for Bumbwini

4.1.4.2 Category level analysis

Category level intensity analysis compares the intensity of gain and loss for a particular class in a given time interval (Figs.13 – 16). It gives a graphical approach of intensity analysis to present results at category (class) level in which the dashed line indicates uniform rate of change. The rate of change to the left of the uniform line (i.e. rate of change less than uniform) indicates dormant class change and to the right of the line (i.e. rate of change greater than uniform) indicates active class change. Also category analysis identifies whether the pattern of category is stable across time intervals in terms of gains and losses. If intensity of a category's gain/loss is greater (changing at a rate faster) or less (changing at a rate slower) than the uniform line for both time intervals, a particular category is said to be stationary; otherwise it is dynamic.

(a) Category level for Kisakasaka

The results of intensity analysis at category level for 2001 – 09 and 2009 – 11 respectively are given in Figs. 13 and 14. During 2001 – 09, all classes showed significant activeness in both gain and loss except for water class which was dormant. "*Jangwa la bahari*" was mostly active in both gaining and losing followed by bare land. Cultivated land changed more actively in gaining while mangrove changed more actively in losing. Using a similar method, Aldwaik and Pontius (2012) found built class to gain less than other classes in northern Massachusetts.

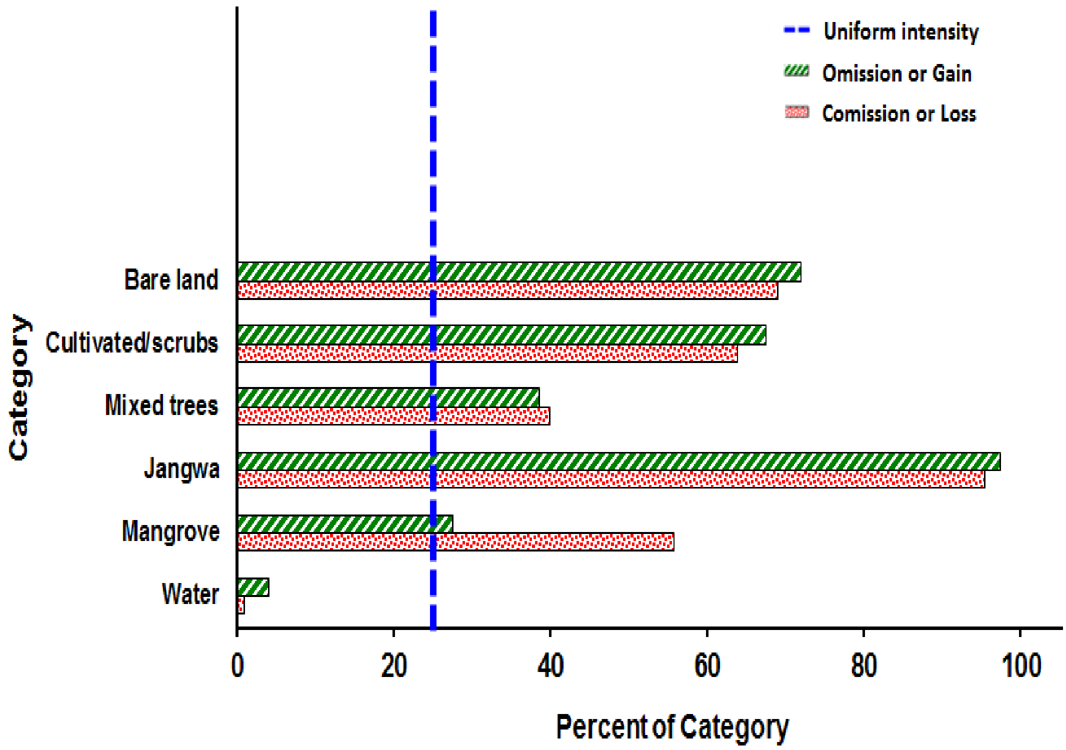

Figure 13: Category intensity analysis for Kisakasaka 2001-2009

During 2009 – 11 period (Fig. 14) all classes were still significantly active in both gaining and losing; while water was dormant. Bare land was mostly active in both gaining and losing, followed by cultivated land in losing and *"Jangwa la bahari*" in gaining. Mangrove was found to gain more actively than losing.

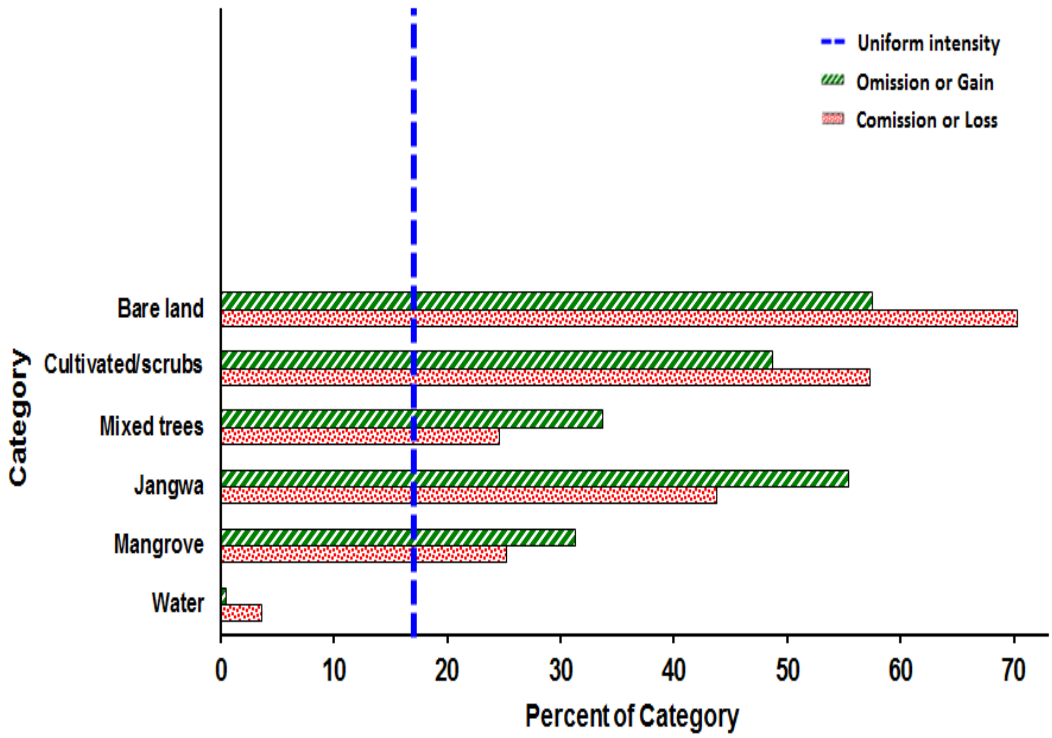

Figure 14: Category intensity analysis for Kisakasaka 2009-2011

(b) Category level for Bumbwini

During the period 2001 – 09 mangrove was dormant in gaining and active in losing (Fig. 15). But bare land was intensively most active in both gaining and losing followed by gain in "*jangwa la bahari*", paddy and slight active in cultivated land/crop land. From the results, it is clear mangrove is losing at a higher rate than it is gaining; because during this time the mangrove were highly exploited leading to significant gaining in "*Jangwa la bahari"*. These results are at variance with those obtained by Wang *et al.* (2003) in their study on mangrove change along the coast of Tanzania. They found that the total area for mangrove in coastal Tanzania was increasing, though there were variations between coastal districts. In another study, Namangaya (2011) found an increase of 57% (33 km^2) in mangrove over Mnazi Bay in Ruvuma River estuary.

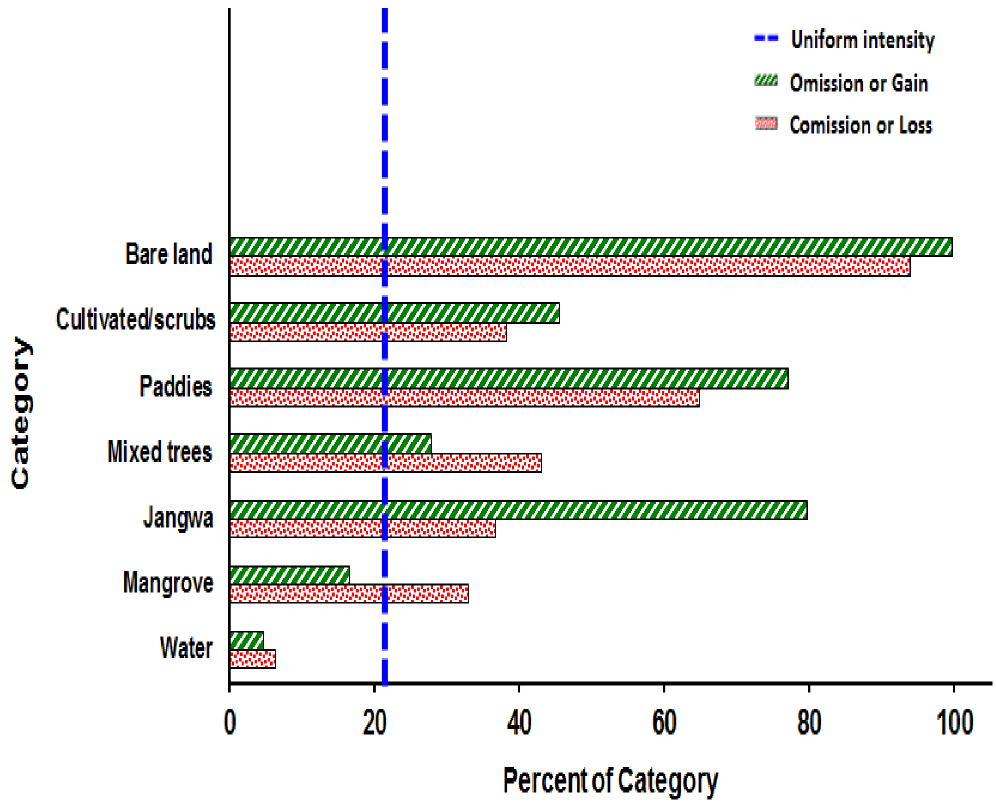

Figure 15: Category intensity analysis for Bumbwini 2001-2009

During the 2009 – 11 period (Fig. 16) bare land was intensively most active in losing followed by paddy, "*jangwa la bahari",* cultivated land and mangrove (gain). Loss in mangrove followed by water, are dormant cover classes over the others. Mangrove is a highly dynamic cover (not stationary) in both loosing and gaining; since the loss intensity of 2001 – 09 (Fig. 15) is greater than the uniform line while in 2009 – 11 (Fig. 16) it is less than the uniform line and the converse is true for mangrove gain. This in part is due to the awareness campaign of stopping mangrove exploitation and replanting of mangrove trees.

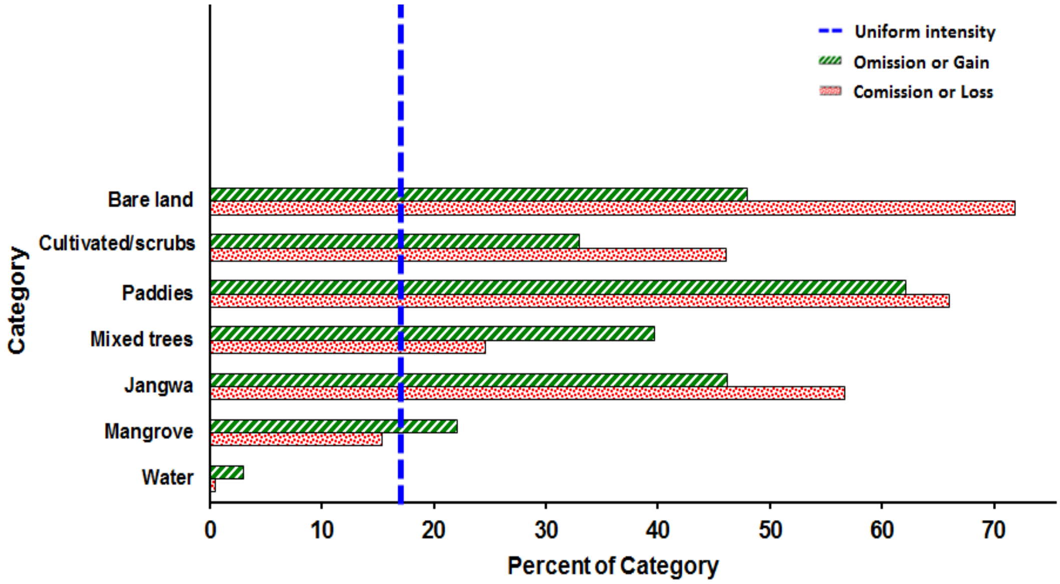

Figure 16: Category intensity analysis for Bumbwini 2009-2011

The results at category level for the two locations at two time intervals can be summarized as follows: Water was identified to be stationary and dormant for both locations. In Kisakasaka all other categories were identified to be active and stationary. In Bumbwini mangrove was very dynamic since it was relatively active in losing for 2001 – 09 and relatively active in gaining during 2009 – 11. This could be attributed to the awareness campaign in which mangroves are being replanted and also employment of conservation measures. Other remaining classes were found to be active and stationary.

4.2 Driving Factors of Land Cover Changes

Land cover change in Zanzibar like other places in the world has been attributed to a combination of factors namely anthropogenic and biophysical (natural) factors. These are discussed in more detail with respect to the findings from this study.

4.2.1 Anthropogenic factors

The following are the activities done by human beings which accelerate the land cover change in the study area:

4.2.1.1 Agricultural activities

Appendices 3.1 and 3.2 show economic activities in which agriculture is the main occupation as it accounts for about 66.4% of people dependent on agriculture as their main occupation and 18.6% of people engaged in agriculture as a second occupation. As stipulated in Appendices 3.3 and 3.4 respectively; 90% of the population are farmers in the area and 63.9% depend on agriculture as their major source of income generation activity. These are the small peasants/farmers using poor technology in their production hence accelerating land cover change. The main crops grown are cassava, sweet potatoes, bananas, paddy and sea weeds. Trees are cut down for sticks used for tying sea weeds during the planting process.

Nevertheless there is scarcity of arable land for agriculture. The same plot (they call it "*konde"*) used by a family over the years is still being used by the whole extended family. They are therefore forced to encroach in other reserved areas (closed forests) to seek arable land for cultivation. These findings are in agreement with those of Makota (2011) who found depletion of land due to continuous cultivation of various crops in Mbinga District. Furthermore; he found that because of shortage of land, farmers cleared upland closed woodland area for cultivation. Similar findings are echoed by Kimaro and Lulandala (2013) in Ngumburuni Forest Reserve, Rufiji District, Tanzania where about 28% of the closed coastal Miombo and riverine forest strata was converted into farmlands.

