LAND USE/COVER CHANGES AND THEIR INFLUENCE ON THE OCCURRENCE OF LANDSLIDES: A CASE STUDY OF THE NORTHERN SLOPES OF THE ULUGURU MOUNTAINS, MOROGORO, TANZANIA

BY

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A DISSERTATION SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN LAND USE PLANNING AND MANAGEMENT OF SOKOINE UNIVERSITY OF AGRICULTURE, MOROGORO, TANZANIA

ABSTRACT

The present study was conducted to assess land use/cover changes and their influence on the occurrence of landslides in the northern slopes of Uluguru Mountains, Tanzania. The study focused on the determination of the historical land use/cover changes between 1964 and 2004, evaluation of the biophysical and socio-economic factors influencing land use/cover changes, and examination of the influence of land use/cover changes on the occurrence of landslides. Field survey, remote sensing and GIS techniques were employed to assess land use/cover dynamics. Landslides were mapped through field surveys using GPS and imported in GIS environment. A questionnaire survey was conducted to collect information on socio-economic activities responsible for land use/cover changes and on landslides. Statistical analysis was done using SAS and SPSS softwares. The study demonstrated that land use/cover is dynamic and varies spatially both in terms of coverage and change. Natural vegetation is increasingly replaced by cultivation and urbanisation. Change to rainfed agriculture is more intensive on the mountain ridges by two-fold that of mountain foothills. Urban expansion is very rapid on undulating plains at a mean rate of about 15 ha per year compared to 2 ha per year on the mountain foothills and <1 ha per year in the mountain ridges. Geomorphic characteristics, soils, rainfall distribution and demographic changes are key factors influencing land use/cover dynamics. Land use/cover dynamics (increase in rainfed and irrigated agriculture) greatly influence the occurrence of landslides ($R = 0.999$, $P < 0.05$). The observed land use/cover dynamics and their relationship with the occurrence and frequency of landslides call for further research on the effectiveness of different land use options on landslide rehabilitation. Farmers should be sensitised on the influence of land use changes on land degradation and the importance of

appropriate soil and water conservation measures to mitigate landslides disasters in the study area.

DECLARATION

I, PROCHES HIERONIMO do hereby declare to the Senate of Sokoine University of Agriculture that this dissertation is my own original work and that it has never been submitted for a degree award in any other University.

Signature...

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This work is dedicated to my father, Mr. Hieronimo E. Msigula, who laid the foundation of my education.

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LIST OF ABBREVIATIONS AND SYMBOLS

AAG	Association of American Geographers
BG	Bushed Grassland
Bugwood	A network of closely related websites focused in the areas of forestry, entomology, invasive species and integrated pest management
CEPS	Centre for Earth and Planetary Studies
CLUSTERS	Classification for Land Use Statistics: Eurostat Remote Sensing
CORINE	Coordinated Information on the European Environment
CW	Closed Woodland
DEM	Digital Elevation Model
EA	Enumeration Area
ERDAS	Earth Resource Data Analysis System
ESRI	Environmental Systems Research Institute
F	Forest
FAO	Food and Agriculture Organisation of the United Nations
G	Grassland
GIS	Geographical Information System
GPS	Geographical Positioning System
IA	Irrigated Agriculture
ISRIC	International Soil Reference and Information Centre
ISSS	International Society of Soil Science
JARS	Japan Association of Remote Sensing
LCCS	Land Cover Classification System
OW	Open Woodland

RA	Rainfed Agriculture
S	Built up area
SAS	Statistical Analysis System
SLUC	Standard Land Use Coding
SP	Sisal Plantations
SPCCSP	Strategic Plan for the Climate Change Science Programme
SPOT XS	System Probatoire d'Observation de la Terre Multispectrum
SPSS	Statistical Package for Social Sciences
TP	Tree Plantations
UNEP	United Nations Environmental Programme
URT	United Republic of Tanzania
USA	United States of America
USDA	United States Department of Agriculture
USGS	United States Geological Survey
UTM	Universal Transverse Mercator Projection
WG	Wooded Grassland

CHAPTER ONE

1.0 INTRODUCTION

1.1 Problem overview and justification

Anthropogenic alterations of the natural landscape by means of urbanization, agriculture and forestry have been a continuous and increasing processes for the past millennium (Vanacker, 2002). Regions of the natural vegetation and land cover are removed and replaced with numerous human-managed systems of altered structure (Lundgren, 1978). During the last century land use and land cover have changed drastically in the tropics due to changing economy and growing population (Meyer and Turner II, 1992). This has caused significant adverse effects on physical and ecological processes (Briassoulis, 2000), on soil and water (Centre for Earth and Planetary Studies, 2001), on local and global climate (Turner *et al.*, 1993) and on biodiversity (Association of American Geographers, 1996).

Recently, efforts have been made to quantify the nature and extent of land use and land cover changes at global scale. Richards (1990) estimated that over the last 300 years, the total global area of forests and woodlands diminished by 19%, grassland and pastures declined by 8% and croplands increased by 466%. Despite the recognition on the magnitude and impact of global changes in land use and land cover, there have been relatively few comprehensive studies on land use changes and their impact (Strategic Plan for the Climatic Change Science Programme, 2003). Furthermore, due to coarse spatial scales, the database obtained from limited studies on land use/cover changes are not very useful for explicit spatial projection of future land use and management decisions. According to Kimaro *et al.* (2003), dynamic land use, intensive agriculture (smallholder rainfed and irrigated farming) and land fragmentation are typical features common in the Eastern Arc Mountains of Tanzania including the Uluguru Mountains. These areas are considered to be rich in biodiversity and display high levels of endemism (Myers *et al.*, 2000; Lovett, 1990). Like in many tropical mountainous areas, information on land use/cover dynamics and their impacts is patchy (Larsson, 1989; Kaoneka, 1993). Therefore, rigorous studies on land use/cover changes and their impact on land resources is of paramount importance for sustainable land use planning and management (FAO, 1995; Kimaro, 2003).

In many studies like those of Poesen *et al.* (1996), Dai *et al.* (2002) and Vanacker (2002), it is reported that land use and land cover change and geomorphic response form a complex and interactive system at different spatial and temporal scales. Geomorphic processes operate in an environment that is characterised by a number of landscape factors including soils, geologic formation, topography, land use, land cover and settlement pattern (Vanacker, 2002). However, past studies on the relationship between land use/cover and geomorphic response have used a lumped approach (Larsson, 1986) where geomorphic responses were linked to average landscape characteristics on rather long time scales (Starkel, 1998). Presently, land use/cover changes occur very rapidly in mountainous areas (Kaoneka, 1993). Under this situation only limited studies have been made to evaluate the effects of short term land use and land cover changes on geomorphic processes such as landslides in spatial context (Vanacker, 2002; Pradhan, 1999). Therefore, studies on land use/cover changes will likely play a major role in the understanding of geomorphologic activities particularly landslides like those occurring in the Uluguru Mountains, Tanzania and in many other parts of the Eastern Arc Mountains. Information from these studies is likely to be of paramount importance in determining the sustainability of future development and in defining human response to environmental changes. The purpose of this study was to establish database on land use and land cover changes for comprehensive understanding of their dynamics, the involved driving forces or agents of change and their influence on geomorphologic activities particularly landslides on the northern slopes of the Uluguru Mountains, Tanzania. The study was aimed to provide valuable information for sound land use planning and management in the area, thereby contributing to landslide hazard mitigation in Morogoro municipality, Tanzania and other areas with similar characteristics.

1.2 Objectives

1.2.1 General objective

The overall objective was to evaluate spatial and temporal land use and land cover changes and to assess their influence on the occurrence and spatial distribution of landslides on the northern slopes of the Uluguru Mountains, Tanzania.

1.2.2 Specific objectives

(i) To determine historical land use and land cover changes between 1964 and 2004

(ii) To evaluate biophysical and socio-economic factors associated with land use/cover changes

(iii) To examine the influence of land use and land cover changes on the occurrence and spatial distribution of landslides in the study area

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Definitions and basic concepts on land use/cover

2.1.1 Land use and land cover

According to FAO (1995), "***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.

"***Land use***" has been referred to as the human purposes that are associated with land cover, which may include raising cattle, recreation, or urban living (Veldkamp and Fresco, 1995). In more detail, land use is the total arrangements, activities, and inputs that people undertake in a certain land cover type (FAO/UNEP, 1999). On the other hand "***land cover***" is the observed physical and biological cover of the earth's surface such as vegetation or man made features (FAO, 1997). It is also defined as the physical, chemical, or biological categorization of the terrestrial surface, which includes grassland, forest, or concrete (Meyer and Turner, 1994). The terms land use and land cover are not synonymous and the literature draws attention to their differences so that they are used properly in studies of land use and land cover change (Briassoulis, 2000). A given land use may take place on one, or more than one piece of land and several land uses may occur on the same piece of land (Avery and Berlin, 1985).

2.1.2 Land use and land cover changes

According to Briassoulis (2000), land use and land cover change has been defined as quantitative changes in the areal extent (increase or decrease) of a given type of land use or land cover, respectively. 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). 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 (Mbilinyi, 2000; Vanacker, 2002; Rugenga, 2002; Ngalande, 2002) have revealed the effect of human activities or arrangements (land use) on land cover. For example, Kaoneka (1993) carried out an analysis of land use changes based on sequential aerial photographs in the Usambara Mountains, Tanzania and found that the natural forest reserve declined at a fairly high rate of 3.8% per year on the expense of farmlands and settlements which increased dramatically by 83% per year. The author reported that this change was mainly due to population increase which resulted into more pressure on forest resources.

Change in land use/cover can have far reaching consequences to farmers' welfare as well as the environment (Bergeron and Pender, 1999). For instance, conversion of a forest or pasture into irrigated cropland may increase farmers' incomes, but may also increase soil erosion, reduce plant biodiversity, or lead to environmental pollution (FAO, 1998; Kimaro, 2003). The study conducted by Rugenga (2002) at Ruaha Mbuyuni, Iringa, Tanzania, revealed that in the temporal period 1976-1999 land use/cover experienced a profound transformation due to irrigated agriculture mainly for onion production. A depletion of about 2131 ha of riverine vegetation was noted of which 64% was contributed by increased irrigated agriculture alone. Despite this depletion, the author also reported that produced onions were sold at good price hence contributed much to the improvement of peoples' income.

According to Veldkamp and Fresco (1995), land use and land cover change is largely driven by the need to meet the increasing resource consumption of the expanding human population. Changes in population density may affect land use choices by increasing the scarcity of land relative to labour, which creates pressure to reduce fallow periods (Bergeron and Pender, 1999; Kimaro, 2003). The increasing population in Uluguru Mountains, Tanzania (Kilasara and Rutatora, 1993; Lulandala *et al.*, 1995), has stimulated wide utilisation of natural resources including land for cultivation and settlements, and forest products such as wood for fuel, building material, and medicinal purposes. The study by Kimaro (2003) revealed that the population pressure in the Uluguru Mountains led to discouragement of fallow cultivation and crop rotation. This is clearly shown by the present land use pattern in the Uluguru Mountains where every piece of land is cultivated (Kimaro *et al.*, 1999). Also, the increased frequency of tillage and soil disturbances has resulted into unstable soils, thus increasing chances of occurrence of landslides (Temple, 1972; Temple and Rapp, 1972; Kimaro *et al.*, 2003).

2.1.3 Land use and land cover classification systems

The analysis of land use change depends critically on the used system of land use and land cover classification (Briassoulis, 2000). The used classification system must fulfill the primary needs of the project, fit the technology and resources available, and simplify all further processing (USDA, 1996). Several land use/cover classification systems have been developed that can readily incorporate land use/cover data obtained by interpreting remotely sensed data (Jensen, 1996). Some have been developed at global and others at sub-global or mostly national level (Michael and Vicksburg, 2006). Major points of difference between various classification systems are their emphasis and ability to incorporate information obtained using remote sensing (Jensen, 1996).

At the global level, the FAO/UNEP Land Cover Classification System (LCCS) is the only universally applicable classification system in operational use at present (Latham, 2001). It enables a comparison of land cover classes regardless of data source, economic sector or country. The LCCS has the best potential to become standard accepted international land cover classification system because of its ability to allow the production of many different speciality maps based on data in the classification scheme. It has the ability to respond to changing needs and definitions in all climatic zones and environmental conditions and is also compatible with the existing classification systems such as the United States Geologic Survey (USGS) Classification System, the United States Fish and Wildlife Service Wetland Classification System, and Coordinated Information on the European Environment (CORINE), (FAO, 2001; Environmental and Natural Resources Services

(SDRN) and FAO, 2004). However it has not yet been accepted by International System Organization (ISO) as the standard international land use/cover classification system (SDRN and FAO, 2004).

At sub-global or national level, the most commonly used system is the United States Geologic Survey (USGS) Classification System. The USGS Classification System is the hierarchical system developed by Anderson *et al.* (1976) at the United States Geologic Survey (Short, 1999; Lillesand and Kiefer, 1987). The system was developed as a national system for land use and land cover classification that would use data from conventional sources and remote sensors on high altitude air craft and satellite platforms (Anderson *et al.*, 1976). It is composed of different levels of land use and land cover categories that have been developed and adopted widely. The system is designed to use four levels (very broad category, broad, detailed, very detailed) of detail of information (Anderson *et al.*, 2001). This multi-level system has been designed because different degrees of detail can be obtained from different data sources depending on the sensor system and image resolution (Lillesand and Kiefer, 2000, Aronoff, 1989). The USGS Classification System is aimed at complete standardisation at levels I and II only. Users of the system can develop their own subcategories for levels III and IV (Avery and Berlin, 1985). Land use and land cover classifications at levels I and II are usually adaptable for evaluation of past changes in land use. Problems arise when more detailed breakdowns are desired, because reliable ground checks cannot be made for older sets of imagery. The USGS system attempts to meet the need for current overview of land use and land cover studies on the basis that it is uniform in categorisation at the generalised first and second levels. The categories of land use and land cover in this classification system can also be related to other land use/cover classification systems such as FAO land suitability classification system, vulnerability of certain management practices, potential for any particular activity, or land value, either intrinsic or speculative.

The Standard Land Use Coding (SLUC) Manual is another land use classification system developed in the United States. The system is land use activity oriented and is primarily dependent on insitu observation to obtain remarkably specific land use information, even to the contents of building (Rhind and Hudson, 1980). Whereas the USGS Land Use/Cover Classification System (Anderson *et al.*, 1976; USGS, 1992) is resource oriented (land cover) the SLUC Manual is people or activity (land use) oriented system.

Another classification system is the United States Fish and Wildlife Service Wetland Classification System. The system is responsible for mapping all wetlands in the United States. It incorporates information extracted from remote sensing data and insitu measurement. The system describes ecological taxa, arranges them in a system useful to resource managers and provides uniformity of concept and terms. Wetlands are classified based on plant characteristics, soils and frequency of flooding.

In Europe, a national land use/cover classification system namely Coordinated Information on the European Environment (CORINE) exists. It was set up in 1985 in the European Community with the objective, among others, to improve data availability and compatibility across the European Community and within the member states. The system is hierarchical and is meant to produce digital land cover databases for use in European Community. Also in Europe, Classification for Land Use Statistics: Eurostat Remote Sensing Programme (CLUSTERS), was being developed in coordination with the European Union Agency for Statistical Information (EUROSTAT). The system is hierarchical and is meant to provide a standard system for studying land use throughout the European territory whilst taking into account national land use classification systems at European level.

Other authors (Mbilinyi, 2000; Vanacker, 2000; Rugenga, 2002) have not adopted any of the already established classification systems but have described different land use/cover classes using general terms and based on field observations outlined by Dent and Young (1981). This was done to meet the primary needs of the respective projects. For example, Vanacker (2002), described the land use/cover of the Austro Ecuatoriano in order to detect land use/cover changes in the area. The description of the land use/cover classes was done following the complexity and multiplicity of the landscape in the study area. Broad land use/cover classes were determined using remote sensing and GIS. Mbilinyi (2000) conducted a field observation to establish different land cover classes in order to assess land degradation and its consequences in the Isimani Division, Iringa, Tanzania. The resulting land use/cover classes enabled land use/cover change detection to be carried out for the period from 1963 to 1995.

2.2 Previous research on land use/cover change

2.2.1 Land use/cover change detection

Change detection is the process of identifying differences in the state of an object or phenomenon by observing it at different times (Lillesand and Kiefer, 2000). Land use/cover change detection is necessary for the management of natural resources (Singh, 1989; Congalton and Macleod, 1994). The change is usually detected by comparison between two multi-date images, or sometimes between an old map and an updated remote sensing image (Aronoff, 1996). The land use/cover change can also be done by comparing seasonal changes and annual changes (Japan Association of Remote Sensing, 1996).

Vanacker (2002) used sequential aerial photographs to assess the effect of short term socio-economic and demographic change on land use dynamics between 1962 and 1995 in the Ecuadorian Andes. The change detection analysis showed that land use in the catchment was dynamic. The area of high alpine tundra vegetation and rangelands decreased by 580 ha and 620 ha respectively, whereas the area covered by secondary forest increased by 350 ha. The author reported that these profound land use changes were mainly driven by the land reform programs in the 1960s and 1970s and rapid demographic growth.

Mbilinyi (2000) used panchromatic aerial photographs (1963 and 1978), Landsat TM Satellite imagery (1995) incorporated into GIS environment to assess land degradation and its consequences in Ismani division, Iringa Region, Tanzania. The land use/cover change detection analysis showed that a large part of miombo woodland decreased by about 2,600 ha (equivalent to 85%) during the period 1963-1978 driven mainly by the resettlement program of the 1970s. The analysis also showed that increase in the coverage of miombo woodland of about 133 ha was realised in the period 1978-1995 mainly due to woodland conservation effort by *Concern* (a non governmental organization) and villagers. The author reported that past human activities and political actions were the main drivers of the observed processes/phenomena in the study area.

Norris (1990) quantified trends of deforestation in Morogoro region, Tanzania by using remote sensing techniques. The results showed that 0.5% of the area outside the rain forest was being converted from woody vegetation to cultivated land and wooded grassland annually. Hamad (2000) used aerial photographs of 1977 and 1989 to assess land resources degradation in Bumbwi-Sudi, Tanzania and found that the introduction of irrigation scheme led to 340 ha increase in area under paddy cultivation. A reduction of about 29% of the natural vegetation was noted for the same year. Firewood gathering, crop cultivation and livestock grazing are socio-economic activities reported to have contributed to land degradation in the area.

2.2.2 Methods used for land use/cover change detection

There are two basic approaches for land use/cover change detection namely (1), Comparative analysis of independently produced classifications from different dates (Post-classification comparison, that is, map to map comparison) (Singh, 1989) and (2), Simultaneous analysis of multitemporal data (multidate classification, image algebra and write function memory insertion) (Jensen, 1996). Both approaches have advantages and disadvantages as discussed below:

The most common approach is the post-classification method (Congalton and Macleod, 1994). The post-classification method is performed when digital data are in either raster or vector format (Ware *et al.*, 1999). In vector format, the change detection is done by comparing pairs of vector-defined polygon coverages, representing land use/cover of the same region but of different years (Singh, 1989, Mbilinyi, 2000). The standard technique for detecting change in this situation is to intersect the pair coverages so as to produce a third coverage which gives the changes (ESRI, 1996). In raster format, the method identifies changes by comparing two independently classified images pixel-by-pixel basis using change detection matrix (Lillesand and Kiefer, 2000). The matrix analysis produces a thematic layer that contains a separate class for every coincidence of classes in two layers. However, the accuracy of the method depends on the accuracy of initial classifications, and errors are compounded (Jensen, 1996).

The post classification method approach has been applied by a number of researchers; Mbilinyi (2000) 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. Ngalande (2002) also 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.

The Simultaneous analysis of multitemporal data approach has three widely used change detection algorithms as discussed below according to (Jensen, 1996):

(a) Multidate composite image change detection: In this procedure, selected bands from temporal images are placed in a single dataset. The composite dataset can then be analysed in a number of ways, such as unsupervised clustering, to extract change information.

(b) Image algebra change detection: The change detection between two temporal images can be identified by ratioing or differencing bands previously rectified to a common base map and resampled to the same pixel size. Image differencing involves subtracting imagery of one date from that of another and in the ratio image each pixel value represents the ratio of pixel values from two temporal images.

(c) Change detection using write function memory insertion: Two or three individual bands of remotely sensed image or scanned aerial photographs acquired at different dates can be overlaid in the digital image processing system to form a colour composite image. Changes are then visually identified using the additive colour theory.

2.3 Drivers of land use/cover changes

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).

2.3.1 Biophysical drivers

In general, land use is viewed to be constrained by biophysical factors such as soil, climate and relief (Turner II *et al.*, 1993). Studies done by Vanacker (2002) on land use/cover dynamics in the Andes Mountains in Ecuador revealed that humidity was used as criterion for selecting a land to be taken out of production during the growing season. The author showed also that gently sloping areas had favored opening of new arable lands driven by good conditions for irrigation. Isabirye (2005) observed in Mayuge district, Uganda that forests occupied soils favorable for agriculture and hence considerable area of these (44%) were taken into cultivation. The author compared these results with Rakai district which have more landscape and soil restricting conditions for agriculture and concluded that land use/cover dynamics were primarily determined by landscape features and soil properties. The study conducted by Kimaro (2003) in the Uluguru Mountains, Tanzania, revealed that the talus slopes in the area were intensively used for banana cultivation intercropped with maize while more than 80% of the V-shaped valleys and landslide scars were cultivated with banana as the main crop. This pattern was mainly being influenced by favorable soil and moisture conditions.

2.3.2 Socio-economic drivers

2.3.2.1 Population growth

Historical land use/cover change has occurred primarily in response to population growth, technological advances, economic opportunities and public policies (Strategic Plan for the Climate Change Science Programme, 2002). Most land cover modification and conversion are 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).

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. The authors reported that as pressure on productive land grew due to population increase, farmers abandoned the practice of leaving fields for fallow as they could only survive by cultivating continuously even if this exhausted the soils. Some studies in Uganda (Zwick and Smith, 2001; Isabirye, 2005) showed that in the 1940s and 1950s many Banyarwanda and Bahutu farmers and Batutsi pastoralists from Rwanda immigrated to Rakai district, Uganda in search of arable and grazing land, later became sedentary pastoralist by cultivating bananas and coffee in addition to grazing. It was observed that this population migration accounted for the expansion of cropland at the expense of grassland over the last forty years in the area. Studies conducted in Uyui district, Tabora region, Tanzania, revealed that from 1988 and 2002, the average household size increased by 2-fold which resulted into increased pressure on limited land resources including fuelwood for tobacco curing, charcoal, timber and agricultural land. This trend resulted into 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) and there has also been discouragement of fallow cultivation and crop rotation in the area (Kimaro, 2003).

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 household 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 loosing 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 mountainous areas and Tanzania in general is becoming degraded due to inadequate attention given to appropriate farming practices resulting in slush and burn, shifting cultivation, cultivation along the slope 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). Before 1980's only few crops such as maize, beans, sweet potatoes and cassava were grown (Yoder and Martin, 1985; Kimaro *et al.*, 1999). 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 (Kimaro *et al.*, 1999). According to the author after 1980's 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 market 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). Currently, vegetables are mostly grown during dry season under furrow and drag hose sprinkler irrigation system (Kimaro, 2003).

According to Kimaro (2003), most farmers in the northern slopes of Uluguru Mountains practised poor land husbandry without proper soil and water conservation measures. 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; Munishi *et al.*, 1998; Kimaro, 2003). For example, the Mindu reservoir which serves the Morogoro town is silting up because of soil erosion up stream in the watershed (UNEP/IISD, 2005).

2.4 Influence of land use/cover changes on the occurrence of landslide

2.4.1 Occurrence of landslides

Landslide is a downward or down slope movement of rocks and or soils under the influence of gravity. Every location on a hill slope can be considered as part of a continuous tug-of-war between the driving force of gravity and resisting forces due to materials that constitute the slope (De Graff, 1991). Both natural processes and human modification of slopes can change this balance in favour of gravity. The strength of slope materials can be reduced due to internal changes such as weathering, seepage, erosion and ground water changes (Ahmad and McCalpin, 1999), while stresses can be increased as a result of external factors such as steepening of slopes through excavations and loading of slopes (Tubb, 1975; Kimaro, 2003). Triggering of landslides depends on several complex but interrelated variables such as prolonged heavy rainfall (Temple and Rapp, 1972), Soil characteristics (Westerberg and Christansson, 1999), slope characteristics (Lopez and Zink, 1991), lithology and geomorphology (Ahmad and McCalpin, 1999; Tubbs, 1975; Westerberg and Christiansson, 1999), vegetation, land use and infrastructure (Larsen and Torres-Sanchez, 1998).

The study conducted by Tubbs (1975) in Seattle, USA, revealed a strong correlation between landslide and the presence of either Lawton clay or pre-vashon sediments. The author reported that although these materials together immediately underlay less than 10% of the study area, they were beneath nearly 80% of the landslides. Westerberg and Christianson (1999) reported that in the highlands of East Africa, linear down cutting of pre-existing drainage lines by extreme fluvial incision and fluvial removal of colluvium resulted in steep morphology that was associated with slope instability. The authors attributed landslides to the presence of geological structures that controlled the development of weak layers serving as potential sliding plains.

Stress on slope stability has been reported by Kimaro (2003) to be one of the soil-terrain factors influencing the frequency of occurrence of landslide in the Uluguru Mountains, Tanzania. The author reported a high correlation (R = 0.9985, $P<0.05$) between landslides and their distance to the roads or pathways. It was reported that this observation could be explained by the fact that road or path construction removes the toe support of the slope, increases the slope angle which weakens the shear resistance and hence making the slopes around the pathways more prone to sliding (Turkelboom, 1999).

2.4.2 Land use/cover dynamics and occurrence of landslides

Several studies have shown the importance of land use/cover in influencing the occurrence of landslides (Dhakal *et al.*, 1999; Luckman *et al.*, 1999; Baeza and Corominas, 2001). Vegetation cover has long been considered important factor in reducing landslide due to root cohesion and diminished runoff (Collins and Bras, 2004). Land use and topographic characteristics of hillslope angle, elevation and aspect are the most important spatial variables governing landslide frequency (Larsen and Torres-Sanchez, 1996). Many of the mountainous areas undergo very rapid land use/cover change at present due to demographic growth and intensification of the cropping systems (Kaoneka, 1993; Lyamuya *et al.*, 1994; Vanacker, 2002; Kilasara and Rutatora, 1993) leading to problems such as increased soil degradation, mass wasting and reservoir sedimentation (Vanacker, 2002).

The study conducted by Larsen and Torres-Sanchez (1998) in Puerto Rico showed that the frequency of landslides increased markedly as land use changed from forest to agriculture to construction of roads and structures such as terraces. In this study, the authors noted that the number of landslides occurring in connection with roads and other structures on average exceeded the number of landslides in forest by 2.3 to 8.4 times. On studying the correlation between landslide frequency and terrain variables on Lantau Island in Hong Kong, Dai *et al.* (2002) showed that land use/cover change, slope gradient, lithology, elevation and slope aspect were the significant predictors of landslide susceptibility. The study done in Gordeleg catchment, Ecuadorian Andes by Vanacker (2002) to assess the influence of land use change on slope stability revealed that the overall susceptibility of slopes to shallow landslides was highly dependent on recent land use change. It was also observed that, the conversion from secondary forest to permanent pasture and/or agricultural fields induced an increased risk of shallow landslides. Ahmad and McCalpin (1999) found that in the Kingston Metropolitan Area, Jamaica, occurrence of some landslides appeared to correlate strongly with distance to roads. The density of active landslides within 90 m was 6.23 times higher than beyond 90 m from roads. Similar observations were made by Vanacker (2002).

