GEOGRAPHICAL INFORMATION SYSTEM AND ANALYTICAL HIERARCHICAL PROCESS BASED LAND USE ALLOCATION FOR SUSTAINABLE NATURAL RESOURCE MANAGEMENT: THE CASE OF ULUGURU MOUNTAIN, MOROGORO, TANZANIA

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

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EXTENDED ABSTRACT

The northern part of the Uluguru mountain slope, which falls within Morogoro urban jurisdiction, has been gradually populated and associated with unregulated human activities which has brought negative impacts on the environment. Natural forests are being converted at a rapid rate to farms and settlements which has a negative impact on biodiversity and the ability of the land to be fruitful.

In order to have a clearer view of this problem, this study assessed the existing land use of the area for the period of thirty years (1990 to 2020). Images of the years 1990, 2000, 2010 and 2020 were obtained from the United State Geological Survey Website (USGS) and processed by classification and change detection techniques using the Geographical Information System (GIS). The combination of cellular automata and Markov (CA-Markovic) model was used to simulate the 2050 LULC of the study area, with images from 2000 and 2010 used to generate a transition probability matrix that aided in the estimation of possible changes, and the 2020 image classification was compared with the simulated 2020 map to validate the model's reliability. The land resources were assessed by using GIS techniques based on various reliable sources of data in raster format to achieve elevation classification, slope, soil, soil moisture index, and land surface temperature to understand the study area for planning purposes. Literature review was used to obtain compatible land uses which could facilitate management of natural resources along the mountain slopes. These proposed land uses obtained were used in a well-structured questionnaire to retrieve expert opinions on the influence of each criteria in allocating land uses at each level of elevation. The influence of criteria as defined by Saaty’s scale on questionnaires was processed by using Analytical Hierarchical Process (AHP) to obtain their weight through a comparison matrix, normalization of the matrix, and geometric mean calculation. The expert’s opinions were checked to see if they were consistent by using the consistency index. The geometric mean obtained via the AHP procedure was used in GIS through a weighted overlay process to produce a proposed land use plan that considers expert opinions on sustainable management of natural resources.

Assessment of existing LULC revealed that agriculture activities and built-up areas are increasing over time, while forest, closed woodland, and open woodland are decreasing while the simulated LULC of 2050 shows continued depletion of natural vegetation and increased urbanization. Land use allocation of the study area by the integration of AHP and GIS came up with a proposed land use plan compatible for management of natural resources that consists of 50.26%, 19.5%, 17.12%, and 13.15% area coverage of conservation agriculture, agroforestry, settlements, and forest, respectively.

From the results, it is clear that there is a significant change in LULC which negatively affects the ecology of the mountain slopes. The increase of agriculture activities and settlements from the year 1990 to 2020 is paralleled by much decreased forest, closed woodland, and open woodland. The land uses suggested via literature review to counteract the situation are agroforestry, conservation agriculture, and forest, while settlements were incorporated due to their existence. Suggested land use allocation for the area based on expert opinions collected by questionnaires reveals that the foothills of the mountain should be utilised for conservation agriculture and settlements, while the highest part of the study area, which is covered by land map units 4 and 5, should be covered more by forest and agroforestry.

Based on the findings of this study, it is recommended that land use allocation be used as a tool to facilitate management of natural resources in ecological sensitive areas. The analytical hierarchical process is an effective method in suitability analysis since it involves opinions from stakeholders or experts on judging factors affecting management of natural resources, and the procedure is transparent and can easily be understood, hence

it is recommended to be adopted. More research on the proper type of conservation agriculture practice and plants that may be compatible for afforestation is also suggested, but also the reallocation of human activities based on compatible land use. Allowing environmentally friendly activities should be regarded as public interest due to the role of the mountain as a source of water and biodiversity. Hence, for the need of evacuation of settlements to allow environmentally friendly activities, land acquisition should follow Tanzania's land policy instruction.

DECLARATION

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

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Dr. P. H . Msigula Date

(Supervisor)

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DEDICATION

I dedicate this dissertation to my wife Sophia and children Cosmas, Colman, and Collins for their love and support throughout my studies. My late parents' efforts and love for me will always be cherished (Cosmas and Catherine).

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LIST OF ABBREVIATIONS

Ahp	Analytical Hierarchical Process
C.I	Consistency Index
Dem	Digital Elevation Model
Gis	Geographical Information System
Lst	Land Surface Temperature
Lulc	Land Use/Land Cover
R,I	Random Inconsistency Index
Smi	Soil Moisture Index
Wgs 84	World Geodetic System Of 1984

CHAPTER ONE

1.0 INTRODUCTION

Uluguru Mountain's northern slopes have long been known for their beauty and attractive view of Morogoro Urban, and the mountain is the main source of water flows for urban and industrial use in the Coast, Morogoro, and Dar Es Salaam Regions. (Temple, 1972), since the mountain possesses an ecologically sensitive area, it deserves special attention for the sustainability of natural resources. Land along the Uluguru slopes is in high demand as a result of migration of people seeking agricultural land, logging, pit-sawing and charcoal burning. These activities result in decrease of natural vegetation, pollution and scarcity of clean water for surrounding communities (Kusiluka *et al*., 2011). Due to demographic pressure, the arable land's carrying capacity is small and a high population contributes to rapid soil erosion, resulting in the loss of soil fertility and land degradation, leading to a high rate of natural resource depletion (FAO, 2020).

A number of efforts for the conservation of Uluguru Mountain have been carried out to mitigate the increased loss of natural resources as a consequence of unplanned human activities along the mountain slope since colonial times. The history of conservation efforts in the Uluguru Mountains dates back to 1909, with around 277 km^2 designated as forest reserves during the German colonial administration (Malisa, 2016) in order to control shifting cultivation on the mountain, which resulted in degradation persisting in non-reserved areas. Another major conservation effort was launched in the mid-1940s to resolve the problems of catchment value loss in Uluguru, known as the Uluguru Land Usage Scheme (ULUS) (Rutatora *et al.,* 1996). In recent years, efforts have been continuously geared toward fighting against persisting degradation. The Uluguru Mountains Biodiversity Conservation Project (UMBCP) was established to encourage community involvement in the conservation of forest patches outside the catchment forest through Participatory Forest Management (PFM) (Paulo *et al.,* 2007). Promotion of conservation and organic agriculture was influenced by the Uluguru Mountain Agriculture Development Project (UMADEP) in order to encourage adoption of these cultivation methods by the surrounding communities (Mussa *et al.,* 2012).

Due to the importance of the Uluguru Mountains, various scholars have expressed their concern over its degradation, as it is reported that some of the endemic snake species, birds species and plants species investigated have been found to be lost in the area (Burges *et al.*, 2002; Hall *et al.*, 2008) due to deforestation caused by clearance of natural vegetation for farming purposes. Soil erosion on the northern slopes of the Uluguru mountains has also caused significant concern (Kimaro *et al.,* 2008), to the point of recommending soil conservation on agricultural fields.

Since degradation has been persisting along the Uluguru Mountain slopes for years, land use suitability planning can also be used as an effective tool to counter this by integrating land resource management to preserve, improve, and allow more productive use of natural resources. Through scientific and systematic analysis of land resources, land use allocation can strengthen management of the whole range of natural resources. Using Geographical Information System (GIS) and Analytical Hierarchical Process (AHP), decision-making for land use planning could be enabled, taking land ability into account in supporting specific land use for strengthening sustainable management of natural resources.

1.1 Problem Statement

The integration of Geographical Information System (GIS) and Analytical Hierarchical Process (AHP) facilitates spatial decision making process for different sectors in regards to suitability analysis. While GIS is a powerful tool to handle spatial data, AHP assist on incorporating consistency expert and stakeholders opinions (Attribute data) on judging relative importance (assigning weights) of different criteria's for suitability analysis. This study considered the integration of AHP and GIS to facilitate management of natural resources since it gives room to understand the landscape characteristics through analysis of land resources and enables accommodating experts' knowledge on planning of the area to achieve the desired goals considering the on-going depletion of Uluguru mountains' natural resources.

Several studies have been done on application of Geographical Information System (GIS) and Analytical Hierarchical Process (AHP) in assessing and allocating areas for urban land uses (Shukla *et al.*, 2011; Ullah, 2014). A study by Zarkesh *et al.* (2010) used the integration of GIS and AHP for allocating areas for rain fed-agriculture, rangelands, and urban development's. Apart from that, a study by Di bonito and Clarkson (2013) used the integration of GIS and AHP for assisting decision making on planning for wildlife conservation. Furthermore a study by Sahani (2019) used the integration of GIS and AHP as well on allocating potential ecotourism sites. Moreover a study by Duc (2006) analyzed land use suitability by using the integration of GIS and AHP method in the same way as the study by Cengiz (2009) for evaluating land use suitability. However, Bagheri *et al.* (2013) applied GIS and AHP for land use suitability analysis on coastal area.

Countrywide, there are a number of studies focused on the management of natural resources in mountainous areas, mostly focused on agriculture practices, planning by

Participatory Rural Appraisal (PRA) and conservation education (Bhatia and Buckley, 1998; Rutatora *et al.,* 1996; Mbaga and Semgalawe, 2000; Komba, 2015; Manase, 2016; Msangi, 2016). However, little has been done on analyzing the spatial classification of land resources in the mountainous area to facilitate experts' evaluation of compatible land use allocation for natural resource management. Therefore, this study used GIS and AHP models to analyse and integrate spatial and non-spatial (experts' opinions) data into descriptive and analytical models as a knowledge base for compatible land use allocation on Uluguru mountain slopes for natural resource management.

1.2 Justification

The findings of this study aims at contributing concepts on conserving natural resources of Uluguru mountain slopes to the society in the area and to various national policies by using remote sensing data, GIS and Analytical Hierarchical Process (Cengiz and Akbulak, 2009; Bagheri *et al.,* 2013). Scientific and rational planning of Uluguru mountain slopes could achieve sustainability, protection and appropriate use of natural resources that will benefit the present and future generation through availability of clean water and good living environment as well as achieving goals of national policies such as National Environmental Policy (2021), Water Sector Policy (2002), National Forest policy (1998) and National Land policy (1995).

1.3 Objectives

1.3.1 Main objective

The main objective of this research is to assess land use trends and allocate compatible land uses for sustainable natural resource management on the northern slopes of Uluguru mountain through integrating Geographic Information System (GIS) and an Analytical Hierarchical Process (AHP).

1.3.2 Specific objectives

The specific objectives of the study were, to;

(i) To assess and project land use land cover scenario of Uluguru Mountain northern slopes.

(ii) Model land use allocation by integrating Analytical Hierarchy Process Model (AHP) and Geographical Information System (GIS) and existing land use.

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CHAPTER TWO

Manuscript One

2.0 ASSESSMENT AND PROJECTION OF LAND USE LAND COVER SCENARIO OF ULUGURU MOUNTAIN NORTHERN SLOPES

2.1 Abstract

Uluguru mountain slopes have been heavily affected by civilization that grows in neighboring towns, whereby activities like harvesting of timber, settlements, and other activities driven by human demands cause the depletion of natural resources rigorously. The original land cover in the area has been continuously altered by the rise of human needs caused by urbanization stimulated by a growing population.