4.2.1.2 Energy

Like Tanzania mainland and other African countries, Zanzibar is inhabited by poor people who depend on nature rather than advanced technology for their livelihoods. Results show that 77.4% of the population of Bumbwini and Kisakasaka use fuel wood as primary source of energy, through collection of dead branches and straws (76%) (Appendix 3.5 and 3.6). Fire wood is the main source of energy for people of low economic power. As a result coral reefs, habitats for fish are destroyed and other upland trees are cut for fire wood. Likewise burning is pointed out as another human activity contributing largely to land cover change in the area. The burning is done for the sake of energy production and land clearance. Kashaigili and Majaliwa (2010) had similar results for Malagarasi Catchment where they found charcoal production being among the major contributors of deforestation in the area.

Plate 3: Clearing forest for charcoal production

4.2.1.3 Fishing activities

With reference to Appendix 3.1; about 12.9% of people over the study area employ themselves in fishing activities as their first major economic occupation; while. 32.5% of people consider fishing activities as their second economic occupation (Appendix 3.2). It was also found that about 53.1% of people are engaged in fishing activities only (Appendix 3.7). In fishing land cover change is manifested in land clearance due to cutting down of trees for constructing boats which are used to accomplish this exercise. Unsustainable fishing practices and mangrove forests degradation are the major threats to the sustainability of the coastal marine ecosystems over the area.

Over-fishing and increased use of illegal fishing methods have resulted in a decline of Catch per Unit Effort. This has also been acknowledged by NEMC (2009) in their report on status of the coast. The report reveals increased fishing pressure in traditional fishing grounds, with destructive fishing methods contributing greatly to undermining the marine ecology and fish habitats through dynamiting the coral reefs and clear cutting of the mangroves. Similarly shallow water trawling for prawns, beach seining and dynamite fishing destroy seaweeds both by uprooting and smothering those which are attached as they put sediments into suspension which ultimately settle on seaweeds (NEMC, 2009).

Plate 4: Construction of fishing boats using coastal ecosystem resources

4.2.1.4 Demography

There have been an increasing number of people in the area over time which in turn plays as a contributory factor for land cover change. Figure 17 and Appendices 4.1, 4.2, 4.3 and 4.4 show significant increase of population from 1988 to 2012 for Bumbwini and Kisakasaka areas, districts, regions and Zanzibar as a whole respectively. According to 2012 census report the total population of Zanzibar stands at 1 303 569 with average annual growth rate of 2.8 (URT, 2013). Though the growth rate has decreased from 3.1 in 2002 (Masore, 2011), still there has been a marked increase in population. Household survey shows 72.1% of the people were born within the villages while 28.9% moved from other places for the sake of establishing new settlements (Appendices 3.8 and 3.9). It would appear that more and more people are engaging themselves in agricultural production or individual farmers are expanding their farms for increased agricultural production (Appendix 3.10).

Out of 31.4% of the respondents who had indicated to have converted land cover from one form to another (Appendix 3.11) leading to land cover change, 32.1% attributed the change to climatic variability/change. This situation may worsen in the foreseeable future as more people (32.9%) are planning to expand their farms for capital gains (Appendices 3.13 and 3.14). The effect of population increase on land cover/use change has also been reported by Kabanza *et al.* (2013); Makota (2011); Namangaya (2011); Kashaigili and Majaliwa (2010) and Hieronimo (2007).

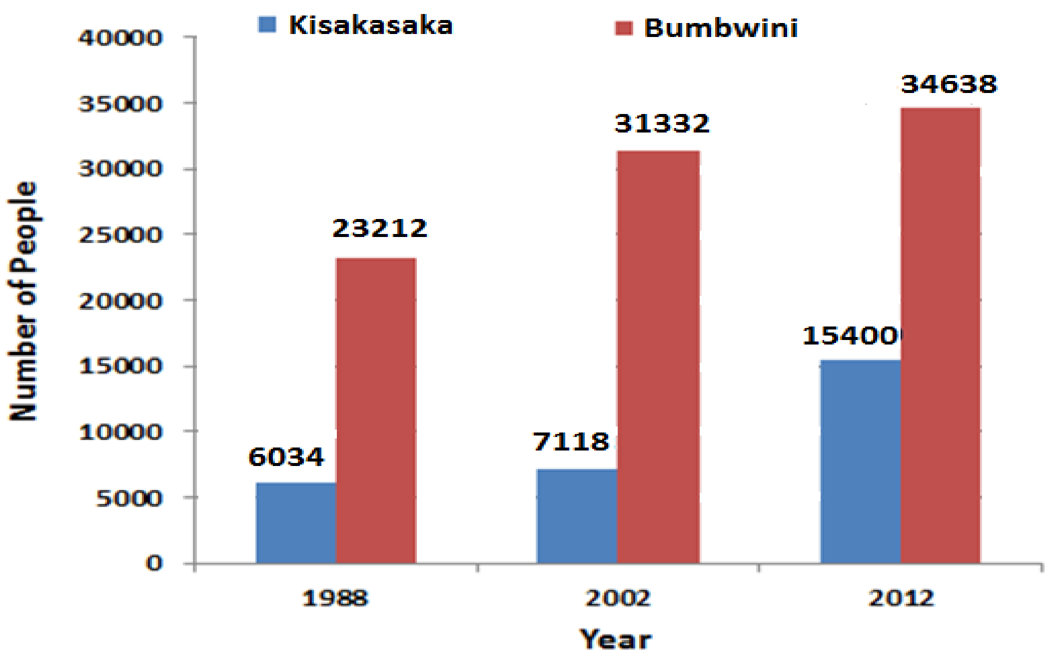

Figure 17: Population growth for Kisakasaka and Bumbwini

4.2.1.5 Livestock keeping

Though other researchers (e.g. Kombo, 2010; Masore, 2011) haven't shown the direct impact of livestock on land use/cover change; it is observed in Bumbwini and Kisakasaka, that people keep animals in a free range system or traditional way, which leads to land degradation and hence exacerbating the degree of land cover change in the island. Kashaigili and Majaliwa (2010) have shown how overgrazing can lead to land use/cover change. URT (2012) also mentioned overgrazing to be a major direct cause of uncontrolled deforestation and degradation in the forests.

Livestock keeping in the study area is a recent development and only a few residents (11.1%) have started keeping cattle since 2006. Out of those keeping livestock, only 22.2% have private pasture feeding facilities. This also applies to other livestock types such as goats which were non existent before 2005. Private pasture feeding system in general is only 5% which is dangerous for land cover in the island. More details are given in Appendices 3.15 – 3.21.

4.2.1.6 Construction

More demand by a rapidly growing population in Zanzibar for construction materials has resulted in depletion of forest resources. The research findings show that the use of poles as building materials accounts for about 27.3% in the study areas (Appendences 3.22 – 3.24). These findings are consistent with those of Kombo (2010). He found that growing population has led to a higher demand for settlements, agriculture and other infrastructure developments which in turn has an impact on the resource base, threatening the productive and protective capacity of the marine resources.

Plate 5: Collection of building materials which contribute to land degradation

4.2.2 Biophysical (natural) factors

Natural factors considered in this study are those caused by climatic behavior. This study used climatic (raifall and temparature) data of over fifty years for analysis to see whether changes in biophisical factors have any impact on land cover in the study areas. The results have revealed some changes in both rainfall and temperature. More details are provided in section 4.3 below.

4.3 Characteristics of Climate Parameters

4.3.1 Rainfall characteristics

4. 3.1.1 Annual rainfall

Cumulative mean daily annual rainfall was computed for all the years of record and plotted (Fig. 18). This kind of analysis (Kingamkono *et al*., 1994) clearly shows the mean onset and cessation dates including the type of rainfall regime for a given area. Like other bi-modal areas along the northern coast, long rains (*masika*) commence around the first week of March and end during the first week of June on average. Likewise the onset date for the short rains (vuli) for Zanzibar is during the fourth week of October ending in the second week of January (Kihupi *et al.*, 2007). This information corroborates the findings from this study as summarized in Table 16. The mean seasonal rainfall (long rains) is 868.5 mm while that for the short rains is 517.6 mm (table 15 and Appendix 5.1).

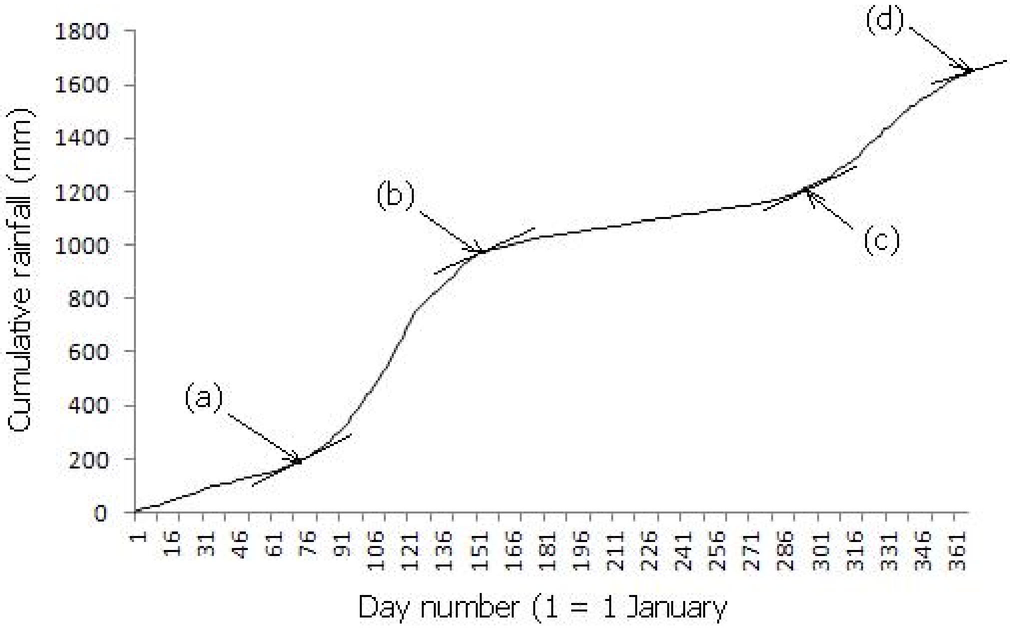

Figure 18: Cumulative mean daily annual rainfall for Zanzibar with points of maximum curvature: (a) onset of long rains, (b) cessation of long rains, (c) onset of short rains, (d) cessation of short rains

Table 15: Mean onset, cessation, length, wet days, extreme events and seasonal total rainfall for Zanzibar

Parameter	Long rainy season	Short rainy season
Onset of growing season	03 March	30 October
End of the growing season	30 May	13 January
Length of the growing season	89 days	76 days
Seasonal total rainfall	868.5 mm	517.6 mm
Extreme events	114.3 mm	82.0 mm
Wet days	88 days	31 days

The analysis depicts periods with high amounts of rainfall which are January, February, March, April and May. Peak rainfall is during April and May. From June to September it is a dry season as depicted in Figure 19 for a dry, normal and wet year representing monthly rainfall that can be expected 80, 50 or 20 percent of time (probability of exceedance) respectively.

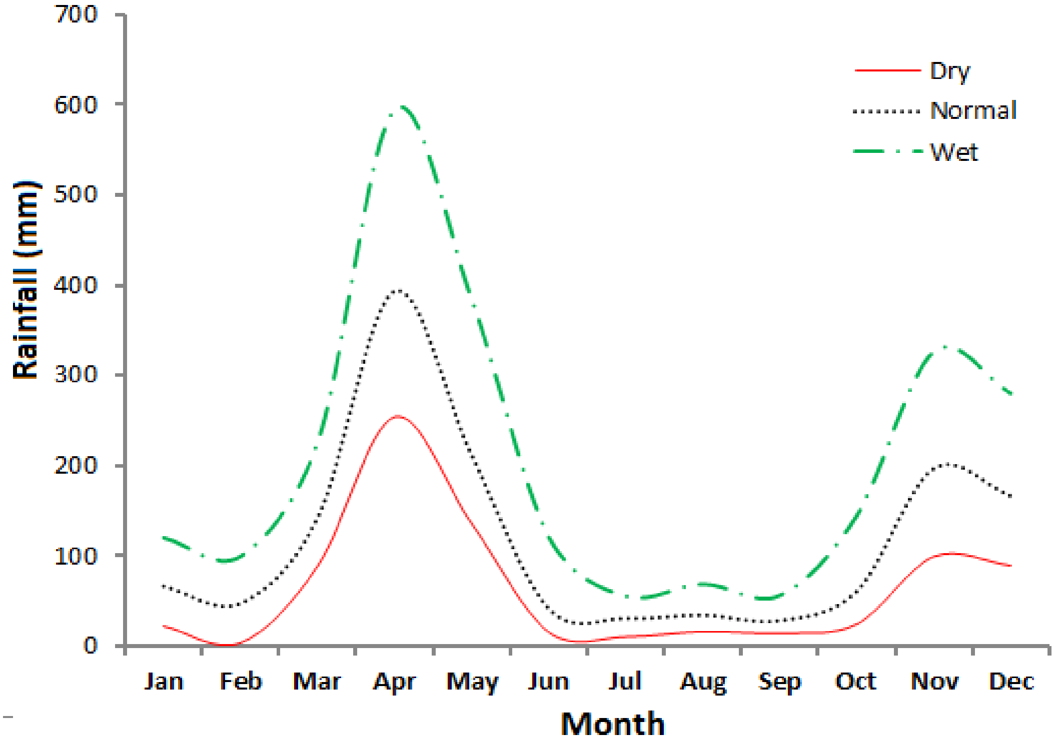

Figure 19: Expected rainfall amounts for each mo nth in Zanzibar with a 20, 50 and 80 per cent probability of exceedance representing a wet, normal and dry year.

On running the Mann-Kendall test on annual rainfall data, the following results as shown in Table 16 were obtained. The results for both Mann-Kendal (Table 16) and simple regression test (Appendix 5.3) show no statistically significant trend, though slight decrease in trend at a rate of 0.351 mm/year, 0.206 mm/year and 0.197 mm/year for February, July and September was observed. Otherwise there is slight increasing trend for the rest of the months, though not significant.