2.4.3 Land use dynamics and occurrence of landslides in Uluguru Mountains, Tanzania

Many studies (Temple, 1972; Kimaro, 2003; Kimaro *et al.*, 2003; Munishi *et al.*, 1998; Temple and Rapp, 1972) investigated the possible relationships between land use changes and landslide occurrences on the Uluguru Mountains, Tanzania. Temple and Rapp, (1972) for example, showed that, 47% of the studied landslide originated in cultivated fields, 46% in grassland and less than 1% in woodland covered areas. The study conducted by Munishi *et al.* (1998) on the northern slopes of Uluguru Mountains, Tanzania, showed that 80.6% of the 67 studied landslide scars were located on roadside and farmland interface and 16.4% were located on farmland under maize, cassava and banana crops. Kimaro (2003) revealed that over 99% of the observed variations in the frequency of occurrence of landslides could be explained by the distance to the road or pathways. However, in these studies, influence of land use/cover change on the occurrence of landslides was not investigated. Due to fast dynamic land use/cover in these fragile areas, comprehensive studies on land use/cover dynamics and their impact on the occurrence of landslide ought to be carried out prior to adopting any appropriate land use plans and management strategy in the area.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Description of the study area

3.1.1 Selection and location of the study area

The study was conducted on the northern slopes of the Uluguru Mountains, Tanzania. The area is located between 350295 E to 354368 E and between 9237500 N to 9243697 N UTM coordinates and has a total surface area of about 79 km^2 (Figure 1). It is situated approximately 200 km from the Indian Ocean. It rises out of the coastal plain at approximately 300 m a.s.l. to a peak of about 2600 m a.s.l (Bhatia and Ringia, 1996). Although formed as a continuous ridge, the mountains are physically divided by the Mgeta – Bunduki depression into the northern Uluguru (20.5 km long and 8 km wide) and the southern Uluguru (25 km long and up to 15.5 km wide). The mountains form an important catchment for rivers and streams that supply water for dwellers in Dar es Salaam, Coast and Morogoro regions.

The study was specifically conducted on three catchments namely the Kikundi, Morogoro and Kilakala river catchments with an area of about 12 km^2, 47 km^2 and 10 km^2 respectively. The catchments were selected as a follow-up of the work on major forms of soil erosion in the Uluguru Mountains by Kimaro (2003) and to a large extent it is representative of a great part (about 60%) of the Uluguru Mountains interms of climate, lithology, soil type and nature of the ecological environment.

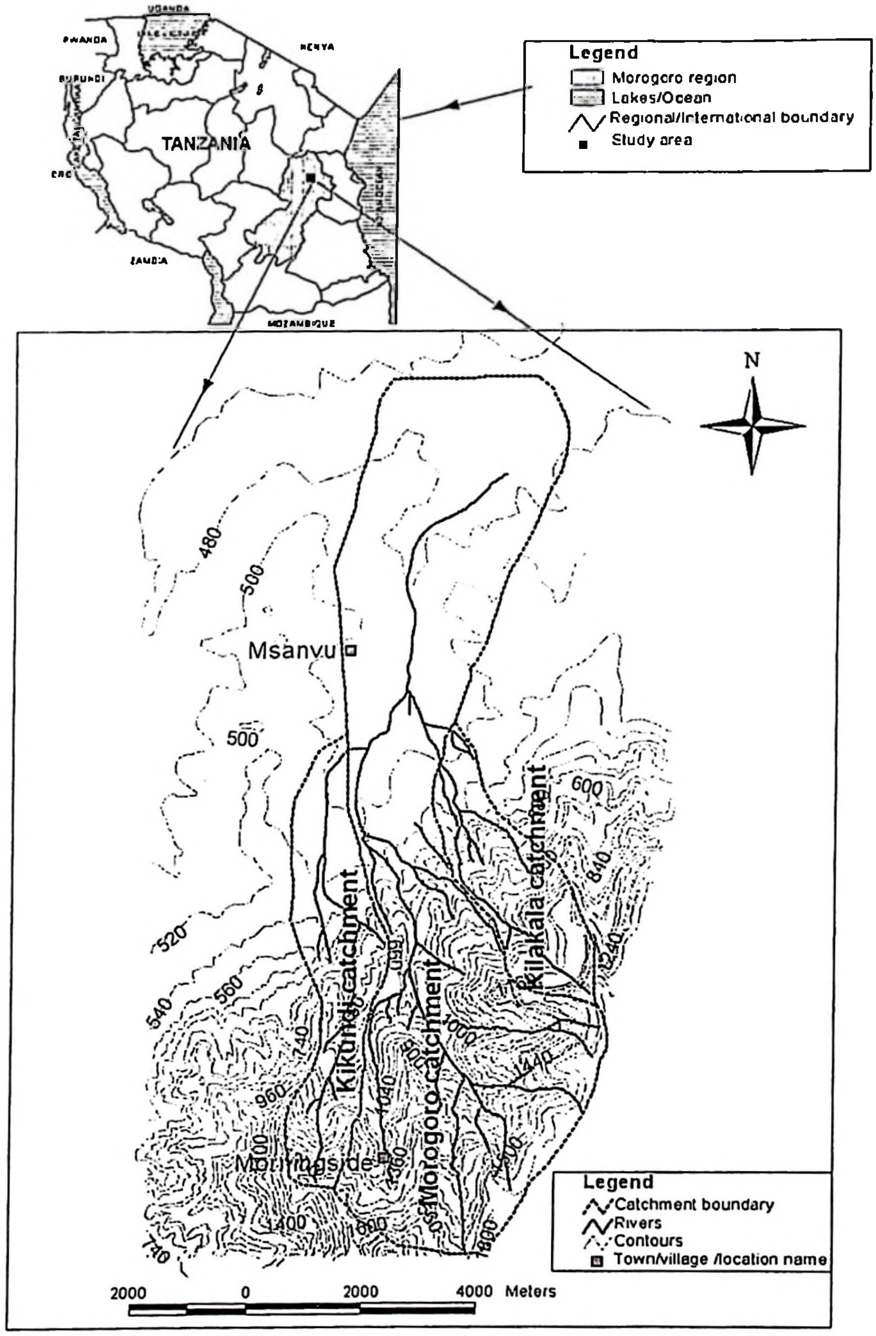

Figure 1: Geographical location of the study area

3.1.2 Geology

The geology of the Uluguru Mountains belongs mostly to the Usagaran system of rocks of the Mozambican belt. The rocks are grouped into three major divisions on the time-scale, Precambrian, Karroo (Paleozoic to Mesozoic) and Neogene. In addition there are some carbonatite intrusions of Jurassic age occuring in some places. The Precambrian rocks occupy the greatest area and consist mainly of granulites, gneisses and crystalline limestone with plagioclase and quartz rich veins (Sampson and Wright, 1964).

The Northern Uluguru Mountains mainly consist of hornblende-pyroxene granulites. They are intensely folded and have in general northerly strikes, which are reflected in the N-S direction of many terrain ridges. Along the northern face of the Uluguru Mountains, the granulites are extensively veined and injected with granitic material. In places, however, injection and migmatization have produced foliated gneisses and augen gneisses.

3.1.3 Geomorphology

The Uluguru Mountains are characterised by rugged relief, strongly dissected with very steep narrow valleys and having steep slope gradients ranging from 20% to more than 80% and an altitude ranging from 550 to 2800 m above sea level (Sampson and Wright, 1964). The northern mountain chain descends sharply to a plain with an altitude that ranges between 400 and 500 m a.s.l. where the residual hills of Mindu, Lugala and Nguru ya Ndege separate the Mkata Plain at the north from the headwaters of the Ngerengere River in the south (Kimaro, 2003). The studied catchments are mountainous (550 m to 2400 m a.s.l.) with strongly dissected mountain ridges and foothills characterised by very steep narrow valleys descending sharply to an undulating plain at 400 to 500 m a.s.l. (Sampson and Wright, 1964; Kimaro, 2003).

3.1.4 Soils

The Uluguru Mountains are characterised by eroded surfaces. The dark topsoil layer is only a few centimetres or missing. Yellowish brown sandy clay loams and sandy loams are common soils on most of the slopes. Gravely shallow soils and rock outcrops are common phenomena on the steep slopes. Saprolite is commonly found at or near the surface with pebbles associated with in situ veins of feldspar and quartz. Dark red coloured and clayey soils occur on the lower slopes below 800 m a.s.l. On this part the soils have finer texture and gravel is less common. Generally, the soils on the mountain ridges are *Endoskeletic* and *Leptic Cambisols* while on the foothills the dominant soils are *Chromic Lixisols* and *Profondic Acrisols* (Msanya *et al.*, 2003).

3.1.5 Climate

The area experiences a sub-humid tropical climate with a bimodal rainfall pattern characterised by two rainfall seasons in a year with a dry season separating the short rains called *vuli* from October to December and long rains called *masika* from March to May. There are about six months of dryness, the peak being September. The mean annual rainfall and temperature vary with altitude. The former ranges from about 900 to 2,300 mm per annum between 500 and at about 1,500 m above sea level.

3.1.6 Vegetation and land use

Four natural vegetation belts can be distinguished in the Uluguru Mountains (Pocs, 1974; Pocs, 1976): the montane forests and the subalpine elfin forests, the submontane forests, the *Pterocarpus-Combretum* and miombo woodland. The montane forests grow between 1500 and 2400 m above sea level. The dominant trees are *Podocarpus milanjianus, Ocotea usambarensis, Afrocrania volkensii, Podocarpus ensiculus, Cyanthea manniana and* *melchiora schliebenii*. In the northern part of the mountains at an altitude higher than 2100 m above sea level and in the southern part at 2400 m above sea level there are elfin forests. The dominant tree species in these forests include *Syzygium parvulum, Syzygium sclerophyllum, Allanblackia ulugurensis, Cussonia lukwangulensis and Polyscias stuhlmanii.* The submontane forests are mainly located in the western slopes of the mountains between 1,500 and 1800 m above sea level. They are a major component of the forest reserve. The most dominant tree species in this group of forests are *Parinari excelsa, Myrianthus holstii, Albizzia gummifera, Newtonia buchananii, Sapium ellipticum, Trema orientalis, Cylicomorpha parviflora, and Ocotea usambarensis*. In the western and northern belt of the Uluguru Mountains there are scattered areas of *Pterocapus-Combretum miombo* woodland. This group comprises of *Pterocapus angolensis, Julbernardia globiflora, Acacia macrothyrsa, Combretum spp and Brachystegia spp.*

Agriculture is the main land use type in the study area. Maize, beans, cocoyams, banana and upland rice are the main crops grown. Others include spice crops like cardamom, cinnamon, cloves and black pepper. The Waluguru community who are the residents of the area economically depend on selling cerials, vegetables and fruits. The cash crops produced in the area are normally sold in Morogoro town and some are transported to Dar es Salaam where a greater market is secured (Massawe, 1992).

3.1.7 Hydrology

The Uluguru Mountains form one of the major stream source areas of Tanzania. Major rivers from these mountains include Ngerengere, Ruvu and Mgeta. Ruvu basin (18 389 km^2) is drained by Ngerengere and Mgeta Rivers. Ruvu River which drains southeast wards is the major source of water for Dar es Salaam city. The Ngerengere River which drains towards the northwest of the mountains is the major water source for Morogoro Municipality.

3.2 Pre-field work

3.2.1 Collection of materials and relevant data

The tasks performed in this phase include literature search, collection and study of the materials as listed below:

- Topographic map at the scale of 1:50 000 (Map sheet 183/3) from Survey and Mapping Division, Dar es Salaam.
- Satellite image (SPOT-XS) acquired in 2000.
- Three sets of panchromatic aerial photographs taken in July (dry season): Panchromatic aerial photograph of 1964 at a scale of 1:35 000, Panchromatic aerial photograph of 1977 at a scale of 1:12 500, and Panchromatic aerial photograph of 1992 at a scale of 1:12 500.
- Land use map of Morogoro river catchment based on the 1970 aerial photographs at a scale of 1:10 000 and ground checking by Rapp *et al.* (1972).
- Geological map at a scale of 1:125 000; Geological Survey of Tanganyika, Morogoro, Quarter degree sheet 183.
- Enumeration Areas (EA) maps for 2002 population census; Morogoro Urban; from National Bureau of Statistics, Dar es Salaam.
- Population and Housing census for 1967, 1988 and 2002; Morogoro Region.
- Digital Soil map: Land resources inventory and suitability assessment for the major land use types in Morogoro Urban District by Msanya *et al.* (2001).
- Hand held Etrex Summit Global Positioning Systems (GPS) instrument.

- Hand held camera and binocular.
- Transparent overlays and tracing papers.
- Morogoro municipal wards map.

3.2.2 Interpretation of maps, aerial photographs and satellite imagery

In preparation for land use/cover mapping, stereoscopic examinations of aerial photographs of 1964 at a scale of 1:35 000, 1977 at a scale of 1:12 500 and 1992 at a scale of 1:12 500 were carried out. Topographic map at a scale of 1:50 000 and Geological map at a scale of 1:125 000 were also interpreted visually to complement the aerial photograph interpretation. The elements land use, vegetation cover, landform, relief, geology, drainage patterns, road networks and settlements were considered in the interoperation.

Land use/cover and geomorphic features for 1964, 1977 and 1992 aerial photographs were interpreted following procedures outlined by Dent and Young (1981) and Lillesand and Kiefer (1987). The interpretation of land use/cover types was restricted to the central portion of each photograph (Vanacker, 2002). Transparencies were used to transfer the interpreted information from aerial photographs for further processing. Three mosaics; one for 1964, the second for 1977 and the third for 1992 were formed from their respective transparencies. The mosaics were geo-referenced to Universal Transversal Mercator (UTM) coordinates, zone 37 south using topographic map (sheet 183/3). After the manual photo interpretation, mosaic formation and geo-referencing, land use/cover maps obtained were digitised and imported in a GIS environment using ARC/INFO and ARCVIEW software.

SPOT-XS satellite image of 2000 was interpreted in ERDAS Imagine and ARCVIEW softwares after necessary digital enhancements were done. The enhanced image was digitised onscreen to delineate different land use/cover categories. Finally, land use/cover maps of 1964, 1977, 1992 and 2004 were compiled at a scale of 1:10 000 and used as base maps for the field surveys.

Digital elevation model (DEM) of the study area was prepared basing on contour lines digitized from a 1:50 000 topographic map. DEM was prepared by TINGRID from surface menu of ARCVIEW spatial analyst. The DEM was used to derive the major geomorphic characteristics of the study areas and was used as base map on which land use/cover and landslide maps were overlaid.

3.2.3 Preparation of questionnaire for socio-economic survey

Semi-structured questionnaires were prepared for socio-economic data collection. The questionnaires included important attribute on: demography, accessibility to urban market, fallowing period, level of literacy, land tenure, peoples' involvement in irrigated agriculture, landslides and other soil and water conservation practices.

3.3 Field work

3.3.1 Land use/cover mapping

Systematic free survey procedures as outlined by Dent and Young (1981) and Landon (1991) at semi-detailed level (scale 1:50 000) were carried out using the results of the aerial photographs and satellite images interpretation and DEM to select observation and sampling points. At each observation site data on geoform, slope, lithology, land use/cover types and soil morphological characteristics were measured and collected. Observation intensity was 50 observations/square kilometre in accordance with procedures outlined by Dent and Young (1981) and Landon (1991). 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 present land use/cover types or classes were described (Dent and Young, 1981). In total, ten land use/cover classes were fully described and georeferenced in Morogoro and Kikundi sub-catchments and six for Kilakala sub-catchment. Georeferencing was done using a hand held Etrex Summit Global Positioning System (GPS). Historical land use/cover for years 1964 and 2004 was verified in the field by interviewing farmers (Anderson *et al.*, 1976). Land use/cover information for 1977 and 1992 was used to synthesise the information obtained for the period 1964 and 2004.

3.3.2 Landslide inventory and mapping

A simplified landslide classification system as proposed by Varnes (1978) was applied. Information on landslide scars location, probable date of occurrence and typology was established by using GPS and visual inspection in the field and interviewing of key informants (Temple and Rapp, 1972; Larsson, 1989; Lundgren, 1978; Kimaro, 2003). Historical occurrence of landslides was obtained by interviewing farmers.

3.3.3 Socio-economic survey

Participatory Rural Appraisal (PRA) was carried out in the field using the prepared semi-structured questionnaire to collect socio-economic data, historical land use/cover and occurrence of landslides. A total of 47 respondents from Kikundi sub-catchment, 50 respondents from Morogoro sub–catchment and 31 from Kilakala sub-catchment were interviewed. A household questionnaire is provided in Appendix A.

3.4 Post Field work

3.4.1 Land use/cover change detection

Land use/cover change detection was implemented through data integration procedures carried out in GIS environment using ARCVIEW computer software. The generated land use/cover maps for 1964 and 2004 for all subcatchments and 1977 and 1992 for only Kikundi subcatchment were analysed using GIS-ARCVIEW following map overlay method. Change detection flow matrix was performed by overlying land use/cover maps for year 1964 and 2004 for all subcatchment and 1977 and 1992 for Kikudi subcatchemnt in order to obtain class-to-class changes (ESRI, 1995) as shown in Figure 2. However, the 1977 and 1992 aerial photograph sets did not cover the mountain ridges part in all three sub-catchments due to unavailability and cloud cover problems respectively. Therefore change detection for all geomorphic units for the three sub-catchments was performed for 1964 and 2004 land use/cover maps. These land use/cover change categories for 1964-2004 scenario was used as independent variables in the simple linear regression analysis to determine their influence on the occurrence of landslide.

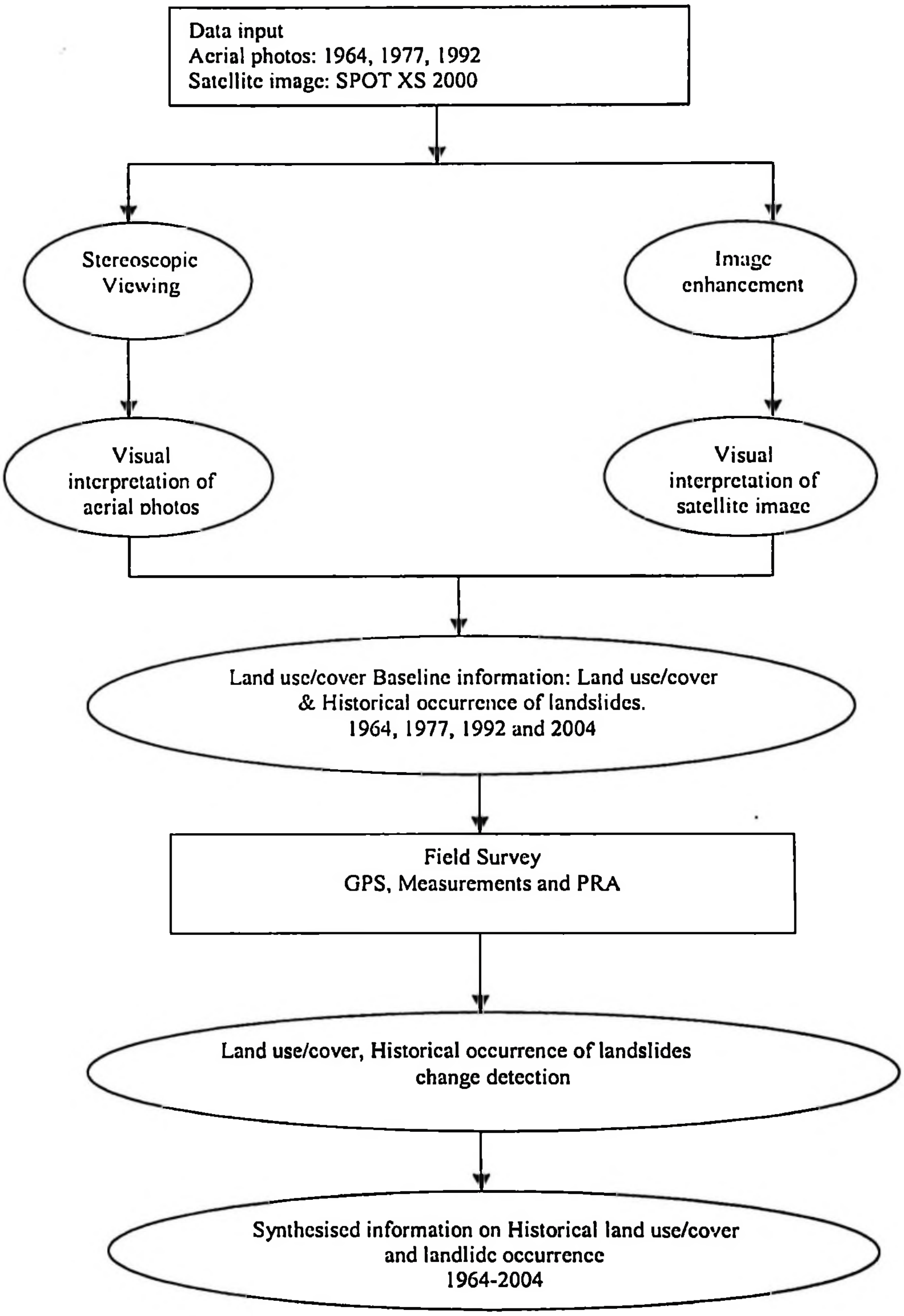

Figure 2: Land use/cover and landslides assessment flow chart

3.4.2 Assessment of biophysical and socio-economic factors considered to influence land use/cover changes

3.4.2.1 Assessment of biophysical factors

Climatic characteristics

Only annual precipitation was considered as a potential climatic factor controlling land use/cover dynamics in the study area. Kimaro (2003) related the mean annual rainfall to altitude in the Uluguru Mountains and found that it correlates significantly with altitude ($P < 0.05$). A map of mean annual rainfall was therefore generated in ARCVIEW GIS using elevation map from Digital Elevation Model (DEM) and the regression equation relating annual rainfall and altitude developed by Kimaro (2003). Then the mean annual rainfall in every geomorphic unit was established in GIS environment (Vanacker, 2002). This information and the land use/cover change categories were used to assess the spatial relationship between rainfall and the observed land use/cover changes in every geomorphic unit.

Geomorphic characteristics

The elevation, dominant slope and relief intensity for every geomorphic unit were adopted from the study by Kimaro (2003). These geomorphic characteristics and land use/cover change categories were related to assess the contribution of different geomorphic characteristics to the observed land use/cover spatial distribution and changes in every geomorphic unit. This approach has been used elsewhere with success (Vanacker, 2002; Kimaro, 2003; Isabirye, 2005). The drainage pattern maps and drainage density sizes for the mountain ridges and foothills were generated and related to the spatial distribution of irrigated agriculture and land use/cover changes classes.

Soil characteristics

The soil characteristics (drainage class, texture, organic carbon, available phosphorus and pH) in every geomorphic unit were established from the studies by Msanya *et al.* (2001) and Kimaro (2003). The relation between spatial distribution of soil characteristics and land use/cover change categories occurring in every geomorphic unit were established by tabular comparison.

3.4.2.2 Assessment of socio-economic factors

The socio-economic information obtained through questionnaire survey was organised into manageable units. Relevant coded information was then subjected to content analysis using the Statistical Package for Social Sciences (SPSS) computer programme. Frequency and cross-tabulation data analysis were used to study the socio-economic activities. Microsoft Excel computer software was used to develop a summary of quantitative information (frequencies) observed during the study period.

The census information in spatial form for 1967 in every geomorphic unit for each sub-catchment was established. The spatial census for mountain ridges and foothills was estimated from figures of 1967 statistics for enumeration area and a count of houses on the 1964 aerial photographs (Rapp *et al.*, 1972). By using a structural counting census method for preparation of Enumeration Area (EA) maps, the number of houses in every geomorphic unit was multiplied by the average household size for 1967 census. The information was digitised and imported in GIS environment.

The census information for 2002 for the three catchments was established by digitizing the Enumeration Area (EA) maps covering the ridges and foothills obtained from National

Bureau of Statistics. Due to inaccuracies of some of the EA maps ground truthing using GPS was done. The updated EA maps were digitized and exported into GIS environment using ARC/INFO/VIEW software. The digital EA maps were then aggregated to obtain the spatial population distribution for every geomorphic unit (Martin, 2001). The spatial population information for undulating plains which is covering the town area was determined by digitising the Morogoro town wards for 1967 and the Morogoro Municipal wards map for 2002. The area weighted average population values from the 1967 and 2002 population census data, the spatial population information for the undulating plains was established. The population change in number and percent between 1967 and 2002 was calculated for further statistical analysis. Simple correlation between population density change and land use/cover change categories were performed using SAS computer programme to establish the influence of population density change and land use/cover change for the 1964-2004 temporal period.

After statistical analysis of the information on land tenure and farming practices obtained from field observations and questionnaire survey in every sub-catchment, the descriptive statistics results summarised and presented in frequency tables were compared with the observed varying frequency and magnitude of land use/cover changes and occurrence of landslides in the respective sub-catchments. This comparison was used to establish the influence of the existing land tenure and farming practices on land use/cover changes and occurrence of landslides.

3.4.3 Assessment of the influence of land use/cover changes on the occurrence of landslides

The spatial pattern of the landslides associated with major land use/cover classes on different geomorphic units for the period between 1964 to 2004 was generated in ARCVIEW GIS based on the landslide inventory information. The inventory information included the probable date of landslide occurrence, the land use/cover before occurrence and land use/cover during and after occurrence and the presence of any interfering human infrastructure such as road or irrigation network.

The landslide frequencies by 1964 and between 1964 and 2004 were established in every geomorphic unit. Five selected key land use/cover change categories hypothesized to influence the frequency of occurrence of landslides on different geomorphic units in the three studied catchments together with landslide frequency changes were used to prepare the dataset for statistical analysis in order to assess the influence of each land use/cover change category on the change of landslide frequency. The change in landslide frequencies were used as dependent variable in the simple linear regression analysis with 1964-2004 land use/cover change categories as independent variables.

3.5 Statistical analysis

Qualitative assessment and descriptive statistics were widely employed in the exploratory analysis of land use/cover changes, landslide data and related driving forces. Wherever it was applicable the degree of association between variables was measured by linear regression and calculation of the Pearson correlation coefficient R. Levels of significance (P) were obtained by F-tests based on analysis of variance. The effect of land use/cover change categories on landslide density changes were statistically analysed according to the General Linear Model (GLM) of the Statistical Analysis System (SAS, 1999).

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Spatial distribution of land use/cover types in the study area

4.1.1 Land use/cover distribution for Kikundi sub-catchment in 1964 and 2004

Temporal and spatial distribution of different land use/cover types for Kikundi sub-catchment is presented in Table 1 and in Figures 3 (a) and 3 (b). Three major geomorphic units are recognized in this sub-catchment namely mountain ridges, mountain foothills and undulating plains. The results illustrate that by 1964 the mountain ridges of this sub-catchment were dominated by bushed grassland occupying 64%, the mountain foothills by closed woodlands occupying 52% of the geomorphic unit total area followed by open woodland which occupied 18%, while undulating plains were dominated by settlements and rainfed agriculture. However, after 1964 there was a differrent trend whereby rainfed agriculture dominated both the mountain ridges and foothills occupying 79% of the mountain ridges and 48% of the mountain foothills while area under settlements increased in the undulating plains. Settlements increased from 34% in 1964 to 76% in 2004, the fact attributed to sisal plantations and industrial development in Morogoro municipality. Sisal plantations occupied only the mountain foothills and the undulating plains by 1964 where as by 2004 this land use type had disappeared in both geomorphic units (Tables 4 (f) and 4 (d)). Open woodland which occupied all geomorphic units (more than 10%) by 1964 progressively decreased to less than 4% in the mountain ridges and undulating plains for the period 1964 to 2004.

Table 1: Coverages and percentage distribution of land use/cover for Kikundi sub-catchment in 1964 and 2004

Geomorphic unit	land use/cover	1964		2004	
		area(ha)	%	area (ha)	%
Mountain ridges	S	8.1	1.8	21.1	4.6
	BG	295.4	64.0	13.4	2.8
	IA	2.7	0.6	26.1	5.7
	OW	63.5	13.6	19.7	4.3
	RA	62.3	13.5	365.7	79.2
	RV	29.8	6.5	15.8	3.4
	Sub-total	**461.8**	**100.0**	**461.8**	**100.0**
Mountain foothills	S	12.5	3.9	82.2	25.7
	BG	16.5	5.2	5.2	1.6
	CW	166.7	52.2	0.0	0.0
	OW	58.8	18.4	63.9	20.0
	RA	12.6	4.0	153.7	48.2
	RV	38.1	12.0	11.3	3.6
	SP	14.0	4.3	0.0	0.0
	IA	0.0	0.0	1.9	0.6
	G	0.0	0.0	1.0	0.3
	Sub-total	**319.2**	**100.0**	**319.2**	**100.0**
Undulating plains	S	168.9	33.6	384.3	76.4
	BG	20.6	4.1	17.0	3.4
	OW	49.1	9.6	0.0	0.0
	RA	115.5	23.0	25.8	5.1
	RV	28.1	5.6	8.6	1.6
	SP	86.1	17.1	0.0	0.0
	WG	35.0	7.0	13.4	2.7
	G	0.0	0.0	53.9	10.7
	TP	0.0	0.0	0.3	0.1
	Sub-total	**503.3**	**100.0**	**503.3**	**100.0**

Note: S=Built up area BG=Bushed grassland IA=Irrigated agriculture OW=Open woodland RA=Rainfed agriculture RV=Riverine vegetation SP=Sisal plantation G=Grassland TP=Tree plantation CW=Closed woodland

Other land use/cover types seem to be evenly distributed in all three geomorphic units but with significant decrease in coverages between 1964 and 2004.