A comprehensive analysis of the existing land use and land cover of the study area was conducted by using a Geographical Information System. Images of the years 1990, 2000, 2010, and 2020 were collected from the United States Geological Survey website (USGS), which were then processed by the random forest algorithm in R software to generate LULC classes for specific years in order to investigate existing land uses. Change detection techniques were employed to detect and identify changes in land cover classes with time. Classification comparisons of LULC statistics were used to assist in the detection of changes.

The total of five land use classes in the area identified through image classification are: built up; agriculture; closed woodland; open woodland; and forest. The coverage for built-up was 1.004km^2, 2.480km^2, 2.678km^2 and 6.136km^2 for the years 1990, 2000, 2010 and 2020, respectively. The area covered for agriculture was 19.376 km^2, 24.690 km^2, 38.186 km^2 and 44.732 km^2 for the years 1990, 2000, 2010 and 2020, respectively. Closed woodland covered 43.297km^2, 36.607km^2, 25.997km^2 and 16.287km^2 for the years 1990, 2000, 2010 and 2020, respectively. The area covered by open woodland was 3.181km^2, 0.758km^2, 0.734km^2 and 0.451km^2 for the years 1990, 2000, 2010 and 2020, respectively. Forest area coverage was 1.575km^2, 0.905km^2, 0.843km^2 and 0.830 km^2 for the years 1990, 2000, 2010 and 2020, respectively. Agriculture and built-up are the only land use types that increase with time, whereby they increase by approximately 1.53 km^2 and 0.25 km^2 per year, respectively. Closed woodland, open woodland, and forest showed that they decreased by 0.9km2, 0.091km^2, and 0.025 km^2 per year, respectively.

The results obtained give indication that human activities continue to increase with time while natural vegetation disappears since agriculture and built-up land use classes increase at the expenses of woodland and forest land use classes. This study provides critical information on continuing degradation along the Uluguru Mountain slopes, this information could be valuable in natural resource policy making and planning for sustainable management.

Keywords: Geographical information system, land use, land cover, classification, change detection

2.2 Introduction

Natural resources constantly influence a country's basic development as well as supporting human survival on the planet. Civilization resulting from human activities is rapidly stretching natural resources as a result of fast population growth and resource overexploitation (Mittal and Gupta, 2006). The land use and land cover change due to human civilization has increased adequately to act as a substantial source of global environmental effects which are difficult to reinstall. Studies state that over 60% of all land changes are the result of human activities while other indirect drivers like climate change contribute another 40% (Song *et al*., 2018).

Uluguru Mountain slopes are one of the areas that have been experiencing negative environmental impacts due to increase of human population which accompanied with human’s demands like charcoal, food and timber (Kusiluka *et al*., 2011) thus assessment of existing land use is vital for future planning and actions towards minimization of degradation as well as restoration of conducive environment for ecosystem in the area. Understanding the current land use in the study area requires a comprehensive analysis of the changes involved, as they are connected to how people use the land over time, LULC change analysis provides planners and policy makers with sufficient information on what to be done to achieve sustainable and environmentally friendly development (Abbas and Fasona, 2012). To assist systematic assessment of existing land uses, the combination of geographic information systems and remote sensing was employed since it is valuable asset that has been widely used as a tool for analyzing existing land use and changes over time to assist long-term planning and policy making as stated in various studies (Merchant *et al*., 2009; Rahman *et al*., 2012; Arunyawat and Shrestha, 2016).

Land use and land cover patterns over thirty years were processed to create a better understanding of land utilisation aspects in the past and present situation. The information achieved is vital on the future of the mountain slopes since it will facilitate on alarming planning authorities about the need of protection, restoration and management of natural resources.

Therefore, the main objective of this study is to assess the land use pattern of Uluguru Mountain slopes as well as to understand the dynamic of LULC for thirty years period (1990 – 2020) and project future LULC by using classification, change detection technique and CA Markov model to retrieve vital information for natural resource management through land use planning. Ultimately this study was designed to answer these questions; (a) What is the LULC pattern of Uluguru Mountain slopes for the 30 years period? (b) What does the future hold for the LULC pattern on the Uluguru Mountain slopes?

2.3 Material and Methods

2.3.1 Study area

The study area is located at the northern slope of Uluguru mountain, its boundary commence on the eastern part situated at the Latitude of 6°48′00″S and Longitude of 39°45′00″E up to the western part at Latitude of 6°55′41″S and Longitude of 37°38′44″E. The altitude is approximately 495m above mean sea level at the foothill of the mountain and about 1 750m at the point it border with Uluguru Nature forest reserve (Fig. 2.1). The coverage of the area of study is approximately 6 928 Ha. The area has average minimum and maximum temperature of 16°C and 33°C, respectively, with minimum and maximum annual rainfall of 821 mm and 1 505 mm, respectively, (Ernest *et al*., 2017).

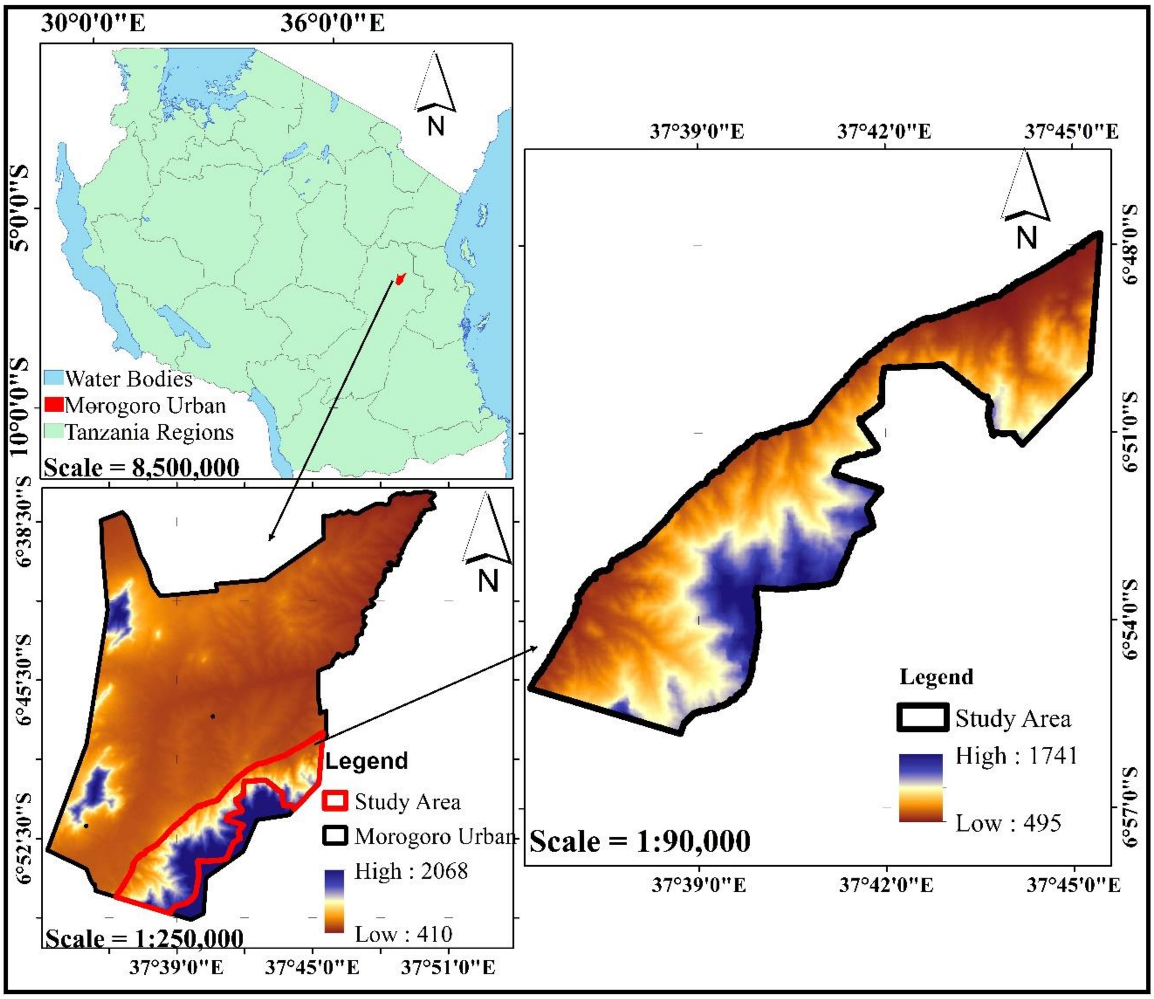

Figure 2.1: Study area location.

2.3.2 Data collection and analysis procedure

2.3.2.1 Satellite image acquisition

The Landsat images were obtained from United States Geological Survey website (https://earthexplorer.usgs.gov/) by using a path and row number 167065 that cover the study area as shown on Table 2.1. For this study, four Landsat time series (1990, 2000, 2010 and 2020) retrieved during the dry season were used. All images were taken during the same time of the year (Dry season) to minimize clouds and seasonal effects.

Table 2.1: Details of satellite image obtained

SN	Date	Season	Data source	Spatial Resolution (m)
1.0	1990-10-24	Dry	Landsat 5 TM	30
2.0	2000-07-07	Dry	Landsat 7 ETM +	30
3.0	2010-10-07	Dry	Landsat 7 ETM +	30
4.0	2020-07-10	Dry	Landsat 8 OLIS	30

2.3.2.2 Images pre-processing (radiometric and geometric correction)

Since its difficult to find images that covers Mountain Uluguru which are free from clouds, the pre-processing of the obtained images was done on removing clouds and cloud shadows by using ERDAS and Geomatica 2015 to obtain clear image that covers the area of interest in the same way as employed by other studies like (Tafesse and Suryabhagavan, 2019). All images were registered to WGS 84 coordinate system zone 37 South for consistency, after that the images were clipped based on the boundary of the study area.

2.3.2.3 Image classification

The corrected images were processed via Arc GIS to generate regions of interest for various land use/cover identified in the study area to facilitate classification by supervised random forest classifier algorithm in R software, the method which has been widely used and reported in other studies (Liaw and Wiener, 2002; Adam *et al*., 2014; Feng *et al*., 2015; Gebere *et al.*, 2016 Camargo *et al*., 2019; Nurfadila *et al.*, 2019). A total of five land cover classes (built-up area, closed woodland, open woodland, agriculture, and forest) were identified on the study area with the Landsat imagery as reference in classification process based on features appearance as described on Table 2.2.

Table 2.2: Descriptions for land use/land cover classification

S/N	Land use / Land cover class	Description
1	Built up	Settlements and other manmade structures associated with it.
2	Agriculture	All lands used for seasonal crops cultivation.
3	Forest	Areas with closed trees and thick canopy
4	Closed woodland	Areas with wood trees with less closed canopy.
5	Open woodland	Area with scattered trees with less cover

2.3.2.4 Classification accuracy assessment

To verify how accurately the pixel was sampled into the proper LULC class, the ground truthing technique during field work and on the Google earth pro software was employed, whereby a total of 25 points for each land use type were collected as identified by the interpreter.

The confusion matrix was generated in reporting accuracy of LULC classification of satellite images of the study area. The method was chosen because it includes errors of inclusion, omission and overall accuracy of classification. Classification accuracy assessment was done by using class values and ground truth points to produce the error matrix that shows different statistics. This method has been used in various studies (Roy *et al*., 2015; Mbungu *et al*., 2016; Rwanga and Ndambuki, 2017).