Table 16: Mann-Kendall trend and Sen's slope estimate for annual rainfall

Time series	First year	Last Year	n	Test Z	Significance	Sen's slope	Interpretation
Jan	1952	2011	60	0.21	NS	0.136	Accept
Feb	1952	2011	60	-1.19	NS	-0.351	Accept
Mar	1952	2011	60	1.29	NS	0.725	Accept
Apr	1952	2011	60	0.74	NS	0.872	Accept
May	1952	2011	60	0.18	NS	0.256	Accept
Jun	1952	2011	60	0.40	NS	0.112	Accept
Jul	1952	2011	60	-1.08	NS	-0.206	Accept
Aug	1952	2011	60	0.00	NS	0.002	Accept
Sep	1952	2011	60	-1.15	NS	-0.197	Accept
Oct	1952	2011	60	0.26	NS	0.115	Accept
Nov	1952	2011	60	0.47	NS	0.358	Accept
Dec	1952	2011	60	0.21	NS	0.156	Accept

Note: NS = Not significant

4. 3.1.2 Length of growing season

(a) Long rains

The results show a decreasing trend of length of growing season for Zanzibar during the long rains, though there is variation over time. As depicted in Fig. 20; for the first two decades, length of growing season was as long as 130 days in the year 1978, but with time length has been getting shorter. The length of growing season in the year 2000 was shortest (about 43 days) in the history of Zanzibar island. Therefore length of growing season for long rains lies between 43-130 days. This decreasing trend in growing season length is statistically significant ($P < 0.05$) for both Mann-Kendall and simple regression tests (Appendices 5.2 and 5.3) and is decreasing at a rate of 0.295 days/year. The results are also supported by findings of Vrieling *et al.* (2013) over the northern part of Tanzania.

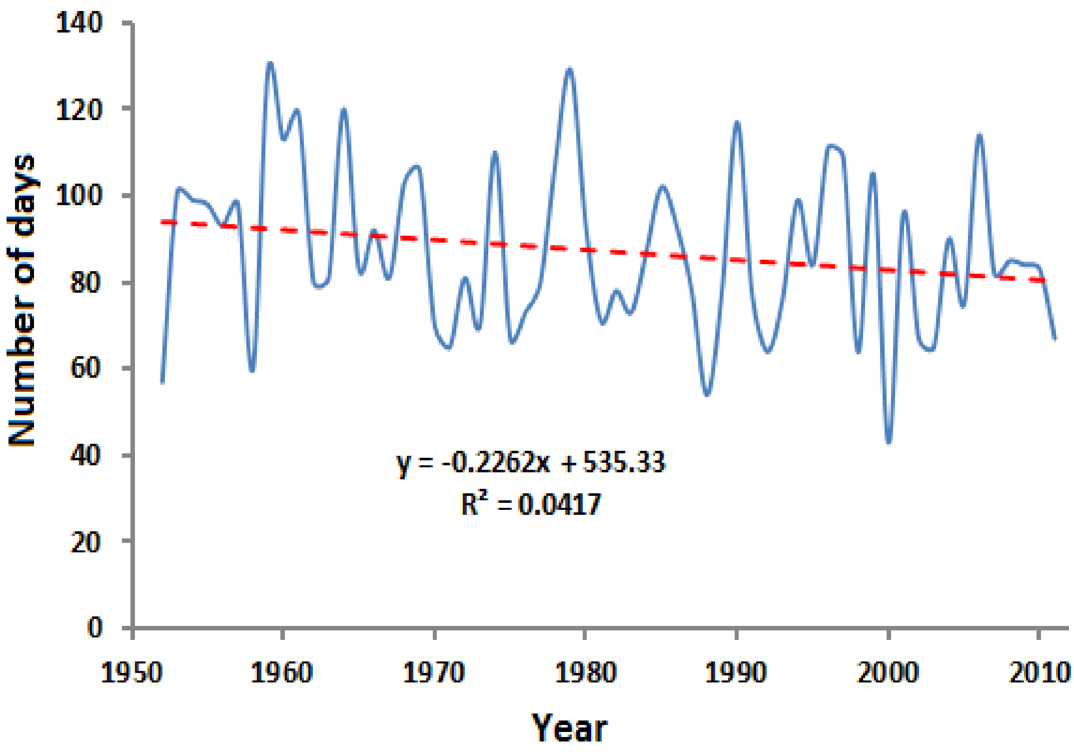

Figure 20: Trend of growing season length for Zanzibar during long rains (the dashed line is the linear trend)

(b) Short rains

The results also indicate a decreasing trend of length of growing season for Zanzibar during the short rainsat a rate of 0.095 days/year, though not statistically significant (Appendices 5.2 and 5.3), with expected variation over time. The length of growing season in the year 1960 was shortest (21 days) in the history of Zanzibar island followed by 1995 (23 days). There is considerable agreement of these results with those of other researchers such as Kihupi *et al.* (2007) and Venalainen and Mhita (1998). In general length of growing season for short rains is between 21-120 days. The large variation can be attributed to disturbances in general circulation in the atmosphere and hence climatic variability and change.

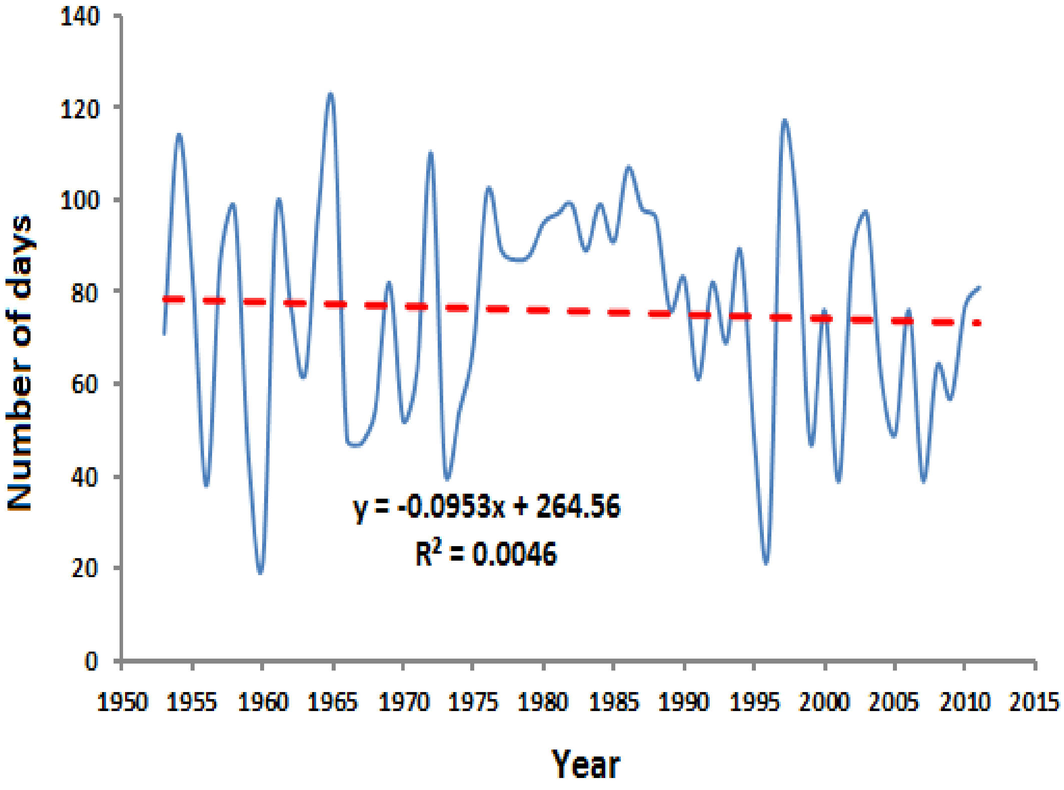

Figure 21: Trend of growing season length for Zanzibar during short rains (the dashed line is the linear trend)

4. 3.1.3 Onset of the growing season

(a) Long rains

The trend for the onset date for the long rains appears to be increasing, in other words rains are progressively starting later than before (Fig. 22). The rate of increase is 0.138 days/year but is not statistically significant (Appendices 5.2 and 5.3). Nevertheless there is considerable inter-annual variation (last week January to first week of April). The net effect however is reduced length of the growing season. This will adversely affect agricultural activities and hence food security in Zanzibar; which in one way or another results in land cover change in the island.

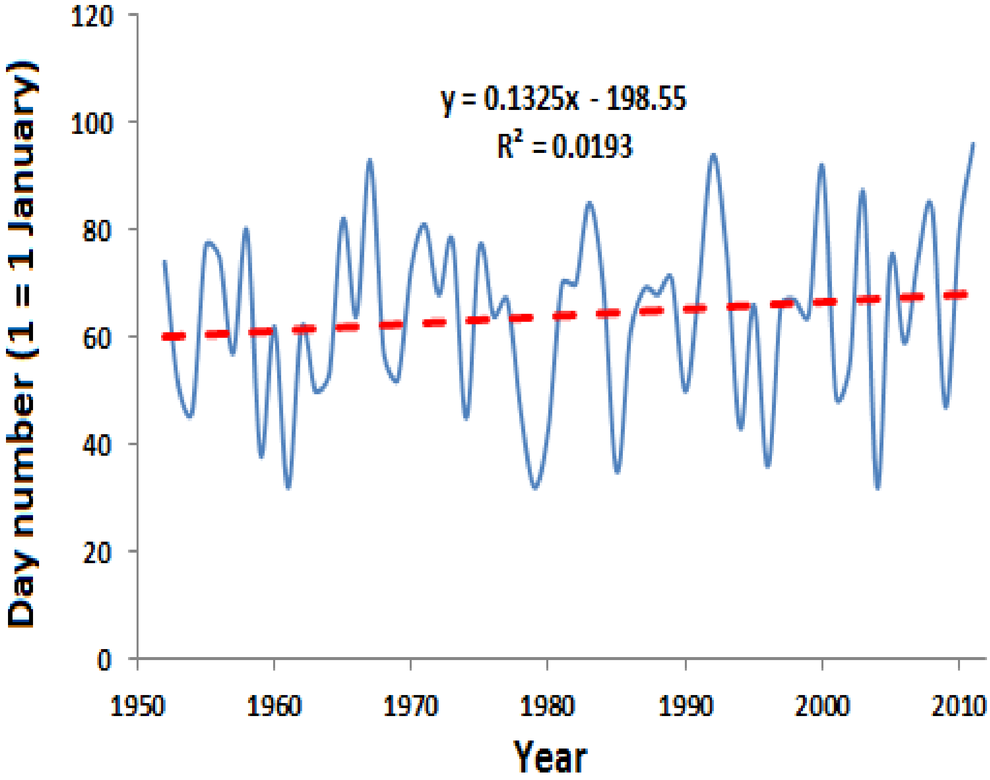

Figure 22: Trend of start date of growing season in Zanzibar during long rains (the dashed line is the linear trend)

(b) Short rains

The trend for the onset date for the short rains is not as pronounced but there is considerable inter-annual variation (last week of October to last week of January) (Fig. 23). Results seem to suggest that, earlier onsets are associated with El-Niño years, an observation that has also been echoed by Kijazi and Reason (2005).

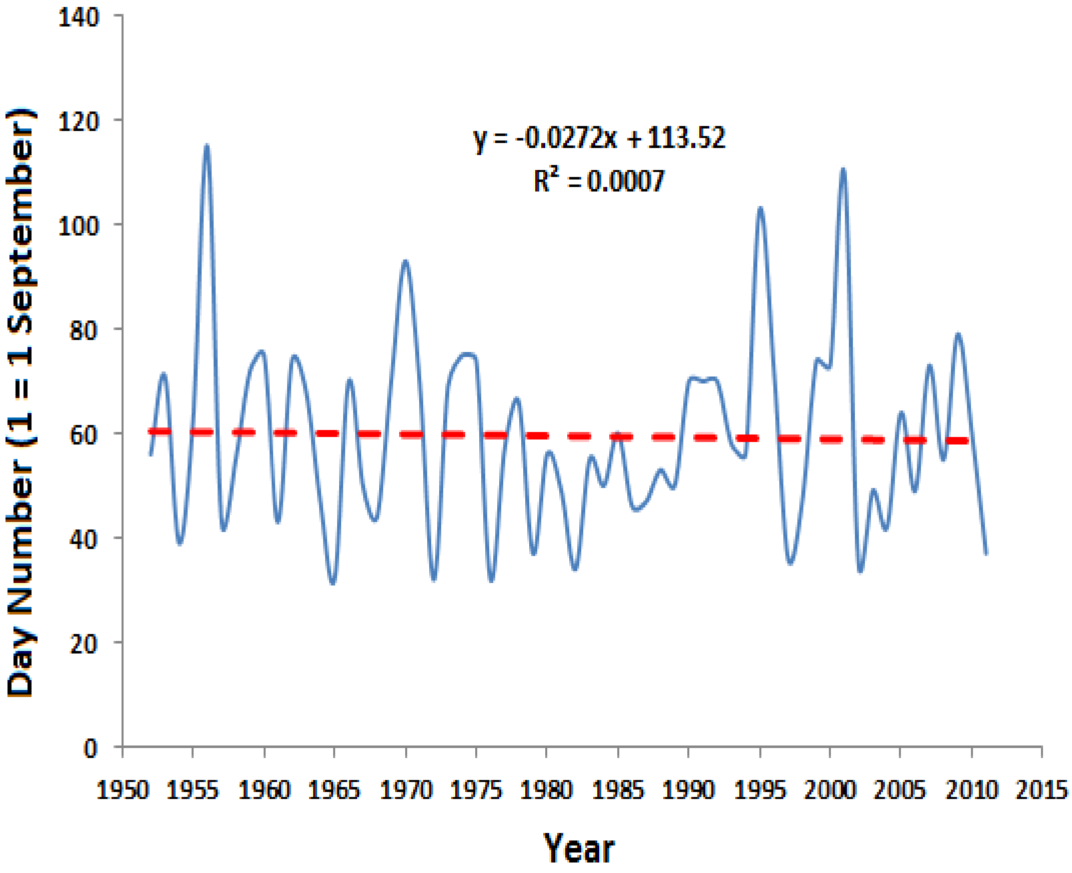

Figure 23: Trend of start date of growing season in Zanzibar during short rains (the dashed line is the linear trend)

4. 3.1.4 End of the growing season

(a) Long rains

Figure 24 shows a decreasing trend for the cessation date in Zanzibar during the long rains, albeit not statistically significant. The trend line represents a decreasing rate of 0.158 days/year (Appendices 5.2 and 5.3). As was for the case of the onset date, there is considerable inter-annual variation in the cessation date. Similar results were reported by Kihupi *et al.* (2007) for other stations in Tanzania where they found rains to be progressively starting later and ending earlier resulting in a shorter growing season.