The land use/cover type namely, irrigated agriculture increased significantly between 1964 and 2004 and seems to dominate in the mountain ridges. Dominance of furrow irrigated agriculture in the mountain ridges is attributed to high density drainage pattern or streams (Figures 9, 10 and 11) and (Table 7) from which farmers obtain water easily for furrow irrigation during dry spells. However the high drainage density in Kilakala sub-catcment (Figure 11) are not streams but dry gullies hence no irrigated agriculture.

The results demonstrate a spatial and temporal variability on the coverages and distribution of different land use/cover types. A profound replacement of natural vegetation with intensive annual cultivation and settlement in the mountain ridges and foothills is likely to increase the severity of land degradation and destruction of the catchment's microclimate hence the need to set appropriate soil and water conservation measures in order to preserve this important sub-catchment.

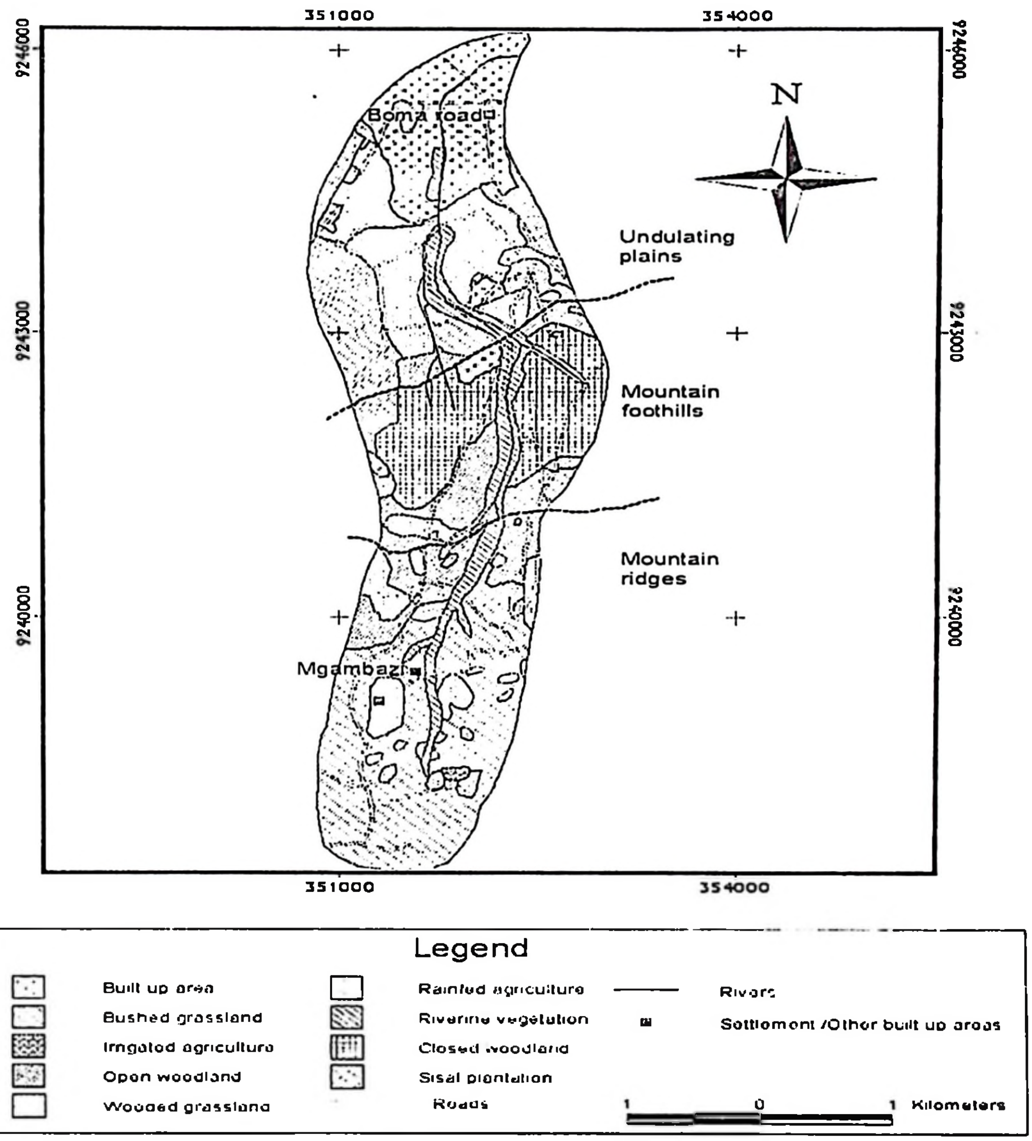

Figure 3 (a): Land use/cover map for Kikundi sub-catchment, 1964

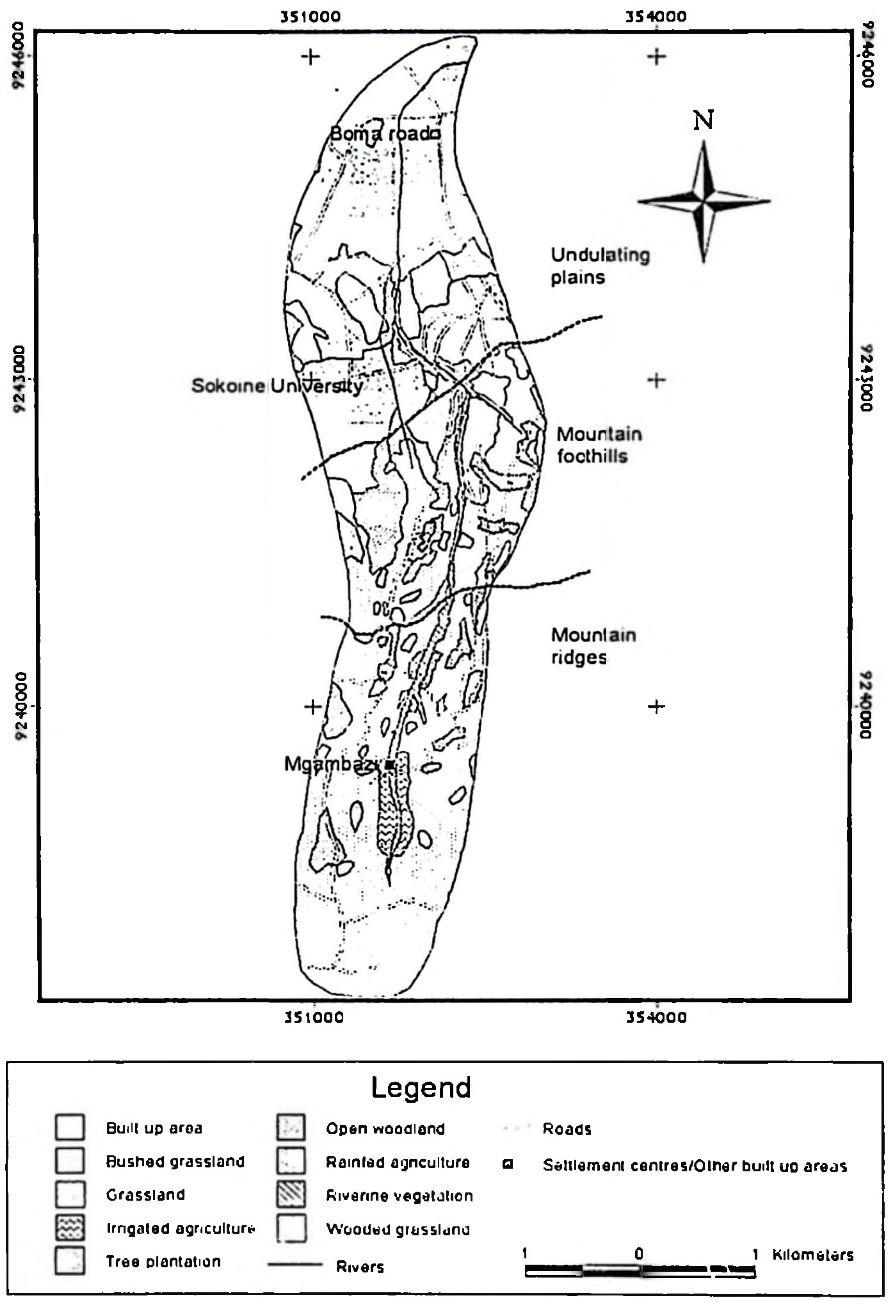

Figure 3 (b): Land use/cover map for Kikundi sub-catchment, 2004

4.1.2 Land use/cover distribution for Morogoro sub-catchment in 1964 and 2004

Temporal and spatial distribution of land use/cover for Morogoro sub-catchment is given in Table 2 and in Figures 4 (a) and 4 (b). The results show that, by 1964, forest, bushed grassland and rainfed agriculture dominated the mountain ridges (Table 2). Open woodland and closed woodland mainly occupied the mountain foothills and the undulating plains. Other land use/cover types seem to be evenly distributed in all three geomorphic units. Settlements seem to occupy the major part of the undulating plains the fact attributed to Morogoro urban development which is closely related to sisal industry.

In the period between 1964 and 2004, the distribution of land use/cover types in the study area show more or less similar pattern as by 1964 (Table 2, Figure 4 (b)). Only the coverage has changed due to land use dynamics (section 4.2) associated with both biophysical and socio-economic factors as discussed in sections 4.3.1. and 4.3.2. Wooded grassland was observed only in the undulating plains by 1964, which significantly decreased between 1964 and 2004. Dominance of furrow irrigated agriculture in the mountain ridges is attributed to high density drainage pattern or streams (Figure 9 and 10) and (Table 7) from which farmer obtain water easily for furrow irrigation during dry spells.

Table 2: Coverages and percentage distribution of land use/cover for Morogoro sub-catchment in 1964 and 2004

Geomorphic unit	Land use/cover	1964		2004	
		area(ha)	%	area (ha)	%
Mountain ridges	F	712.0	41.0	655.6	37.7
	BG	505.9	29.9	4.4	0.3
	RA	284.5	16.4	809.2	46.5
	RV	123.4	7.1	42.8	2.5
	G	88.6	5.1	76.9	4.4
	S	18.9	1.2	49.9	2.9
	IA	3.5	0.2	99.0	5.6
	OW	2.2	0.1	1.2	0.1
	Sub-total	**1739.0**	**100.0**	**1739.0**	**100.0**
Mountain foothills	S	11.1	2.7	192.6	46.4
	BG	92.6	22.3	10.9	2.6
	CW	129.9	31.3	0.0	0.0
	OW	63.0	15.2	14.7	3.5
	RA	66.9	16.1	171.0	41.2
	RV	51.9	12.4	26.2	6.3
	Sub-total	**415.4**	**100.0**	**415.4**	**100.0**
Undulating plains	S	459.7	18.4	1774.9	71.1
	BG	197.4	7.9	3.9	0.2
	OW	492.8	19.7	7.8	0.3
	RA	743.1	29.8	679.9	27.2
	RV	65.6	2.6	17.8	0.6
	SP	502.7	20.1	0.0	0.0
	W	4.6	0.2	4.3	0.2
	WG	31.7	1.3	9.0	0.4
	Sub-total	**2497.6**	**100.0**	**2497.6**	**100.0**

Note: S=Built up area BG=Bushed grassland F=Forest G=Grassalnd IA=Irrigated agriculture OW=Open woodland RA=Rainfed agriculture RV=Riverine vegetation SP=Sisal plantations W=Water body WG=Wooded grassland CW=Closed woodland

The land use/cover coverages indicates that in the mountain ridges forest was the largest cover by 1964 occupying 41.0% of the mountain ridges total area followed by bushed grassland (29.9%). Rainfed agriculture occupied 16.4% whereas irrigated agriculture occupied only 0.2%. Built up area (settlements) occupied 1.2% while other classes in total occupied 12.3% of the mountain ridges area.

The results show further that for the mountain foothills by 1964, closed woodland was the largest cover occupying 31.3% followed by bushed grassland (22.3%). Rainfed agriculture occupied 16.1% of the area and at this time there was no irrigated agriculture in the foothills. Built up area (settlements) occupied 2.7% and other types occupied 27.7% of the total area. In the undulating plains, rainfed agriculture was the largest cover by 1964 occupying 29.8% of the undulating plain area followed by sisal plantations (20.1%). Open woodland occupied 19.7% and built up area occupied 18.4%. Other classes together occupied 12.0% of the total area.

For the period between 1964 and 2004, rainfed agriculture was the largest cover in the mountain ridges of this sub-catchment occupying 46.5%. The second largest cover was forest which occupied 37.7%. Irrigated agriculture is the third class covering 5.6% of the total mountain ridges area. Built up area occupied 2.9% and the remaining bushed grassland covered only 0.3%. In the mountain foothills, built up area was the largest cover between 1964 and 2004 occupying 46.4% followed by rainfed agriculture which occupied 41.2%. Other cover types together occupied 12.5%.

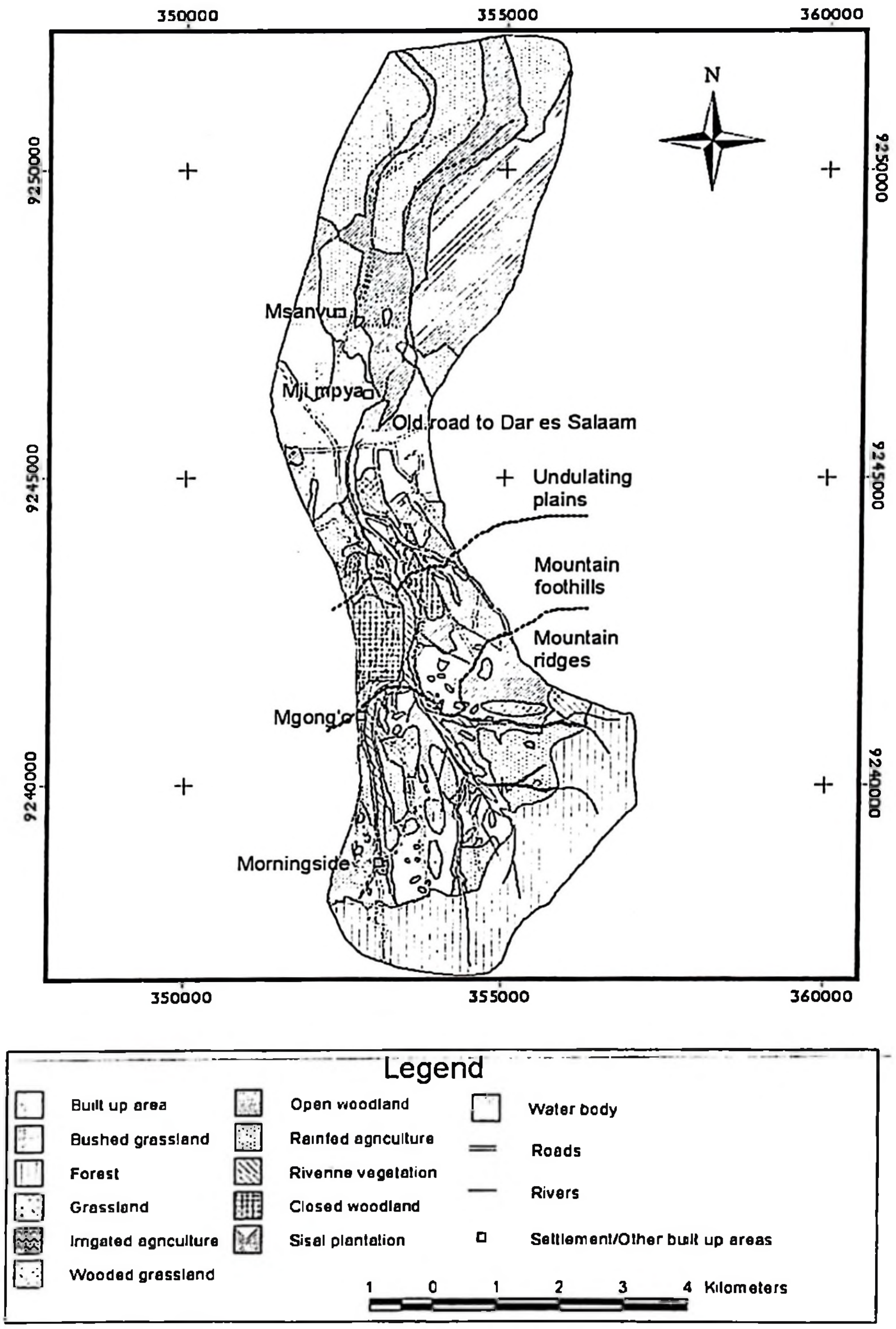

Figure 4 (a): Land use/cover map for Morogoro sub-catchment, 1964

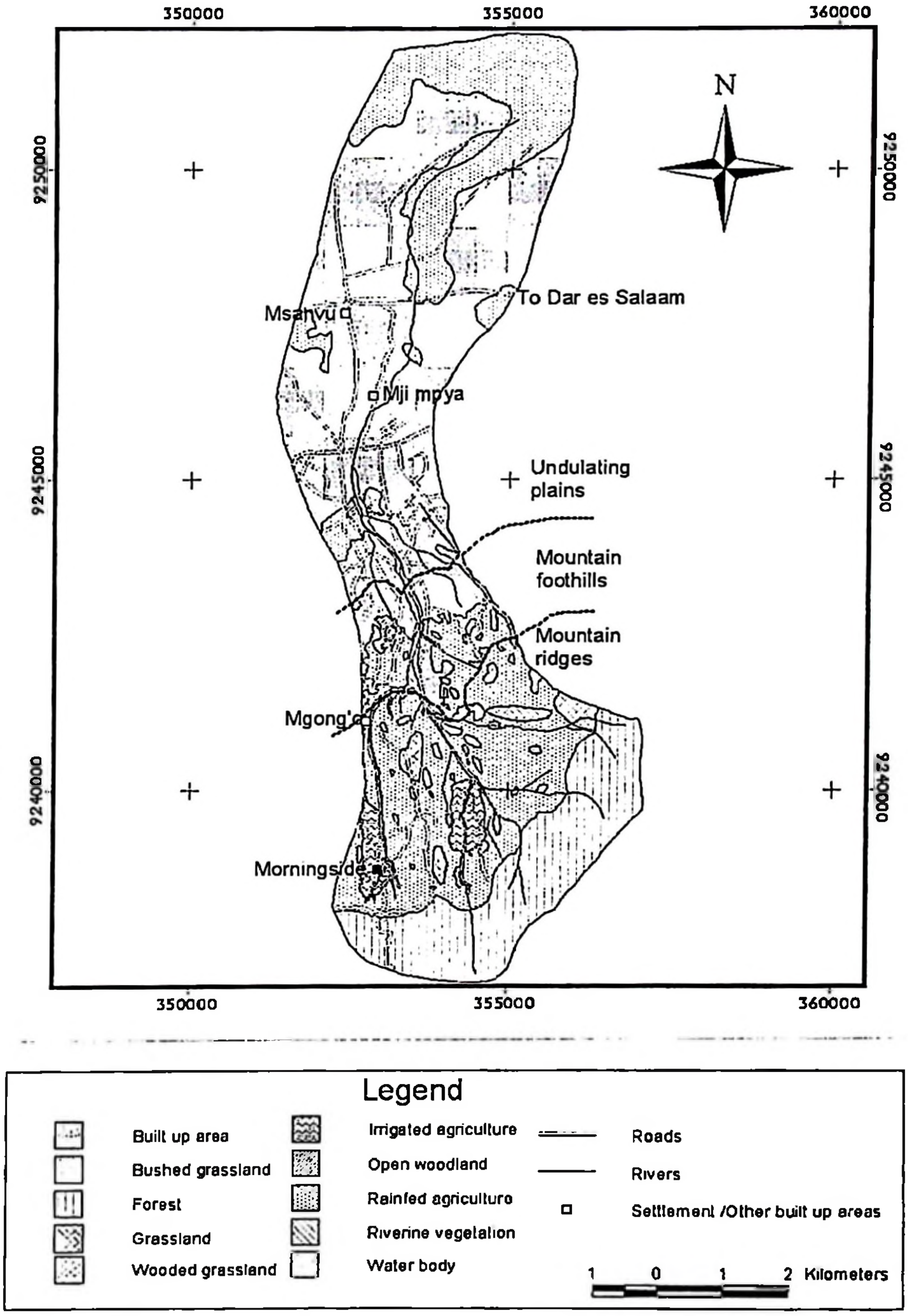

Figure 4 (b): Land use/cover map for Morogoro sub-catchment, 2004

In the undulating plains built up area was the largest cover occupying 71.1% followed by rainfed agriculture which occupied 27.2%. Other cover types occupied 1.7% while sisal plantation was completely transformed to other cover types as discussed in section 4.2.1. The results demonstrate a spatial and temporal variability of coverages of different land use/cover types. By 1964 the mountain ridges and foothills were dominated by natural vegetation. The undulating plains were dominated by settlements by 1964 and the same class dominated between 1964 and 2004 but at an increased amount. Between 1964 and 2004 a decline in the dominance of forest, woodland and bushed grassland was observed in the mountain ridges and foothills. These are constantly replaced with intensive annual cultivation which has increased the severity of soil erosion hence the need to set appropriate soil and water conservation measures in order to preserve this important catchment.

4.1.3 Land use/cover distribution for Kilakala sub-catchment in 1964 and 2004

Temporal and spatial distribution of land use/cover coverages for Kilakala sub-catchment are given in Table 3 and in Figures 5 (a) and 5 (b). The results show that, by 1964, forest, bushed grassland and rainfed agriculture dominated the mountain ridges (Table 3). Open woodland and closed woodland occupied the mountain foothills. Other land use/cover types except sisal plantations seem to be evenly distributed in all three geomorphic units. Settlements seem to occupy the major part of the undulating plains also attributed to Morogoro urban development which historically is closely related to sisal industry.

Table 3: Coverages and percentage distribution of land use/cover for Kilakala sub-catchment in 1964 and 2004

Geomorphic unit	Land use/cover	1964		2004	
		area(ha)	%	area (ha)	%
Mountain ridges	RA	79.6	21.1	178.3	47.3
	F	137.1	36.4	122.0	32.4
	BG	111.5	29.6	54.3	14.4
	OW	28.0	7.4	7.9	2.1
	S	6.3	1.6	9.2	2.4
	RV	14.5	3.9	5.3	1.4
	Sub-total	**377.0**	**100.0**	**377.0**	**100.0**
Mountain foothills	RA	86.8	31.1	185.8	66.5
	BG	90.1	32.3	25.9	9.3
	S	15.5	5.6	23.9	8.6
	OW	64.4	23.1	37.1	13.3
	RV	21.2	7.3	6.6	2.3
	CW	1.3	0.5	0.0	0.0
	Sub-total	**279.3**	**100.0**	**279.3**	**100.0**
Undulating plains	S	146.2	38.8	355.3	94.4
	BG	46.7	12.5	0.0	0.0
	RA	135.8	36.1	14.1	3.7
	RV	42.3	11.2	7.0	1.9
	SP	5.4	1.4	0.0	0.0
	Sub-total	**376.4**	**100.0**	**376.4**	**100.0**

Note: S=Built up area BG=Bushed grassland F=Forest OW=Open woodland RA=Rainfed agriculture RV=Riverine vegetation SP=Sisal plantation

In the period between 1964 and 2004, the distribution of land use/cover types in the study area show more or less similar pattern as by 1964 except for sisal plantations which had disappeared by 2004 (Table 3, Figures 5 (a) and 5 (b)). Many of the land use/cover types studied show that only the coverage has changed due to land use dynamics (section 4.2) associated with both biophysical and socio-economic factors as discussed in sections 4.3.1 and 4.3.2. There was no irrigated agriculture in this sub-catchment probably due to availabilty of irrigation water compared to other sub-catchments.

The land use/cover illustrate that in the mountain ridges forest was the largest cover by 1964 occupying 36.4% of the mountain ridges total area followed by bushed grassland which occupied 29.6% of the total mountain ridges area. Rainfed agriculture was occupying 21.1% whereas built up area (settlements) occupied 1.6%. Open woodland and riverine vegetation was occupying 7.4% and 3.9% of the mountain ridges area respectively. In the mountain foothills, bushed grassland was the largest cover by 1964 occupying 32.3% of the geomorphic unit area followed by rainfed agriculture which occupied 31.1%. The third cover was open woodland which occupied 23.1%. Riverine vegetation occupied 7.6% whereas built up area occupied 5.6% of the mountain foothills area. In the undulating plains, built up area was the largest cover by 1964 occupying 38.8% of the undulating plain area followed by rainfed agriculture (36.1%). Bushed grassland occupied 12.5% whereas remaining classes occupied 12.7% of the total area.

In the period between 1964 and 2004, the mountain ridges had rainfed agriculture as the largest cover type occupying 47.3%. The second largest cover was forest and this occupied 32.4%.