2.3.2.5 Change detection

Change detection techniques facilitated analysis of changes in land uses between images of the same area taken at different times, this facilitated to determine which land use type changed to the other. Classified Images of land cover classification from various time intervals were used to detect and identify changes in land cover types with time. The change detection techniques guided a better understanding of the underlying land-use changes.

Classification comparisons of land cover statistics were used to assist in the detection of changes, this method has been reported on other studies (Mallupattu and Sreenivasula-Reddy, 2013; Tewabe and Fentahun, 2020). For each epoch, the areas covered by each land cover category were compared. Then, direction of changes for each land cover type was determined (Positive or negative).

2.3.2.6 LULC Projection

To be able to predict future LULC in the study area, the CA-Markov model was applied to anticipate future situations based on two data sets of LULC from different eras to derive a transition probability matrix. This research used the LULC maps of the years 2000 and 2010 to obtain a transition probability matrix to facilitate simulation of 2050 LULC of the study area with elevation, slope, distance from the river and distance from the road used as drivers.

The Markov process foresees future states of a system based on the preceding state by developing a transition probability matrix of LU/LC change starting from time one to time two. It shows the nature of changes as well as forms the basis of future development forecasting (Burke and Logsdon, 1996). This transition of one state to another state is assisted by the transition probability matrix (Semegnew *et al.*, 2021) expressed as:

$$S(t, t+1) = P_{ij} \times S(t) \quad \ldots (1)$$

Where S (t) is status of state at the time t, and the state status at the time t+1; Pij is the transition probability matrix which is calculated as;

$$Pij = \begin{matrix} P1,1 & P1,2 & P1,3 & P1,n \\ P2,1 & P2,2 & P2,3 & P2,n \\ Pn,1 & Pn,2 & Pn,3 & Pn,n \end{matrix} \quad \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where; Pij is the probability of transforming from state of time i to a state of time j and Pn is the probability of any time. This probability matrix express the possibility of one land use/land cover class to change to another class.

The probability matrix was used to simulate the 2020 LULC and compare with the classified land use/land cover map, and kappa statistics facilitated accuracy assessment to verify required standards of being in a high level of agreement (75%≤Kappa<100) or medium level of agreement (50%≤kappa≤75%) were met (Verstegena *et al.*, 2019; Semegnew *et al.*, 2021) to be reliable for 2050 LULC simulation.

2.4 Results

2.4.1 Classification accuracy

The accuracy assessment process gave the output of 90.4%, 80%, 80.8% and 85.6% overall classification accuracy for 1990, 2000, 2010 and 2020 with 88%, 75%, 80.8% and 82% of kappa statistics respectively as indicated in the Table 2.3 whereby User accuracy (UA) describes how accurate a forecast for a particular class is from the user's perspective, while producer accuracy (PA) describes how accurate a prediction is from the model's perspective.

Table 2.3: Classification accuracy results

Land cover	1990		2000		2010		2020	
	PA	**UA**	**PA**	**UA**	**PA**	**UA**	**PA**	**UA**
Forest	96	86	84	78	64	76	96	83
Built up	96	86	100	100	84	95	100	96
Agriculture	92	72	80	65	88	69	84	100
Closed Woodland	68	74	68	85	76	100	92	79
Open Woodland	67	87	92	82	84	91	80	95
Overall accuracy	90.4		80		80.8		85.6	
Kappa Statistic	0.88		0.75		0.81		0.82	

2.4.2 Classification output

Through the classification process of satellite images of the years 1990, 2000, 2010, and 2020, five land use classes were identified, which are: built-up area, closed woodland, open woodland, agriculture, and forest as shown in Fig. 2.2.

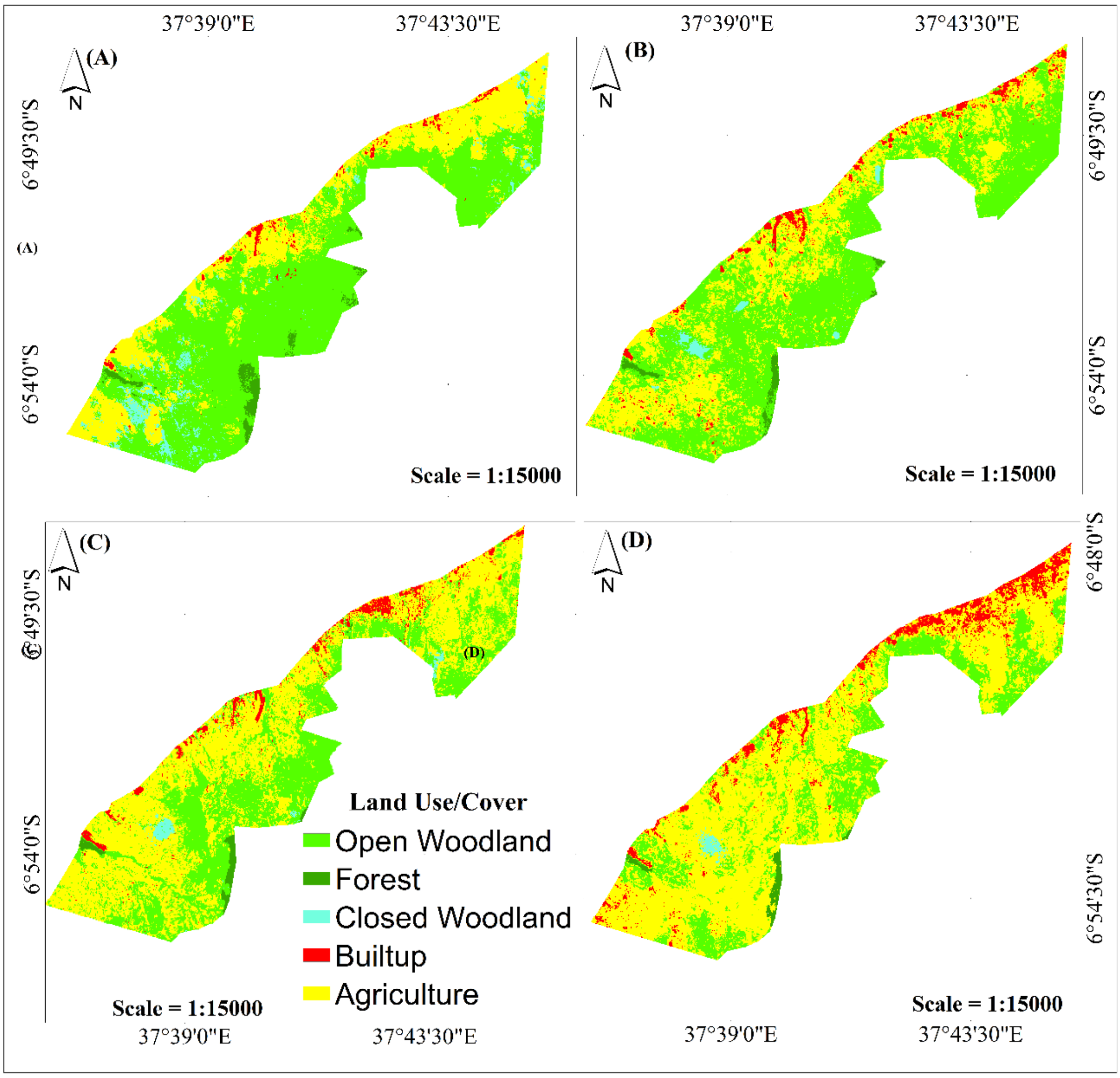

Figure 2.2: Land use / Land Cover classification of 1990 (A), 2000 (B), 2010 (C) and 2020 (D).

In 1990, the majority land use in the study area was open woodland, which covered 43.3 km^2 (63.27%), while in the year 2000, the majority land use type in the study area was open woodland, which covered 39.61 km^2 (57.87%), in the year 2010, the majority land use type in the area was agriculture, which covered 38.18 km^2 (55.79%), and finally, in the year 2020, the majority land use type was agriculture, whereby a total of 44.73 km^2(65.63%) coverage was determined in the study area (Fig. 2.3).

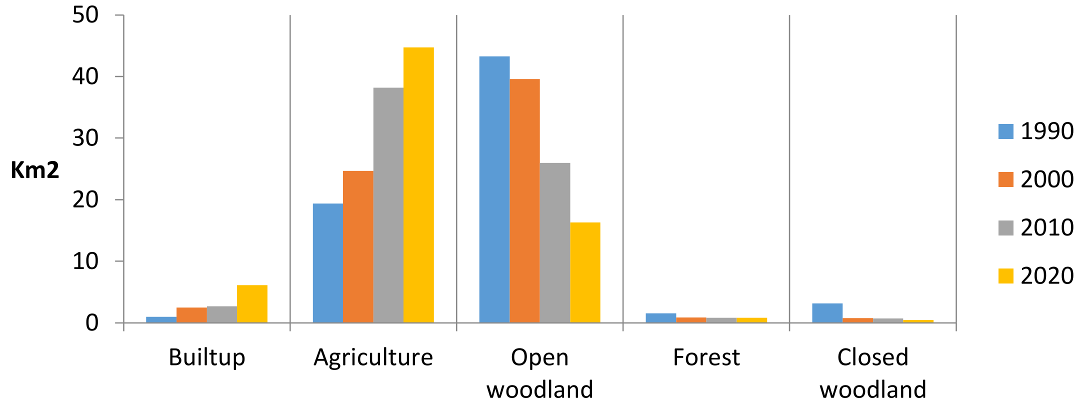

Figure 2.3: Trend for land use/land cover pattern from 1990 – 2020

2.4.3 Change detection

The analysis of changes was done over a thirty-year period divided into three ten-year packages from 1990 to 2020. The years 1990 to 2000 discovered that built-up areas (settlements) increased by 1.51km^2, which diverged from open woodland, closed woodland, and forest and lost zero hectares. The area covered by agriculture activities increased by 11.58 km^2, which was transformed from closed woodland, open woodland, and forest, whereby it lost 7.75 km^2. The area covered by Open woodland increased by 7.43 km^2, which converged from agriculture, open woodland, and forest while losing a total of 12.42 km^2. Closed woodland increased by 0.51 km^2, which was gained from agriculture, open woodland, and forest while losing 3.05 km^2. Finally, the area covered by forest was increased by 0.18 km^2, which was converted from closed woodland only and lost 0.92 km^2. The scenario of LULC loss and gain is expressed in Table 2.4.

Table 2.4: Gain and loss of land use/land cover for the 1990 – 2000 period.

Land Use/	**1990_2000 changes (km^2)**	
Land Cover	**Loss**	**Gain**
Built-up	0	1.51
Agriculture	7.75	11.58
Open woodland	12.43	7.43
Forest	0.92	0.18
Closed woodland	3.05	0.51

The second package land use change analysis, which is between the years 2000 and 2010, revealed that built up area (settlements) increased by 2.96 km^2, which gained from agriculture and open woodland and lost zero hectares. The agriculture area increased by 18.46 km^2 shifted from closed woodland, open woodland, and forest, whereby it lost a total of 6.17 km^2. The area covered by open woodland increased by 5.5 km^2, which was gained from agriculture, closed woodland and forest, whereby it lost a total of 18.14 km^2. The area covered by closed woodland increased by 0.51 km^2, which converged from agriculture, open woodland, and forest, whereby it lost 0.56 km^2. Finally, the forest area gained by 0.25 km^2 was obtained from closed woodland and open woodland while the lost total was 0.27 km^2. The loss and gain of LULC from the year 2000 – 2010 is expressed in Table 2.5 and Fig. 2.4.