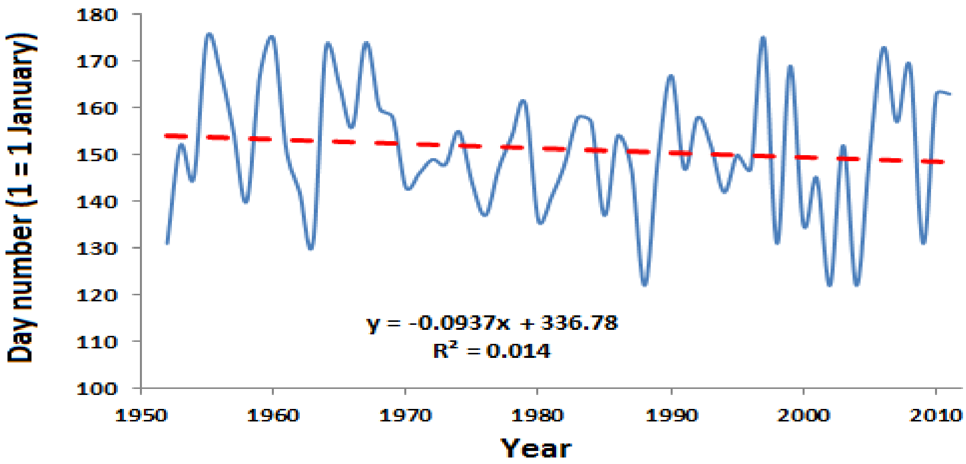

Figure 24: Trend of end date of growing season in Zanzibar during long rains (the dashed line is the linear trend)

(b) Short rains

Cessation date for the short rainy season in Zanzibar follows a similar trend as for the long rains with considerable variability (Fig. 25). Though it is not statistically significant (P<0.05) the trend line represents a decreasing rate of 0.1days/year (Appendices 5.2 and 5.3). In general, short rains are rather unreliable and unpredictable compared to long rains. This is in consistent with findings of other workers (e.g. Kihupi *et al.*, 2007)

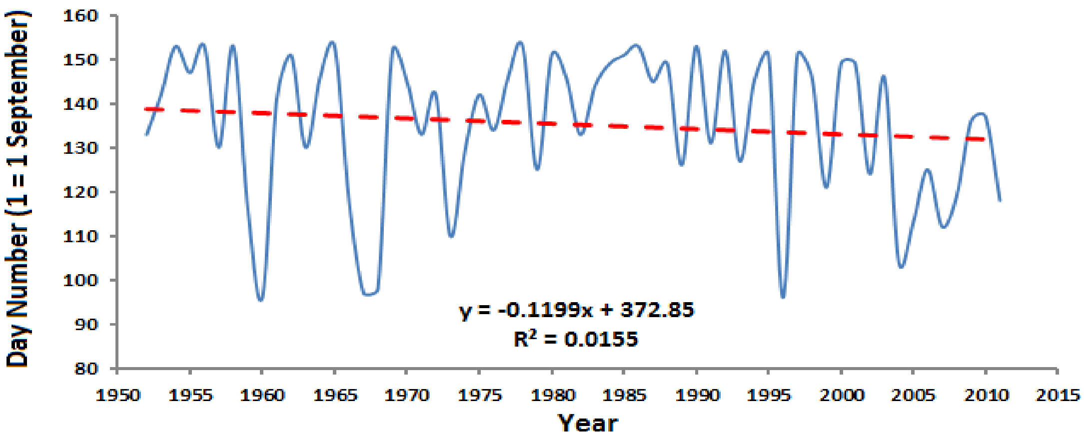

Figure 25: Trend of end date of growing season in Zanzibar during short rains (the dashed line is the linear trend)

4. 3.1.5 Total amount of rainfall in a season

(a) Long rains

Although there is no apparent trend in seasonal (long rains) rainfall for Zanzibar, there is significant inter-annual variation (Fig. 26). The results depict 2003 as being the driest year in the history of Zanzibar and 1979 being the wettest year. The results for both Mann-Kendal and simple regression test (Appendices 5.2 and 5.3) show no statistically significant trend.

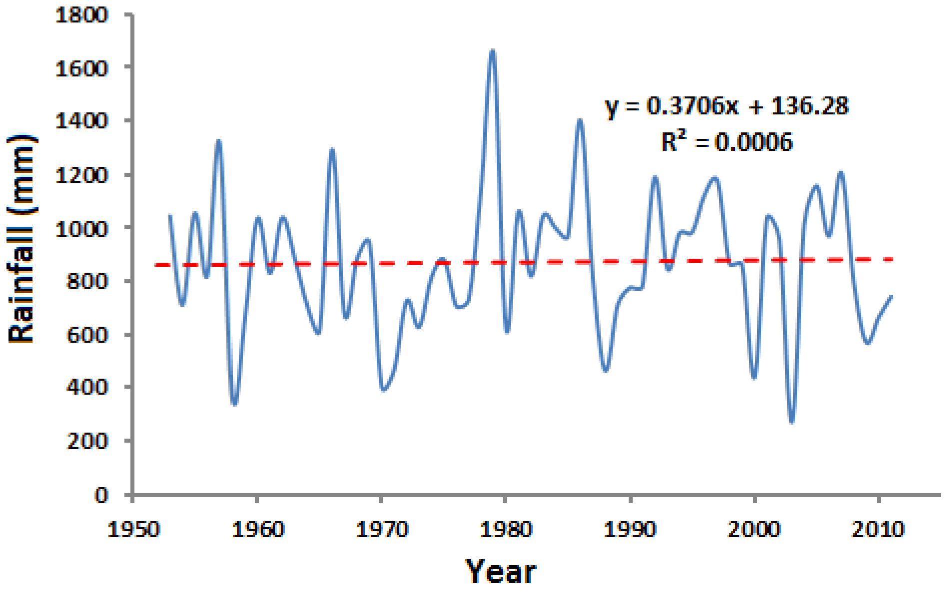

Figure 26: Trend of seasonal rainfall for Zanzibar during long rains (the dashed line is the linear trend)

(b) Short rains

As was the case for the long rains, there is no apparent trend in the seasonal (short rains) rainfall for Zanzibar (Fig. 27). However inter-annual variation is significant. The peaks in the seasonal rainfall appear to coincide with El-Niño events of 1963, 1972, 1977, 1986 and 1997 (Blench and Marriage, 1998). Strong evidence of the erratic nature of rainfall patterns from year to year can be seen with extremely low rainfall in 1960 and 1996 and high rainfall totals in 1978 and 1997 (Appendices 5.2 and 5.3).

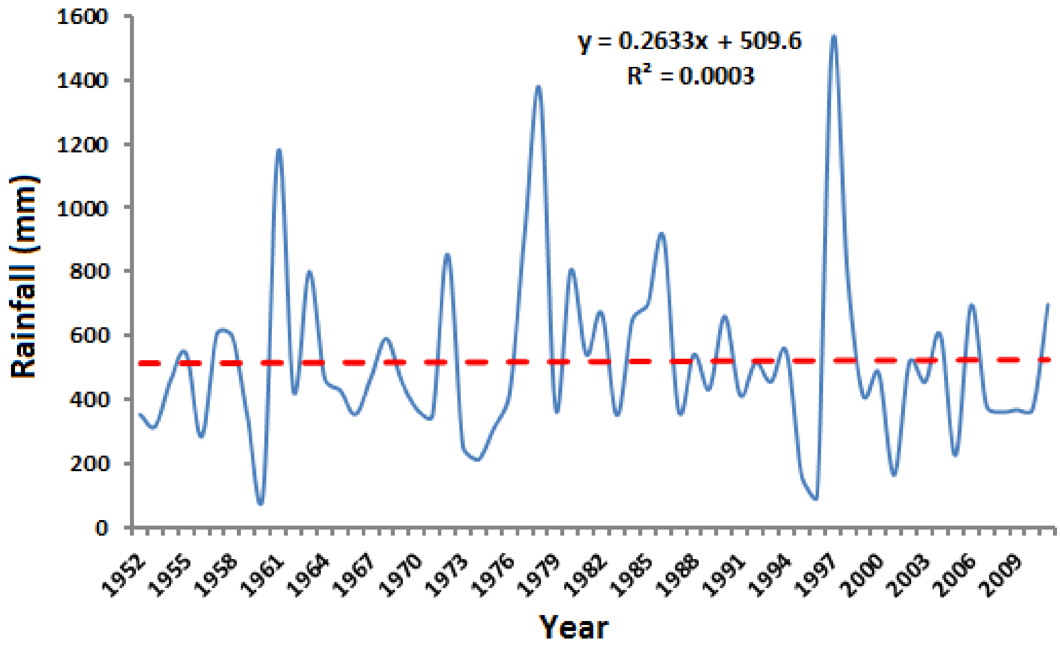

Figure 27: Trend of seasonal rainfall for Zanzibar during short rains (the dashed line is the linear trend)

4. 3.1.6 Extreme events

(a) Long rainy season

Figure 28 indicates a steady, though not statistically significant increase of extreme rainfall events with time for Zanzibar. The first decade had an extreme event of 250 mm followed by a drastic fall of rainfall in the next decade. Within the next five years Zanzibar witnessed a very and most heavy rainfall event which occurred in 1979 when it recorded 320 mm followed by 240 mm in 1985. Though there is variation of extreme events; severity, socio and economic damage of drought and floods appear to increase with time as shown in Appendices 6.1, 6.2, 6.3 and 6.4.

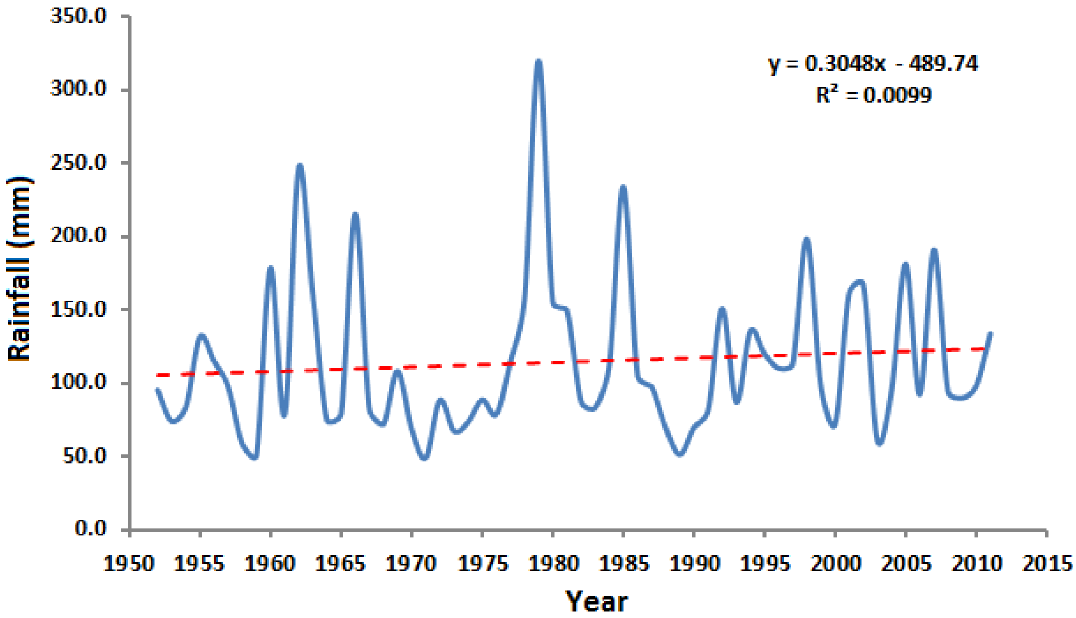

Figure 28: Trend of extreme (maximum) rainfall events for Zanzibar during long rains (the dashed line is the linear trend)

(b) Short rainy season

The trend of extreme rainfall events for the short rainy period in Zanzibar (Fig. 29) is similar to that of the long rainy season. Most of the events fall between 50 mm -100 mm. The first very and most heavy rainfall event occurred in 1978 when it recorded 320 mm followed by a dramatic fall in 1985 (180 mm). The second heavy event occurred in 1998 with 200 mm. This was the time of severe flooding caused by El Niño. It resulted in food crisis, disease infection, drowning, damaged water facilities (dams, boreholes, water troughs) and disruptions in market infrastructure and road systems, though in some marginal agricultural areas, the additional rainfall led to higher production (Kandji *et.al*, 2006).

Further incidents of floods in Zanzibar occurred in 2000/2001 and 2009. Extreme shortages of rainfall occurred in 1996/1997 and 1999/2000 and a very severe drought was recorded in 2005/2006 (URT 2007). The severe drought impacted on the agricultural sector since it only grew by 5.2% compared to 5.8 growth rate in 2004. This triggered food and power crisis in most parts of Tanzania (URT 2007).

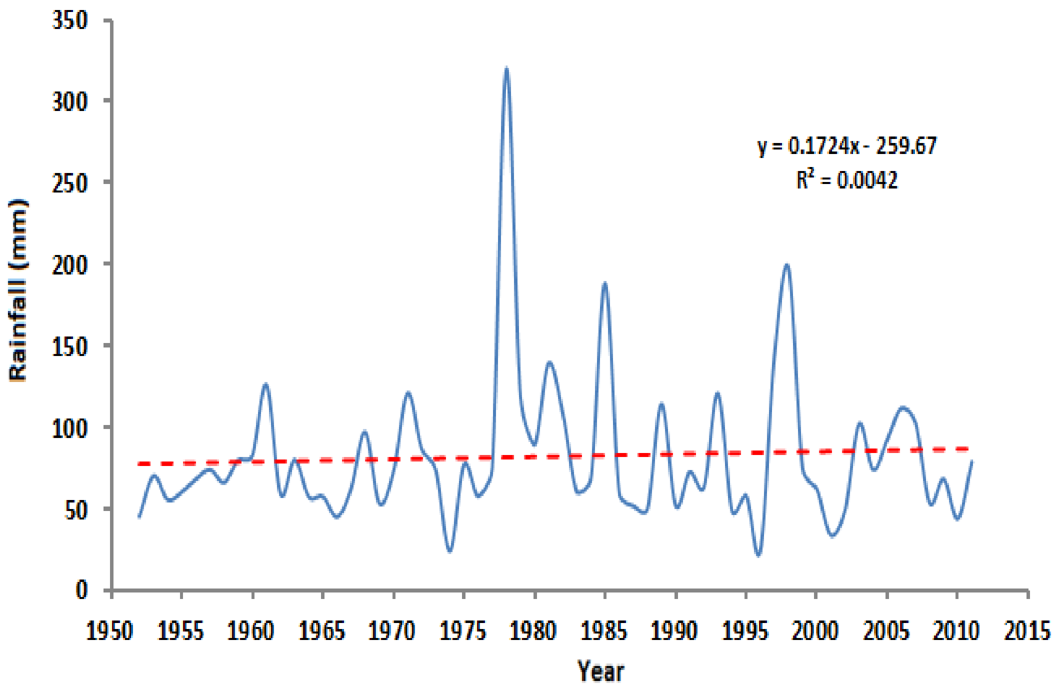

Figure 29: Trend of extreme (maximum) rainfall events for Zanzibar during short rains (the dashed line is the linear trend)

4. 3.1.7 Wet days

(a) Long rainy season

The number of wet days within the growing season (long rains) in Zanzibar shows a decreasing trend at a rate of 0.125 days/year (Fig. 30 and Appendix 5.2). This trend is statistically significant ($P<0.05$) using simple regression test (Appendix 5.3). Days with rainfall are getting fewer and fewer. Although the number of wet days appears to be decreasing with time, seasonal rainfall is more or less constant but with a slight indication of extreme events increasing with time which is logical.