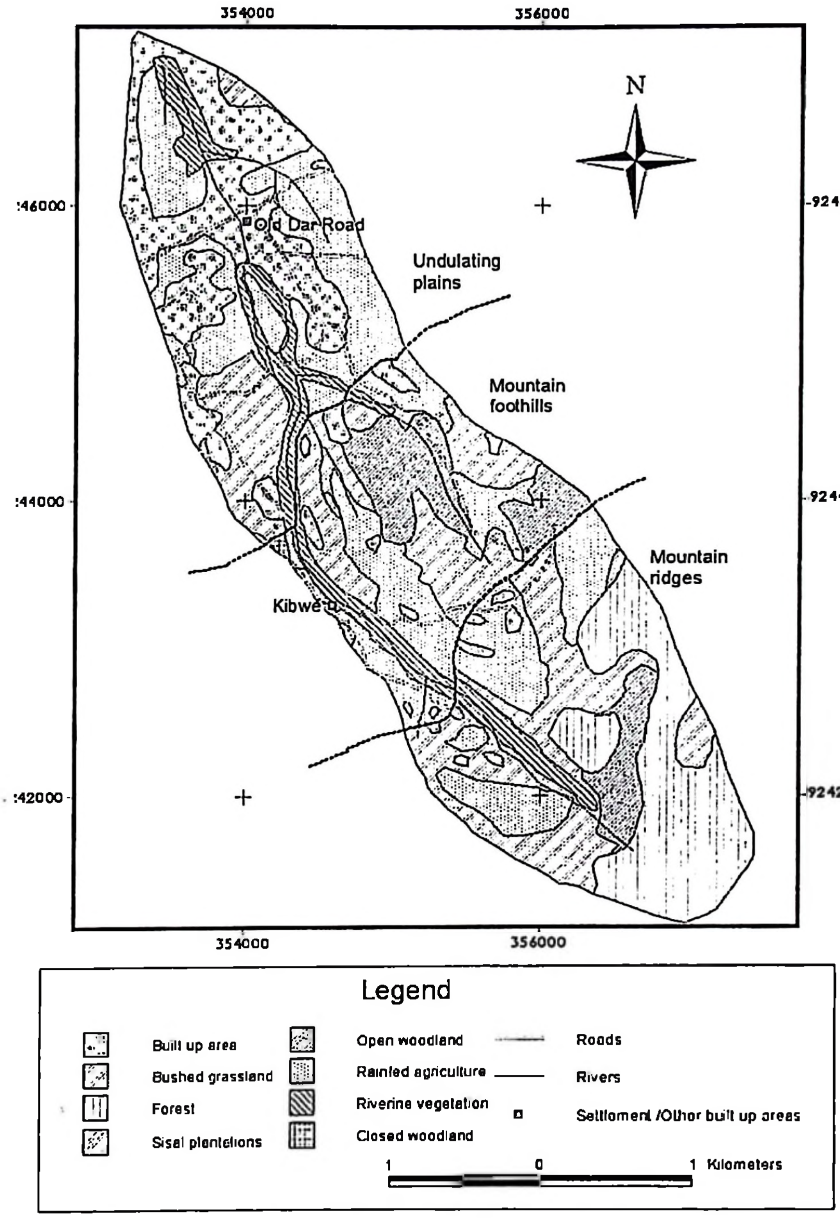

Figure 5 (a): Land use/cover map for Kilakala sub-catchment, 1964

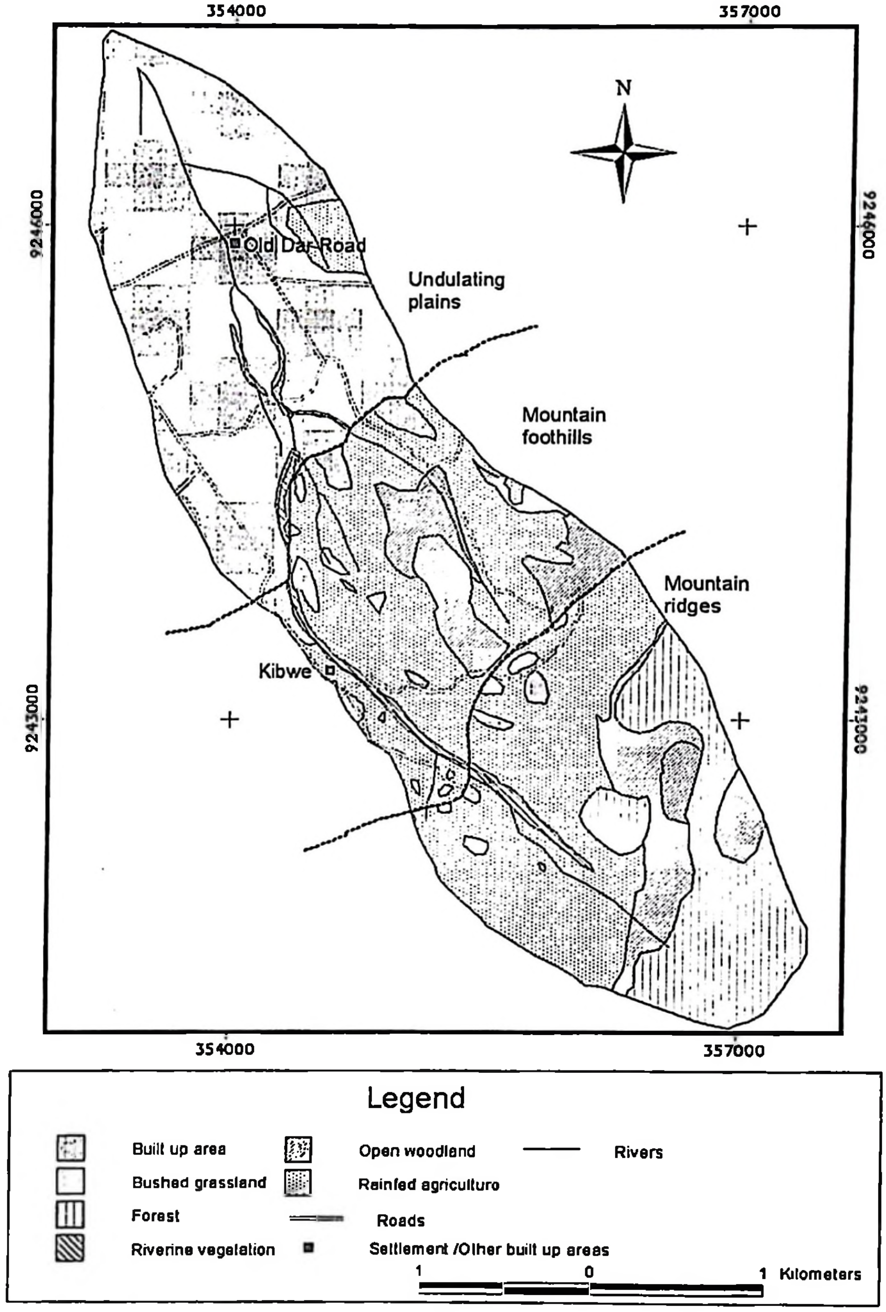

Figure 5 (b): Land use/cover map for Kilakala sub-catchment, 2004

Bushed grassland occupied 14.4%. The built up area (settlements) occupied 2.4% and the remaining classes covered only about 3.5% of the mountain ridges total area. For the mountain foothills, rainfed agriculture was the largest cover occupying 66.5% followed by open woodland which occupied 13.3%. Bushed grassland occupied 9.3% and the built up area (settlements) was occupying 8.6%. Riverine vegetation occupied 2.3% of the mountain foothills area. For the undulating plains built up area was the largest cover occupying 94.4% followed by rainfed agriculture which occupied 3.7%. Other coverage for undulating plains was riverine vegetation which was occupying 1.9%.

The results demonstrate a spatial and temporal variability of coverages of different land use/cover types. By 1964 the mountain ridges and foothills were dominated by natural vegetation. The undulating plains were dominated by settlements by 1964 and the same class dominated between 1964 and 2004 but at an increased amount. Between 1964 and 2004 a decline of the dominance of forest, woodland and bushed grassland was observed in the mountain ridges and foothills. These are constantly replaced with intensive annual cultivation which has increased the severity of soil erosion particularly landslides hence the need to set appropriate soil and water conservation measures in order to preserve this important catchment.

4.2 Land use/cover dynamics for the period 1964-2004

4.2.1 Land use/cover changes analysis for Kikundi sub-catchment

The temporal period 1964-2004 has experienced considerable land use/cover transformations in the Kikundi sub-catchment. In this period all classes have either profoundly increased or decreased at the expense of other classes. Figures 6 (a), 6 (b) and 6 (c) are change detection maps for mountain ridges, mountain foothills and undulating plains respectively. Tables 4 (a) through 4 (f) depict the results from change detection analysis between 1964 and 2004.

Table 4 (a) shows that in the mountain ridges rainfed agriculture has increased rapidly at the rate of 7.6 ha (12%) per year. The area under settlement has also increased at a rate of 0.3 ha (4%) per year. The observed changes could be attributed to population dynamics (Lyamuya *et al.*, 1994; Senkondo, 1993) (Table 10). Since 1990s, irrigated agriculture has continuously increased at a high rate of about 0.6 ha per year equivalent to 22.5% per year. This change could be explained by farmers' shift from annual farming to seasonal vegetable production motivated by lucrative market in Morogoro and Dar es Salaam cities (Kimaro, 2003). Natural vegetation such as bushed grassland, open woodland and riverine vegetation decreased at a rate of less or equal to 2% per year which could be explained by expansion of both rainfed and irrigated agriculture, cutting of trees for fuel wood (Table 20) and house construction (Table 21).

Table 4 (b) provides detailed information on the nature of land use/cover transformations in the mountain ridges. The results reveal that between 1964 and 2004 a substantial area under bushed grassland were changed to rainfed and irrigated agriculture. The results also reveal further that about 14% of rainfed agriculture was transformed to built up area and irrigated agriculture.

Table 4 (a): Laud use/cover chauges iu Kikundi sub-catchment for mountain ridges between 1964 and 2004

Geomorphic unit	Land use/cover	Period		
		1964-2004 (40years)		
		area (ha)	%	Rate(ha/yr)
Mountain ridges	S	13.0	161.1	0.3
	BG	-282.0	-95.5	-7.1
	IA	23.5	898.8	0.6
	OW	-43.8	-69.0	-1.1
	RA	303.3	486.7	7.6
	RV	-14.0	-47.1	-0.4

Note: S=Built up area BG=Bushed grassland IA=Irrigated agriculture OW=Open woodland RA=Rainfed agriculture RV=Riverine vegetation

(+) indicates increase and (-) indicates decrease. Percentage is with respect to the land use/cover value in the preceding year.

Table 4 (b): Laud use/cover chauge detection matrix in Kikundi sub-catchment for mountain ridges between 1964 and 2004

LU 1964	Changed to (as observed in 2004) (ha)						**Total (ha)**
	S	BG	IA	OW	RA	RV	
S	8.1	0.0	0.0	0.0	0.0	0.0	8.1
BG	5.2	13.4	15.0	0.0	261.8	0.0	295.4
IA	0.0	0.0	0.0	0.0	2.6	0.0	2.6
OW	3.5	0.0	1.5	19.7	38.9	0.0	63.5
RA	4.3	0.0	4.5	0.0	53.5	0.0	62.3
RV	0.0	0.0	5.1	0.0	8.9	15.8	29.9
Total	**21.1**	**13.4**	**26.1**	**19.7**	**365.7**	**15.8**	**461.8**

Note: S=Built up area BG=Bushed grassland IA=Irrigated agriculture OW=Open woodland RA=Raifed agriculture RV=Riverine vegetation

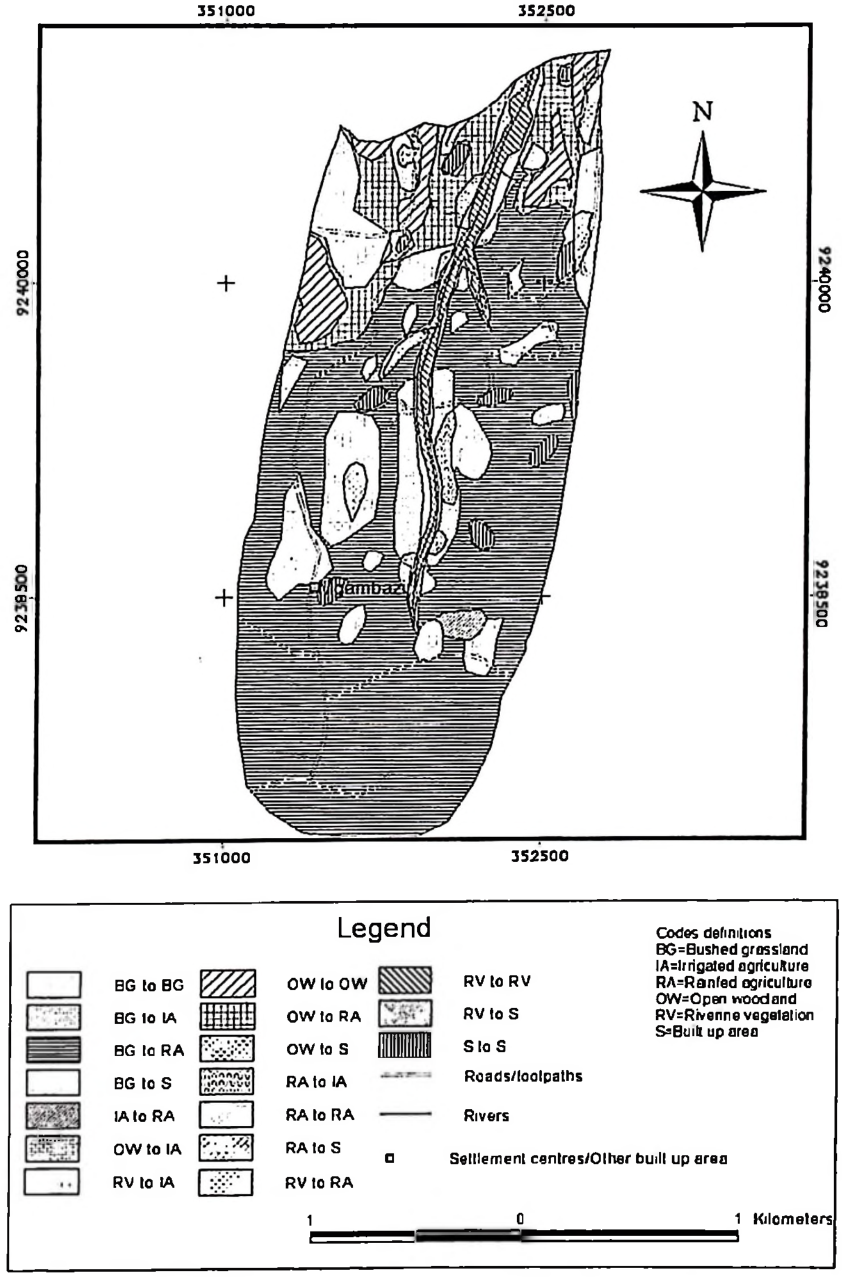

Figure 6 (a): Land use/cover change detection map for mountain ridges in Kikundi sub-catchment between 1964 and 2004

In the mountain foothills three land use/cover categories namely built up area, rainfed agriculture and open woodland have continuously been increasing. The rainfed agriculture has increased tremendously at a rate of 3.5 ha (28%) per year. The mountain foothills that were about 83% covered by woodland and riverine vegetation by 1964 (Table 1) have experienced a profound conversion from natural vegetation cover to cultivated fields and built up areas. Only 23.6% of woodland and riverine vegetation was remaining in this unit by 2004 (Table 4 (d)). Built up area has continuously increased at a rate of almost 2 ha (14%) per year. This increase was mainly due to expansion of urban area towards the mountain foothills. Two land use/cover types namely irrigated agriculture and grassland (fallow) have emerged between 1964 and 2004 (Table 4 (d)). The land use type namely irrigated agriculture started after 1977 as observed in the change detection matrix between 1977 and 1992 (Appendix B). However, some observations as reported by farmers indicated that irrigated agriculture in this unit was continuously decreasing from 1992 to 2004. This could be explained by unavailability of irrigation water caused by the declining water flows experienced in the major parts of the Eastern Arc Mountains of Tanzania (TFCG, 2005). The closed woodland was also observed to decrease at fast rate of 4.2 ha (2.5%) per year due to conversion from closed woodland to rainfed agriculture and built up area (Table 4 (d)).

Table 4 (c): Land use/cover changes in Kikundi sub-catchment for mountain foothills between 1964 and 2004

Geomorphic unit	Land use/cover	Period 1964-2004 (40years)		
		Area (ha)	%	Rate (ha/yr)
Mountain foothills	S	69.7	558.8	1.7
	BG	-11.4	-68.7	-0.3
	CW	-166.7	-100.0	-4.2
	OW	5.0	8.6	0.1
	RA	141.2	1120.1	3.5
	RV	-26.8	-70.3	-0.7
	SP	-14.0	-100.0	-0.4
	IA	1.9		0.1
	G	1.0		0.1

Note: S=Built up area BG=Bushed grassland IA=Irrigated agriculture OW=Open woodland RA=Rainfed agriculture RV=Riverine vegetation CW=Closed woodland SP=Sisal plantation G=Grassland (+) indicates increase and (-) indicates decrease. Percentage is with respect to the land use/cover value in the preceding year.

Table 4 (d): Land use/cover change detection matrix in Kikundi sub-catchment for mountain foothills between 1964 and 2004

LU 1964	Changed to (as observed in 2004) (ha)							Total (ha)
	S	BG	OW	RA	RV	G	IA	
S	12.5	0.0	0.0	0.0	0.0	0.0	0.0	12.5
BG	2.4	2.1	0.0	12.0	0.0	0.0	0.0	16.6
CW	37.9	0.0	56.5	72.3	0.0	0.0	0.0	166.7
OW	6.7	3.1	8.9	37.2	0.0	0.9	1.9	58.8
RA	3.5	0.0	0.0	9.1	0.0	0.0	0.0	12.6
RV	9.5	0.0	0.0	17.3	11.4	0.0	0.0	38.0
SP	9.7	0.0	0.0	4.3	0.0	0.0	0.0	14.0
Total	**82.2**	**5.2**	**65.5**	**152.2**	**11.4**	**0.9**	**1.9**	**319.2**

Note: S=Built up area BG=Bushed grassland CW=Closed woodland OW=Open woodland

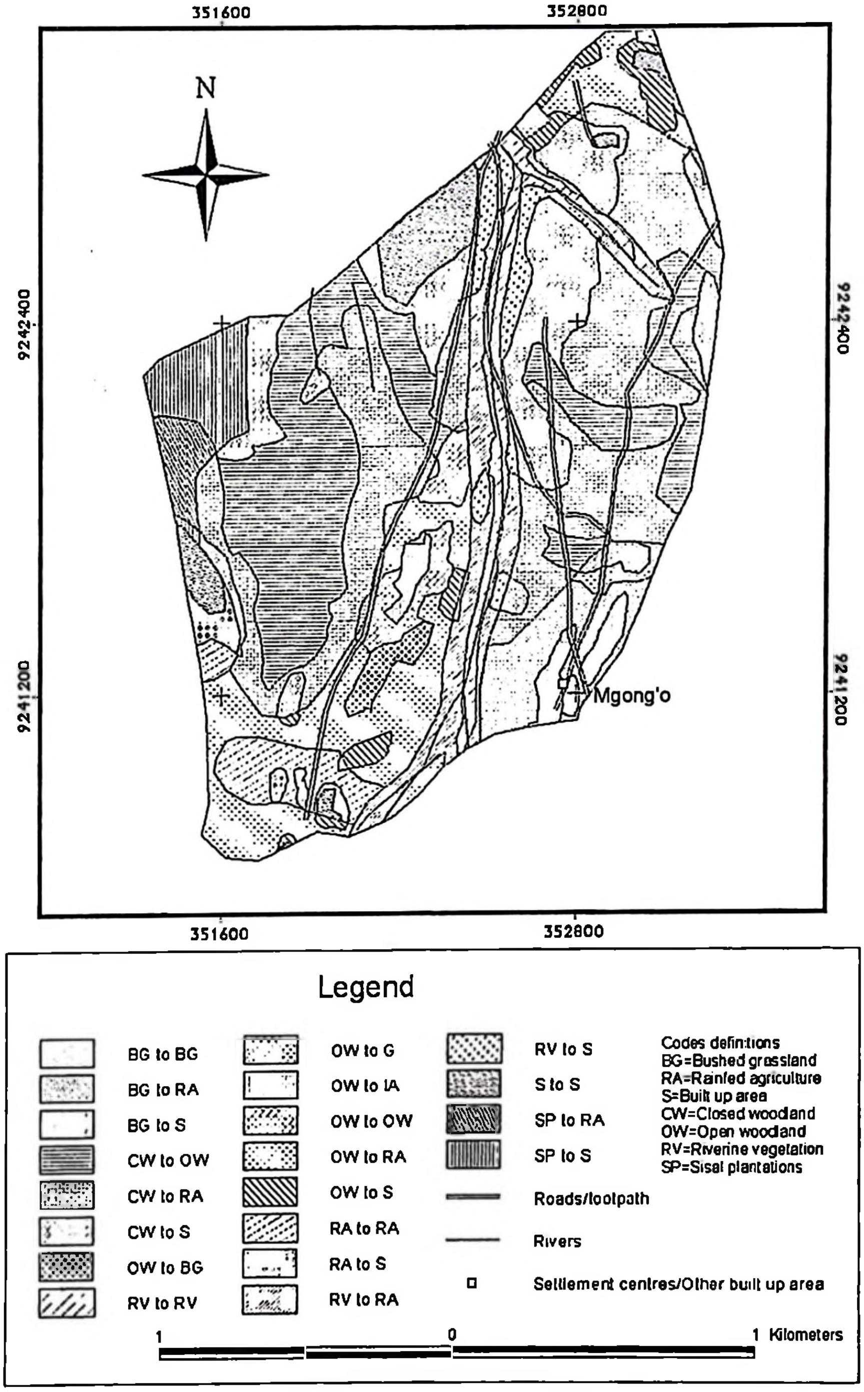

Figure 6 (b): Land use/cover change detection map for mountain foothills in Kikundi sub-catchment between 1964 and 2004

In the undulating, settlements have continuously increased at a rate of about 128% per year. Most of the natural vegetation cover and sisal plantations decreased at a rate ranging from 60 to 100% between 1964 and 2004 (Table 4 (e)). The results in Table 4 (f) show that by 2004, area under settlement increased tremendously at the expense of other cover types such as bushed grassland, open woodland, rainfed agriculture, sisal plantations and wooded grassland. The observed changes could be explained by population growth (Table 10), expansion of Morogoro municipality in terms of settlements, industries and services such as colleges, schools, religious centers and tourism.

Table 4 (e): Land use/cover changes in Kikundi sub-catchment for undulating plains between 1964 and 2004

Geomorphic unit	Land use/cover	Period		
		1964-2004 (40years)		
		Area (ha)	%	Rate (ha/yr)
Undulating plains	S	215.4	127.6	5.4
	BG	-3.5	-17.1	-0.1
	OW	-49.1	-100.0	-1.2
	RA	-89.8	-77.7	-2.2
	RV	-19.5	-69.4	-0.5
	SP	-86.1	-100.0	-2.2
	WG	-21.7	-61.8	-0.5
	G	53.9		1.4
	TP	0.3		0.0

Note: S=Built up area BG=Bushed grassland OW=Open woodland RA=Rainfed agriculture RV=Riverine vegetation SP=Sisal plantation WG=Wooded grassland G=Grassland TP=Tree plantation
(+) indicates increase and (-) indicates decrease. Percentage is with respect to the land use/cover value in the preceding year.

The results demonstrate that land use/cover in the catchment is highly dynamic with cultivation activities more intensive in the mountain ridges compared to the foothills and the foothills being more encroached by the rapid urban expansion in the undulating plains.

This increase of cultivation activities particularly vegetable production and settlement areas due to population dynamics and demand of vegetables in Morogoro municipality and Dar es Salaam city has posed pressure on land resources hence the need for appropriate land use planning and management to avoid further resource degradation.

Table 4 (f): Land use/cover change detection matrix in Kikundi sub-catchment for undulating plains for the period 1964-2004

LU 1964	Changed to (as observed in 2004) (ha)								Total (ha)
	S	BG	OW	RA	RV	G	WG	TP	
S	168.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	168.9
BG	14.7	5.1	0.0	0.7	0.0	0.0	0.0	0.0	20.5
OW	43.9	0.0	0.0	5.3	0.0	0.0	0.0	0.0	49.1
RA	65.5	0.0	0.0	13.2	0.0	23.4	13.4	0.0	115.5
RV	10.7	0.0	0.0	3.0	10.2	4.2	0.0	0.0	28.1
SP	47.9	10.3	0.0	3.6	0.0	24.1	0.0	0.3	86.1
WG	32.7	0.0	0.0	0.0	0.0	2.3	0.0	0.0	35.0
Total	**384.3**	**15.4**	**0.0**	**25.8**	**10.2**	**54.0**	**13.4**	**0.3**	**503.3**

Note: S=Built up area BG=Bushed grassland OW=Open woodland RA=Rainfed agriculture RV=Riverine vegetation SP=Sisal plantation WG=Wooded grassland

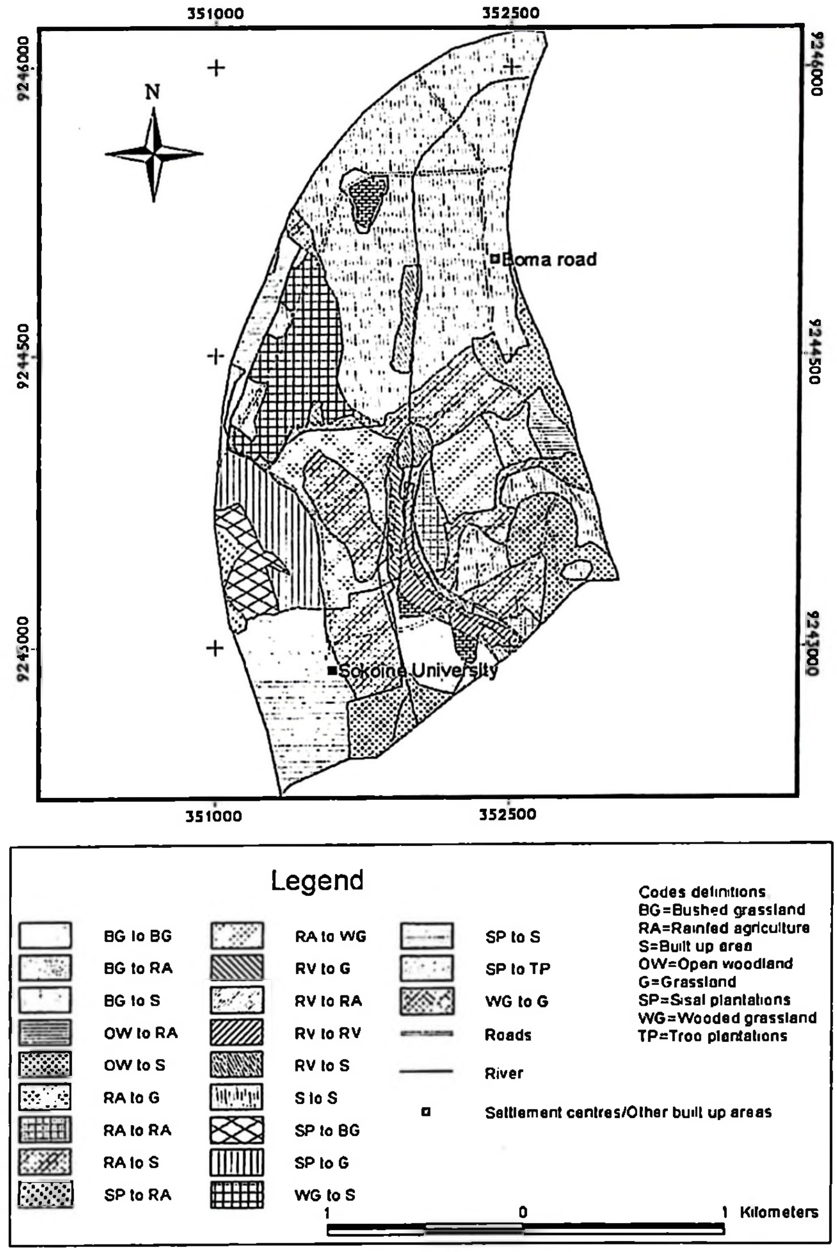

Figure 6 (c): Land use/cover change detection map for undulating plains in Kikundi sub-catchment between 1964 and 2004

4.2.2 Land use/cover change analysis for Morogoro sub-catchment

The results show that land use/cover in all three geomorphic units of Morogoro sub-catchment is highly dynamic. Figures 7 (a), 7 (b) and 7 (c) are change detection maps for mountain ridges, mountain foothills and undulating plains for Morogoro sub-catchment respectively. Table 5 (a) through 5 (f) present the detailed information on the nature of land use/cover transformations in Morogoro sub-catchment between 1964 and 2004. In the mountain ridges bushed grassland cover was reducing at a rate of 12.54 ha (2.5%) per year. The decrease observed on this cover in this period was mainly due to increased agricultural activities. During this period, rainfed agriculture has been increasing rapidly at the rate of 13.12 ha (4.6%) per year. This could be attributed to increased population (Lyamuya *et al.*, 1994; Senkondo, 1993) (Table 10) and shifting from annual crop farming to seasonal vegetable production (Kimaro, 2003). The area under forest was decreasing at a slower rate of about 1.41 ha (0.2%) per year which could be due to expansion of agricultural frontier and encroachment towards the forest land (Figure 7 (a)) and tree cutting for fuel wood and construction and other uses as shown in the change detection matrix (Table 5(b)). The built up area (settlements) coverage was increasing at a rate of 0.8 ha (4%) per year and this is also attributed to population increase (Table 10). The riverine vegetation and grassland (fallow) have been reducing at a rate of 2.0 ha (1.6%) and 0.3 ha (0.3%) per year respectively. The observed trend could also be explained by increase in both rainfed and irrigated agriculture as revealed by the change detection matrix given in Table 5(b).

Table 5 (a): Land use/cover changes for Mountain ridges in Morogoro sub-catchment between 1964 and 2004

Geomorphic unit	Land use/cover	Period 1964-2004 (40 years) Area (ha)	%	Rate (ha/yr)
Mountain ridges	S	31.0	164.2	0.8
	BG	-501.4	-99.1	-12.5
	F	-56.5	-7.9	-1.4
	G	-11.7	-13.2	-0.3
	IA	95.5	2716.9	2.4
	OW	-1.0	-44.5	-0.0
	RA	524.7	184.4	13.1
	RV	-80.6	-65.3	-2.0

Note: S=Built up area BG=Bushed grassland F=Forest G=Grassland IA=Irrigated agriculture OW=Open woodland RA=rainfed agriculture RV=Riverine vegetation

(+) indicates increase and (-) indicates decrease. Percentage is with respect to the land use/cover value in the preceding year.