Table 2.5: Gain and Loss of Land Use/Land cover for the 2000 – 2010 period

Land Use/	**2000_2010 Changes (Km^2)**	
Land Cover	**Loss**	**Gain**
Builtup	0	2.96
Agriculture	6.17	18.42
Open Woodland	18.14	5.5
Forest	0.27	0.25
Closed Woodland	0.56	0.51

The third package for land use change analysis, which is between the years 2010 and 2020, revealed that built up area (settlements) has increased by 3.69km^2, gained from agriculture, closed woodland, and open woodland, while losing zero hectares. The area covered by agriculture increased by 14.24 km^2, which was gained from closed woodland, open woodland, and forest, while a total of 9.37 km^2 was lost. Open woodland area increased by 5.3 5 km^2, that gained from agriculture, open woodland, and forest while losing 15.80 km^2. Closed woodland coverage area increased by 0.16 km^2, which gained from agriculture, closed woodland, and forest while losing a total of 0.42 km^2. Finally, the area covered by forest increased by 0.10 km^2, owing to the convergence of closed and open woodland, while decreasing by 0.16 km^2. Table 2.6 and Fig. 2.4 express the loss and gain of LULC from the year 2010 – 2020.

Table 2.6: Gain and loss of land use/land cover for the 2010 – 2020 period.

Land Use/ Land Cover	**2010_2020 Changes (Km^2)**	
	Loss	**Gain**
Built-up	0	3.69
Agriculture	9.37	14.24
Open woodland	15.80	5.35
Forest	0.16	0.10
Closed woodland	0.42	0.16

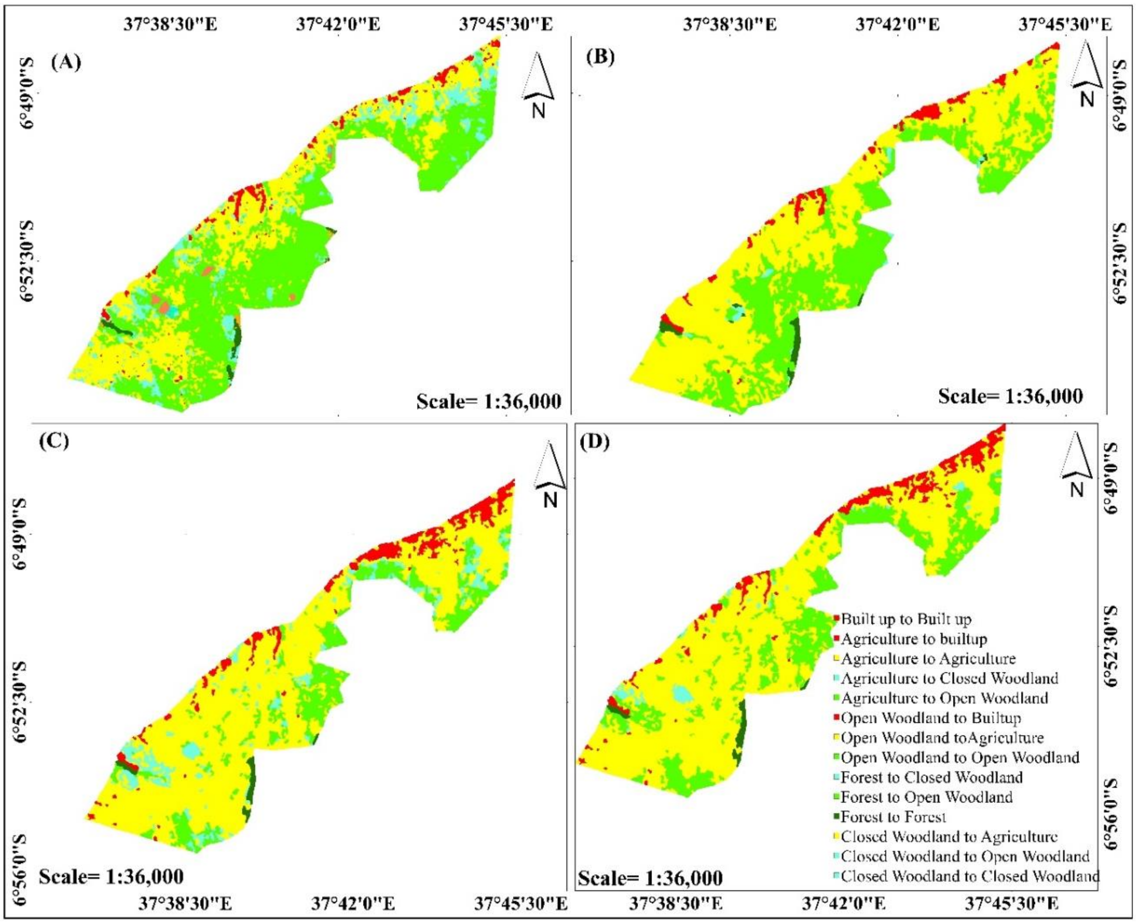

Figure 2.4: Land use change detection plan from 1990 to 2000 (A), 2000 to 2010 (B), 2010 to 2020 (C) and 1990 to 2020 (D) (1 –Built up 2 –Agriculture 3- Open woodland 4- Forest 5- Closed woodland)

2.4.4 Predicted LU/LC of 2050

Validation of the CA-Markov that was done by using actual and simulated maps of the year 2020 and produced 77.6% of the overall kappa value, which falls within the agreement standard, hence making it reliable for simulation purposes. The model predicts the LULC of 2050 using the transition probability matrix, which facilitates information about potential changes and is shown in Table 2.7.

Table 2.7: Transition probability matrix

	Built-up	Agriculture	Open Woodland	Forest	Closed woodland
Builtup	0.163279	0.605016	0.018809	0.197492	0.009404
Agriculture	0.014586	0.820529	0.000903	0.160192	0.003791
Open Woodland	0.035117	0.605351	0.020903	0.338629	0
Forest	0.003675	0.777291	0.001791	0.173363	0.043881
Closed woodland	0.003826	0.476664	0.002295	0.063887	0.453328

To understand the trend of changes between 2020 and 2050, the area obtained from the 2020 LULC classification map was used together with the simulated LULC map of 2050 (Table 2.8).

Table 2.8: LULC area changes between the years 2020 and simulated 2050

	2020		2050		2020 -2050
	Area (km^2)	%	Area (km^2)	%	Area change (km^2)
Built up	6.14	8.95	14.68	22.67	8.54
Agriculture	44.73	65.19	40.96	63.25	-3.77
Closed Woodland	0.49	0.714	0.126	0.19	-0.364
Forest	0.83	1.21	0.58	0.90	-0.25
Open Woodland	16.42	23.93	8.41	12.99	-8.01

The increase of urbanisation is spotted since built-up areas show an increase of 13.72% while open woodland, agriculture, closed woodland, and forest show a decrease of 12.79%, 4.09%, and 21.72%, respectively. Agriculture, despite covering a majority of the area compared to other LULC, has shown a bit of a decrease in the expenses of urbanisation while natural vegetation keeps depleting with time as shown on Fig. 2.5.

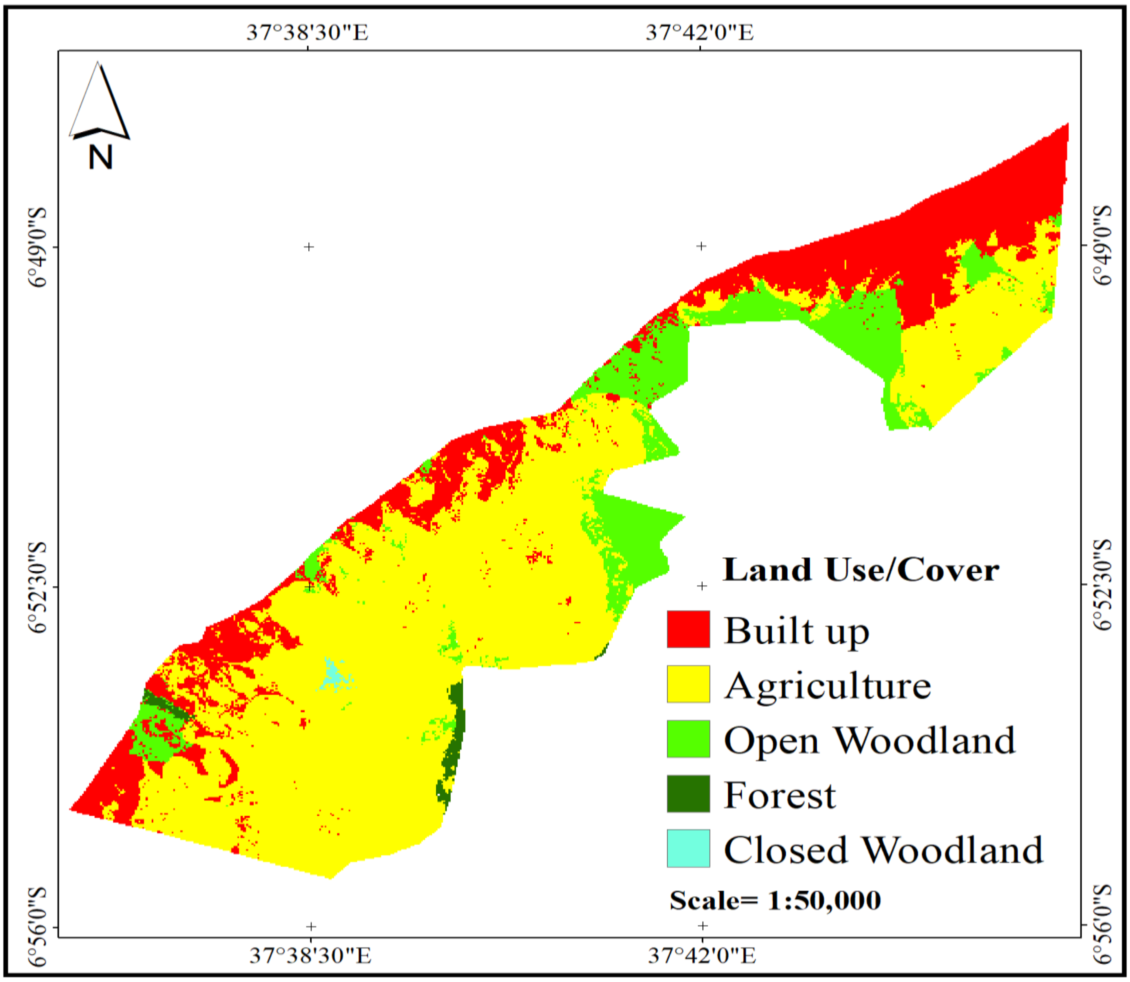

Figure 2.5: Simulated Land use/cover of the year 2050

2.5 Discussion

Landsat images were used to create LULC maps of the years 1990, 2000, 2010, and 2020, which were within the accurate standards required to make them reliable in facilitating awareness of the LULC scenario of the study area. The LULC change results reveal that closed woodlands, open woodlands, and forest were diminishing tremendously, mostly being transformed into farmlands and built up, which were also revealed by other studies conducted in the Uluguru Mountains (Yanda and Munishi, 2007; Mbungu, 2016; Ngondo *et al.*,2022). The increase of the population in Morogoro Municipality has been reported by other studies (Kusiluka *et al.*, 2011) as one of the factors that causes increasing urbanization pressure and agriculture activities along the mountain slopes due to the scarcity of land for settlements and cultivation (Ojoyi *et al.*, 2017).