Although the trend of wet days is significant using simple regression test, this is not the case with Mann-Kendall test (Appendix 5.2). This is only parameter for which the results of significance test differ between the two methods, (i.e simple regression and Mann-Kendall tests (Appendix 5.4).

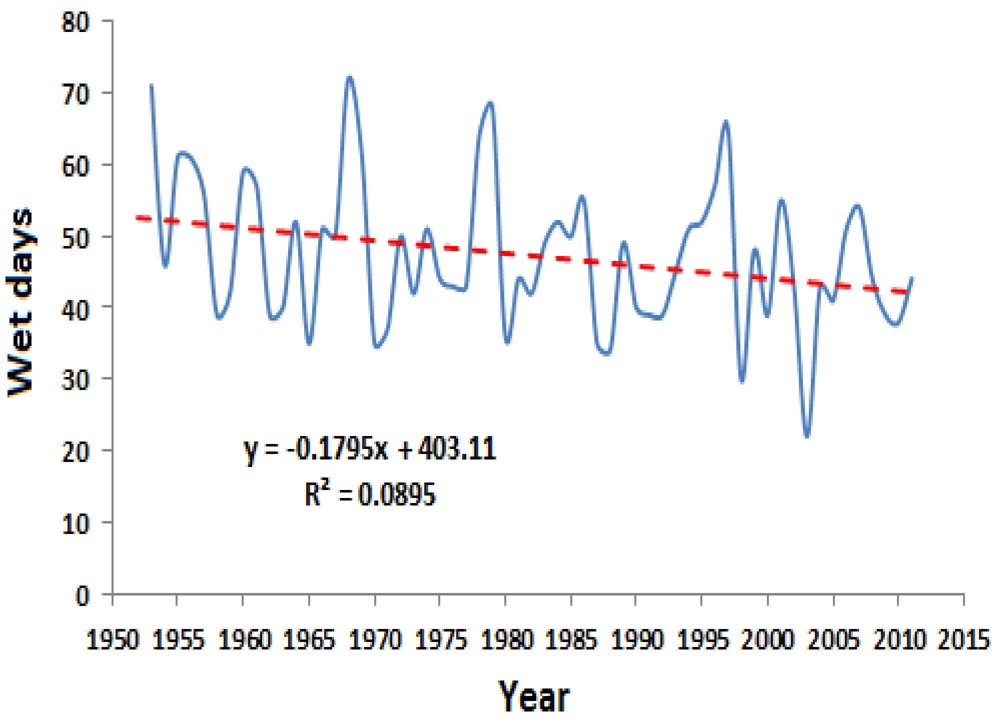

Figure 30: Trend of number of wet days for Zanzibar during long rains (the dashed line is the linear trend)

(b) Short rainy season

The trend of the number of wet days during the short rains in Zanzibar (Fig. 31) is similar to that of the long rains although not as pronounced; and not statistically significant with decreasing rate of 0.083 days/year (Appendices 5.2). The maximum number of wet days was observed in 1995 which had 86 days. This is the highest that has ever been recorded for the past 60 years for both short and long rains, followed by 75 days in 1998. The minimum number of wet days was in 1960 which had only 9 days, the lowest ever recorded for the past 60 years, followed by 10 days in 1996.

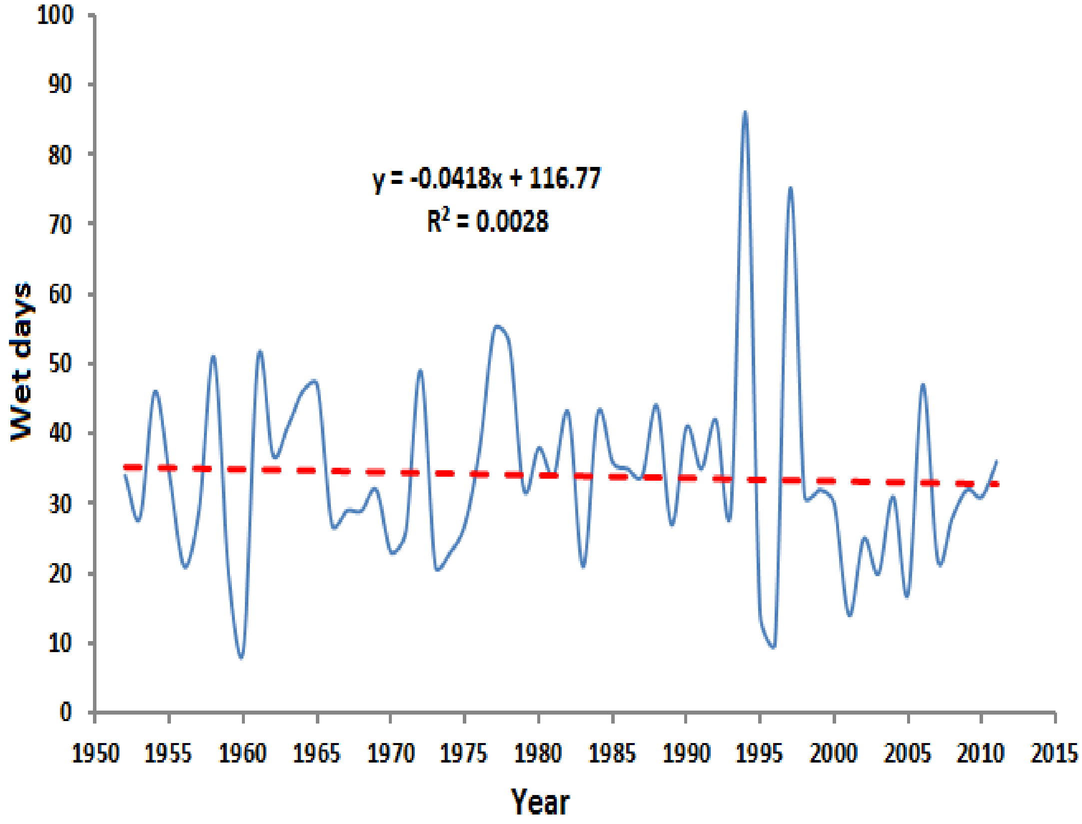

Figure 31: Trend of number of wet days for Zanzibar during short rains (the dashed line is the linear trend)

4. 3.1.8 Dry spells

In order to see whether long dry spells have significantly changed with time especially during the rainy season, the rainfall data was divided into temporal periods and analysed accordingly as shown in Figure 32. It is quite apparent, especially during the short rainy season that the probability of having long dry spells (10 days or more) is much higher in recent years than it was before. This coupled with other changes in the growing season characteristics point to an uncertain future if appropriate measures are not taken immediately to mitigate the situation.

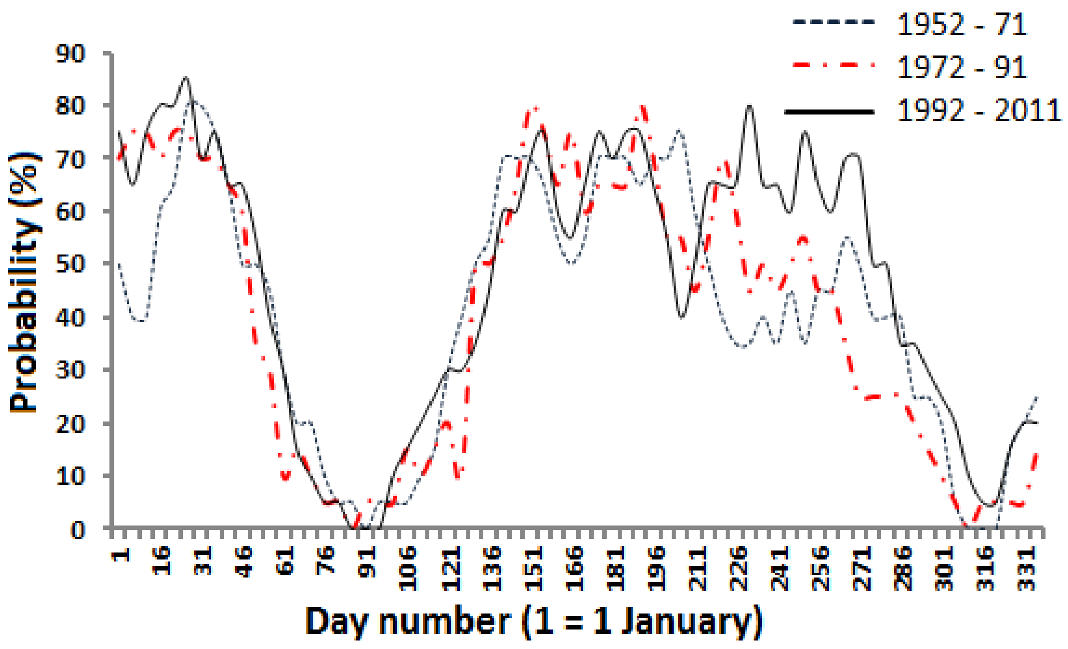

Figure 32: Trend of probability of a 10-day dry spell within a 30-day period following the date indicated on the horizontal axis for Zanzibar for the respective temporal periods

During both rainy seasons (*Masika* and *Vuli*), there are variations in the onset of rains, most of the time experiencing late onset and early cessation. Both onset and cessation dates are unpredictable in both rainy seasons. Recently no one can exactly tell when rains can start or end. Rain may start later or earlier but last for a short period of time and sometimes become more intense as attested by respondents. Generally, these findings support the changing and very unpredictable nature of rainfall in the study areas, in which the timing and distribution/intensity of rain can lead to crop failure even in years with normal total annual rainfall. A careful comparison of community perceptions to 60 years of rainfall data reveals a more nuanced picture, but one which still provides significant evidence in support of perceived changes in rainfall patterns in Zanzibar over the last 10 to 30 years.

4. 3.2 Temperature characteristics

4. 3.2.1 Mean maximum temperature

Figure 33 shows that there is an increasing trend of mean maximum temperature. Only in mid 1980s did the mean maximum temperature fall to 30.0^{0}C. The highest was in 2010 for which 31.4^{0}C was recorded followed by 1988 which recorded 31.2^{0}C. An analysis carried out by New *et al.* (2006) as part of a wider assessment for Africa showed clear evidence of decreasing number of cold days and nights and an increase in the number of heat waves and in the frequency of hot nights.

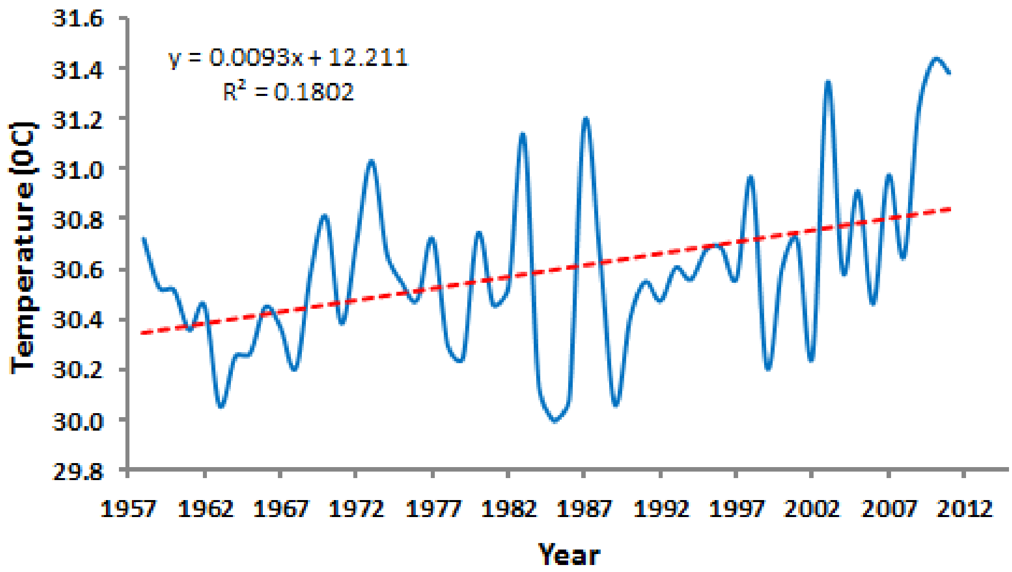

Figure 33: Mean maximum temperature for Zanzibar (the dashed line is the linear trend)

On running the Mann-Kendall test on mean maximum temperature data, the following results as shown in Table 17 were obtained. Only for the months of January, February and September was the trend statistically significant ($P<0.05$) with January being very highly significant. The rate of increase is 0.024^{0}C, 0.022^{0}C and 0.01^{0}C per year for January, February and September respectively. Other months do not show any significant change tendency.

Table 17: Mann-Kendall trend and Sen's slope estimate for mean maximum temperature

Time series	First year	Last Year	n	Test Z	Significance	Sen's slope	Interpretation
Jan	1958	2011	54	3.65	***	0.024	Reject
Feb	1958	2011	54	3.03	**	0.022	Reject
Mar	1958	2011	54	1.58	NS	0.011	Accept
Apr	1958	2011	54	0.57	NS	0.003	Accept
May	1958	2011	54	-0.56	NS	-0.003	Accept
Jun	1958	2011	54	-0.34	NS	-0.001	Accept
Jul	1958	2011	54	1.43	NS	0.006	Accept
Aug	1958	2011	54	0.05	NS	0	Accept
Sep	1958	2011	54	2.06	*	0.01	Reject
Oct	1958	2011	54	1.78	NS	0.01	Accept
Nov	1958	2011	54	1.06	NS	0.006	Accept
Dec	1958	2011	54	2.01	NS	0.013	Accept

Note: *** = Very highly significant (P<0.001), ** = Highly significant (P<0.01),

* = Significant (P<0.05)

4. 3.2.2 Mean minimum temperature

The mean minimum temperature also shows a rising trend at a rate greater than that for the mean maximum temperature (Fig. 34). The lowest mean minimum temperature ever recorded in Zanzibar was in the year 1966 with a mean minimum temperature of 16.6^{0}C. From there on, the trend was an upward spiral. This is consistent with findings of a number of studies on global warming (IPCC, 2007b).