Table 5 (b): Land use/cover change detection matrix for mountain ridges in Morogoro sub-catchment between 1964 and 2004

LU 1964	Changed to (as observed in 2004 (ha) S	BG	F	G	IA	OW	RA	RV	**Total (ha)**
S	18.0	0.0	0.0	0.0	0.1	0.0	0.9	0.0	18.9
BG	19.3	4.4	0.0	0.5	66.7	0.0	415.0	0.0	505.9
F	0.0	0.0	655.5	1.4	0.0	0.0	55.1	0.0	712.0
G	0.0	0.0	0.0	75.1	0.0	0.0	13.5	0.0	88.6
IA	0.0	0.0	0.0	0.0	3.5	0.0	0.0	0.0	3.5
OW	0.0	0.0	0.0	0.0	0.5	1.2	0.4	0.0	2.1
RA	10.3	0.0	0.0	0.0	20.0	0.0	254.3	0.0	284.5
RV	2.4	0.0	0.0	0.0	8.2	0.0	70.0	42.7	123.5
Total (ha)	**50.0**	**4.4**	**655.5**	**77.0**	**99.0**	**1.2**	**809.2**	**42.7**	**1739.0**

Note: S=Built up area BG=Bushed grassland F=Forest G=Grassland IA=Irrigated agriculture OW=Open woodland RA=Rainfed agriculture RV=Riverine vegetation

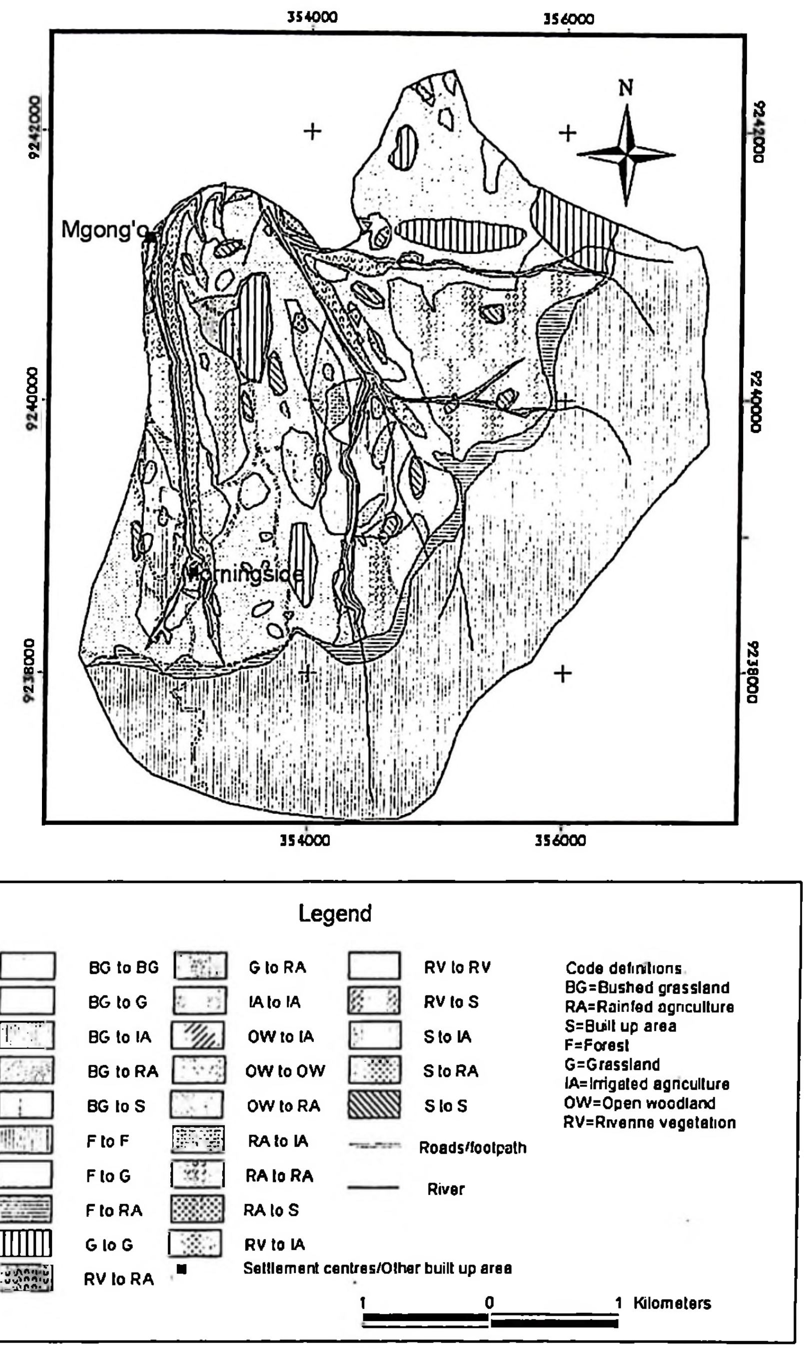

Figure 7 (a): Land use/cover change detection map for mountain ridges in Morogoro sub-catchment between 1964 and 2004

In the mountain foothills, built up area and rainfed agriculture were continuously increasing while most of the natural vegetation covers were decreasing. It is evident from Table 5 (c) that the built up area was increasing at a faster rate of about 4.5 ha per year equivalent to 41% per year. This increase was mainly due to urban advancement (covering the undulating plains) towards the mountain foothills. The rainfed agriculture was increasing at a rate of about 4% per year. However, this trend is slightly lower compared to that of mountain ridges mainly due biophysical characteristics as discussed in section 4.3.1. The results show further that natural vegetation covers in this unit were continuously decreasing at a rate of about 2% between 1964 and 2004. The degradation of natural vegetations in this unit could be attributed to urban advancement towards the rural mountain foothills and increase of urban population.

Table 5 (c): Land use/cover changes for mountain foothills in Morogoro sub-catchment between 1964 and 2004

Geomorphic unit		Period		
	Land use/cover	1964-2004 (40 years)		
		Area (ha)	%	Rate (ha/yr)
Mountain foothills	S	181.5	1634.4	4.5
	BG	-81.7	-88.2	-2.0
	CW	-129.9	-100.0	-3.3
	OW	-48.3	-76.7	-1.2
	RA	104.1	155.7	2.6
	RV	-25.7	-49.5	-0.6

Note: S=Built up area BG=Bushed grassland OW=Open woodland RA=rainfed agriculture RV=Riverine vegetation CW=Closed woodland. (+) indicates increase and (-) indicates decrease. Percentage is with respect to the land use/cover value in the preceding year.

Table 5 (d): Land use/cover change detection matrix for mountain foothills in Morogoro sub-catchment between 1964 and 2004

LU 1964	Changed to (as observed in 2004 (ha)						Total (ha)
	S	BG	CW	OW	RA	RV	
S	11.1	0.0	0.0	0.0	0.0	0.0	11.1
BG	28.1	10.0	0.0	0.0	54.5	0.0	92.6
CW	64.0	1.0	0.0	13.4	51.5	0.0	129.9
OW	34.1	0.0	0.0	1.3	27.6	0.0	63.0
RA	35.5	0.0	0.0	0.0	31.3	0.0	66.8
RV	18.8	0.0	0.0	0.0	6.1	27.1	52.0
Total	**191.6**	**11.0**	**0.0**	**14.7**	**171.0**	**27.1**	**415.4**

Note: S=Built up area BG=Bushed grassland CW=Closed woodland OW=Open woodland RA=Rainfed agriculture RV=Riverine vegetation

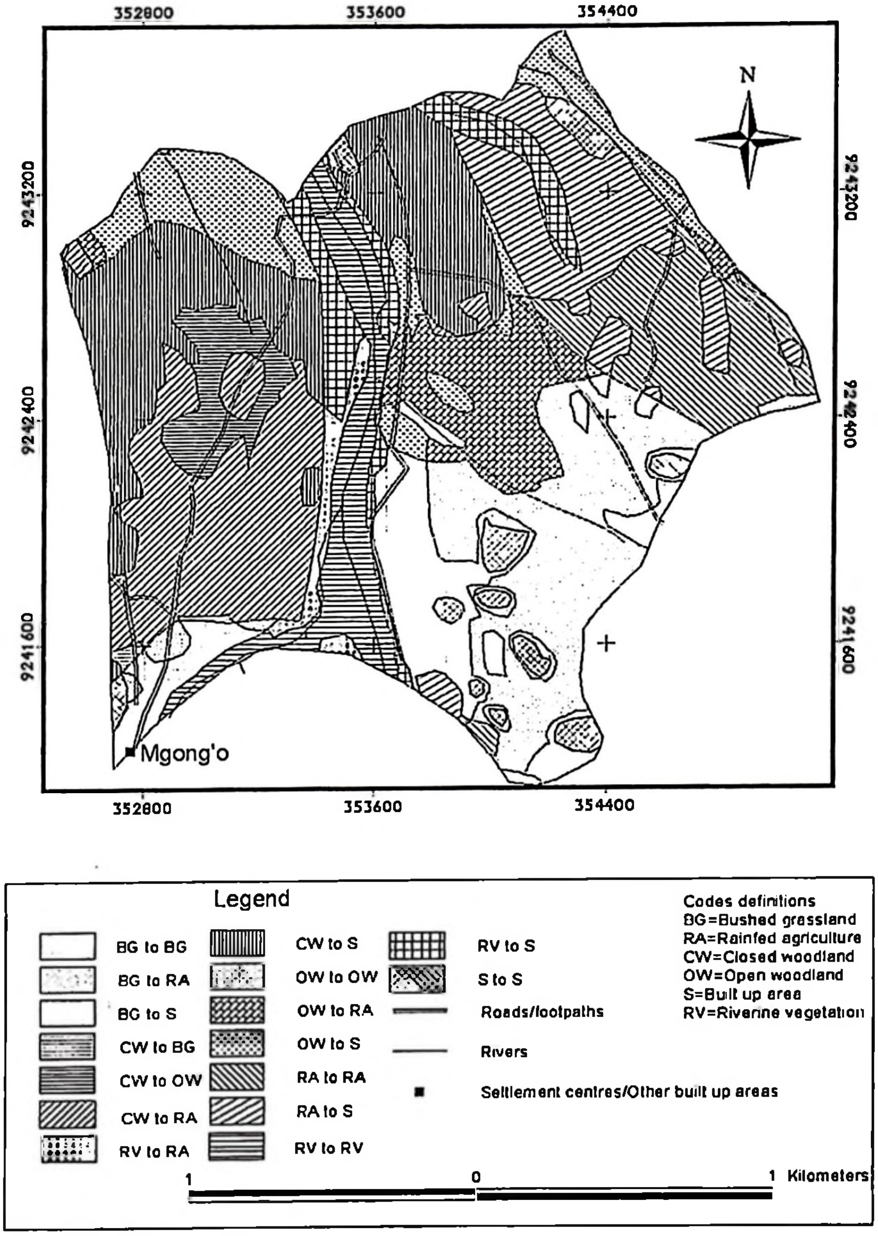

Figure 7 (b): Land use/cover change detection map for mountain foothills in Morogoro sub-catchment between 1964 and 2004

The undulating plains experienced profound increase of built up area at a rate of 32.88 ha per year equivalent to 7% per year. All other cover types in the undulating plains were decreasing. Rainfed agriculture in the plains was continuously decreasing at a rate of 1.58 ha per year equivalent to 0.2% as revealed by the change detection matrix that about 59% of rainfed agriculture was transformed to built up area (Table 5(f)). Sisal plantations which has been continuously decreasing at a rate of 12.57 ha per year equivalent to 2.5% per year were completely transformed to built up area (357 ha) and rainfed agriculture (145 ha) by 2004 (Table 5(f)). Open woodland, wooded grassland and riverine vegetation were all decreasing at rate of about 2% per year at the expense of settlements and agriculture.

The results demonstrate that land use/cover in the catchment is highly dynamic with cultivation more intensive in the mountain ridges compared to the foothills and the foothills being more encroached by the rapid urban expansion in the undulating plains. In this situation natural vegetation is more replaced with cultivation and settlements. The increase in settlement and cultivation particularly vegetable production due to population dynamics and demand of vegetables in Morogoro municipality and Dar es Salaam city has posed pressure on land resources hence the need for appropriate land use plans.

Table 5 (e): Land use/cover changes for undulating plains in Morogoro sub-catchment between 1964 and 2004

Geomorphic unit	Land use/cover	Period 1964-2004(40 years)		
		Area (ha)	%	Rate (ha/yr)
Undulating plains	S	1315.2	286.1	32.9
	BG	-193.5	-98.0	-4.8
	OW	-485.0	-98.4	-12.1
	RA	-63.1	-8.5	-1.6
	RV	-47.8	-72.8	-1.2
	SP	-502.7	-100.0	-12.6
	W	-0.4	-7.7	-0.0
	WG	-22.7	-71.6	-0.6

Note: S=Built up area BG=Bushed grassland OW=Open woodland RA=rainfed agriculture RV=Riverine vegetation SP=Sisal plantation W=Water body WG=Wooded grassland

(+) indicates increase and (-) indicates decrease. Percentage is with respect to the land use/cover value in the preceding year.

Table 5 (f): Land use/cover change detection matrix for undulating plains in Morogoro sub-catchment between 1964 and 2004

LU 1964	Changed to (as observed in 2004 (ha)							**Total (ha)**
	S	BG	OW	RA	RV	W	WG	
S	459.7	0.0	0.0	0.0	0.0	0.0	0.0	459.7
BG	165.7	3.9	0.0	27.8	0.0	0.0	0.0	197.4
OW	283.0	0.0	7.8	202.0	0.0	0.0	0.0	492.8
RA	437.8	0.0	0.0	305.2	0.0	0.0	0.0	743.0
RV	47.9	0.0	0.0	0.0	17.8	0.0	0.0	65.7
SP	357.9	0.0	0.0	144.9	0.0	0.0	0.0	502.8
W	0.0	0.0	0.0	0.0	0.0	4.3	0.0	4.3
WG	22.8	0.0	0.0	0.0	0.0	0.0	9.1	31.9
Total	**1774.8**	**3.9**	**7.8**	**679.9**	**17.8**	**4.3**	**9.1**	**2497.6**

Note: S=Built up area BG=Bushed grassland OW=Open woodland RA=Rainfed agriculture RV=Riverine vegetation SP=Sisal plantation W=Water body WG=Wooded grassland

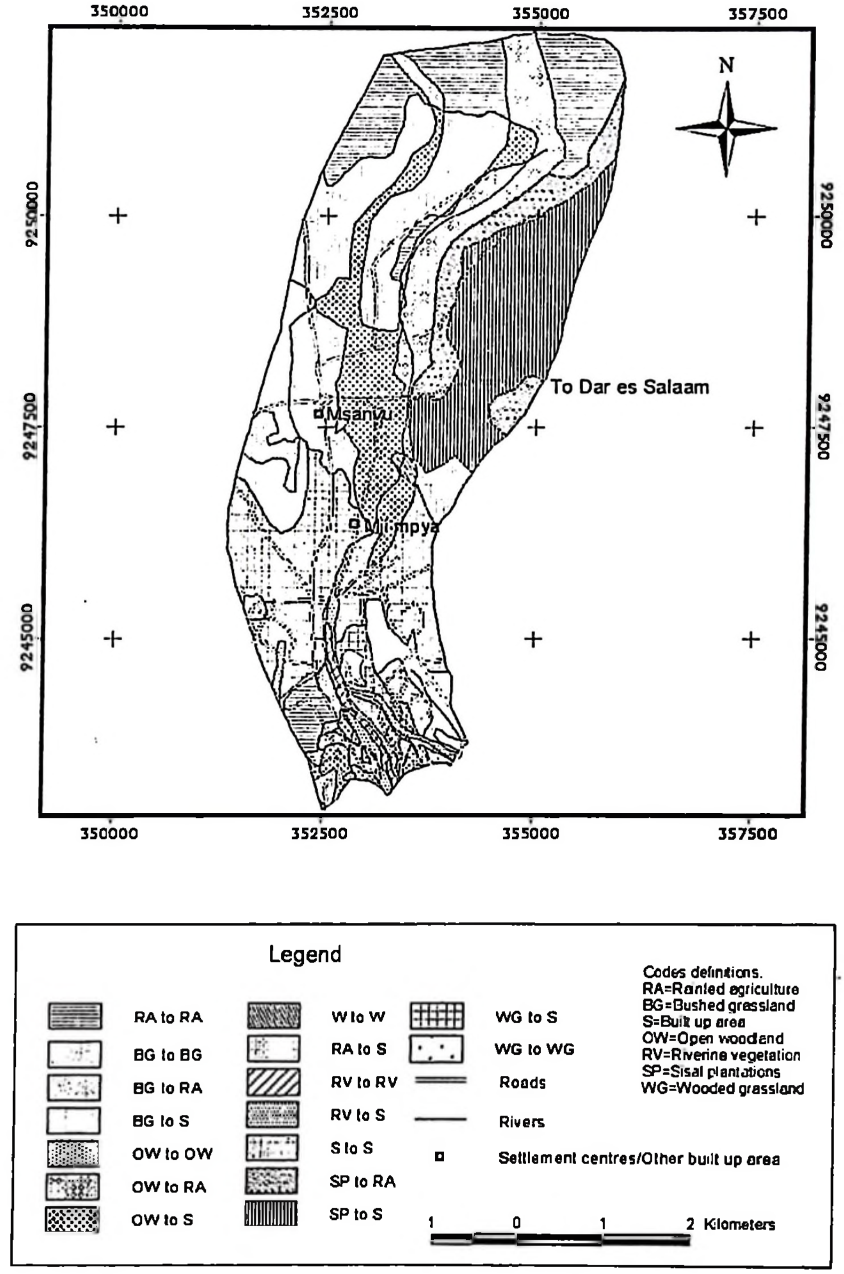

Figure 7 (c): Land use/cover change detection map for undulating plains in Morogoro sub-catchment between 1964 and 2004

4.2.3 Land use/cover change analysis for Kilakala sub-catchment

Kilakala sub-catchment has experienced considerable land use/cover transformations between 1964 and 2004. In this period all classes have either increased or decreased at the expense of other classes. Figures 8 (a), 8 (b) and 8 (c) are change detection maps for mountain ridges, mountain foothills and undulating plains respectively. Tables 6 (a) through 6 (f) provide detailed account on the nature of land use/cover transformation in Kilakala sub-catchment between 1964 and 2004.

Table 6 (a) shows that in the mountain ridges rainfed agriculture has been increasing rapidly at the rate of 2.5 ha per year equivalent to 3% per year. Built up area has also been increasing at a rate of 0.1 ha per year equivalent to 1.2% per year. The increase in rainfed agriculture could be attributed to population increase (Lyamuya et al., 1994; Senkondo, 1993) (Table 10), taking into account that more than 80% of the interviewed households rely on farming activities as their major source of income (Table 16). Bushed grassland was decreasing at a rate of 1.43 ha per year equivalent to 1.3% per year. Open woodland and riverine vegetation was decreasing at a rate of about 2%. The results illustrate further that the decrease in natural vegetation cover observed in the mountain ridges was mainly due to increased area under cultivation. (Table 6 (b)), cutting of trees for fuel wood (Table 20) and house construction (Table 21).

The change detection matrix (Table 6 (b)) show that all land use/cover types in this unit except built up area have transformed into rainfed agriculture. The results further show that most of the rainfed agriculture was contributed by the cover type bushed grassland that is 86.2 ha in comparison to 1.7 ha, 3.3 ha and 9.2 ha from forest, open woodland and riverine vegetation respectively.

Table 6 (a): Land use/cover changes for mountain ridges in Kilakala sub- catchment between 1964 and 2004

Geomorphic unit	Land use/cover	Period		
		1964-2004 (40 years)		
		Area (ha)	%	Rate (ha/yr)
Mountain ridges	S	3.0	47.3	0.1
	BG	-57.3	-51.3	-1.4
	F	-15.1	-11.0	-0.4
	OW	-20.2	-72.1	-0.5
	RA	98.7	124.0	2.5
	RV	-9.2	-63.2	-0.2

Note: S=Built up area BG=Bushed grassland F=Forest OW=Open woodland RA=Rainfed agriculture RV=Riverine vegetation SP=Sisal plantation

(+) indicates increase and (-) indicates decrease. Percentage is with respect to the land use/cover value in the preceding year.

Table 6 (b): Land use/cover change detection matrix for mountain ridges in Kilakalasub-catchment between 1964 and 2004

LU 1964	Changed to (as observed in 2004) (ha)						**Total (ha)**
	S	BG	F	OW	RA	RV	
S	6.3	0.0	0.0	0.0	0.0	0.0	6.3
BG	1.4	24.0	0.0	0.0	86.2	0.0	111.6
F	0.0	13.4	122.0	0.0	1.7	0.0	137.1
OW	0.0	16.9	0.0	7.7	3.2	0.0	27.9
RA	1.5		0.0	0.0	78.1	0.0	79.6
RV	0.0	0.0	0.0	0.0	9.2	5.3	14.5
Total	**9.2**	**54.3**	**122.0**	**7.7**	**178.3**	**5.3**	**377.0**

Note: S=Built up area BG=Bushed grassland F=Forest OW=Open woodland

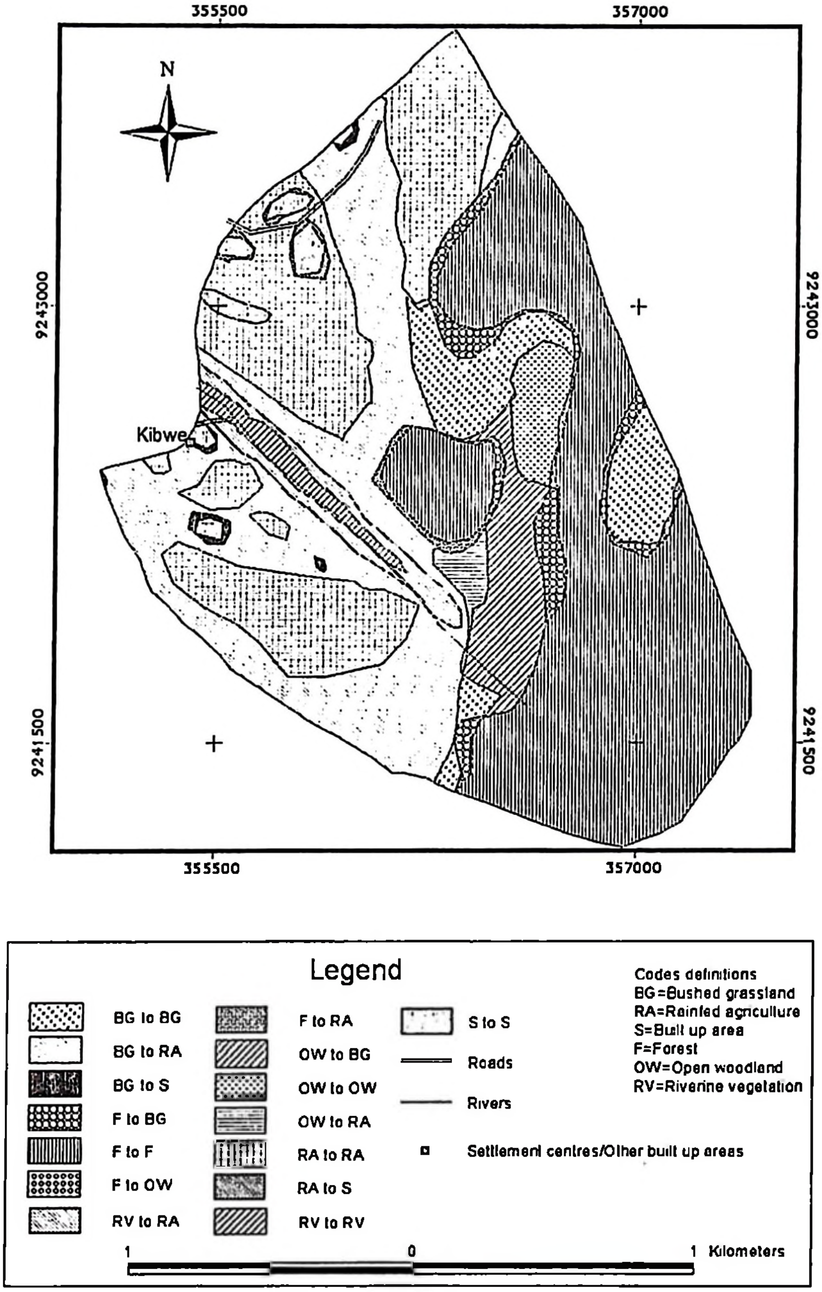

Figure 8 (a): Land use/cover change detection map for mountain ridges in Kilakala sub-catchment between 1964 and 2004

In the mountain foothills, two land use/cover categories namely, built up area and rainfed agriculture have been increasing. Rainfed agriculture has increased tremendously at a rate of 2.5 ha per year equivalent to 2.8% per year. Built up area has been increasing profoundly at a rate of 1.7 ha per year equivalent to 14% per year. The observed increase of built up area is mainly due to expansion of urban settlements towards the mountain foothills. The bushed grassland and closed woodland showed a decreasing trend of about 2% per year. This decrease was mainly due to increased area under rainfed agriculture and cutting of trees for fuel and construction purposes. Riverine vegetation and open woodland also decreased at a rate of 0.4 ha (equivalent to 1.7%) and 0.68 ha (equivalent to 1%) per year respectively for similar reasons. The change detection matrix (Table 6 (d)) shows that all classes except built up area have transformed to rainfed agriculture. The table shows that most changes in the land use type rainfed agriculture was contributed by the class bushed grassland (65.3 ha) in comparison to 22.8 ha and 13 ha from open woodland and riverine vegetation respectively. The table also shows that all classes have been transforming to built up area class with most of the increase of being contributed by both rainfed agriculture and bushed grassland.

Table 6 (c): Land use/cover changes for mountain foothills in Kilakala sub-catchment between 1964 and 2004

Geomorphic unit	Land use/cover	Period		
		1964-2004 (40 years)		
		Area (ha)	%	Rate (ha/yr)
Mountain foothills	S	8.4	54.0	0.2
	BG	-64.1	-71.2	-1.6
	CW	-1.3	-100.0	-0.0
	OW	-27.3	-42.3	-0.7
	RA	99.0	113.9	2.5
	RV	-14.6	-69.1	-0.4

Note: S=Built up area BG=Bushed CW=Closed woodland OW=Open woodland RA=Rainfed agriculture RV=Riverine vegetation

(+) indicates increase and (-) indicates decrease. Percentage is with respect to the land use/cover value in the preceding year.

Table 6 (d): Land use/cover change detection matrix for mountain foothills in Kilakala sub-catchment between 1964 and 2004

LU 1964	Changed to (as observed in 2004) (ha)					**Total (ha)**
	S	BG	OW	RA	RV	
S	15.6	0.0	0.0	0.0	0.0	15.6
BG	3.2	21.5	0.0	65.3	0.0	90.0
CW	1.3	0.0	0.0	0.0	0.0	1.3
OW	0.1	4.5	37.1	22.8	0.0	64.4
RA	3.5	0.0	0.0	83.3	0.0	86.8
RV	1.7	0.0	0.0	13.0	6.5	21.2
Total	**25.4**	**26.0**	**37.1**	**184.4**	**6.5**	**279.3**

Note: S=Built up area BG=Bushed grassland CW=Closed woodland OW=Open woodland RA=Rainfed agriculture RV=Riverine vegetation

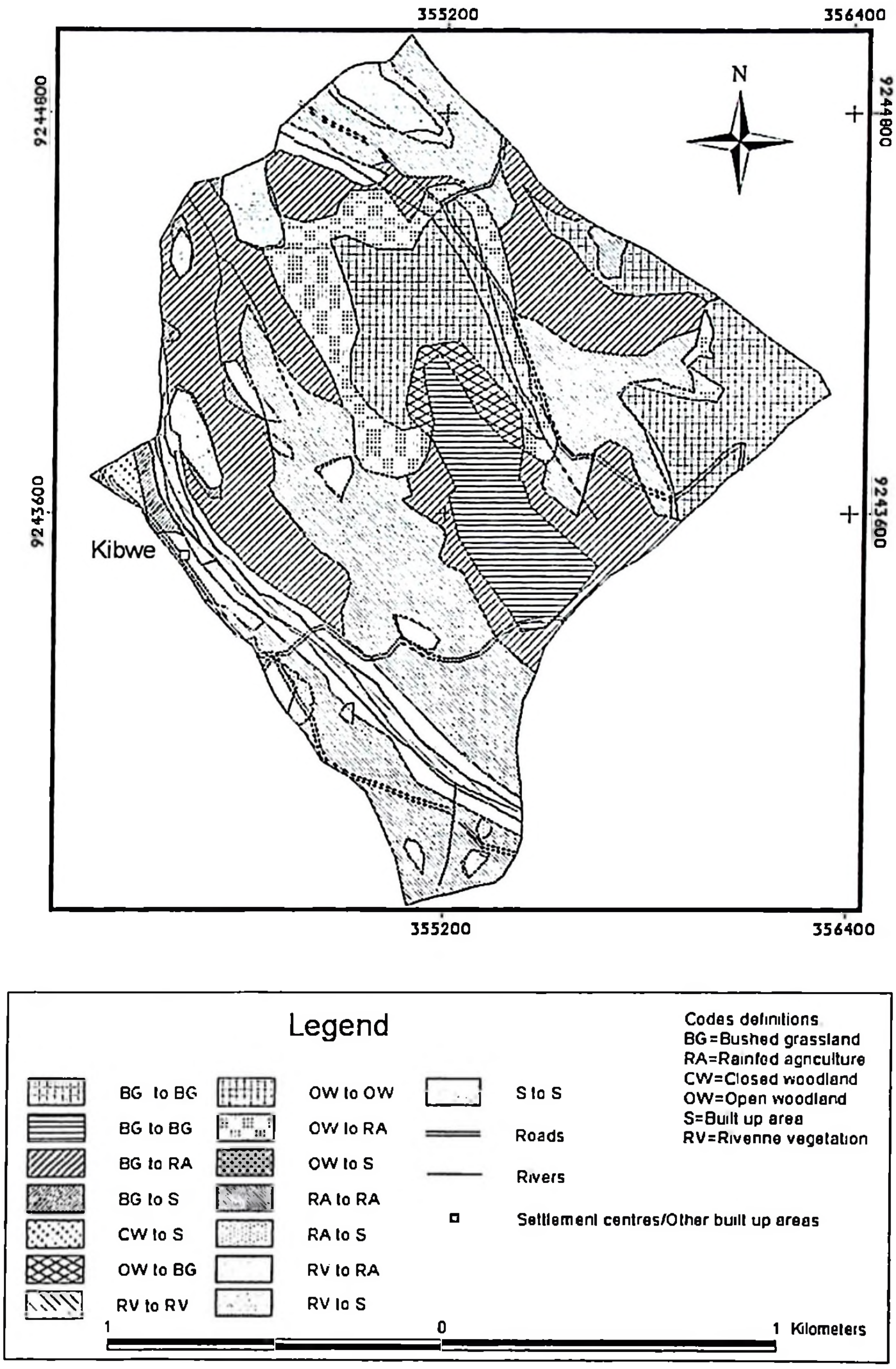

Figure 8 (b): Land use/cover change detection map for mountain foothills in Kilakala sub-catchment between 1964 and 2004

In the undulating plains land use/cover types have also experienced considerable transformations between 1964 and 2004. Built up area has been increasing tremendously at a rate of 5.2 ha per year equivalent to 3.6% per year. This increase was mainly due to expansion of urban built up area including settlements, industries and services such as colleges, schools, government offices and tourism. Population increase (URT, 2002) has also contributed greatly to settlement expansion (Table 10). Rainfed agriculture was decreasing at the rate of 3.0 ha per year equivalent to 2.2% per year for the similar reason. Bushed grassland and riverine vegetation were also decreasing whereas by 2004 sisal plantations had completely transformed to built up area (Table 6 (f)).