The availability of fresh air, biodiversity and quality water in the uluguru has been put in danger due to the distraction of LULC of the catchment because of the on-going human activities in the area (Shimelis *et al*., 2016; Duveillera *et al*,. 2020; Verstegen, *at al*., 2019). The limited supply of clean and safe water, loss of endemic species and soil erosion in the area raise some concern and have been kept on articulated as results of the constant depletion of natural resources (Massawe *et al*., 2019; Hall *et al.*, 2008; Burgess *et al*., 2002; Kimaro *et al.*, 2008).

The CA-Markov model facilitated simulation of LULC in 2050 for a critical understanding of the future situation if the identified existing status persists without intervention. The evaluation was based on the current status, with elevation, slope, distance from the river and distance from the road being considered as drivers. The results of CA-Markov model show that natural vegetation will keep disappearing and urbanization will continue to increase in the same way as it was revealed by 30 years LULC changes that assessed between the year 1990 and 2020 (Ngondo *et al.*,2022).

2.6 Conclusion

The changes explored suggest that rapid population growth in areas neighbouring mountain slopes stimulates demand for agricultural lands, settlements, logging for timber and wood, charcoal burning, and other environmentally distorting activities. Human activities without rational and sustainable planning have already had a negative impact on the sustainability of natural resources along the Uluguru Mountain slopes, to the point where, if allowed unchecked, the area will eventually become uninhabitable. Uluguru North Slope is neighbouring the Morogoro urban area, hence exposed to urbanization, which causes land resource pressure for human needs and hence makes it susceptible to destruction of natural resources. Innovative approaches are needed to the land use system of an area to be able to counteract the situation for environmental sustainability. This study could provide alarming light as the baseline information on actions needed as well as strategies on management of natural recourses together with the policy making process regarding planning on slopping lands.

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CHAPTER THREE

Manuscript Two

3.0 INTEGRATED ANALYTICAL HIERARCHICAL PROCESS AND GEOGRAPHICAL INFORMATION SYSTEM FOR ALLOCATION OF COMPATIBLE LAND USES ALONG ULUGURU MOUNTAIN SLOPES

CHAPTER FOUR

4.0 GENERAL DISCUSSION

4.1 Land Use Land Cover Scenario of the Study Area

Through satellite image analysis of the years 1990, 2000, 2010, and 2020, this study investigated the LULC scenario of the north part of the Uluguru Mountain slopes that fall within Morogoro Municipality for a thirty-year period, which revealed that there are significant changes in LULC whereby settlements and agriculture appear to rise with time, while natural vegetation decreases.

Eventually, based on different studies conducted on Uluguru mountain slopes, the drivers of LULC changes appear to be the conversion of natural vegetation to farmlands and settlements. The simulated LULC of the year 2050 reveals that there is continued depletion of natural resources at the expense of urbanization.

With these findings, it is clear that civilization's activities in the area do not support the long-term sustainability of natural resources. Areas covered by natural vegetation are converted to farmland, settlements, and exposed to timber harvesting and other un-environmental activities, implying that if the situation remains unchanged, the area will be environmentally unhabitable.

4.2 Proposed Compatible Land Use

The criteria assessment in the study area indicated that they fluctuate as the terrain changes, and therefore that elevation changes do have direct impact on the criteria values obtained. The changes of criteria values plays major role in influences expert opinions on the type of proposed compatible land use to be allocated in different land map units created. For the sake of insuring land use sustainability environmentally, lands property and stakeholders demands (Prakash, 2003) were the driving factor in facilitating proposed compatible land use allocation in the area.

In comparison to other land map units, the foothill suggested by experts as suitable for settlements and conservational agriculture. This area is situated between 449 and 702 meters above mean sea level has a gentle slope, low rainfall, and is warm, making it less prone to erosion and having a low elevation, making it safe for settlements. Because of its location at the foot of the mountain, it is characterised by soil nutrient deposition, making it fertile and conducive to conservation agriculture. Suggested a compatible land use allocation at the foothill indicates that Conservation agriculture covers 49.77 percent, 45.73 percent for settlements (Appendix 4).

Land Mapping units 2 and 3 are suggested to be more suitable for conservation agriculture and agroforestry because they have a moderate slope and can be used for the type of agriculture that supports natural resource management by increasing land cover to reduce direct impacts of erosion agents on the land surface. In land map unit 2, suggested compatible land use coverage are 6.87%, 46.29%, 46.42% and 0.41% for Settlements, Conservational agriculture, Agroforestry and Forest respectively while compatible land use coverage for land map unit 3 are 0.67%, 84.46%, 11.32% and 3.54% for Settlements, Conservation agriculture, Agroforestry and Forest respectively (Appendix 4).

The highest elevation of the study area situated at land map unit 4 and 5, this is part of the mountain which possess steep slope, low temperature and high rainfall compares to other units. Expert's opinions suggest that the area should be allocated for forest land use type. Erosion and minor landslides are most likely to impact the land if it is exposed without vegetation cover due to the steep slope and high elevation of these two land map units. The forest can provide vegetative cover and land adhesion to prevent landslides. In land map unit 4, suggested compatible land use coverage are 4.34%, 10.11%, 3.83% and 81.72% for Settlements, Conservational agriculture, Agroforestry and Forest respectively while compatible land use coverage for land map unit 5 are 0.47%, 5.70%, 6.30% and 87.55% for Settlements, Conservation agriculture, Agroforestry and Forest respectively (Appendix 4).

CHAPTER FIVE

5.0 GENERAL CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

This study focused on determining how land use changes over time and foreseeing the future scenario of LULC along Uluguru Mountain slopes. The simulated LULC of 2050 revels the continuation of human activities has effects on the diminishing of natural resources.

literature review revealed that conservation agriculture, agroforestry, and forest can all be employed in the area for conservation and economic interests. Settlements were included in the list in order to allocate the population that continues to encroach on the mountain slopes to an area that has been proposed as suitable for settlements.

Activities that won't prevent the land surface from vegetation coverings, which will limit direct contacts of erosion agents, are essential while using land along mountain slopes to mitigate the impacts of erosion. Agriculture, settlements, and other economic activities must be allocated in accordance with the available land resources as population growth continues over time, food demand increases, and economic activities congestion results, threatening the sustainability of natural resources.

5.2 Recommendations

In light of the gaps revealed in the findings of this study, it is recommended that ongoing activities should be reallocated in accordance with the compatible land use obtained, and if evacuation is required during the process, Tanzania's land policy of 1995 could be a helpful instrument.

Since management of the mountain slopes carries public attention due to its importance for the availability of quality water for society's consumption and biodiversity, the matter should be taken as one of public interest, and affected people during the evacuation will be given prompt and fair compensation, as stated by Tanzania's land policy of 1995.

APPENDICES

Appendix 1: Questionnaire (Expert opinion)

Objective; Analyse alternative land uses and their influence on strengthening Natural resources management Along Uluguru mountain slope.

Expert Name:………………….

Area of expertise:……………...

Institution:……………………...

1. What is your opinion on the relative importance (influence) of the following criteria on allocating settlement at the foothill of Uluguru sloping mountain (497-702m)?

Settlements	SLOPE (08-12%)	TEMPERATURE (17.9-21.30c)	RAINFALL (770-886mm)	SOIL PROPERTIES	SMI (0.101-0.737%)	LST (10-260c)
SLOPE (08-12%)	1					
TEMPERATURE(17.9-21.30c)		1				
RAINFALL(770-886mm)			1			
SOIL PROPERTIES				1		
SMI (0.101-0.737)					1	
LST(10-260c)						1

(Rate by using saaty scale whereby 1 = Equal important, 3 = Moderate important of one over another, 5 = Essential or strong important of one over another, 7 = Very strong or demonstrated importance, 9 = Absolute importance).

2. What is your opinion on the relative importance (influence) of the following criteria on allocating Agroforestry at the foothill of Uluguru sloping mountain (497-702m)?

Agroforestry	SLOPE (08-12%)	TEMPERATURE (17.9-21.30c)	RAINFALL (770-886mm)	SOIL PROPERTIES	SMI (0.101-0.737%)	LST (10-260c)
SLOPE (08-12%)	1					
TEMPERATURE (17.9-21.30c)		1				
RAINFALL(770-886mm)			1			
SOIL PROPERTIES				1		
SMI (0.101-0.737)					1	
LST(10-260c)						1

(Rate by using saaty scale whereby 1 = Equal important, 3 = Moderate important of one over another, 5 = Essential or strong important of one over another, 7 = Very strong or demonstrated importance, 9 = Absolute importance).

3. What is your opinion on the relative importance (influence) of the following criteria on allocating Conservation Agriculture at the foothill of Uluguru sloping mountain (497-702m)?

Conservation Agriculture	SLOPE(08-12%)	TEMPERATURE (17.9-21.30c)	RAINFALL (770-886mm)	SOIL PROPERTIES	SMI (0.101-0.737%)	LST (10-260c)
SLOPE (08-12%)	1					
TEMPERATURE (17.9-21.30c)		1				
RAINFALL (770-886mm)			1			
SOIL PROPERTIES				1		
SMI (0.101-0.737)					1	
LST(10-260c)						1

(Rate by using saaty scale whereby 1 = Equal important, 3 = Moderate important of one over another, 5 = Essential or strong important of one over another, 7 = Very strong or demonstrated importance, 9 = Absolute importance).

4. What is your opinion on the relative importance (influence) of the following criteria on allocating Forest at the foothill of Uluguru sloping mountain (497-702m)?

FOREST	SLOPE(08-12%)	TEMPERATURE (17.9-21.30c)	RAINFALL(770-886mm)	SOIL PROPERTIES	SMI(0.101-0.737%)	LST(10-260c)
SLOPE (08-12%)	1					
TEMPERATURE(17.9-21.30c)		1				
RAINFALL(770-886mm)			1			
SOIL PROPERTIES				1		
SMI (0.101-0.737)					1	
LST(10-260c)						1

(Rate by using saaty scale whereby 1 = Equal important, 3 = Moderate important of one over another, 5 = Essential or strong important of one over another, 7 = Very strong or demonstrated importance, 9 = Absolute importance).

5. What is your opinion on the relative importance (influence) of the following criteria on allocating settlement at the low to middle elevation of the Uluguru sloping mountain (702-882m)?

Settlements	SLOPE (12-20%)	TEMPERATURE (17.9-19.1)	RAINFALL (770-886mm)	SOIL PROPERTIES	SMI (0.081-0.885%)	LST (7-10c)
SLOPE (12-20%)	1					
TEMPERATURE (17.9-19.1)		1				
RAINFALL(770-886MM)			1			
SOIL PROPERTIES				1		
SMI(0.73-0.88)					1	
LST(7-10^{0}c)						1

(Rate by using saaty scale whereby 1 = Equal important, 3 = Moderate important of one over another, 5 = Essential or strong important of one over another, 7 = Very strong or demonstrated importance, 9 = Absolute importance).

6. What is your opinion on the relative importance (influence) of the following criteria on allocating Agroforestry at the low to middle elevation of the Uluguru sloping mountain (702-882m)?