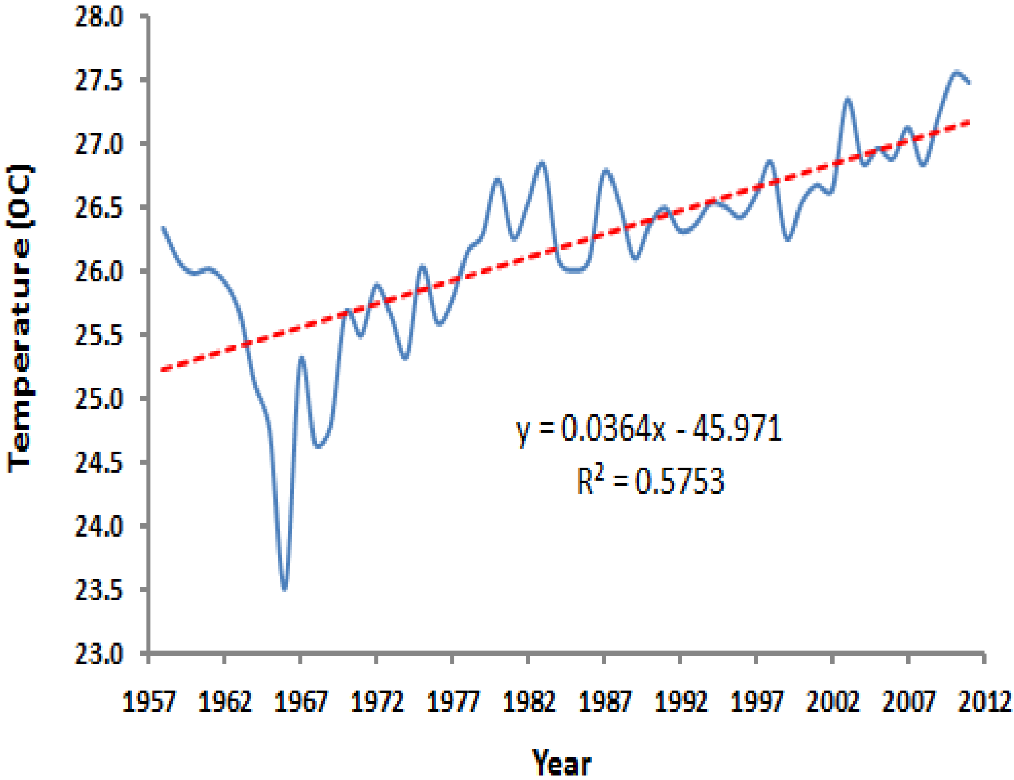

Figure 34: Mean minimum temperature for Zanzibar (the dashed line is the linear trend)

According to Mann-Kendall test, all months show a very highly significant (P<0.01) rising (positive) trend over the 54-year period (Table 18). Similar results were obtained using the simple regression test. The rate of increase is greater than 0.051^{0}C/year for all months except for April, May and June. The highest rate of increase is 0.065^{0}C/year for the month of October and the lowest rate is 0.044^{0}C/year for the month of May.

Table 18: Mann-Kendall trend and Sen's slope estimate for mean minimum temperature

Time series	First Year	Last Year	n	Test Z	Significance	Sen's slope	Interpretation
Jan	1958	2011	54	6.83	***	0.059	Reject
Feb	1958	2011	54	6.24	***	0.055	Reject
Mar	1958	2011	54	6.51	***	0.062	Reject
Apr	1958	2011	54	5.92	***	0.047	Reject
May	1958	2011	54	5.63	***	0.044	Reject
Jun	1958	2011	54	5.9	***	0.047	Reject
Jul	1958	2011	54	6.27	***	0.054	Reject
Aug	1958	2011	54	5.44	***	0.051	Reject
Sep	1958	2011	54	5.99	***	0.063	Reject
Oct	1958	2011	54	6.05	***	0.065	Reject
Nov	1958	2011	54	5.63	***	0.051	Reject
Dec	1958	2011	54	6.17	***	0.053	Reject

Note: *** = Very highly significant ($P<0.001$),

4. 3.2.3 Mean temperature

The mean temperature also shows a rising trend almost at the same rate as that for the mean minimum temperature (Fig. 35). The lowest mean temperature ever recorded in Zanzibar was in 1966 with a mean temperature of 23.5^0C. This is also consistent with a number of studies on global warming (IPCC, 2007b).

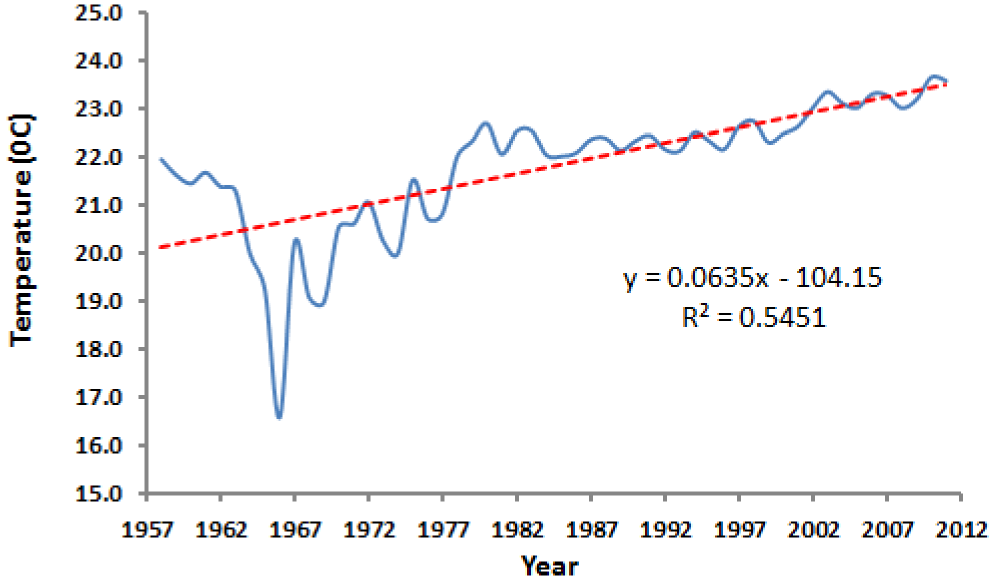

Figure 35: Mean temperature for Zanzibar (the dashed line is the linear trend)

4. 3.2.4 Temperature trends in general

Ghalharia *et al.* (2012) found a meaningful increasing trend in minimum, maximum and mean temperature in Iran. Also Karmeshu (2012) revealed statistically significant increasing trends in temperature in the North eastern United States except for Pennsylvania and Maine. Generally, the rising trend in temperature is seen even in sea surface temperature (SSTs) trends in the western Indian Ocean region. It has been shown using low resolution satellite data and a limited number of *in-situ* measurements that the minimum and maximum sea surface temperatures in East African coastal waters have been increasing at a rate of 0.018^0C/yr over the last 50 years (Mclanahan *et al.*, 2007). The results further indicate significant spatial variability with patterns of maximum SSTs increasing from inshore to offshore locations and the minimum SSTs increasing from south to north. The rate of temperature rise was generally higher in ENSO years than during the non-ENSO years. The 1997-1998 El-Niño event had both ENSO and IOD components (Saji *et al.*, 1999) and was associated with massive coral bleaching in the entire western Indian Ocean region.

Significant increase of minimum temperature and changes in rainfall patterns in Zanzibar translate directly into impacts on crop and livestock production and hence food security. Further, impact of climate has potentially negative effects on coastal ecosystem and the services they provide. The degradation and potential loss of ecosystem will cascade through to many sectors affecting coastal infrastructures and increasing demand for arable land which in turn could also contribute to land cover change over the study area.

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Based on results from satellite imagery interpretations, change detection and intensity analysis carried out between 2001 and 2011; land cover in the study area appears to be highly dynamic. The study revealed that between year 2001 and 2011, the mangrove, cultivated land/shrubs and bare land covers declined while mixed trees and "jangwa la bahari" increased in Kisakasaka. During the same time period, cultivated land/shrubs, mangrove and mixed trees covers declined while paddy, bare lands and *"Jangwa la bahari*" increased with alarming rate in Bumbwini. The rate of change for Bumbwini appears to be higher than that for Kisakasaka. Furthermore the 2009 – 11 period had a much faster rate of change than the 2001 – 09 period. It was also revealed that, there was a significant increase of population from 1988 to 2012 for Kisakasaka and Bumbwini areas.

Although there appears to be no significant trend in rainfall amount (both seasonal and annual totals), the length of growing season and number of wet days show a significant negative trend ($P<0.05$). There is also a subtle increase in extreme events over time though not statistically significant which in a way would explain the decreasing trend of rainy days while the total rainfall is more or less constant. This is also reflected in the observed increase of severity of socio and economic damage caused by drought and floods. Both mean and minimum temperature portray a highly significant ($P<0.01$) positive trend.

Significant increase of minimum temperature and changes in rainfall patterns in Zanzibar translate directly into impacts on crop and livestock production and hence food security. The effects of climate change have had a negative impact on food production in the study areas. This along with other factors affecting production such as technical know-how, financing and access to markets; have resulted in food insecurity at different levels. Further impact of climate change has potentially negative effects on coastal ecosystem and the services they provide.

It can thus be inferred from the findings of this study that, changes in climate together with population pressure have mainly contributed significant changes in land cover observed over the area. The degradation and potential loss of ecosystem will cascade through to many sectors affecting coastal infrastructures hence increased demand for arable land which in turn could also contribute to land cover change over the study area.

5.2 Recommendations

Based on the findings of this study, it is recommended that concerted actions be undertaken to reverse the observed/perceived changes. These could include:

i. Strict conservation measures to ensure sustainability of coastal ecosystems. The coastal management team should be strengthened interms of human resource and facilities.

ii. Mitigation and adaptation to climate change in relation to land use and food security issues to address the adverse repercations like: establishment of irrigation schemes, rainwater harvesting, use of improved early maturing crop varieties, post-harvest management technologies, natural resource management like re-forestation and improved cultural practices. It is necessary to strengthen the resilience of rural people and to help them cope with this additional threat to food security. Particularly in the agriculture sector, climate change adaptation can go hand-in-hand with mitigation. Climate change adaptation and mitigation measures need to be integrated into the overall development approaches and agenda.

iii. Use of higher resolution images in future studies to achieve much better results. Landsat images used in this study were of low resolution (30 m by 30 m).

iv. Longer period of investigation using remotely sensed data than the one used in the present study to enable correlation (modelling) of change of biophysical data.

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APPENDICES

Appendix 1: Household Survey Questionnaire

General information

1. Date of interview…………………………………………..…………
2. Name of enumerator……………………………………...……......
3. Name of Village………………………….…………………………..
4. Name of Ward…………………………………………………..…
5. Name of Division…………………………………………….………
6. Identification number of household…………………………….……
7. Name of household head…………………………….…...……….
8. Sex of respondent: Male ☐ Female ☐
9. Age of respondents in years (If possible estimate the age group).

   i) 1- 19 ☐ ii) 20-40 ☐ iii) 41-60 ☐ iv) > 61 ☐

10. Marital status of respondent

    i) Married ☐ ii) Not married ☐ iii) Divorced ☐

    iv) Widowed ☐ v) Other specify:………………………….

11. What is your education level

    i) No formal education ☐ ii) Formal education ☐

    iii) Adult education ☐ iv) Primary education ☐

    v) Secondary education ☐ vi) Certificate level ☐

    vii) Diploma level ☐ viii) University ☐

12. How many are you in your family? ☐
13. What is your main occupation? Mention them according to ranking

    i)…………..................................ii)………………………………

    iii)………………………………iv)……………………………...

14. Place of birth……………………………………………..……………

15. Years of residence in this village………………………..…………….

16. Did you shift to this village?……………………………..…………….

i) Yes ii) No

17. If yes, what are the reasons for shifting…………………............……….

i) Land availability ii) Inheritance of land iii) Farming

iv) Residential housing v) Other (specify)

Socio-economic status

18. What is your social position?…………………… ……………..………..

1. Peasant/small scale farmer 2. Political leader 3. Traditional leader

4. Employee (specify)……………………………………………………

19. What is the major source of your income?………………....………………

1. Farming activities
2. Non-farm activities
3. Both 1&2
4. Other (specify)……………………………………………………

20. Do you practicefishing? i) Yes ii) No

21. If yes, which fishing means do mostly use?

i) Ground fishing………………… ii) Sailing boat fishing…………………

iii) Machine boat fishing……………iv) Other (specify)……….……………

22. Where do you always fishing?

i) Coral reefs…………………ii) Mangrove area……………………………

iii) Other (Specify)……………………………………………………..

23. Why are you fishing in this place?...

24. What is your average income from fishing per day/month/year? …………...…..

25. What is your average monthly income from farm (TAS)?……………………..…

26. What is your average monthly income from other activities (TAS)?…………….

27. What is your average expenditure per month? (TAS)…………………………..…

Land use and land tenure

28. How is land owned in your village?

i) Private ii) Communal iii) Hiring iv) Bought

iii) Other specify……………………

29. Who makes most of the decision on land use in this household?

i) Male ii) Female iii) Both male and female

30. Does your household own land for agricultural use?………….…………

1.Yes 2.No

31. If yes, how did you acquire the land?……………………………………..…..

1. Purchased 2. Rented 3.Inherited 4. Both 1&3

5. Both 2&3 6. Others (specify)……………………..….….

32. How long have you owned the land (years)?……………………..…..

33. How large is your land area (acres)?…………………………………….

34. How many land cover do you posses? ………………………………….

35.Did you convert land cover from one type to another?

1. Yes 2. No

36. If yes, what could be the reason(s) for the conversion?………………….

…………………………….……., ………………………………….