The results demonstrate that land use/cover in the catchment is highly dynamic with cultivation more intensive in the mountain ridges compared to the foothills and the foothills being more encroached by the rapid urban expansion in the undulating plains. In this situation natural vegetation is more replaced with cultivated and settlement areas. The replacement of natural vegetation with intensive annual crops production has clearly caused land degradation hence the need for appropriate land use plans.

Table 6 (e): Land use/cover changes for undulating plains in Kilakala sub-catchmentbetween 1964 and 2004

Geomorphic unit	Land use/cover	Period		
		1964-2004 (40 years)		
		Area (ha)	%	Rate (ha/yr)
Undulating plains	S	209.1	143.0	5.2
	BG	-46.7	-100.0	-1.2
	RA	-121.7	-89.6	-3.0
	RV	-35.3	-83.5	-0.9
	SP	-5.4	-100.0	-0.1

Note: S=Built up area BG=Bushed grassland RA=Rainfed agriculture RV=Riverine vegetation SP=Sisal plantation

(+) indicates increase and (-) indicates decrease. Percentage is with respect to the land use/cover value in the preceding year.

Table 6 (f): Land use/cover change detection matrix for undulating plains in Kilakala sub-catchment between 1964 and 2004

LU 1964	Changed to (as observed in 2004) (ha)			**Total (ha)**
	S	RA	RV	
S	146.2	0.0	0.0	146.2
BG	46.7	0.0	0.0	46.7
RA	121.7	14.1	0.0	135.8
RV	35.3	0.0	7.0	42.3
SP	5.4	0.0	0.0	5.4
Total	**355.3**	**14.1**	**7.0**	**376.4**

Note: S=Built up area BG=Bushed grassland RA=Rainfed agriculture RV=Riverine vegetation SP=Sisal plantation

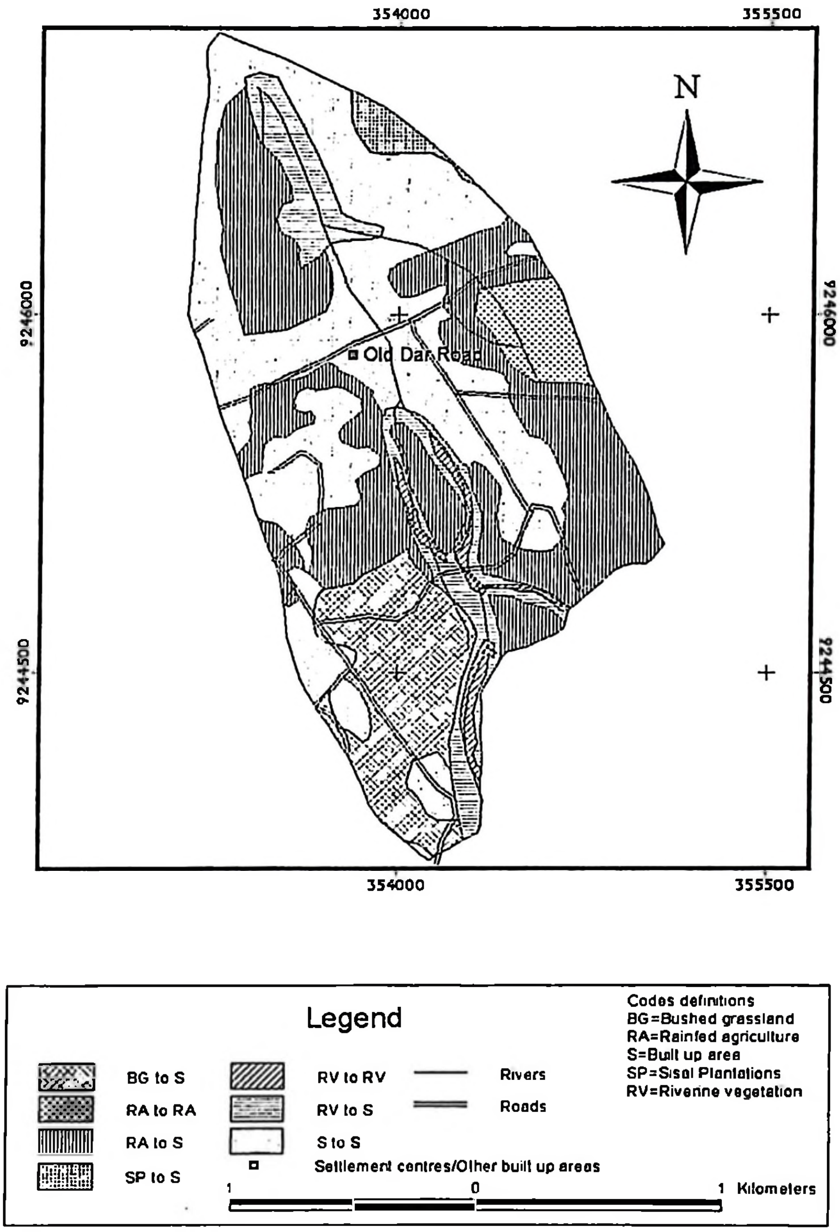

Figure 8 (c): Land use/cover change detection map for undulating plains in Kilakala sub-catchment between 1964 and 2004

4.3 Factors influencing land use/cover changes in the study area

4.3.1 Biophysical factors

4.3.1.1Geomorphic characteristics

Some selected geomorphic characteristics are presented in Table 7. The land use/cover pattern of the study area is closely related to geomorphic characteristics. Forest and irrigated and rainfed agriculture are mostly located in the mountain ridges at an altitude ranging from 800 m to 1800 m. Open woodland and scattered natural vegetation are located in the mountain foothills at an altitude ranging from 500 m to 900 m (Table 7). The undulating plains are mostly covered by built up area (urban settlement, industries and services such as offices, schools and colleges). Similar observations were made by Rapp *et al.* (1972) and Kimaro, (2003).

Table 7 and Figures 9, 10 and 11 show the drainage pattern and density of the studied sub-catchment in the study area. The Kikundi and Morogoro sub-catchments' mountain ridges are characterized by higher drainage density than the foothills. This has probably influenced more irrigation activities, mostly for vegetable production, in the mountain ridges than in the foothills despite the fact that vegetables are grown everywhere in the study area irrespective of the soil condition (Kimaro, 2003). However, in Kilakala sub-catchment there are farmers who are not practicing irrigated agriculture (Table 23) probably due water scarcity. About 10% of the mountain ridges are used for vegetable production like carrots, spinach, salads, onions, leaks, cabbages, celery and sprouting broccoli also as reported by Kimaro *et al.* (1999) and Kimaro (2003).

Vegetables are grown in this unit both during the rainy season and dry spells under furrow and drag horse sprinkler irrigation system. The higher mountain ridges are left fallow mainly during the high rainfall intensity especially in the month of April (Kimaro, 2003).

4.3.1.2 Soil characteristics

Some selected soil morphological and chemical characteristics are presented in Table 8. The studied soil characteristics are closely related to geomorphic characteristics of the studied area (Table 7) and hence the land use pattern. There is considerable spatial variation in soil depth, texture, drainage conditions and soil chemical properties (Table 8). The intensification of rainfed agriculture between 1964 and 2004 in the mountain ridges as compared to mountain foothills could be partly attributed to relatively favourable soil conditions and climate (Section 4.3.1.3). The relatively favourable soil texture and fertility in the mountain ridges compared to the soils on the other geomorphic units have favoured production of annual and seasonal crops such as maize, beans, bananas and vegetables in this unit.

Table 7: Geomorphic characteristics of the study area

Catchment Unit	Geomorphic characteristics				
	Geomorphic unit	Elevation (m)	Dominant slope (%)	Drainage density (km/km2	Relief intensity
Kikundi	Mountain ridges	800-1800	40-80	5.4	Residual hills and ridges, Rockfalls, Rockslides, Tallus slopes, Incision and V-shaped valleys
	Mountain foothills	500-900	30-50	4	Hillslopes and valley side gullies, Incision and V-shaped valleys
	Undulating plains	400-500	0-20	N/A	Undulating plains
Morogoro	Mountain ridges	800-1800	40-80	2.8	Residual hills and ridges, Rockfalls, Rockslides, Tallus slopes, Incision and V-shaped valleys
	Mountain foothills	500-900	30-50	2.6	Hillslopes and valley side gullies, incision and V-shaped valleys
	Undulating plains	400-500	0-20		Undulating plains and Flood plain
Kilakala	Mountain ridges	800-1800	40-80	3.5	Residual hills and ridges, Rockfalls, Rockslides, Tallus slopes, Incision and V-shaped valleys
	Mountain foothills	500-900	30-50	5.5	Hillslopes and valley side gullies, Incision and V-shape d valleys
	Undulating plains	400-500	0-20	N/A	Undulating plains

Note: N/A=Not applicable

Source: Kimaro (2003)

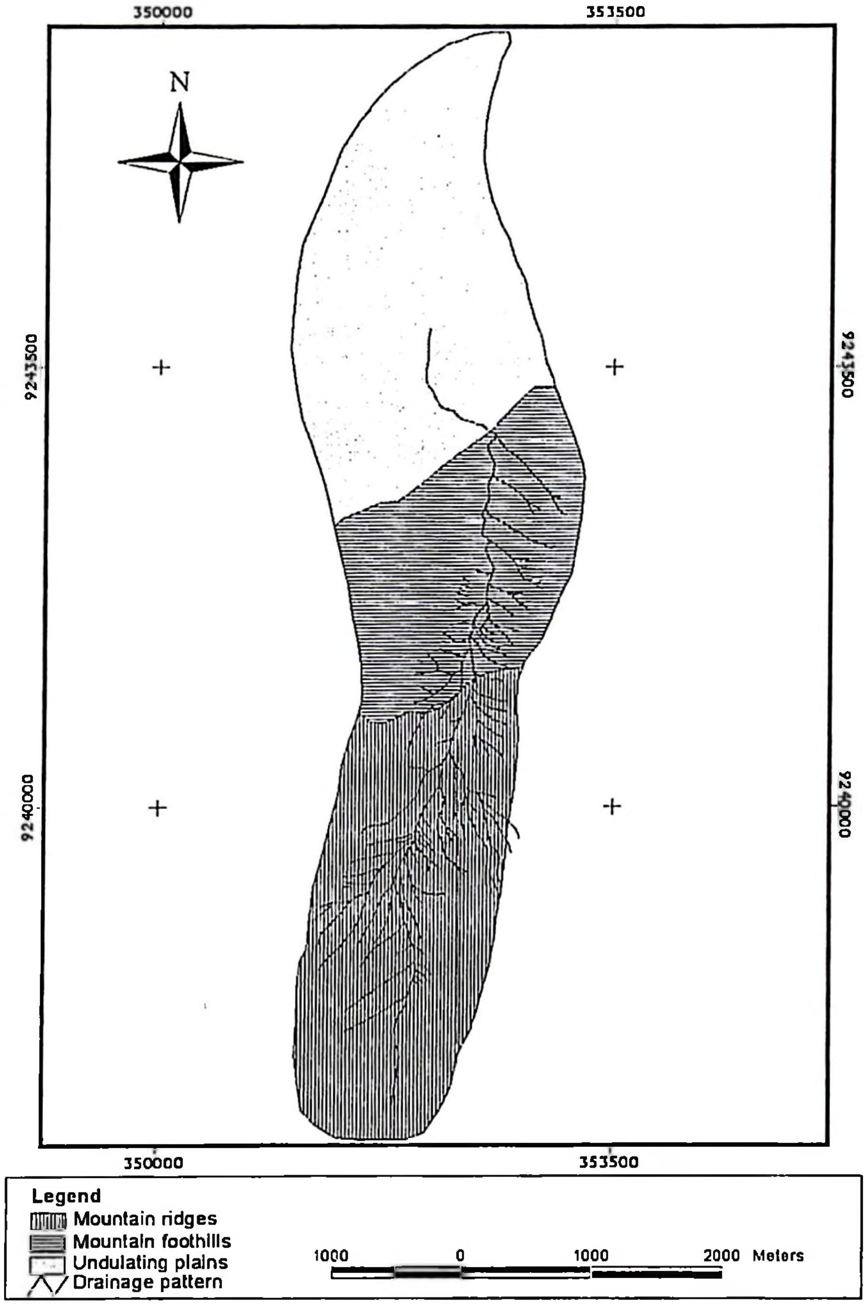

Figure 9: Drainage pattern of Kikundi sub-catchment

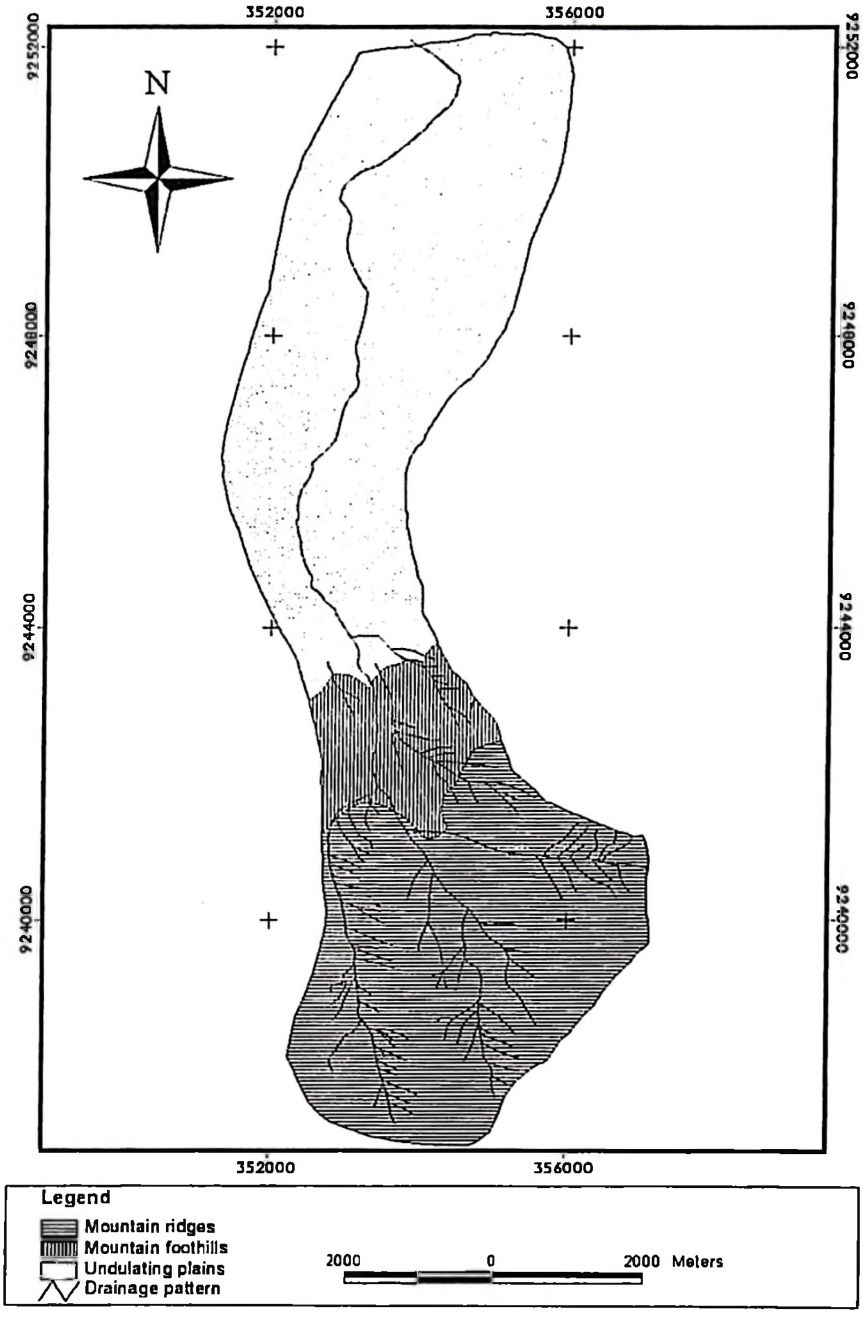

Figure 10: Drainage pattern Morogoro sub-catchment

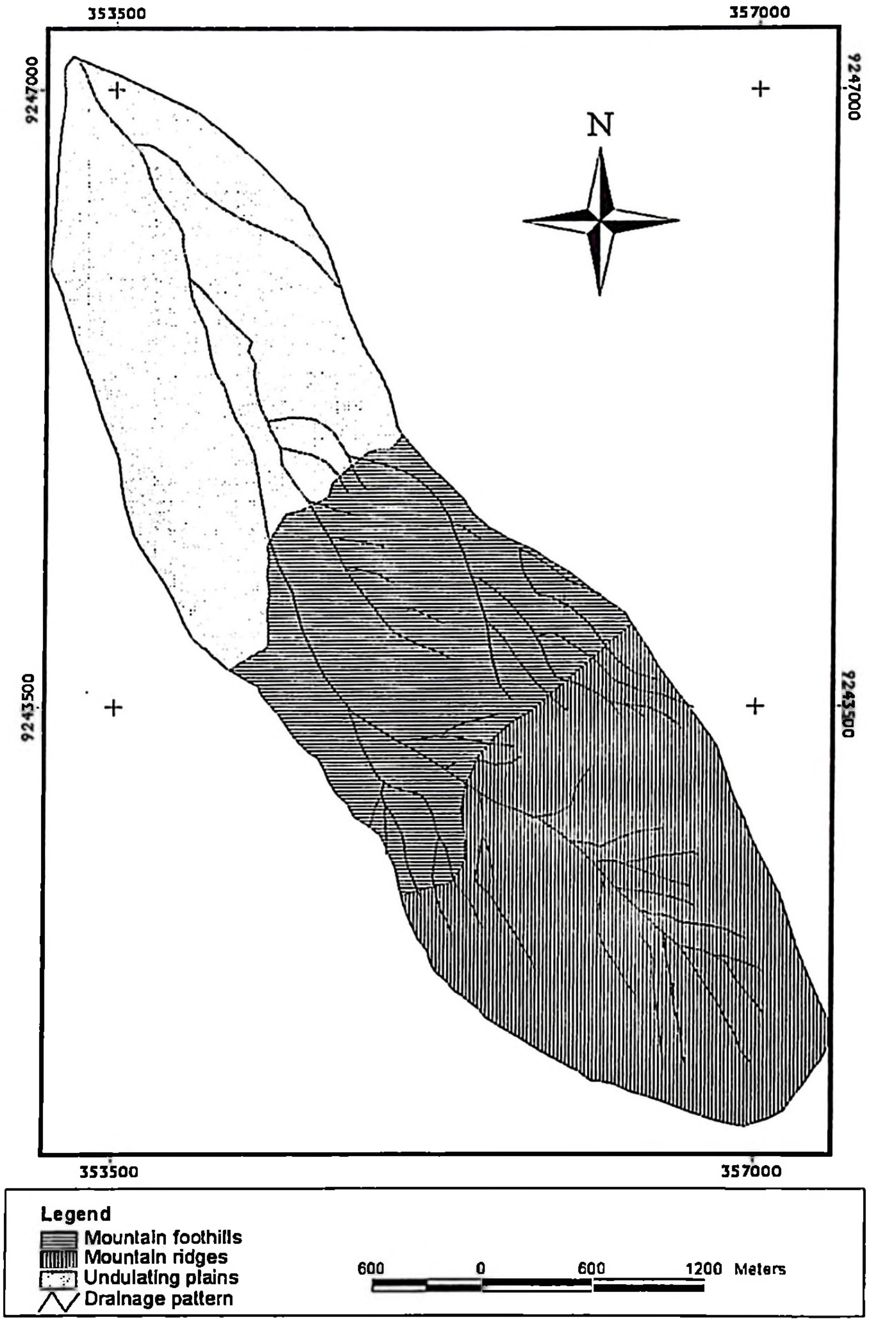

Figure 11: Drainage pattern Kilakala sub-catchment

Table 8: Soil properties for three geomorphic units in the study area

Geomorphic unit	Morphological characteristics	Chemical characteristics			Dominant soil type
		pH	Organic Carbon (OC%)	Available P (mg/Kg)	
Mountain ridges	Complex of shallow, excessively drained and moderately deep to deep well drained Sandy Clay Loams	Slightly acid to acid (pH= 5.1-6.0)	0.1 – 0.2	1.0 - 5.0	Orthieutric Cambisols, Orthieutric Regosols, Lithic Leptosols
Mountain foothills	Moderately deep to deep Sandy Clay	Medium to slightly acidic (pH=5.5-6.5)	0.5 -1.0	1.0 - 2.0	Chromic Lixisols and Profondic Acrisols
Undulating plains	Very deep, well drained Sandy Clay	Moderately acid (pH= 4.5 - 6.5)	0.3 - 0.7	1.2 - 1.8	Acrisols and Lixisols

Source: Msanya *et al.* (2001) and Kimaro (2003)

4.3.1.3 Rainfall pattern

Rainfall patterns of the mountain ridges, foothills and undulating plains in the study area are given in Table 9. The mean annual rainfall is closely related to altitude where higher altitudes receive more rain than lower altitudes. Mean annual rainfall of the mountain ridges is 1844 mm, while on the foothills is 1363 mm. These results show that the mountain ridges with an altitude ranging from 800 to 1800 m asl receive more rain compared to the foothills with an altitude ranging from 500 to 900 m asl. This rainfall pattern is related to the observed land use/cover patterns and their respective transformations. The spatial variation in the location of woodlands and rainforest at different altitudinal levels where forest class is in higher rainfall receiving geomorphic units indicates the relationship between land use/cover patterns and rainfall distribution. There are also more agricultural activities in the mountain ridges compared to the foothills.

Table 9: Rainfall distribution in the study area

Catchment unit	Geomorphic unit	Average annual rainfall (mm)
Kikundi	Mountain ridges	1841
	Mountain foothills	1268
	Undulating plains	1125
Morogoro	Mountain ridges	1853
	Mountain foothills	1268
	Undulating plains	1125
Kilakala	Mountain ridges	1840
	Mountain foothills	1553
	Undulating plains	1125

4.3.2 Socio-economic factors

4.3.2.1 Human population dynamics

Human population changes in the study area between 1964 and 2004 are presented in Table 10. The results show a spatial variation of population increase among sub-catchments and among geomorphic units of every sub-catchment. In the Kikundi sub-catchment the population has increased by average of about 311% (equivalent to about 8% annual growth) and in Morogoro sub-catchment the increase is about 395% (equivalent to 10% annual growth) whereas in Kilakala sub-catchment a lowest increase of about 48% (equivalent to 1.2% annual growth) was recorded. The observed high population increase in Morogoro sub-catchment compared to others could be attributed to recent tremendous advancement of settlements frontier towards the mountain foothills and lower parts of the undulating plains originally not occupied, as revealed in section (4.2.2), and the favourable conditions for agricultural production on its mountain ridges. The low population increase in the Kilakala sub-catchment could be due to outmigration of young people because of inadequate agricultural land on the sub-catchment's ridges and foothills. Kikundi sub-catchment undulating plain has demonstrated low population gowth may be due to its big area being occupied by government farms, offices, colleges and schools whereby the increase of residential houses in the period between 1964 and 2004 is minimal.

Generally, the results reveal an increase in population in the study area. The results reveal an increased population from 323% to 458% for Morogoro, 493 to 752% for Kikundi and 14% to 101% for Kilakala sub-catchments with an average annual growth rate of more than 10% which is far above the national average annual population growth rate of 2.9% (URT, 2002). The observed population dynamics has increased pressure on limited land resources including farm expansion, fuel wood requirements and degradation of natural vegetation.

Table 10: Human population changes in the study area

Catchment	Geomorphic unit	Population		Population change	
		1964	2004	Number	Percent
Morogoro	Mountain ridges	612	2 590	1 978	323.2
	Mountain foothills	328	1 656	1 328	404.9
	Undulating plains	13 226	73 789	60 563	458.0
Kikundi	Mountain ridges	300	698	398	132.7
	Mountain foothills	201	1713	1512	752.2
	Undulating plains	7 006	10 462	3 456	49.33
Kilakala	Mountain ridges	188	245	57	30.3
	Mountain foothills	516	587	71	13.8
	Undulating plains	4 572	9 182	4 618	101.0

The correlation matrix (Table 11) reveals the effect of population dynamics on land use/cover changes in the study area. Significant correlation was obtained between population density and built up area (r= 0.8406, p=0.0361) indicating the effect of high demographic growth in the intensification of ongoing land use changes which include the expansion of urban settlements, clearing of native woodland and intensification of agricultural land.

Table 11: Correlation matrix between population density and land use/cover dynamics for mountain ridges and foothills in the study area

	Pop	Settle	BG	CI	RV	WD
Pop	1.00000	0.84063	0.48398	0.64721	-0.18679	-0.44115
		0.0361	0.3307	0.1647	0.7231	0.3812
Settle	0.84063	1.00000	0.44473	0.40328	-0.39299	-0.22509
	*0.0361		0.3769	0.4279	0.4409	0.6681
BG	0.48398	0.44473	1.00000	0.15648	-0.49507	0.15897
	0.3307	0.3769		0.7672	0.3181	0.7636
CI	0.64721	0.40328	0.15648	1.00000	-0.00822	-0.72881
	0.1647	0.4279	0.7672		0.9877	0.1003
RV	-0.18679	-0.39299	-0.49507	-0.00822	1.00000	-0.63114
	0.7231	0.4409	0.3181	0.9877		0.179
WD	-0.44115	-0.22509	0.15897	-0.72881	-0.63114	1.00000
	0.3812	0.6681	0.7636	0.1003	0.179	

The Pearson correlation coefficient is given for each tabulation. The significance of each correlation is given below each coefficient.

* Significant at 5%

Note: BG = Bushed grassland decrease, Settle = Settlement area increase, pop = population density increase, CI = Cultivated fields increase, RV= Riverine vegetation decrease, WD = Wooded grassland decrease

4.3.2.2 Land tenure system

A customary land tenure system is practised in the area. Field observations showed intensive reduction of field sizes as a result of land fragmentation. About 75% of the respondents have land sizes ranging from 0.2 ha to 2.4 ha (Table 12). Land fragmentation in the studied sub-catchments could be due to high population growth and intensification in agricultural production. The results show that an average land allocated to production of crops such as bananas, vegetables, and maize was largest than fallow land or land under agroforestry.