Agroforestry	SLOPE (12-20%)	TEMPERATURE (17.9-19.1)	RAINFALL (770-886mm)	SOIL PROPERTIES	SMI(0.081-0.885%)	LST(7-10c)
SLOPE (12-20%)	1					
TEMPERATURE (17.9-19.1)		1				
RAINFALL(770-886MM)			1			
SOIL PROPERTIES				1		
SMI(0.073-0.885)					1	
LST(7-10^{0}c)						1

(Rate by using saaty scale whereby 1 = Equal important, 3 = Moderate important of one over another, 5 = Essential or strong important of one over another, 7 = Very strong or demonstrated importance, 9 = Absolute importance).

7. What is your opinion on the relative importance (influence) of the following criteria on allocating Conservation Agriculture at the low to middle elevation of the Uluguru sloping mountain (702-882m)?

Conservation Agriculture	SLOPE (12-20%)	TEMPERATURE (17.9-19.1)	RAINFALL (770-886mm)	SOIL PROPERTIES	SMI (0.081-0.885%)	LST (7-10c)
SLOPE (12-20%)	1					
TEMPERATURE (17.9-19.1)		1				
RAINFALL(770-886MM)			1			
SOIL PROPERTIES				1		
SMI(0.081-0.885)					1	
LST(7-10^0c)						1

(Rate by using saaty scale whereby 1 = Equal important, 3 = Moderate important of one over another, 5 = Essential or strong important of one over another, 7 = Very strong or demonstrated importance, 9 = Absolute importance).

8. What is your opinion on the relative importance (influence) of the following criteria on allocating Forest at the low to middle elevation of the Uluguru sloping mountain (702-882m)?

Forest	SLOPE (12-20%)	TEMPERATURE (17.9-19.1)	RAINFALL (770-886mm)	SOIL PROPERTIES	SMI (0.081-0.885%)	LST (7-10c)
SLOPE (12-20%)	1					
TEMPERATURE (17.9-19.1)		1				
RAINFALL(770-886MM)			1			
SOIL PROPERTIES				1		
SMI(0.075-0.885)					1	
LST(7-10^0c)						1

(Rate by using saaty scale whereby 1 = Equal important, 3 = Moderate important of one over another, 5 = Essential or strong important of one over another, 7 = Very strong or demonstrated importance, 9 = Absolute importance).

9. What is your opinion on the relative importance (influence) of the following criteria on allocating settlement at the middle elevation of the Uluguru sloping mountain (882-1094m)?

SETTLEMENT	SLOPE (20-28%)	TEMPERATUR (16.2-17.8^{0}c)	RAINFALL (886-953mm)	SOIL PROPERTIES	SMI (-1.44×10^{-8} - 0.872%)	LST (3-10^{0}c)
SLOPE (20-28%)	1					
TEMPERATURE (16.2-17.8^{0}c)		1				
RAINFALL(886-953mm)			1			
SOIL PROPERTIES				1		
SMI(0.885 -0.887)					1	
LST(3-10^{0}c)						1

(Rate by using saaty scale whereby 1 = Equal important, 3 = Moderate important of one over another, 5 = Essential or strong important of one over another, 7 = Very strong or demonstrated importance, 9 = Absolute importance).

10. What is your opinion on the relative importance (influence) of the following criteria on allocating Agroforestry Agriculture at the middle elevation of the Uluguru sloping mountain (882-1094m)?

Agroforestry	SLOPE (20-28%)	TEMPERATUR (16.2-17.8^{0}c)	RAINFALL (886-953mm)	SOIL PROPERTIES	SMI (-1.44×10^{-8} - 0.872%)	LST (3-10^{0}c)
SLOPE (20-28%)	1					
TEMPERATURE (16.2-17.8^{0}c)		1				
RAINFALL(886-953mm)			1			
SOIL PROPERTIES				1		
SMI(0.885-0.887)					1	
LST(3-10^{0}c)						1

(Rate by using saaty scale whereby 1 = Equal important, 3 = Moderate important of one over another, 5 = Essential or strong important of one over another, 7 = Very strong or demonstrated importance, 9 = Absolute importance).

11. What is your opinion on the relative importance (influence) of the following criteria on allocating Conservation Agriculture at the middle elevation of the Uluguru sloping mountain (882-1094m)?

Conservation Agriculture	SLOPE (20-28%)	TEMPERATUR (16.2-17.8^{0}c)	RAINFALL (886-953mm)	SOIL PROPERTIES	SMI (-1.44×10^{-8} - 0.872%)	LST (3-10^{0}c)
SLOPE (20-28%)	1					
TEMPERATURE (16.2-17.8^{0}c)		1				

RAINFALL(886-953mm)			1			
SOIL PROPERTIES				1		
SMI(0.885-0.887)					1	
LST(3-10^{0}c)						1

(Rate by using saaty scale whereby 1 = Equal important, 3 = Moderate important of one over another, 5 = Essential or strong important of one over another, 7 = Very strong or demonstrated importance, 9 = Absolute importance).

12. What is your opinion on the relative importance (influence) of the following criteria on allocating Forest at the middle elevation of the Uluguru sloping mountain (882-1094m)?

SETTLEMENT	SLOPE (20-28%)	TEMPERATUR (16.2-17.8^{0}c)	RAINFALL (886-953mm)	SOIL PROPERTIES	SMI (-1.44×10^{-8} - 0.872%)	LST (3-10^{0}c)
SLOPE (20-28%)	1					
TEMPERATURE (16.2-17.8^{0}c)		1				
RAINFALL(886-953mm)			1			
SOIL PROPERTIES				1		
SMI(0.885-0.887)					1	
LST(3-10^{0}c)						1

(Rate by using saaty scale whereby 1 = Equal important, 3 = Moderate important of one over another, 5 = Essential or strong important of one over another, 7 = Very strong or demonstrated importance, 9 = Absolute importance).

13. What is your opinion on the relative importance (influence) of the following criteria on allocating settlement at the moderate steep slope elevation of the Uluguru sloping mountain (1094-1341)?

SETTLEMENT	SLOPE (28-38%)	TEMPERATURE (16.2-17.8^{0}c)	RAINFALL (886-953mm)	SOIL PROPERTIES	SMI (0.143-0.99%.)	LST(3-7^{0}c)
SLOPE (28-38)	1					
TEMPERATURE (16.2-17.8^{0}c)		1				
RAINFALL(886-953mm)			1			

SOIL PROPERTIES				1		
SMI(0.87-0.91)					1	
LST(3-7^{0}c)						1

(Rate by using saaty scale whereby 1 = Equal important, 3 = Moderate important of one over another, 5 = Essential or strong important of one over another, 7 = Very strong or demonstrated importance, 9 = Absolute importance).

14. What is your opinion on the relative importance (influence) of the following criteria on allocating Agroforestry at the moderate steep slope elevation of the Uluguru sloping mountain (882-1094m)?

Agroforestry	SLOPE (28-38%)	TEMPERATURE (16.2-17.8^{0}c)	RAINFALL (886-953mm)	SOIL PROPERTIES	SMI (0.143-0.99%.)	LST(3-7^{0}c)
SLOPE (28-38)	1					
TEMPERATURE (16.2-17.8^{0}c)		1				
RAINFALL(886-953mm)			1			
SOIL PROPERTIES				1		
SMI(0.87-0.91)					1	
LST(3-7^{0}c)						1

(Rate by using saaty scale whereby 1 = Equal important, 3 = Moderate important of one over another, 5 = Essential or strong important of one over another, 7 = Very strong or demonstrated importance, 9 = Absolute importance).

15. What is your opinion on the relative importance (influence) of the following criteria on allocating Conservation Agriculture at the moderate steep slope elevation of the Uluguru sloping mountain (882-1094m)?

Conservation Agriculture	SLOPE (28-38%)	TEMPERATURE (16.2-17.8^{0}c)	RAINFALL (886-953mm)	SOIL PROPERTIES	SMI (0.143-0.99%.)	LST(3-7^{0}c)
SLOPE (28-38)	1					
TEMPERATURE (16.2-17.8^{0}c)		1				
RAINFALL(886-953mm)			1			
SOIL PROPERTIES				1		
SMI(0.87-0.91)					1	
LST(3-7^{0}c)						1

(Rate by using saaty scale whereby 1 = Equal important, 3 = Moderate important of one over another, 5 = Essential or strong important of one over another, 7 = Very strong or demonstrated importance, 9 = Absolute importance).

16. What is your opinion on the relative importance (influence) of the following criteria on allocating Forest at the moderate steep slope elevation of the Uluguru sloping mountain (882-1094m)?

Forest	SLOPE (28-38%)	TEMPERATURE (16.2-17.8^{0}c)	RAINFALL (886-953mm)	SOIL PROPERTIES	SMI (0.143-0.99%.)	LST(3-7^{0}c)
SLOPE (28-38)	1					
TEMPERATURE (16.2-17.8^{0}c)		1				
RAINFALL(886-953mm)			1			
SOIL PROPERTIES				1		
SMI(0.87-0.91.)					1	
LST(3-7^{0}c)						1

(Rate by using saaty scale whereby 1 = Equal important, 3 = Moderate important of one over another, 5 = Essential or strong important of one over another, 7 = Very strong or demonstrated importance, 9 = Absolute importance).

17. What is your opinion on the relative importance (influence) of the following criteria on allocating Settlement at the steep slope elevation of the Uluguru sloping mountain (1341-1772m)?

Settlement	SLOPE (38-72%)	TEMPERATURE (16.2-17.8^{0}c)	RAINFALL(1023-1111mm)	SOIL PROPERTIES	SMI (0.28 - 0.97)	LST(-9-3^{0}c ()
SLOPE (38-72%)	1					
TEMPERATURE (16.2-17.8^{0}c)		1				
RAINFALL(1023-1111mm)			1			
SOIL PROPERTIES				1		
SMI (0.91 - 0.97					1	
LST(-9-3^{0}c)						1

(Rate by using saaty scale whereby 1 = Equal important, 3 = Moderate important of one over another, 5 = Essential or strong important of one over another, 7 = Very strong or demonstrated importance, 9 = Absolute importance).

18. What is your opinion on the relative importance (influence) of the following criteria on allocating Conservation Agriculture at the steep slope elevation of the Uluguru sloping mountain (1341-1772m)?

Conservation Agriculture	SLOPE (38-72%)	TEMPERATURE (16.2-17.8^{0}c)	RAINFALL(1023-1111mm)	SOIL PROPERTIES	SMI (0.28 - 0.97)	LST(-9-3^{0}c ()
SLOPE (38-72%)	1					
TEMPERATURE (16.2-17.8^{0}c)		1				
RAINFALL(1023-1111mm)			1			
SOIL PROPERTIES				1		
SMI (0.91 - 0.97)					1	
LST(-9-3^{0}c)						1

(Rate by using saaty scale whereby 1 = Equal important, 3 = Moderate important of one over another, 5 = Essential or strong important of one over another, 7 = Very strong or demonstrated importance, 9 = Absolute importance).

19. What is your opinion on the relative importance (influence) of the following criteria on allocating Agroforestry at the steep slope elevation of the Uluguru sloping mountain (1341-1772m)?

Agroforestry	SLOPE (38-72%)	TEMPERATURE (16.2-17.8^{0}c)	RAINFALL(1023-1111mm)	SOIL PROPERTIES	SMI (0.28 - 0.97)	LST(-9-3^{0}c ()
SLOPE (38-72%)	1					
TEMPERATURE (16.2-17.8^{0}c)		1				
RAINFALL(1023-1111mm)			1			
SOIL PROPERTIES				1		
SMI (0.91 - 0.97					1	
LST(-9-3^{0}c)						1

(Rate by using saaty scale whereby 1 = Equal important, 3 = Moderate important of one over another, 5 = Essential or strong important of one over another, 7 = Very strong or demonstrated importance, 9 = Absolute importance).