37. Do you keep any livestock?……………………………………………

1. Yes 2. No

38. If yes, which type, breed, quantity and feeding system?………………..

39. Is your land/farm adequate?……………………………..……………

1. Yes 2. No

40. If not what are your plans?……………………………………………….

41. How is the trend of cultivated land in the village?………………………..

1. Increasing 2. Decreasing 3. Same

42. Do you plan to expand your farm?………………………………… …...

1. Yes 2. No

43. If yes, why?……………………………………………….………..

1. Look for arable land 2. Increased capital base

3. Increased household size 4. Easy availability of land

5. Improved input 6. Other (Specify)…………………….……

Household assets and energy supply

44. Do you own this house or rent?………………………………………………

1. Own 2. Rent 3. Other (specify)……………….……….……

45. What are the materials used to build your house

47. Does your household own………………………………………………

1. Bicycle 2. Motorcycle 3. Car

4. Both 1 &2 5. Both 2 &3 6. None of those

7. Other (Specify)…………………………………………………….

48. What is your primary source of fuel for your household?

49. Do you face any fuel problem?…………………………..………………

1. Yes 2. No

50. If yes, what measures are you taking to solve the problem?

1. Private tree planting. 2. Agroforestly.

3. No measure taken. 4. Other (Specify) ……………

51. Where do you get your firewood from?…………..km.

Other Information on coastal marine ecosystems

53. Do you know mangrove? i). Yes……………ii). No…….………

54. If yes, what do you think is the main uses of the mangrove in your area?

Please mention in ranking:………………., ……………….., ………………

55. Who own the mangrove forests?

i)………………………………….. ii). ………………………………

iii)…………………………………..

56. Who manage the mangrove forests?

i)……………………………… ii).……………………..……

iii)…………………………………..

57. Is there a permit in mangrove forests?

i). Yes……………… Ii). No………………………

58. If yes, which permit?

i). Entrance …………… ii).Cutting ………………iii). Fishing ………..…

iv). Both………………..iii). Other (specify) ………………………………

4. What do you think are the benefit obtained from mangrove? Mention.

………………………, ……………………..…, ………………………,

59. Are you aware of climate change? i) Yes ii) No

60. If yes, where did you learn and gather information on climate change?

i) Parents ii) Radio and television iii) Seminars/workshops/study tour

iv) Friends and relatives v) Reading magazines vi) Extension services

vii) Pamphlets on climate change viii) Others (specify)………………

61. What are the impacts of climate change in your area?……………….…………

62. How do you mitigate these changes?……………………………….……………

63. How do you adopt these changes?…………………………………………………

64. How do you compare the distribution and intensity of rainfall in your area?…..…

THANK YOU VERY MUCH

Appendix 2: Key informants checklist

CHECKLISTS FOR FGDS AND IN-DEPTH INTERVIEWS

A. CHECKLIST FOR FOCUS GROUP DISCUSSIONS WITH VILLAGERS

1. What are the main economical activities?
2. Do you have farms/own land outside your village?
3. Why are you farming outside your village?
4. What are the main land covers possessed in your village?
5. Have there been land cover changes in the past 30 years?
6. What could be the main reasons for these changes?
7. What are the implications of land cover changes on people's livelihood?
8. Have the land cover changes causes land shortages, how?
9. Have the land cover changes caused by scarcity of land, how?
10. What are the other problems resulting from land cover changes?
11. Do you experience decrease in income resulting from land cover changes, how?
12. Is mangrove forests potential for supporting your income? How?
13. What land cover management system could suit in your areas?
14. Have you experienced natural disasters due to land cover changes?
15. What natural disasters that have occurred in the past 30 years?
16. How did people get affected by such natural disasters?
17. Did you experience mangrove cover change for the past 30 years?
18. Was the mangrove change towards increases or decreases?
19. What are the main reasons for this mangrove changes?
20. What are the collective efforts among community members to reduce effects of mangrove cover changes?

B. CHECKLIST FOR FOCUS GROUP DISCUSSIONS WITH VILLAGE GOVERNMENT

1. What is the total population in the village?
2. How many households *(kaya)* in the village?
3. What are the main economic activities for the local communities in this village?
4. How many types of land cover are possessed in your area?
5. Is the coastal areas potential for tourism development to support community's income?
6. What are the land cover changes observed in the area in the past thirty (30) years?
7. How do community members participate in coastal marine resources management activities?
8. What problems do you experience working with the local community in coastal marine resources management?
9. Are there village members who are farming outside their village? If yes, why and since when?
10. Are there people from other villages coming to farm in your village? If yes, why and since when?
11. What are the conditions of acquiring land in the village?

C. CHECKLIST FOR IN-DEPTH INTERVIEWS WITH DISTRICT COASTAL MANAGEMENT OFFICER (DCMO)

1. What are the main uses of mangrove products in the district?
2. Have the availability of mangrove products being affected due to land cover changes?
3. What is the status of coastal marine ecosystems in the district?
4. What are the factors influencing coastal marine ecosystems in the district?
5. How do you engage local communities in mangrove rehabilitation programmes?
6. What are the main land cover changes taking place in the areas?
7. What are the existing coastal resources management/conservation projects undertaken in the study area?
8. How community members do engaged in coastal resources management programs?
9. How many organizations are dealing with coastal resources management?
10. What problems do you experience working with local communities in coastal resources management?
11. Is the coastal marine ecosystems potential for tourism development?
12. Is these developments potential to support community’s income?

Appendix 3: Results for social household survey

Appendix 3.1 First occupation

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	None	3	1	1.1	1.1
	Agriculture	186	65	66.4	67.5
	Fishing	36	12.6	12.9	80.4
	Selling fish	1	0.3	0.4	80.7
	Small bussiness	17	5.9	6.1	86.8
	Livestock keepeng	3	1	1.1	87.9
	Tailoring	14	4.9	5	92.9
	Manson	1	0.3	0.4	93.2
	Employed	16	5.6	5.7	98.9
	Labor	3	1	1.1	100
	Total	280	97.9	100	
Missing	System	6	2.1		
Total		286	100		

Appendix 3.2: Secondoccupation

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Agriculture	52	18.2	18.6	18.6
	Fishing	91	31.8	32.5	51.1
	Selling fish	1	0.3	0.4	51.4
	Small bussiness	18	6.3	6.4	57.9
	Livestock keeping	14	4.9	5	62.9
	Tailoring	31	10.8	11.1	73.9
	Employed	4	1.4	1.4	75.4
	Labour	3	1	1.1	76.4
	none	66	23.1	23.6	100
	Total	280	97.9	100	
Missing	System	6	2.1		
Total		286	100		

Appendix 3.3: Social position of the household

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Farmer	251	87.8	90	90
	Political leader	4	1.4	1.4	91.4
	Traditional leader	2	0.7	0.7	92.1
	Employee	20	7	7.2	99.3
	none	1	0.3	0.4	99.6
	11	1	0.3	0.4	100
	Total	279	97.6	100	
Missing	System	7	2.4		
Total		286	100		

Appendix 3.4: Major source of income

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Agriculture	179	62.6	63.9	63.9
	Non agricultural activities	44	15.4	15.7	79.6
	1&2	52	18.2	18.6	98.2
	0thers	5	1.7	1.8	100
	Total	280	97.9	100	
Missing	System	6	2.1		
Total		286	100		

Appendix 3.5: Woodas primary source of energy

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Fuel wood	216	75.5	77.4	77.4
	Others	11	3.8	3.9	81.4
	none	52	18.2	18.6	100
	Total	279	97.6	100	
Missing	System	7	2.4		
Total		286	100		

Appendix 3.6: Where do you get wood for energy?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Tree cutting	1	0.3	0.4	0.4
	Collection of dead branches and staws	212	74.1	76	76.3
	none	66	23.1	23.7	100
	Total	279	97.6	100	
Missing	System	7	2.4		
Total		286	100		

Appendix 3.7: Do you practice fishing?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	None	7	2.4	2.5	2.5
	YES	146	51.0	53.1	55.6
	NO	122	42.7	44.4	100.0
	Total	275	96.2	100.0	
Missing	System	11	3.8		
Total		286	100.0		

Appendix 3.8: Place of birth

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Within the village	202	70.6	72.1	72.1
	Out of the village	78	27.3	27.9	100
	Total	280	97.9	100	
Missing	System	6	2.1		
Total		286	100		

Appendix 3.9: **Did you moveto this village?**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	YES	81	28.3	28.9	28.9
	NO	198	69.2	70.7	99.6
		1	0.3	0.4	100
	Total	280	97.9	100	
Missing	System	6	2.1		
Total		286	100		

Appendix 3.10:How is the trend of cultivated land in this village?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Increasing	134	46.9	47.9	47.9
	Decreasing	55	19.2	19.6	67.5
	Same	91	31.8	32.5	100
	Total	280	97.9	100	
Missing	System	6	2.1		
Total		286	100		

Appendix 3.11: Did you convert land cover from one type to another?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid		1	0.3	0.4	0.4
	YES	88	30.8	31.4	31.8
	NO	191	66.8	68.2	100
	Total	280	97.9	100	
Missing	System	6	2.1		
Total		286	100		

Appendix 3.12: If yes, what could be the reason for conversion?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	For fish pond cultivation	1	0.3	0.4	0.4
	Due to climate change	90	31.5	32.1	32.5
	none	189	66.1	67.5	100
	Total	280	97.9	100	
Missing	System	6	2.1		
Total		286	100		

Appendix 3.13: Do you have a plan to expand your farm?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Yes	92	32.2	32.9	32.9
	No	188	65.7	67.1	100
	Total	280	97.9	100	
Missing	System	6	2.1		
Total		286	100		

Appendix 3.14: If yes, why?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Looking for arable land	22	7.7	7.9	7.9
	Increased capital base	53	18.5	18.9	26.8
	Increased house hold size	9	3.1	3.2	30
	Easy availability of land	1	0.3	0.4	30.4
	Improved input	5	1.7	1.8	32.1
	Others	4	1.4	1.4	33.6
	none	186	65	66.4	100
	Total	280	97.9	100	
Missing	System	6	2.1		
Total		286	100		

Appendix 3.15: When did you start raising cattle?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1990-1995	17	5.9	6.1	6.1
	1996-2000	9	3.1	3.2	9.3
	2001-2005	11	3.8	3.9	13.2
	Above 2006	31	10.8	11.1	24.3
	none	212	74.1	75.7	100
	Total	280	97.9	100	
Missing	System	6	2.1		
Total		286	100		

Appendix 3.16: What is the livestock feeding system?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Zero grazing	8	2.8	2.9	2.9
	Private pasture	62	21.7	22.2	25.1
	Communal pasture	7	2.4	2.5	27.6
	On farm land	10	3.5	3.6	31.2
	none	192	67.1	68.8	100
	Total	279	97.6	100	
Missing	System	7	2.4		
Total		286	100		

Appendix 3.17: When did you start raising goats?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1990-1995	4	1.4	1.4	1.4
	1996-2000	3	1	1.1	2.5
	2001-2005	8	2.8	2.9	5.4
	Above 2006	4	1.4	1.4	6.8
	none	261	91.3	93.2	100
	Total	280	97.9	100	
Missing	System	6	2.1		
Total		286	100		

Appendix 3.18: What is thelivestock feedingsystem?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Zero grazing	5	1.7	1.8	1.8
	Private pasture	14	4.9	5	6.8
	Communal pasture	4	1.4	1.4	8.2
	On farm land	3	1	1.1	9.3
	none	254	88.8	90.7	100
	Total	280	97.9	100	
Missing	System	6	2.1		
Total		286	100		

Appendix 3.19: When did you start raising donkeys?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1990-1995	5	1.7	1.8	1.8
	none	275	96.2	98.2	100
	Total	280	97.9	100	
Missing	System	6	2.1		
Total		286	100		

Appendix 3.20: What is thelivestock feedingsystem?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Zero grazing	6	2.1	2.1	2.1
	Private pasture	13	4.5	4.6	6.8
	Communal pasture	1	0.3	0.4	7.1
	none	260	90.9	92.9	100
	Total	280	97.9	100	
Missing	System	6	2.1		
Total		286	100		

Appendix 3.21: What is the livestock feeding system?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Zero grazing	2	0.7	0.7	0.7
	Private pasture	5	1.7	1.8	2.5
	none	273	95.5	97.5	100
	Total	280	97.9	100	
Missing	System	6	2.1		
Total		286	100		

Appendix 3.22: What are the materials used for walls?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Cement block	153	53.5	54.6	54.6
	Bunt bricks	6	2.1	2.1	56.8
	Un bunt bricks	2	0.7	0.7	57.5
	Poles & muds	78	27.3	27.9	85.4
	Muds	18	6.3	6.4	91.8
	Stones	22	7.7	7.9	99.6
	1&5	1	0.3	0.4	100
	Total	280	97.9	100	
Missing	System	6	2.1		
Total		286	100		

Appendix 3.23: What are the materials used for roof?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Corrugated sheet	194	67.8	69.3	69.3
	Tiles	8	2.8	2.9	72.1
	Grass/straws	16	5.6	5.7	77.9
	Grass+mud	6	2.1	2.1	80
	Other	56	19.6	20	100
	Total	280	97.9	100	
Missing	System	6	2.1		
Total		286	100		

Appendix 3.24: What are the materials used for floor?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Cement	139	48.6	49.6	49.6
	Earth	135	47.2	48.2	97.9
	Others	5	1.7	1.8	99.6
	none	1	0.3	0.4	100
	Total	280	97.9	100	
Missing	System	6	2.1		
Total		286	100		

Appendix 4: Population distribution

Appendix 4.1: Population data for Kisakasaka and Bumbwini for 1988, 2002 and 2013

Year	Area	Shehia (Ward)	Male	Female	Total
1988	Bumbwini	Makoba + Mafufuni	2424	2525	4949
		Misufini	2783	2894	5677
		Muwanda	204	205	409
		Mto wa Pwani	272	299	571
	Kisakasaka	Kibondeni + Kisakasaka	3079	2955	6034
	Total		**11186**	**11403**	**17640**
2002	Bumbwini	Makoba + Mafufuni	3437	3503	6940
		Misufini	3751	3909	7660
		Muwanda	264	221	485
		Mto wa Pwani	289	292	581
	Kisakasaka	Kibondeni + Kisakasaka	3625	3493	7118
	Total		**11366**	**11418**	**22784**
2012	Bumbwini	Makoba + Mafufuni	3703	3606	7309
		Misufini	3920	4066	7986
		Muwanda	485	465	950
		Mto wa Pwani	516	558	1074
	Kisakasaka	Kibondeni + Kisakasaka	7468	7932	15400
	Total		**16092**	**16627**	**32719**

Source: Bureau of Statistics Zanzibar (2013)