Table 12: Distribution of farm sizes in the study area

Catchment	Farm size (hectares)	Frequency	Percent
Kikundi	0.2-1.2	15	32
	1.6-2.4	22	47
	2.8-3.6	6	13
	4-4.9	3	6
	5.3-6	1	2
	Total	47	100
Morogoro	0.2-1.2	16	32
	1.6-2.4	20	40
	2.8-3.6	8	16
	4-4.9	2	4
	5.3-6	3	6
	Above 6	1	2
	Total	50	100
Kilakala	0.2-1.2	21	68
	1.6-2.4	4	13
	2.8-3.6	6	19
	Total	31	100

4.3.2.3 Farming practices

Land fallowing practices

Table 13 (a) shows that about 60% of the respondents in the studied sub-catchments of Kikundi and Morogoro practise seasonal fallow. In Kilakala sub-catchment only about

30% of respondents practise land fallow (Table 13 (b)). Generally, in all sub-catchments majority (more than 70%) of those practising land fallowing practise seasonal fallow. As reported by Kimaro *et al.* (1999) only few crops such as maize, beans, sweet potato and cassava were grown in the study area before 1980.

Table 13 (a): Response to land fallow practice by household heads in the study area

Catchment	Land fallow practice	Frequency	Percent
Kikundi	Yes	29	61.7
	No	18	38.3
Morogoro	Yes	29	58.0
	No	21	42.0
Kilakala	Yes	9	29.0
	No	22	71.0

Table 13 (b): Land fallowing period by households in the study area

Catchment	Fallow period	Frequency	Percent
Kikundi	Seasonal	23	85.2
	One to two years	4	14.8
Morogoro	Seasonal	25	86.2
	One to two years	4	13.8
Kilakala	Seasonal	8	72.7
	One to two years	3	27.3

A common rotation was two to three years followed by a fallow period of three to four years. After 1980's the intensification of cropping system increased due to population pressure, land scarcity and expansion of nearby Morogoro municipality and Dar es Salaam city (Kimaro, 2003). Hence fallow cultivation and crop rotation were discouraged and continuous cultivation intensified. As a result the dominant fallow period in the study area is seasonal and continuous (less than three years) in some area.

Irrigated agriculture practice

Table 14 (a) shows that more than 50% of respondents in Kikundi and Morogoro sub-catchments practice irrigated agriculture. Irrigated agriculture is mainly practised during dry spells during cultivation of vegetables to meet the increased and growing demand of the increasing population in the nearby towns (Kimaro, 2003).

Table 14 (a): Proportion of farmers practising irrigated agriculture in the study area

Catchment	Response	Frequency	Percent
Kikundi	Yes	23	51.1
	No	22	48.9
Morogoro	Yes	26	52.0
	No	24	48.0
Kilakala	Yes	0	0.0
	No	31	100.0

Table 14 (b): Commencement of irrigated agriculture in the study area

Catchment	Time period	Frequency	Percent
Kikundi	1991 - 2004	20	95.2
	1981 - 1990	1	4.8
Morogoro	1991 - 2004	22	78.6
	1981 - 1990	5	17.8
	Before 1970	1	3.6

Table 14 (b) shows that more than 75% of the respondents for Kikundi and Morogoro sub-catchments have started irrigated agriculture between 1991 and 2004. These observations coincide very well with probable dates of occurrence of landslides associated with irrigated agriculture presented in Appendix D.

4.4 Influence of land use/cover dynamics on the occurrence of landslides

Landslides inventory for mountain ridges and foothills of the study area by 1964 and between 1964 and 2004 is presented in Table 15 and Appendix D. The spatial pattern showing landslide scars that occurred between 1964 and 2004 and their association to different land use/cover types in the same period is also presented in Figures 12, 13 and 14. The results show that the frequency of landslides in the mountain ridges is higher than in the mountain foothills for all sub-catchments. The results show that more than 75 % of historical (by 1964) landslides and 69 % of recent (between 1964 and 2004) landslides in Morogoro and Kikundi sub-catchments respectively occurred in the mountain ridges (Table 15). These results are in accordance with earlier study by Kimaro (2003) who reported less frequency occurrence of landslide in the mountain foothills than in the mountain ridges. Table 15 also reveals that in the period between 1964 to 2004 the frequency of landslides in the study area has increased by about 80% compared to the number observed by 1964 equivalent to 2% increase per year. This increase is probably due to increased agricultural activities including irrigation (Table 15 and Figures 12, 13 and 14).

Table 15: Landslide frequency by 1964 and between 1964 and 2004

Catchment	Geomorphic unit	Assoc to LU/C	Landslide number by 1964	Landslide number between1964 and 2004	Landslide frequency change
Morogoro	Mountain ridges	Rainfed agric	1	32	
		Irrigated agric	N/A	18	
		Other use/cover	25	15	
		Sub total	**26**	**65**	**39**
	Mountain foothills	Rainfed agric	2	8	
		Irrigated agric	N/A		
		Other use/cover	11	11	
		Sub total	**13**	**19**	**6**
Kikundi	Mountain ridges	Rainfed agric	4	21	
		Irrigated agric	N/A	4	
		Other use/cover	27	12	
		Sub total	**31**	**37**	**6**
	Mountain foothills	Rainfed agric	N/A	8	
		Irrigated agric	N/A	10	
		Other use/cover	6	7	
		Sub total	**6**	**25**	**19**
Kilakala	Mountain ridges	Rainfed agric	3	11	
		Irrigated agric	N/A	N/A	
		Other use/cover	6	0	
		Sub total	**9**	**11**	**2**
	Mountain foothills	Rainfed agric	5	9	
		Irrigated agric	N/A	N/A	
		Other use/cover	3	1	
		Sub total	**8**	**10**	**2**
Grand total			93	167	74

Note: LU/C= Land use/cover Assoc=Association N/A = Not applicable

Table 15 also reveals that in the foothills of Kikundi sub-catchment landslide frequency increase by 1964 and 1964 and 2004 is higher (more than 3 times) compared to the frequency increase in the mountain ridges. This could be due to the recent construction of the irrigation canal conveying water from the mountain ridge water sources to the foothills. This canal triggered 8 landslides which is about 30% of the total landslides occurred in Kikundi foothills in the recent years between 1964 and 2004 (Figure 15 and Table 15).

Influence of land use/cover change on the frequency of occurrence of landslides in the study area is presented in Table 17 and 18.

Table 16: Amount of some selected key land use/cover change classes influencing the occurrence of landslides in the study areas between 1964 and 2004

Catchment	Geoform	NLUC	VCD (ha)	CI	SI	WD	**Total (ha)**
Morogoro	MR	1054.9	22.1	650.4	10.3	1.4	1739.1
	MF	80.8	46.9	139.7	35.5	112.5	415.4
Kikundi	MR	110.5	5.2	338.3	4.3	3.5	461.8
	MF	44	11.5	145.0	13.2	106.0	319.7
Kilakala	MR	243.4	1.4	100.3	1.5	30.3	376.9
	MF	164.1	4.9	101.1	3.5	5.8	279.4

Note: NLUC=No land use change VCD=Vegetation cover decrease CI=Cultivated area increase SI=Built up area increase WD=Woody vegetation decrease MR=Mountain ridges MF=Mountain foothills

Significant correlations were observed between some selected land use/cover change categories and the changes on the occurrence of landslide in the mountain ridges. Comparatively, increase in rainfed and irrigated agriculture (cultivated fields) show a high correlation ($R = 0.999$, $P < 0.05$). These results could be explained by the effect of low soil stability due to cultivation frequency of annual crops and construction of irrigation canals on highly susceptible lands. Earlier studies (Munishi *et al.*, 1996; Temple and Rapp, 1972) reported that chances of occurrence of landslides due to soil disturbances and cultivation of annual crops in the study area is high because of the tight time schedule of farming activities and frequency of soil disturbance (Munishi *et al.*, 1998; Kimaro, 2003).

Table 17: Influence of land use/cover change on the occurrence of landslides in the mountain ridges of all studied sub-catchments

Land use/cover	Regression coefficients	Coefficient of determination (R^2)	Correlation coefficient (R)	Probability
NLUC	0.3356	0.278	0.527	0.6464
VCD	0.52036	0.972	0.986	0.1067
CI	0.76736	0.999	0.999	*0.0205
SI	0.75232	0.993	0.996	*0.0543
WD	-0.45967	0.992	0.996	0.0569

* Significant at 5%

Note: NLUC=No land use change VCD=Vegetation cover decrease CI=Cultivated area increase SI=Built up area increase WD=Woody vegetation decrease

From the results as discussed on land use/cover dynamics (Section 4.2) and increased pressure on the land due to population (Table 10), it is clear that the observed soil disturbance has increased soil instability and hence frequency of occurrence of landslides in this unit. (Vanacker, 2002) noted that with increasing deforestation, seepage forces become an important factor in inducing the development of landslides. Earlier study by Kimaro (2003) reported the association of irrigation canal with the frequency of occurrence of landslides. Similar observations are also reported in this study that high landslides frequency associated with irrigation canal could be attributed to subsurface seepage, piping through course pores and high overland flow from irrigation canals. Other studies (Larsen and Torres-Sanchez, 1998; Vanacker, 2002; Collins and Bras, 2004) observed that average frequency of landslides increased markedly as land use changed from forest to agriculture. Majority of landslides (47%) that occurred in Mgeta area, Tanzania in 1970, originated from cultivated fields and similar number from grassland (Temple and Rapp, 1972). Increase in built up areas has also showed a significant correlation with the frequency of occurrence of landslides. Urbanisation and road network development have been reported to destabilize hillslopes hence favoring the occurrence of landslides (Tubbs, 1975; Ahmad and McCalpin, 1999; Vanacker, 2002).

Table 18 shows the results of the influence of land use/cover dynamics on the occurrence of landslides in the mountain foothills. These results show that no significant correlation between frequency of landslide occurrence and land use/cover dynamics. This could be due to the landslide frequency increase in the foothills mostly caused by recently constructed irrigation canals (Figure 15) (Vanacker, 2002).

Table 18: Influence of land use/cover change on the occurrence of landslides in the mountain foothills of all three studied sub-catchments

Land use/cover	Reg coefficients	R2	Correlation coefficient	Probability
NLUC	-1.59258	0.945	0.972	0.1506
VCD	0.17905	0.036	0.189	0.8788
CI	4.42564	0.396	0.629	0.395
SI	0.37388	0.162	0.403	0.736
WD	0.47269	0.552	0.743	0.4673

Note: NLUC=No land use change VCD=Vegetation cover decrease CI=Cultivated area increase SI=Built up area increase WD=Woody vegetation decrease

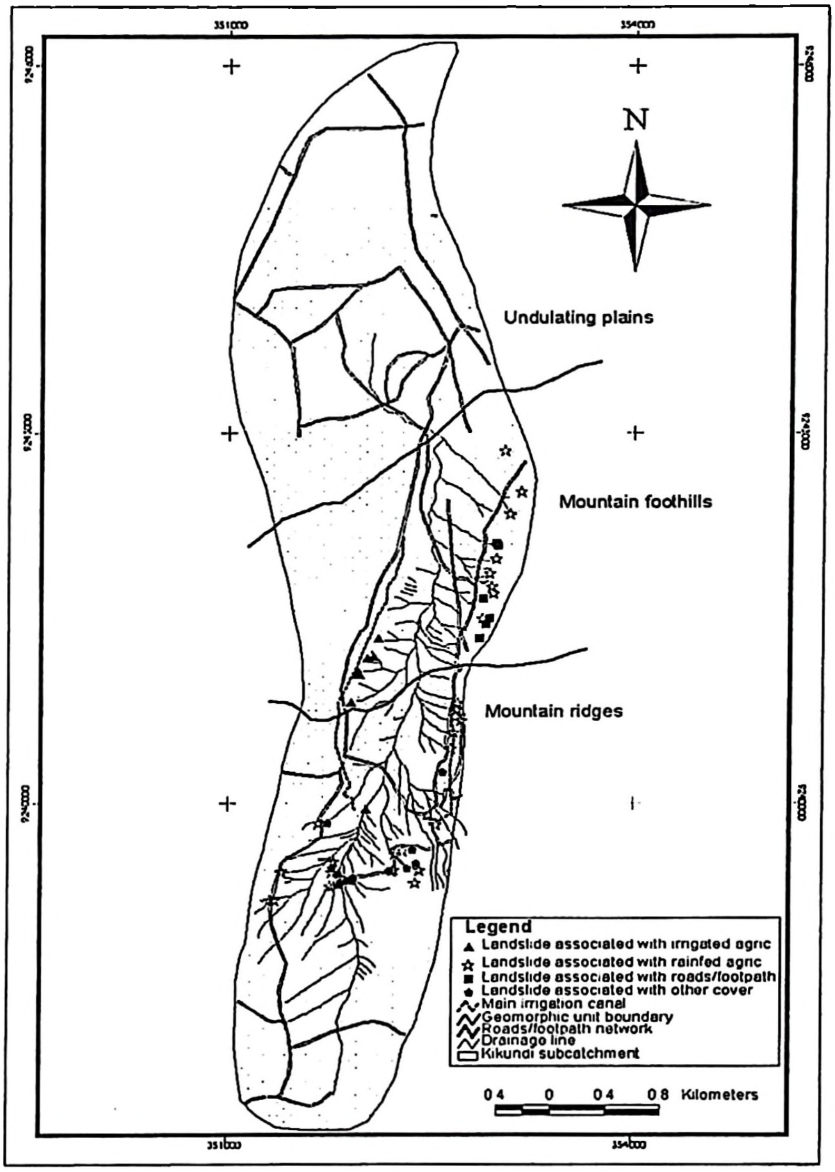

Figure 12: Kikundi sub-catchment geomorphic map showing spatial pattern of recent landslide scars associated with different land use/cover types

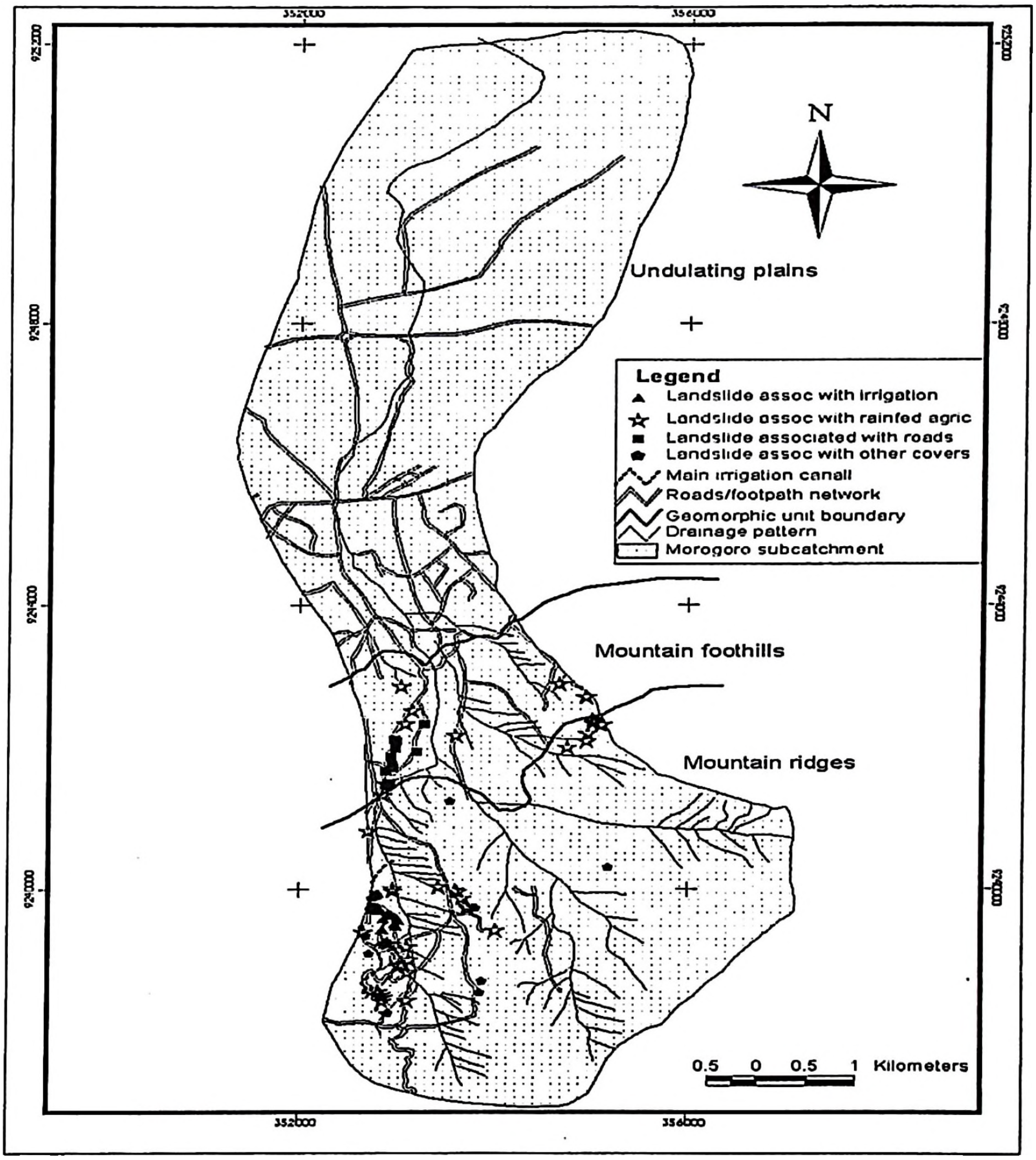

Figure 13: Morogoro sub-catchment geomorphic map showing spatial pattern of recent landslide scars associated with different land use/cover types

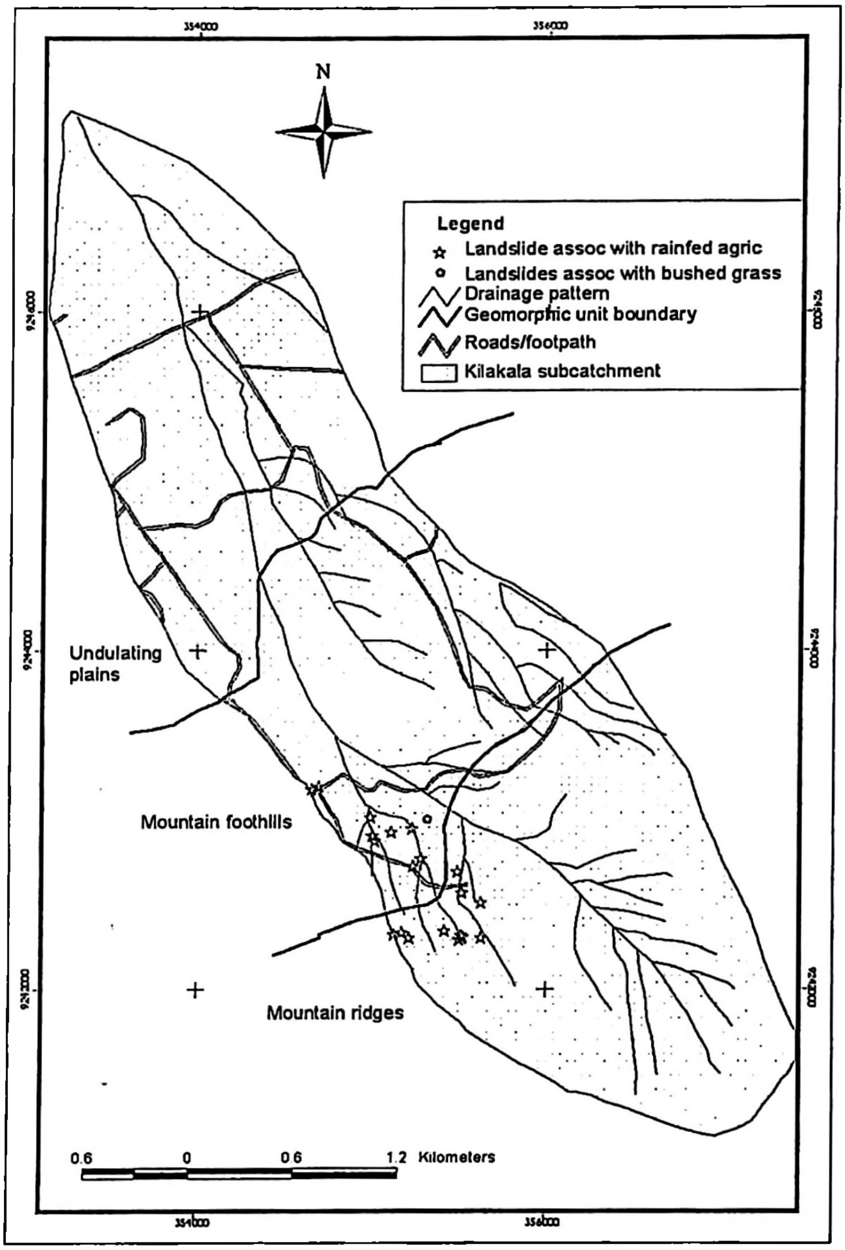

Figure 14: Kilakala sub-catchment geomorphic map showing spatial pattern of recent landslide scars associated with different land use/cover types

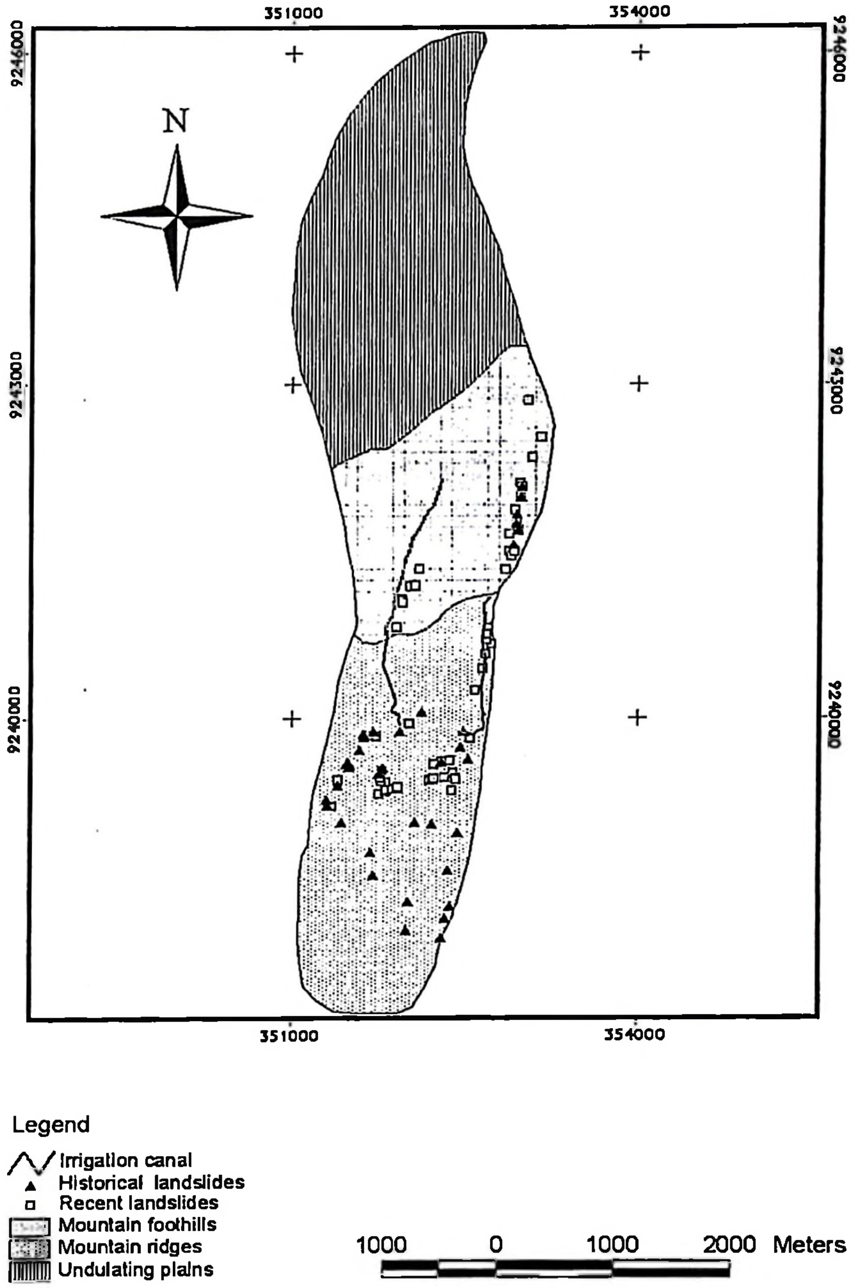

Figure 15: Landslide distribution maps for Kikundi sub-catchment

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

The study has demonstrated that significant relationship exit between land use/cover changes and the occurrence of landslides on the northern slopes of Uluguru Mountains, Tanzania. The change detection analysis between 1964 and 2004 has revealed that land use and land cover in the study area is highly dynamic. The land use/cover changes vary spatially along the landscape. Natural vegetation was increasingly being replaced by rainfed and irrigated agriculture and urbanisation in all the studied geomorphic units. Change to rainfed and irrigated agriculture is more intensive and 2-fold greater in the mountain ridges than in the mountain foothills. Urban expansion is very rapid in the undulating plains at a mean rate of about 15 ha per year compared to 2 ha per year in the mountain foothills. The mountain foothills are more encroached by the urban expansion at a mean rate of 2 ha per year than the mountain ridges with a mean rate of less than 1 ha per year.

Spatial variations of land use/cover distribution and changes observed in this study are greatly influenced by both biophysical and socio-economic factors. Geomorphic characteristics, soil properties and rainfall pattern are key biophysical factors while human population dynamics; land tenure system and farming practices are the most important socio-economic drivers.

The results of this study demonstrate that land use/cover dynamics greatly influence the occurrence and frequency of landslides. Increase in rainfed and irrigated agriculture on the unstable lands of the mountain ridges is responsible for the higher frequency of landslides compared to the other geomorphic units. The frequency of landslides associated with both rainfed and irrigated agriculture on the mountain ridges is at least 3-fold that of the foothills.

The observed land use/cover dynamics and their relationship with the occurrence and frequency of landslide calls for further research on the effectiveness of different land use options on landslide rehabilitation in the study area. Soil and water conservation measures such as agroforestry techniques, relevant cropping systems and proper management of irrigation earth canals for rehabilitation of landslides particularly in the mountain ridges ought to be given high priority.

Farmers should be sensitised on the severity and influence of land use changes on land degradation and the importance of appropriate soil and water conservation measures to mitigate landslides hazards in the study area. This will require a multidisplinary and participatory approach where various stakeholders including land users (beneficiaries), extensionists, researchers and politicians are fully involved.

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APPENDICES

Appendix A: Household Questionuaire for Socio-Economic Data and Landslides Information

Questionnaire number……………………
Date of interview …………………………
Ward………………………………………
Village……………………………………
GPS Coordinates: X…………………… Y:……………

1.0 Background information

1.1 Name of respondent (head of household)……………………………………
1.2 Sex of respondent…………………………………………………………
1. Male 2. Female.

1.3 Age………………. years.
1.4 Marital status……………
1. Single 2. Married 3. Divorced 4. Widowed 5. Other (specify)……….

1.5 Tribe……………………………………………………………………
1.6 Place of birth……………………………………………………………
1.7 Years of residence in this village………………………………………
1.8 Place of usual residence…………………………………………………

1.9 Did you shift to this village?……………………………………………
1. Yes 2. No

1.10 If yes in 1.9, what are the reasons for shifting…………………………
1. Land availability 2. Inheritance of land 3. Farming 4. Residential housing

1.11 What is your main occupation?…………………………………………..
1. Farming 2. Business man/woman 3. Teacher 4. Politician 5. Government worker 6.No occupation 7.Charcoal 8. Other (Specify) ………………….

If main occupation is charcoal where do you get raw materials…………………

1.12 Wealth category...

1 = Rich 2 = Intermediate 3 = Poor

(From the wealth category database by key informants)

1.13 Household composition (number)

Category	Members (number)	How many contribute Off/On farm work?
Adults		
Male	....	....
Female	....	....
Children		
Male	....	....
Female	....	....
Dependants		
Male	....	....
Female	....	....
Total	....	....

1.14 What is your belief (religion)? ....

1. Pagan 2. Catholic 3. Lutheran 4. Pentecost 5. Moravian 6. Islamic
7. SDA 8. Other (specify)...

2.0 Farmer's socio-economic status

2.1 What is your highest level of education?..

1.No formal education

2. Adult education

3. Primary education

4. Secondary

5.College.

6.Other (specify)...