20. What is your opinion on the relative importance (influence) of the following criteria on allocating Forest at the steep slope elevation of the Uluguru sloping mountain (1341-1772m)?

Forest	SLOPE (38-72%)	TEMPERATURE (16.2-17.8^{0}c)	RAINFALL(1023-1111mm)	SOIL PROPERTIES	SMI (0.28 - 0.97)	LST(-9-3^{0}c ()
SLOPE (38-72%)	1					
TEMPERATURE (16.2-17.8^{0}c)		1				
RAINFALL(1023-1111mm)			1			
SOIL PROPERTIES				1		
SMI (0.91 - 0.97					1	
LST(-9-3^{0}c)						1

(Rate by using saaty scale whereby 1 = Equal important, 3 = Moderate important of one over another, 5 = Essential or strong important of one over another, 7 = Very strong or demonstrated importance, 9 = Absolute importance).

Appendix 2: Geometric mean of criteria

Settlement											
	Average	**Average**	**Average**	**Average**	**Average**	**Average**	**Average**	**Average**	**Average**	**Average**	**GM**
SLOPE	0.166223	0.206015283	0.1268807	0.1082114	0.185286	0.187696468	0.107696468	0.1043412	0.2472668	0.446623	0.170110915
TEMPERATURE	0.052662	0.048725357	0.1395197	0.161784	0.162614	0.044992706	0.044992706	0.0497965	0.1871908	0.154908	0.087898631
RAINFALL	0.191324	0.156401241	0.1970026	0.1451871	0.202206	0.26812463	0.26812463	0.2484045	0.1988272	0.1468	0.197480262
SOIL PROPERTIES	0.173268	0.144356645	0.1236699	0.1459231	0.139348	0.16384839	0.16484839	0.1652853	0.0921923	0.123002	0.141351777
SMI	0.080303	0.056031938	0.0492975	0.0524366	0.046791	0.100727424	0.100727424	0.1134268	0.1015454	0.069841	0.073241596
LST	0.03622	0.043469538	0.0556296	0.0564578	0.063755	0.034610382	0.034610382	0.0387456	0.0329774	0.028826	0.041146325
total	0.7	0.655	1	1	1	1	1	1	1	1	0.71
forest											
	Average	**Average**	**Average**	**Average**	**Average**	**Average**	**Average**	**Average**	**Average**	**Average**	**GM**
SLOPE	0.320186	0.015725793	0.0151917	0.0920555	0.122327	0.12507303	0.300073	0.0253974	0.2014196	0.007788	0.06471302
TEMPERATURE	0.045802	0.339676969	0.0533113	0.1529682	0.11206	0.053742682	0.120442682	0.05482	0.0137969	0.038514	0.069634863
RAINFALL	0.10200	0.009724201	0.312	0.0440339	0.100055	0.122534526	0.110412109	0.1025595	0.1417448	0.126183	0.089730368
SOIL PROPERTIES	0.008918	0.077765741	0.1505581	0.0330433	0.100013	0.13749697	0.01049697	0.2130125	0.0431648	0.183859	0.062019152
SMI	0.034467	0.017360341	0.0465124	0.133242	0.054452	0.044124275	0.012124275	0.066568	0.0898607	0.089265	0.047435499
LST	0.035512	0.04044143	0.0076827	0.0474871	0.033763	0.024628517	0.044828517	0.0440427	0.0370131	0.05439	0.033407698
total	1	1	1	1	1	1	1	1	1	1	0.37
agroforest											
	Average	**Average**	**Average**	**Average**	**Average**	**Average**	**Average**	**Average**	**Average**	**Average**	**GM**
SLOPE	0.04391	0.052238306	0.0063444	0.0004903	0.016694	0.044970955	0.054497096	0.0044971	0.1356457	0.007829	0.016384442
TEMPERATURE	0.033546	0.038175809	0.103673	0.036428	0.110086	0.050330907	0.050330907	0.0503309	0.1614787	0.241681	0.069552358

RAINFALL	0.00874	0.134190451	0.1579659	0.2000636	0.257953	0.212529461	0.103529461	0.1235295	0.1380822	0.144723	0.11790801
SOIL PROPERTIES	0.065771	0.133286764	0.1257144	0.1990574	0.006402	0.222534824	0.149534824	0.1695348	0.1009575	0.125408	0.100031262
SMI	0.156092	0.072451704	0.0658824	0.0823363	0.065257	0.122817386	0.142817386	0.1428174	0.062319	0.065647	0.091476041
LST	0.121942	0.055656966	0.0604198	0.0554244	0.063608	0.024290326	0.001290326	0.0292903	0.041517	0.054711	0.035312031
total	0	0	1	1	1	1	1	1	1	1	0.43
Conservation Agriculture											
	Average	**Average**	**Average**	**Average**	**Average**	**Average**	**Average**	**Average**	**Average**	**Average**	**GM**
SLOPE	0.105285	0.066632249	0.0718401	0.0493595	0.009746	0.107569976	0.157569976	0.10757	0.0030603	0.100425	0.051678319
TEMPERATURE	0.042042	0.044959499	0.2009289	0.0459242	0.131096	0.050622068	0.050622068	0.0506221	0.241141	0.206227	0.082581249
RAINFALL	0.103611	0.12268193	0.1358086	0.1814839	0.187783	0.208716221	0.038716221	0.1387162	0.1264411	0.198955	0.132428913
SOIL PROPERTIES	0.158231	0.023670139	0.0123646	0.186969	0.118375	0.237797368	0.257797368	0.2177974	0.103087	0.082338	0.101509024
SMI	0.079128	0.087921744	0.0512133	0.0803541	0.043077	0.102366176	0.132366176	0.1323662	0.079566	0.074573	0.081622027
LST	0.051703	0.05413444	0.0678445	0.0559093	0.049924	0.032928191	0.032928191	0.0329282	0.0387047	0.037483	0.044041234
total	0.54	0.4	0.54	0.6	0.54	0.74	0.67	0.68	0.592	0.7	0.493860767

agroforest											
	Average	Average	Average	Average	Average	Average	Average	Average	Average	Average	GM
SLOPE	0.129156	0.044812	0.122536	0.102491	0.104497	0.00857	0.143777	0.087781	0.013723	0.078693	0.062345
TEMPERATURE	0.113156	0.110752	0.037977	0.046718	0.050331	0.04742	0.0446	0.0563	0.043147	0.044689	0.055079
RAINFALL	0.147601	0.045836	0.143149	0.147151	0.123529	0.137849	0.125372	0.120481	0.370369	0.415634	0.149675
SOIL PROPERTIES	0.046112	0.007679	0.121517	0.13511	0.139535	0.107864	0.100151	0.101976	0.087109	0.156193	0.081
SMI	0.08162	0.074885	0.109306	0.105659	0.142817	0.0842	0.068674	0.09759	0.048013	0.04897	0.081777
LST	0.043855	0.046036	0.051515	0.042871	0.02929	0.054097	0.047425	0.045206	0.057639	0.055821	0.046643
total	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**0.8**	**0.476519**
Conservation Agriculture											
	Average	Average	Average	Average	Average	Average	Average	Average	Average	Average	GM
SLOPE	0.148774	0.175656	0.103159	0.127169	0.08757	0.14033	0.101536	0.039659	0.127539	0.221688	0.116975
TEMPERATURE	0.10861	0.109735	0.108033	0.043598	0.050622	0.075983	0.065243	0.12425	0.058052	0.058477	0.075403
RAINFALL	0.15766	0.106522	0.108535	0.129544	0.128716	0.120799	0.147798	0.103666	0.1493	0.324553	0.139171
SOIL PROPERTIES	0.12225	0.089098	0.109264	0.162022	0.157797	0.118244	0.19974	0.108326	0.176777	0.178313	0.137716
SMI	0.077706	0.085857	0.082094	0.092188	0.132366	0.046738	0.056474	0.111843	0.048663	0.053822	0.074358
LST	0.045001	0.053132	0.067597	0.035479	0.032928	0.039907	0.049209	0.017143	0.039669	0.033147	0.039103
total	**0.66**	**0.62**	**0.6**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**0.582727**

Settlement											
	Average	Average	Average	Average	Average	Average	Average	Average	Average	Average	gm
SLOPE	0.113287	0.10074	0.008481	0.110406	0.343459	0.00386113	0.102001	0.062771	0.062771	0.004934761	0.04414508
TEMPERATURE	0.048407	0.04579	0.06369	0.062655	0.066668	0.000763455	0.063297	0.063297	0.063297	0.204819704	0.043340321
RAINFALL	0.102058	0.002229	0.080762	0.132397	0.210694	0.000224617	0.008678	0.01278	0.258678	0.103376585	0.028400868
SOIL PROPERTIES	0.120125	0.100312	0.100026	0.152399	0.104665	0.00086132	0.000108	0.133708	0.103708	0.099028054	0.03458511
SMI	0.063383	0.062708	0.062367	0.000201	0.045138	0.110038715	0.110073	0.111673	0.015673	0.058388931	0.035024301
LST	0.04374	0.036922	0.031675	0.005523	0.042376	0.021234701	0.035312	0.035874	0.035874	0.034288771	0.028825715
total	1	1	1	1	1	1	1	1	1	1	0.214321397
forest											
	Average	Average	Average	Average	Average	Average	Average	Average	Average	Average	gm
SLOPE	0.106187	0.124456	0.019456	0.213112	0.000676	0.000268097	0.015944	0.001868	0.016868	0.163855197	0.015532865
TEMPERATURE	0.041317	0.047289	0.04367	0.058467	0.060737	0.029066689	0.041033	0.031557	0.021557	0.100075889	0.043561008
RAINFALL	0.381494	0.012446	0.104373	0.044367	0.003234	0.007271453	0.001861	0.014577	0.001771	0.200363632	0.018607702
SOIL PROPERTIES	0.213823	0.222367	0.009613	0.20187	0.010312	0.008303537	0.100952	0.005581	0.115581	0.153925239	0.048963858
SMI	0.053384	0.0602	0.051596	0.032677	0.063581	0.033824058	0.002797	0.002879	0.100288	0.07987479	0.030732107
LST	0.043796	0.033242	0.041292	0.045507	0.049119	0.033266165	0.034413	0.010129	0.040129	0.026905253	0.033311245
total	1	1	1	1	1	1	1	1	1	1	0.190708785
agroforest											
	Average	Average	Average	Average	Average	Average	Average	Average	Average	Average	gm
SLOPE()	0.130155	0.119514	0.210051	0.262659	0.207556	0.0000868	0.123701	0.114819	0.314819	0.401244965	0.087965308
TEMPERATURE ()	0.089814	0.030457	0.059278	0.060572	0.062984	0.043418244	0.126234	0.123118	0.129118	0.197399539	0.079926775
RAINFALL()	0.19353	0.220156	0.195068	0.236304	0.21796	0.028746579	0.234306	0.241147	0.241147	0.164709197	0.175435068
SOIL()	0.163151	0.167066	0.195176	0.157947	0.195964	0.134249595	0.093262	0.043741	0.093741	0.110005519	0.12498082