Appendix 4.2 District population

District	Year	Male	Female	Total
North B (Kaskazini B)	2012	40,548	41,127	81,675
	2002	26,372	26,233	52,605
	1988	18,106	18,903	37,009
West (Magharibi)	2012	176,979	193,666	370,645
	2002	91,429	93,281	184,710
	1988	26,085	24,166	50,251

Appendix 4.3: Region population

Region	Year	Male	Female	Total
North (Kaskazini)	2012	92,114	95,341	187,455
	2002	67,093	69,860	136,953
	1988	46,310	50,689	96,999
Urban West (Mjini Magharibi)	2012	283,590	310,088	593,678
	2002	190,937	200,065	391,002
	1988	104,074	103,803	207,877

Appendix 4.4: Zanzibar (country) population

Region	Population (Number)			Population Increase	Average Annual Rate(Percent)	
	2002 Census Counts	2012 Projected Population	2012 Census Counts	2002 - 2012 (Number)	1988-2002	2002-2012
Kaskazini Unguja	136,639	189,574	187,455	50,816	2.5	3.2
Kusini Unguja	94,244	117,475	115,588	21,344	2.1	2.0
Mjini Magharibi	390,074	506,907	593,678	203,604	4.5	4.2
Kaskazini Pemba	185,326	275,806	211,732	26,406	2.1	1.3
Kusini Pemba	175,471	269,030	195,116	19,645	2.3	1.1
Tanzania, Zanzibar	981,754	1,358,792	1,303,569	321,815	3.1	2.8

Appendix 5: Climate characteristics over Zanzibar

Appendix 5.1: ***Table showing Start, End, Length, Total and Extreme events of Seasonal Rainfall in Zanzibar***

	Long Season					Short Season				
Year	**Start**	**End**	**Length**	**Total**	**Extreme event**	**Start**	**End**	**Length**	**Total**	**Extreme event**
1952	14-Mar	10-May	57	301.1	95.3	26-Oct	11-Jan	77	353.7	45.2
1953	20-Feb	31-May	101	1045.4	73.9	10-Nov	20-Jan	71	317.2	70.1
1954	15-Feb	24-May	99	710.9	83.6	09-Oct	31-Jan	114	461.5	55.4
1955	17-Mar	23-Jun	98	1056.6	131.6	02-Nov	25-Jan	84	545	60.2
1956	03-Mar	16-Jun	107	904.4	115.1	24-Dec	31-Jan	38	283.4	68.1
1957	26-Feb	19-May	111	1320.5	97.5	13-Oct	08-Jan	87	604	73.9
1958	17-Mar	14-Jun	60	360.7	58.7	25-Oct	31-Jan	98	597.1	66
1959	07-Feb	19-May	129	666.3	50.8	11-Nov	25-Dec	44	342	79.8
1960	02-Mar	23-Jun	113	1036.5	178.6	14-Nov	05-Dec	21	102	82.6
1961	01-Feb	30-May	119	831	78.5	13-Oct	19-Jan	98	1179.1	126
1962	02-Mar	21-May	80	1040.1	247.1	13-Nov	29-Jan	77	425.2	58.9
1963	19-Feb	10-May	81	882.9	159.9	07-Nov	08-Jan	62	800	80
1964	22-Feb	21-Jun	120	709	74.7	17-Oct	24-Jan	99	466.4	57.2
1965	22-Mar	13-Jun	83	616.9	79.3	02-Oct	31-Jan	121	430.1	57.3
1966	04-Mar	04-Jun	92	1294.8	215.4	09-Nov	27-Dec	48	353.8	44.9
1967	02-Apr	22-Jun	81	675	82.7	20-Oct	06-Dec	47	466.4	62.2
1968	26-Feb	08-Jun	103	883.4	72	14-Oct	07-Dec	54	591.5	96.9
1969	21-Feb	06-Jun	106	945.9	108.4	07-Nov	30-Jan	82	458.4	53.1
1970	13-Mar	22-May	99	481.6	68.6	02-Dec	23-Jan	52	369.6	72.6
1971	21-Mar	25-May	65	468.1	49.1	09-Nov	11-Jan	63	348.3	120.8
1972	08-Mar	28-May	81	726.9	88.4	02-Oct	20-Jan	110	853.8	86.8
1973	18-Mar	27-May	70	627.8	67.4	08-Nov	19-Dec	41	253.9	73.5

1974	14-Feb	03-Jun	110	815.8	73.5	14-Nov	07-Jan	54	211.9	24
1975	17-Mar	23-May	67	882.1	88.8	13-Nov	20-Jan	68	311.9	77
1976	04-Mar	16-May	73	706	78.8	02-Oct	12-Jan	102	415.4	57.5
1977	07-Mar	26-May	80	730.3	114.8	27-Oct	24-Jan	89	919.2	74.6
1978	15-Feb	02-Jun	108	1148	157.4	05-Nov	31-Jan	87	1365.4	320
1979	01-Feb	09-Jun	129	1653.4	320	07-Oct	03-Jan	88	372.3	119
1980	12-Feb	15-May	93	622.1	155.4	26-Oct	29-Jan	95	805.5	89.3
1981	10-Mar	20-May	71	1061.7	150.1	19-Oct	24-Jan	97	541.4	139.3
1982	10-Mar	27-May	78	819.4	87.7	04-Oct	11-Jan	99	671.2	108.3
1983	25-Mar	06-Jun	73	1045.5	83.2	25-Oct	22-Jan	89	350.6	60.3
1984	10-Mar	05-Jun	87	999.4	112.2	20-Oct	27-Jan	99	647.9	68.8
1985	04-Feb	16-May	102	969.2	234.1	30-Oct	29-Jan	91	699.1	188.3
1986	01-Mar	02-Jun	93	1402.9	105.3	16-Oct	31-Jan	107	910.2	59.6
1987	09-Mar	26-May	78	810.7	97.7	17-Oct	23-Jan	98	364.1	51.7
1988	12-Feb	30-Apr	54	463.9	69.5	23-Oct	27-Jan	96	541.5	49.6
1989	11-Mar	28-May	78	711.6	51.4	20-Oct	04-Jan	76	433.3	114.1
1990	19-Feb	12-May	117	776.5	69.9	09-Nov	31-Jan	83	661.3	51.9
1991	10-Mar	26-May	77	781.5	81.5	09-Nov	09-Jan	61	413.5	72.5
1992	03-Apr	06-Jun	64	1191.4	151	09-Nov	30-Jan	82	515.9	63
1993	16-Mar	31-May	76	847.6	87	28-Oct	05-Jan	69	455.2	120.6
1994	12-Feb	21-May	99	981.2	135.7	26-Oct	23-Jan	89	550.2	48.4
1995	06-Mar	29-May	84	984.3	120	12-Dec	29-Jan	48	160.3	58
1996	05-Feb	26-May	111	1124.4	110.2	11-Nov	05-Dec	24	99.4	24.1
1997	06-Mar	23-Jun	109	1178.8	113.3	06-Oct	29-Jan	115	1524.5	144.3
1998	07-Mar	10-May	64	865.8	198.6	17-Oct	24-Jan	99	778.7	197.6
1999	04-Mar	17-Jun	105	861.2	97.8	13-Nov	30-Dec	47	412	74.7
2000	01-Mar	16-May	74	706.9	72	12-Nov	27-Jan	76	485.5	62.2
2001	18-Feb	24-May	96	1037.7	161.4	19-Dec	27-Jan	39	163.3	33.5
2002	24-Feb	30-Apr	67	957.8	167.1	05-Oct	02-Jan	89	517.9	48.9
2003	27-Mar	31-May	65	270.9	60.8	19-Oct	24-Jan	97	454.3	101.9
2004	01-Feb	27-Apr	90	1011.7	94.8	12-Oct	13-Dec	62	604	73.8

2005	15-Mar	31-May	75	1158.7	181.5	03-Nov	22-Dec	49	225.5	92.4
2006	01-Mar	21-Jun	114	969.9	92.4	19-Oct	03-Jan	76	695.9	111.6
2007	15-Mar	05-Jun	82	1207.3	191.1	12-Nov	21-Dec	39	380.5	102.4
2008	24-Mar	17-Jun	85	792.4	94.4	25-Oct	28-Dec	64	361.6	53.3
2009	16-Feb	10-May	84	570.4	89.9	18-Nov	14-Jan	57	368.4	68.1
2010	20-Mar	11-Jun	83	665.1	98.2	30-Oct	15-Jan	77	369.3	43.7
2011	05-Apr	11-Jun	67	742.6	133.8	07-Oct	27-Dec	81	697.6	78.8
Mean	**03-Mar**	**30-May**	**89**	**868.5**	**114.3**	**30-Oct**	**13-Jan**	**76**	**517.6**	**82**

Appendix 5.2: Results of Mann-Kendall significance test for rainfall parameters

	First year	Last Year	n	Test Z	Sen' Slope	Interpretation	Trend	Remark
LONG RAINS								
Onset	1952	2011	60	0.9636	0.1384	Accept	Increasing	Not significant
End	1952	2011	60	-1.3086	-0.1579	Accept	Decreasing	Not significant
Length	1952	2011	60	-1.9271	-0.2952	Reject	Decreasing	Significant
Seasonal rainfall	1952	2011	60	0.4018	0.9992	Accept	Increasing	Not significant
Extreme events	1952	2011	60	1.467	0.3962	Accept	Increasing	Not significant
Wet days	1952	2011	60	-1.4372	-0.125	Accept	Decreasing	Not significant
SHORT RAINS								
Onset	1952	2011	60	-0.0447	0	Accept	Decreasing	Not Significant
End	1952	2011	60	-1.2271	-0.1	Accept	Decreasing	Not Significant
Length	1952	2011	60	-0.5361	-0.0952	Accept	Decreasing	Not Significant
Wet days	1952	2011	60	-0.83	-0.0833	Accept	Decreasing	Not Significant
Seasonal rainfall	1952	2011	60	0.236	0.3118	Accept	Increasing	Not Significant
extreme amount	1952	2011	60	0.4018	0.077	Accept	Increasing	Not Significant

Appendix 5.3: Significance of climate characteristics obtained from simple regression test (tabulated values)

LONG RAINS				
	R2	R	Slope	Remark
Onset	0.0193	0.13892444	0.1325	Not significant
End	0.014	0.118321596	-0.0937	Not significant
Length	0.0417	0.204205779	-0.2262	Significant
Seasonal rainfall	0.0006	0.024494897	0.3706	Not significant
Extreme events	0.0099	0.099498744	0.3048	Not significant
Wet days	0.0895	0.299165506	-0.1795	Significant
SHORT RAINS				
Onset	0.0007	0.026457513	-0.0953	Not significant
End	0.0155	0.124498996	-0.0272	Not significant
Length	0.0046	0.0678233	-0.1199	Not significant
Seasonal rainfall	0.0003	0.017320508	0.2633	Not significant
Extreme events	0.0042	0.064807407	0.1724	Not significant
Wet days	0.0028	0.052915026	-0.0418	Not significant
Annual Rainfall	0.014	0.118321	2.8883	Not significant
Tabulated value = 0.25, d.f = 59				
Mean max. temp	0.1802	0.424499706	0.0093	Highly sign
Mean min. temp	0.5451	0.738308878	0.0364	Highly sign
Mean temp	0.5753	0.758485333	0.0635	Highly sign
Tabulated value = 0.273, d.f = 53				

Appendix 5.4: Comparison of the significant results between Mann-Kendall and simple regression test

	Long Rains		Short rains	
	Mann-Kendall	**Simple test**	**Mann-Kendall**	**Simple test**
Onset	Not significant	Not significant	Not Significant	Not significant
End	Not significant	Not significant	Not Significant	Not significant
Length	Significant	Significant	Not Significant	Not significant
Seasonal rainfall	Not significant	Not significant	Not Significant	Not significant
Extreme events	Not significant	Not significant	Not Significant	Not significant
Wet days	Not significant	Significant	Not Significant	Not significant
Annual Rainfall	Not significant	Not significant		
Mean max. temp	Significant	Highly significant		
Mean min. temp	Very highly significant	Highly significant		
Mean temp	Very highly significant	Highly significant		

Appendix 6: Extremes and disasters over Zanzibar

Appendix 6.1: *2005 Floods over Zanzibar*

Detailed Locations	Zanzibar mtoni, Kariakoo, Jangombe, Magomeni,Darajabovu, and Zanzibar town centre.
Began	16 April 2005
Ended	18April 2005
Duration in Days	3
Casualties	1 dead, hundreds homeless
Main case	Heavy rain
Severity	1.0
Affected area (sq km)	510
Magnitude	3.2
Note	Heaviest rains in 40years
SOURCE: Dartmouth floods Observatory, Global Active Archive of Large Flood Events.	

Appendix 6.2: Top ten natural disasters and the number of people affected from 1960s to 1990s in Tanzania

No.	Disaster type	Date	No Affected
1	Drought	1996	3,000,000
2	Drought	1984	1,900,000
3	Drought	1991	800,000
4	Flood	12-Feb-93	201,543
5	Flood	03-Apr-90	162,000
6	Flood	07-Apr-89	141,056
7	Drought	1988	110,000
8	Flood	Jun-79	90,000
9	Flood	May-74	68,000
10	Flood	Mar-68	57,000

Source: EM-DAT: The OURTA/CRED International Disaster Database, www.em-dat.net

Appendix 6.3: Top ten natural disasters and their economic damage from 1960s to 1990s in Tanzania

No.	Disaster type	Date	DamageUS* (000's)
1	Flood	12-Feb-1993	3,510
2	Flood	May-1974	3,000
3	Flood	Mar-1968	1,000
4	Flood	3-Apr-1990	280
5	Earthquake	19-May-1901	Nil
6	Earthquake	19-Jul-1908	Nil
7	Earthquake	13-Dec-1910	Nil
8	Earthquake	10-Dec-1913	Nil
9	Flood	May-1964	Nil
10	Earthquake	7-May-1964	Nil

Source: EM-DAT: The OURTA/CRED International Disaster Database,www.em-dat.net

Appendix 6.4: Droughts and floods incidents in Tanzania from 1901 to 2007

	Number of Events	Killed	Injured	Homeless	Affected	Total Affected	Damage US$ (000's)
Drought	6	0	0	0	5,883,483	5,883,483	0
average per event	-	0	0	0	980,581	980,581	0
Flood	27	542	75	106,252	770,695	877,022	7,790
average per event	-	20	3	3,935	28,544	32,482	289

Source: EM-DAT: The OURTA/CRED International Disaster Database, www.em-dat.net