2.2 What is your social position?.......................... ....

1.Peasant/small scale farmer

2.Political leader

3.Traditional leader

4. Employee (specify)...

2.3 What is the major source of your income?..

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

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

2.5 What is your average monthly income from off-farm (TAS)?...............

3.0 Land use and land tenure

3.1 Does your household own land for agricultural use?........................

1. Yes 2. No

3.2 If 2.1 is yes, how did you acquire the land?..................................

1. Purchased 2. Rented 3. Inherited 4. Both 1&3 5. Both 2&3

6. Others (specify)..

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

3.4 How large is your land area (acres)?..

3.5 How large is your cultivated fields (acres) and how far is each field from home?...................................

Field No.	Size (acre)	Distance from homestead (km)
1.		
2.		
3.		
4.		
5.		
6.		

3.7 How many acres do you cultivate every season (total)?............................

3.8 For how long have you been cultivating those acres?...............................

3.9 What type of land use system do you practice?.......................................

1. Irrigated agriculture 2. Rain-fed agriculture 3. Both 1 & 2

3.10 If irrigated agriculture in 3.9 or both which type: ....

1. Surface 2. Overhead 3. Both 1 & 2

Do you perceive the problem of soil erosion (landslide) around your irrigated field?..

1. Yes 2. No

If yes, how many and when did they occur?.......................................

No.	Slide type : Geoform	Coordinate X : Y	Year of occurrence	Distance to canal (m)
1.	:	:		
2.	:	:		
3.	:	:		
4.	:	:		

3.11 Which cropping system(s) do you practice?..............................

1. Crop rotation 2. Intercropping 3. Agroforestry 4. Monocropping 5. Other (Specify)...

3.12 Do you practice land fallow?...

1. Yes 2. No

3.13 If yes in 3.12, how many years do you allow your field to fallow?........................

1. One 2. Two 3. Seasonal 4. Zero 5. Other (Specify).....................................

3.14 Have you abandoned any farm?..

1. Yes 2. No

3.15 If yes, Why?...

3.16 Do you keep any livestock?...

1.Yes 2. No

3.17 If yes in 3.13, which type, breed, quantity and feeding system?............................

Type of Livestock	No. Kept	Year When Started To raise	Livestock feeding System 1=zero grazing 2=private pastures 3=communal pastures 4=on farm land	Breed 1=local 2=pure 3=cross
Cattle				
Goats				
Sheep				
Donkeys				
Rabbits				
Chicken				
Ducks				
Others (specify)				

3.15Do you access any extension services?...

1.Yes 2. No

3.16 Is your land/farm adequate?...

1.Yes 2. No

3.17 If not what are your plans?...

3.18 Are you planning to change the present land use?..

1.Yes 2. No

3.19 If yes in 3.18, what kind of land use do you envisage? and why?

Kind of land use	Reason

3.20 How is the trend of cultivated land in the village?...

1. Increasing 2. Decreasing 3. Same

3.21 Do you plan to expand your farm?...

1. Yes 2. No

3.22 If yes in 3.21, 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)...............................

4 Household assets and energy supply

4.1 Do you own this house or rent?...

1. Own 2. Rent

4.2 What are the materials used to build your house

Item	Value	Response
House construction material		
Walls	1=cement block 2=burnt bricks 3=unburnt bricks 4=poles+mud 5=mud 6=grass/straw 7=stones	
Roof	1=corugat fe sheet 2=tiles 3=grass/straw 4=straw+mud 5=others	
Floor	1=cement 2=earth 3=others (specify)	

4.3 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)..

4.4 What is your primary source of fuel for your household

Item	Value	Response
Source of energy for cooking and lighting	1=electricity 2=charcoal 3=wood 4=kerosene 5=others 9specify)	
If 2 and 3 where do you normally get it	1=cutting trees 2=collecting dried straws and trees 3=others (specify)	

4.5 Do you face any fuel problem?..

1. Yes 2. No

4.7 If yes in 3.2, what measures are you taking to solve the problem? (1) Private tree planting. (2). Agroforestly. (3). No measure taken. (4). Other (Specify) ....

4.8 Where do you get your firewood from?.............km.

4.9 Where do you get your water from?.................km.

5.0 Employment and cash income

5.1 Do you have access to village/local market to sell your produce?..........................

1. Yes 2. No

5.2 If yes in 6.1, how far is your homestead to the village/local market (in km)...............

5.3 Do you have access to the town market to sell your produce?....................... ....

1 . Yes 2. No

5.4 If Yes in 6.3 above, how far is your homestead to the town market (in km)..............

6. Soil conservation

6.1 Do you percieve problem of soil erosion on your field?......................................

1. Yes 2. No

6.2. Yes hat features lead you to believe that such problem exists?

1.. 3...................................

2.. 4.................................

6.3 What kind of erosion..

1. Landslides 2. Rill/Interill erosion 3. Gully erosion

4. Other (specify)..

6.4 Do you take some measures or practices to control soil erosion?...........

1. Yes 2. No

6.5 If Yes, which of the following measures do you take?.......................

1. Apply fertilizers (N/P/K/Manure/Lime) 2.Mulching

3. Terracing 4. Contour tillage 5. fanya juu 6. Crop residue 7. Crop rotation

8.Agroforestry 9. Others (specify)..

7.0 Other farm and homestead characteristics

7.1 Do you have credit?..

1. Yes 2. No

7.2 If yes in 7.1: Purpose..

Conditions..

Sources: 1.Bank 2.Co-operative 3.Family 4.Middleman: ....

7.3 How much do you spend on food monthly (TAS)?..

7.4 How far is your household to the village main road (km)?..................................

7.5 Do you have recently extended farmlands?..

1. Yes 2. No

7.6 If yes in 7.5, how many acres?..

7.7 Do you use any improved seed variety?..

1. Yes 2. No

7.8 What is the number of your land parcels?..

7.9 What is the sizes of those land parcels (acres)?..

8.0 What is the distribution of total farm sizes (acres)..

1. 0 - 3. 2. 3 – 6 3. 9 – 12 4. 12 – 15 5. 15 and above

8.0 Irrigated agriculture activities

8.1 Do you irrigate some of your farms?...

1. Yes. 2. No.

8.2 If Yes in 8.1, What is the size of your irrigated field (acre)..................................

8.3 What is the type of irrigation do you practise?..

1. Drag hose sprinkler irrigation 2. Using watering cane. 3. Surface irrigation 4. Both 1 and 2 5. Both 1 and 3.

8.4 When did you start irrigation (year)...

8. 5 When was the irrigation canal conveying water to your farm(s) constructed?............

8.6 What are the materials used to construct the canal?..

1. Earth 2. Lined with cement/nylon materials 3. PVC pipes 4. Both 1 and 2.

8.7 What is the distance from the canal to the farm (m)..

8.8 What type of crops do you irrigate?...

8.9 What were the land use/cover of your irrigated plot(s) before starting irrigation...

8.10 Do you perceive any landslide problems in your irrigated fields?..........................

1. Yes 2. No

8.11 If yes, in 8.10 when did the landslide(s) occur (year)..

8.12 What are the problems you face in irrigated agriculture?...................................

8.13 Is there any landslide problem(s) in your neighbors irrigated farms?.....................

1. Yes 2. No

8.14 If yes in 8.13, what is the distance from your neghbours farm to the irrigation canal (m)?...

8.15 Why did you decide to irrigate?..

1. Unreliable rainfall 2. To increase crop production 3. To start vegetable production. 4. Adviced by a friend/groups/government

8.16 Does irrigation canal cause landslide?...

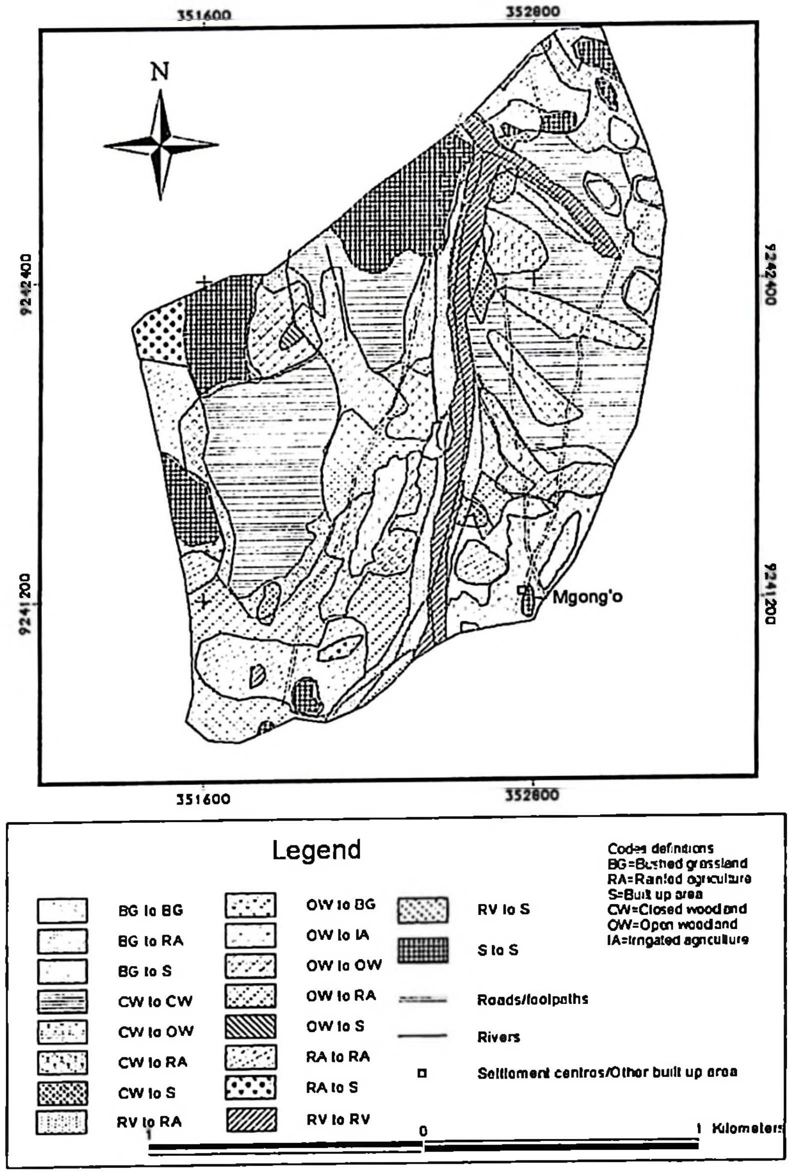
1. Yes 2. No 3. I don't know

Appendix B: Kikuudi mountain foothills change detection matrix for the 1977-1992 scenario

LU 1977	Changed to (as observed in 1992) (ha)							TOTAL (ha)
	S	BG	CW	OW	RA	RV	IA	
S	29.3	0.0	0.0	0.0	0.0	0.0	0.0	29.3
BG	1.8	10.4	0.0	0.0	4.2	0.0	0.0	16.3
CW	5.5	0.0	82.2	8.7	40.3	0.0	0.0	136.8
OW	1.3	0.2	0.0	22.1	34.1	0.0	3.9	61.7
RA	8.8	0.0	0.0	0.0	30.9	0.0	0.0	39.7
RV	2.7	0.0	0.0	0.0	14.3	18.4	0.0	35.4
TOTAL	**49.5**	**10.6**	**82.2**	**30.9**	**123.8**	**18.4**	**3.9**	**319.2**

Note: S=Built up area BG=Bushed grassland CW=Closed woodland OW=Open woodland RA=Rainfed agriculture RV=Riverine vegetation

Appendix C: Land use/cover change detection map for mountain foothills in Kikundi sub-catchment between 1977 and 1992



Appendix D: Landslide inventory

Appendix D1: Morogoro sub-catchment Mountain ridges landslide after 1964

SN	X COORDINA	Y COORDINA	YEAR	TYPOLOGY	ASSOC TO LU/COVER
1	352803	9239924	2005	Debris	Irrigated agriculture
2	352795	9239910	2003	Debris	Irrigated agriculture
3	352776	9239896	2003	Debris	Irrigated agriculture
4	352930	9239652	1998	Debris	Irrigated agriculture
5	352970	9239624	2004	Debris	Irrigated agriculture
6	353029	9239586	1998	Debris	Irrigated agriculture
7	353034	9239550	1998	Debris	Irrigated agriculture
8	353000	9239508	1998	Debris	Irrigated agriculture
9	353018	9239468	2000	Debris	Irrigated agriculture
10	353129	9239180	2003	Debris	Rainfed agriculture
11	352932	9239224	1998	Debris	Rainfed agriculture
12	352907	9239254	1998	Debris	Irrigated agriculture
13	353049	9238908	1994	Debris	Rainfed agriculture
14	352878	9239426	2004	Debris	Irrigated agriculture
15	352888	9239574	2003	Debris	Irrigated/Roadside
16	352837	9239686	1980	debris	irrigated/Roadside
17	352839	9239726	2005	Debris	Irrigated agriculture
18	352761	9239788	2003	Debris	Irrigated/Roadside
19	353083	9238920	2003	Debris	Rainfed agriculture
20	353153	9238990	2005	Debris	Rainfed agriculture
21	353145	9238822	2005	Debris	Rainfed agriculture
22	353132	9238424	1998	Debris	Rainfed agriculture
23	352877	9238414	2005	Debris	Rainfed agriculture
24	352933	9238246	1983	Deep	Woodland
25	352886	9238468	1999	Debris	Rainfed agriculture
26	352752	9239694	2005	Debris	Built up area
27	353571	9241236	2002	Debris	Grass fallow
28	354048	9239408	2004	Debris	Rainfed agriculture
29	352744	9240668	2004	Rotational	Bushed grassland
30	352977	9240006	2000	Debris	Rainfed agriculture
31	352981	9239974	2005	Debris	Rainfed agriculture
32	352812	9239932	2003	Debris	Irrigated agriculture
33	352832	9239938	Recent	Debris	Irrigated agriculture
34	352731	9239074	2004	Rotational	Roadside
35	352704	9239332	2005	Debris	Settlement
36	352684	9239394	2005	Rotational	Rainfed agriculture
37	352749	9239698	2005	Debris	Settlement

SN	X_COORDINA	Y_COORDINA	YEAR	TYPOLOGY	ASSOC TO LU/COVER
38	355115	9242310	1998	Debris	Rainfed agriculture
39	355136	9242322	2001	Debris	Rainfed agriculture
40	352731	9239074	2004	Rotational	Grassland
41	352704	9239332	2005	Debris	Settlement
42	352684	9239394	2005	Rotational	Rainfed agriculture
43	352863	9238506	2005	Debris	Rainfed agriculture
44	352840	9238552	1998	Debris	Rainfed agriculture
45	352827	9238556	2005	Debris	Rainfed agriculture
46	352769	9238552	2005	Debris	Rainfed agriculture
47	355193	9240292	1983	Debris	Woodland
48	352719	9240812	2000	debris	Cultivated/Roads
49	352871	9241328	1997	debris	Cultivated/Roads
50	353450	9240026	1970S	debris	Rainfed agriculture
51	353625	9239976	1970S	debris	Rainfed agriculture
52	353653	9239956	1980S	debris	Rainfed agriculture
53	353701	9239870	1970S	debris	Rainfed agriculture
54	353758	9239760	1970S	debris	Rainfed agriculture
55	353774	9239724	1980S	debris	Rainfed agriculture
56	353834	9239724	1980S	debris	Grass fallow
57	352832	9239938	1970S	debris	Irrigated agriculture
58	355039	9242392	1980s	debris	Rainfed agriculture
59	355054	9242354	1970s	debris	Rainfed agriculture
60	355034	9242352	1980s	debris	Rainfed agriculture
61	354775	9242004	1970	debris	Rainfed agriculture
62	354977	9242094	1980s	debris	Rainfed agriculture
63	354990	9242194	1980s	debris	Rainfed agriculture
64	353880	9238533	1970s	Rockfalls	Rock outcrop
65	353912	9238690	1970s	Rockfalls	Rock outcrop

Appendix D2: Morogoro mountain ridges landslides by 1964

SN	X COORDINA	Y COORDINA	YEAR	PREVIUS LU	TYPOLOGY
1	352870	9239740	Histor	Bushed grass	Amph
2	353084	9239208	Histor	Bushland	Rockfall
3	352961	9239050	Histor	Grassland	Debris
4	353050	9239084	Histor	Grassland	Rockfall
5	353073	9238982	Histor	Grassland	Debris
6	353198	9238888	1930	Bushed grass	Rockfall
7	352774	9239630	Histor	Bushed grass	Debris
8	352807	9239649	Histor	Grassland	Rotational
9	352806	9239656	Histor	Grassland	Rotational
10	352811	9239614	Histor	Rocky	Rockfall
11	353135	9240414	1952	Cultivated	Rotational
12	353060	9240328	Histor	Grassland	Debris
13	353070	9240320	Histor	Grassland	Debris
14	353016	9239952	Histor	Grass	Debris
15	352874	9239864	Histor	Grass	Rotational
16	353412	9240018	Histor	Prob Grass	Debris
17	353497	9240437	histor	Rock outcrop	rockfall
18	353893	9240368	histor	Rock outcrop	rockfall
19	354138	9239664	histor	Rock outcrop	rockfall
20	352586	9238414	histor	Rock outcrop	rockfall
21	352642	9238659	histor	Rock outcrop	rockfall
22	352378	9238646	histor	Rock outcrop	rockfall
23	353893	9238929	histor	Rock outcrop	rockfall
24	353560	9239180	histor	Rock outcrop	rockfall
25	353321	9239268	histor	Rock outcrop	rockfall
26	353685	9239689	histor	Rock outcrop	rockfall

Appendix D3: Morogoro mountain foothills landslides after 1964

SN	X COORDINA	Y COORDINA	YEAR	TYPOLOGY	ASSOC TO LU/COVER
1	353629	9242176	2000	Debris	Cultivation/Road
2	352900	9241494	1994	Rotational	Cultivation/Road
3	353058	9242854	1990	Debris	Rainfed agriculture
4	354967	9242710	1960s	debris	Rainfed agriculture
5	354694	9242896	1970	rotational	Rainfed agriculture
6	354971	9242708	2003	Debris	Rainfed agriculture
7	353180	9242524	2000	debris	Cultivation/Road
8	353102	9242341	2000	debris	Cultivation/Road
9	352991	9242101	2005	debris	Roadside
10	353010	9242079	2000	debris	Roadside
11	353001	9241978	2000	debris	Roadside
12	352953	9241860	2000	debris	Roadside
13	352980	9241694	2000	debris	Roadside
14	352917	9241446	2000	debris	Roadside
15	352946	9241489	2000	debris	Roadside
16	353229	9241932	1990	debris	Roadside
17	353307	9242329	2005	debris	Roadside
18	352900	9241650	2000	debris	Roadside
19	352965	9241748	1980	debris	Roadside

Appendix D4: Morogoro mountain foothills landslides by 1964

SN	X_COORDINA	Y_COORDINA	YEAR	PREVIUS_LU	TYPOLOGY
1	355050	9242488	1950	Grass	Debris
2	353726	9242374	1947	Cultivated	Debris
3	354967	9242710	1960s	Cultivated	debris
4	354772	9242745	Histor	Bushed grass	Debris
5	353250	9242054	histor	Rock outcrop	rockfall
6	353225	9242090	histor	Rock outcrop	rockfall
7	353226	9241941	histor	Rock outcrop	rockfall
8	352937	9241553	histor	not known	debris
9	352979	9241687	histor	not known	debris
10	352961	9241746	histor	not known	debris
11	352966	9241826	histor	not known	debris
12	353006	9241990	histor	not known	debris
13	353007	9242080	histor	not known	debris

Appendix D5: Kikundi mountain ridges landslides after 1964

SN	X COORDINA	Y COORDINA	YEAR	TYPOLOGY	ASSOC TO LU/COVER
1	352034	9239954	2005	Debris	Irrigated agriculture
2	352566	9239824	2005	Debris	Rainfed agriculture
3	352744	9240668	2004	Rotational	Rainfed agriculture
4	352608	9240250	2005	Debris	Roadside
5	352705	9240706	2004	Debris	Cultivated/Settlement
6	352412	9239512	2005	Debris	Settlement/Roads
7	352410	9239360	1995	Debris	Rainfed agriculture
8	352433	9239464	2000	Debris	Rainfed agriculture
9	352443	9239460	2005	Debris	Rainfed agriculture
10	351746	9239838	2005	Debris	Fallow/Roadside
11	351405	9239442	2005	Debris	Rainfed agriculture
12	351409	9239460	2003	Debris	Rainfed agriculture
13	351321	9239218	1980	Rotational	Rainfed agriculture
14	351359	9239214	1985	Debris	Rainfed agriculture
15	351799	9239530	2005	Debris	Rainfed agriculture
16	351771	9239328	2003	Debris	Rainfed agriculture
17	351832	9239346	1998	Debris	Irrigated agriculture
18	351841	9239364	1998	Debris	Irrigated agriculture
19	351883	9239374	1998	Debris	Irrigated agriculture
20	351935	9239372	1995	Rotational	Sugar fallow
21	351931	9239386	1995	Rotational	Sugar fallow
22	351940	9239392	1995	Rotational	Sugar fallow
23	352210	9239452	1998	Debris	Bushed grassland
24	352234	9239454	1998	Debris	Rainfed agriculture
25	352251	9239464	1998	debris	Rainfed agriculture
26	352342	9239472	2005	debris	Roadside
27	352387	9239620	2005	debris	Settlement/Roads
28	352314	9239616	1980	rotational	Rainfed agriculture
29	352252	9239590	1998	Debris	Rainfed agriculture
30	351831	9239436	1998	Debris	Irrigated agriculture
31	351787	9239442	2003	Debris	Rainfed agriculture
32	351778	9239472	2004	Debris	Grass fallow
33	352719	9240812	2000	debris	Cultivated/Settl
34	352673	9240441	2000	rockfall	Rainfed agriculture
35	352693	9240570	1998	debris	Rainfed agriculture
36	352709	9240757	1980	debris	Cultivated/Settlement
37	351682	9239842	1970s	debris	Rainfed agriculture

Appendix D6: Kikundi mountain ridges landslides by 1964

SN	X_COORDINA	Y_COORDINA	YEAR	PREVIUS_LU	TYPOLOGY
1	352482	9239744	1947	Cultivated	Rock/debri
2	352546	9239642	Histor	Grass	Rotational
3	352505	9239890	Histor	Grassland	Amph
4	351951	9239890	Histor	Grassland	Rotational
5	352139	9240062	Histor	Bushed grass	Debris
6	351641	9239840	Histor	Grass	Debris
7	351724	9239884	Histor	Grass	Debris
8	351630	9239860	Histor	Grass	Debris
9	351482	9239594	Histor	Grassland	Rotational
10	351505	9239574	Histor	Grassland	Big rotati
11	351519	9239586	Histor	Grassland	Debris
12	351496	9239614	Histor	Grassland	Big rotati
13	351405	9239408	Histor	Bushed grass	Debris
14	351309	9239284	Histor	Grassland	Rotational
15	351316	9239230	Histor	Grass fallow	Debris
16	351595	9239724	Histor	Grass fallow	Debris
17	351807	9239565	Histor	Grassland	Debris
18	351772	9239516	Histor	Grassland	Debris
19	352314	9239616	1960	Grass fallow	rotational
20	352315	9238043	Histor	Cultivated	Amph
21	352347	9238219	histor	Cultivated	Amph
22	352391	9238326	histor	Cultivated	amph
23	352014	9238112	histor	Rock outcrop	rockfall
24	352454	9238986	histor	Rock outcrop	rockfall
25	352026	9238370	histor	Rock outcrop	rockfall
26	352378	9238646	histor	Rock outcrop	rockfall
27	352234	9239061	histor	Grassland	rockfall
28	352083	9239080	histor	Grassland	rockfall
29	351719	9238609	histor	Not known	rockfall
30	351693	9238816	histor	Not known	rockfall
31	351442	9239074	histor	Not known	rockfall

Appendix D7: Kikundi mountain foothills landslides after 1964.

SN	X COORDINA	Y COORDINA	YEAR	TYPOLOGY	ASSOC TO LU/COVER
1	351969	9241070	2002	Rotational	Irrigated agriculture
2	351975	9241052	2001	Debris	Irrigated agriculture
3	351976	9241042	2003	Debris	Irrigated agriculture
4	352042	9241176	2003	Rotational	Irrigated agriculture
5	352120	9241334	2003	Debris	Irrigated agriculture
6	352900	9241494	1994	Rotational	Rainfed agriculture
7	353058	9242854	1990	Debris	Rainfed agriculture
8	353180	9242524	2000	debris	Rainfed agriculture
9	353102	9242341	2000	debris	Rainfed agriculture
10	352991	9242101	2005	debris	Roadside
11	353010	9242079	2000	debris	Roadside
12	353001	9241978	2000	debris	Rainfed agriculture
13	352953	9241860	2000	debris	Rainfed agriculture
14	352980	9241694	2000	debris	Rainfed agriculture
15	352917	9241446	2000	debris	Roadside
16	352946	9241489	2000	debris	Roadside
17	352871	9241328	1997	debris	Roadside
18	352900	9241650	2000	debris	Roadside
19	352965	9241748	1980	debris	Rainfed agriculture
20	352085	9241188	1998	debris	Irrigated agriculture
21	351970	9241062	1998	debris	Irrigated agriculture
22	351970	9241052	1998	debris	Irrigated agriculture
23	351979	9241038	1998	debris	Irrigated agriculture
24	351918	9240819	1998	debris	Irrigated agriculture
25	351828	9240192	1990	debris	Roadside

Appendix D8: Kikundi mountain foothills landslides by 1964

S_N	X COORDINA	Y COORDINA	YEAR	PREVIUS LU	TYPOLOGY
1	352937	9241553	histor	roadside	debris
2	352979	9241687	histor	roadside	debris
3	352961	9241746	histor	roadside	debris
4	352966	9241826	histor	roadside	debris
5	353006	9241990	histor	roadside	debris
6	353007	9242080	histor	roadside	debris

Appendix D9: Kilakala mountain ridges landslides after 1964

S N	X COORDINA	Y COORDINA	YEAR	TYPOLOGY	ASSOC TO LU/COVER
1	355529	9242564	1998	Debris	Rainfed agriculture
2	355500	9242692	1998	Rotational	Rainfed agriculture
3	355136	9242322	2001	Debris	Rainfed agriculture
4	355183	9242332	1990	Debris	Rainfed agriculture
5	355227	9242298	1990	Debris	Rainfed agriculture
6	355535	9242306	1990	Debris	Rainfed agriculture
7	355524	9242316	1990	Debris	Rainfed agriculture
8	355640	9242300	2002	Debris	Rainfed agriculture
9	355430	9242340	1970s	Debris	Rainfed agriculture
10	355512	9242290	1970s	Debris	Rainfed agriculture
11	355637	9242508	1980s		Rainfed agriculture

Appendix D10: Kilakala mountain ridges landslides by 1964

SN	X COORDINA	Y COORDINA	YEAR	PREVIUS LU	TYPOLOGY
1	355663	9242660	Histor	Grass	Rotational
2	355702	9242634	Histor	Grass	Rotational
3	355732	9242530	1950	Cultivated	Debris
4	355600	9242364	1930s	bushland	Debris
5	355592	9242414	1930s	Bushland	debris
6	355545	9242430	Histor	Bushed grass	Debris
7	355450	9242558	Histor	Cultivated	Debris
8	355265	9242294	Histor	Grass	Debris
9	355220	9242362	histor	Cultivated	Debris

Appendix D11: Kilakala mountain foothills landslides after 1964

SN	X COORDINA	Y COORDINA	YEAR	TYPOLOGY	ASSOC TO LU/COVER
1	355011	9242904	1990	Debris	Rainfed agriculture
2	355001	9243014	1967	Debris	Rainfed agriculture
3	355120	9242924	1980	Rotational	Rainfed agriculture
4	355245	9242722	1970	Rotational	Rainfed agriculture
5	355294	9242768	2000	Debris	Rainfed agriculture
6	355244	9242948	1970s	Debris	Rainfed agriculture
7	355324	9243000	1970s	Rotational	Bushed grassland
8	354665	9243180	1985	Debris	Rainfed agriculture
9	354707	9243198	2001	Debris	Rainfed agriculture
10	355026	9242872	2001	Rotational	Rainfed agriculture

Appendix D12: Kilakala mountain foothills landslides by 1964

S_N	X COORDINA	Y COORDINA	YEAR	PREVIUS_LU	TYPOLOGY
1	355354	9242988	1930s	Cultivated	Debris
2	355375	9242970	1940s	Grass	Debris
3	355375	9242964	1940s	Grass	Rockfalls
4	355436	9242630	Histor	Cultivated	Debris
5	355383	9242672	Histor	Cultivated	Debris
6	355001	9243014	1967	cultivated	debris
7	355244	9242948	1960s	cultivated	debris
8	355324	9243000	1960s	fallow	rotational