SMI()	0.053472	0.073018	0.060501	0.058989	0.057035	0.007901866	0.076811	0.143995	0.143995	0.087224806	0.062240221
LST()	0.039878	0.05979	0.078826	0.053562	0.058501	0.031468907	0.045686	0.077181	0.077181	0.039415973	0.053683392
total	1	1	1	1	1	1	1	1	1	1	0.584231584
Conservation Agriculture											
	Average	Average	Average	Average	Average	Average	Average	Average	Average	Average	GM
SLOPE()	0.215697	0.11173	0.110551	0.135615	0.003038	0.004800622	0.214801	0.123095	0.123095	0.100906944	0.066653989
TEMPERATURE ()	0.044269	0.059393	0.061124	0.057601	0.053602	0.038586378	0.038586	0.045575	0.045575	0.10051211	0.052338487
RAINFALL()	0.093896	0.006273	0.34848	0.309625	0.207837	0.00631679	0.427632	0.212707	0.082707	0.132014874	0.098138717
SOIL()	0.003441	0.123937	0.151075	0.151127	0.009534	0.124299985	0.1243	0.117202	0.057202	0.11815233	0.063906219
SMI()	0.092811	0.053456	0.08524	0.070395	0.087168	0.103675338	0.103675	0.121552	0.131552	0.141628245	0.095510332
LST()	0.036885	0.04521	0.043529	0.045637	0.038821	0.031005998	0.031006	0.059868	0.059868	0.047446396	0.04288179
total	1	1	1	1	1	1	1	1	1	1	0.419429534

Settlement										
	Average	Average	Average	Average	Average	Average	Average	Average	Average	Average	GM
SLOPE()	0.233007	0.117628	0.044608	0.001141	0.001141	0.000653	0.110653	0.101477	0.111647652	0.131276517	0.026503617
TEMPERATURE ()	0.033579	0.038376	0.043164	0.044717	0.044717	0.040439	0.040439	0.311155	0.113154824	0.111154824	0.060987095
RAINFALL()	0.37203	0.343957	0.129406	0.109561	0.019561	0.007071	0.170712	0.106645	0.078645461	0.101645461	0.090417934
SOIL()	0.162911	0.189373	0.115401	0.100724	0.101724	0.000522	0.110022	0.081283	0.181282738	0.001282738	0.045688146
SMI()	0.105228	0.092145	0.080434	0.085622	0.005622	0.001389	0.117389	0.092851	0.192850891	0.012850891	0.041197419
LST()	0.033246	0.036521	0.046987	0.050234	0.050234	0.029526	0.021526	0.04359	0.043589569	0.013589569	0.034461932
total	1	1	0	0	0	0	1	1	1	0	0.299256143
forest											
	Average	**Average**	**Average**	**Average**	**Average**	**Average**	**Average**	**Average**	**Average**	**Average**	**GM**
SLOPE	0.188281	0.111348	0.122963	0.244807	0.216453	0.244799	0.124799	0.221597	0.101596701	0.011596701	0.126977018
TEMPERATURE	0.066341	0.0775	0.079078	0.075346	0.08024	0.037762	0.037762	0.145941	0.245940643	0.243940643	0.088858634
RAINFALL	0.252533	0.237537	0.210517	0.329444	0.127131	0.105343	0.405343	0.157892	0.127892198	0.157892198	0.193079645
SOIL PRPERTIES	0.244156	0.232362	0.138227	0.184254	0.175984	0.112265	0.242265	0.112719	0.112418667	0.112718667	0.158295247
SMI	0.112301	0.089075	0.084009	0.089514	0.066648	0.117655	0.117655	0.076461	0.076460856	0.076460856	0.088954465
LST	0.036388	0.052177	0.045206	0.045634	0.063544	0.022177	0.022177	0.025391	0.025390935	0.025390935	0.033898684
total	1	1	1	1	1	1	1	1	1	1	0.690063694
agroforest											
	Average	**Average**	**Average**	**Average**	**Average**	**Average**	**Average**	**Average**	**Average**	**Average**	**GM**
SLOPE	0.042571	0.05609	0.073688	0.100816	0.011539	0.112342	0.001429	0.104008	0.044487681	0.111087681	0.041951911
TEMPERATURE	0.057818	0.092326	0.050035	0.011633	0.103554	0.047795	0.110019	0.062159	0.142129476	0.132159476	0.067540929
RAINFALL	0.218665	0.099325	0.103275	0.102422	0.111767	0.21501	0.11	0.110365	0.02000000	0.104247047	0.103402638
SOIL PROPERTIES	0.10066	0.136558	0.103536	0.13267	0.11	0.07124	0.200007	0.123659	0.113659476	0.100649476	0.1153943

SMI	0.045543	0.017256	0.105525	0.102518	0.13426	0.022115	0.012124	0.103621	0.04362079	0.00962079	0.040965043
LST	0.044343	0.098446	0.079937	0.054439	0.030187	0.031527	0.114342	0.047108	0.142107872	0.045107872	0.060191553
total	1	1	1	1	1	1	1	1	1	1	0.429446374
Conservation Agriculture											
	Average	**Average**	**Average**	**Average**	**Average**	**Average**	**Average**	**Average**	**Average**	**Average**	**GM**
SLOPE	0.003941	0.141657	0.102946	0.018721	0.022123	0.117397	0.16707	0.009922	0.109922276	0.009922276	0.03718367
TEMPERATURE	0.101698	0.127814	0.121724	0.119908	0.097334	0.046978	0.109149	0.100969	0.197969015	0.100969015	0.106690709
RAINFALL	0.002238	0.202116	0.276044	0.167298	0.316595	0.476162	0.120177	0.100885	0.100884517	0.100884517	0.114537557
SOIL PRPERTIES	0.133087	0.110911	0.187383	0.188701	0.171086	0.101115	0.10595	0.093468	0.093468239	0.093468239	0.122821445
SMI	0.06003	0.082708	0.0761	0.058411	0.049928	0.310779	0.063608	0.070223	0.07022334	0.07022334	0.077224447
LST	0.045019	0.034794	0.035804	0.021961	0.042933	0.027569	0.034047	0.037533	0.037532612	0.037532612	0.034825641
total	1	1	1	1	1	1	1	1	1	1	0.493283468

Settlement											
	Average	Average	Average	Average	Average	Average	Average	Average	Average	Average	**GM**
SLOPE	0.049022	0.002927	0.100192	0.042985	0.041227	0.012345	0.1005951	0.210011	0.019349	0.019349	0.03464
TEMPERATURE	0.035191	0.057086	0.063311	0.06322	0.32206	0.226305	0.0054606	0.043325	0.114325	0.324325	0.074319
RAINFALL	0.220523	0.201414	0.211444	0.230072	0.018055	0.132783	0.1732539	0.232463	0.014363	0.004463	0.081777
SOIL PROPERTIES	0.2113	0.060162	0.057558	0.054101	0.041113	0.045331	0.0587644	0.006536	0.096536	0.006536	0.042192
SMI	0.032272	0.1515	0.079512	0.061114	0.043662	0.124984	0.2041069	0.013689	0.223689	0.163689	0.081708
LST	0.049692	0.04391	0.031983	0.048507	0.043883	0.0385	0.0284394	0.036638	0.036638	0.036638	0.038932
total	1	1	1	1	1	1	1	1	1	1	0.35
forest											
	Average	Average	Average	Average	Average	Average	Average	Average	Average	Average	**GM**
SLOPE	0.204312	0.295804	0.276344	0.279083	0.111669	0.23561	0.144282	0.237557	0.227557	0.137557	0.205077
TEMPERATURE	0.107172	0.093836	0.103673	0.108111	0.110086	0.042428	0.1501927	0.148378	0.138378	0.148378	0.10919
RAINFALL	0.271699	0.30074	0.257966	0.340368	0.297953	0.467755	0.2616999	0.257947	0.257947	0.257947	0.291901
SOIL PROPERTIES	0.154694	0.135703	0.135714	0.138815	0.146402	0.130485	0.0830906	0.184679	0.084679	0.084679	0.123588
SMI	0.104236	0.119593	0.065882	0.065194	0.045257	0.090246	0.1229748	0.131803	0.131803	0.131803	0.095266
LST	0.057887	0.054324	0.06042	0.068429	0.063608	0.033476	0.0377599	0.039637	0.039637	0.039637	0.048013
total	0.9	1	1	1	0.8	1	0.8	1	1	0.8	0.873034
agroforest											
	Average	Average	Average	Average	Average	Average	Average	Average	Average	Average	**GM**
SLOPE	0.100112	0.000621	0.014881	0.000314	0.014236	0.114422	0.0023381	0.097644	0.002644	0.003242	0.007883

TEMPERATURE	0.160278	0.012294	0.11252	0.10006	0.122614	0.113426	0.1002328	0.104075	0.112045	0.114075	0.091501
RAINFALL	0.238336	0.3005	0.250003	0.232283	0.102206	0.222065	0.0102279	0.021123	0.004113	0.000153	0.040812
SOIL PROPERTIES	0.012824	0.130859	0.00367	0.109208	0.120348	0.100376	0.1023873	0.100169	0.100569	0.100569	0.062026
SMI	0.056041	0.047196	0.149297	0.260007	0.214791	0.100094	0.1290142	0.142157	0.185337	0.343157	0.13838
LST	0.045409	0.045527	0.15463	0.04446	0.113755	0.100611	0.2502038	0.250202	0.420512	0.438002	0.134064
total	1	1	1	1	1	1	1	1	1	1	0.474665
Conservation Agriculture											
	Average	Average	Average	Average	Average	Average	Average	Average	Average	Average	**GM**
SLOPE	0.124308	0.100833	0.01424	0.016046	0.103651	0.100073	0.1000088	0.111746	0.110546	0.213746	0.077528
TEMPERATURE	0.142268	0.100007	0.200313	0.200009	0.251096	0.02322	0.2039322	0.200038	0.220394	0.237394	0.153139
RAINFALL	0.142631	0.104248	0.105809	0.102847	0.087783	0.141445	0.1000274	0.100059	0.132059	0.100059	0.110265
SOIL PROPERTIES	0.009133	0.100394	0.102365	0.112001	0.100375	0.101418	0.1000886	0.128742	0.000742	0.128742	0.051521
SMI	0.031606	0.046763	0.042213	0.041225	0.013077	0.10871	0.0621409	0.068236	0.048236	0.058236	0.046121
LST	0.050054	0.053972	0.067845	0.06058	0.014924	0.027034	0.037942	0.042823	0.002823	0.042823	0.031221
total	1	1	1	1	1	1	1	1	1	1	0.469795

Appendix 3: Physico-chemical properties and clay mineralogy of the soils of Morogoro Urban District

Landform	Soil depth	Soil drainage	Soil texture	pH	OC %	N %	P mg/kg	ESP	CEC cmol(+)/kg	BS %	Clay mineralogy
Uluguru mountain strongly dissected ridge slopes (Units M1, M2, M3)	S-MD	E-W	grSCL, SC-C	5.5-6.0	0.1-1.2	0.01-0.05	1.0-5.0	Tr	4.0-12.0	20-85	kaolinite (84%), gibbsite (7%), illite (5%), mica-vermiculite (4%)
Uluguru mountain foothills (Unit P1)	D-VD	W	SC-C	5.0-6.5	0.5-1.0	0.01-0.10	1.0-2.0	Tr	10.0-13.0	30-65	kaolinite (80%), mica-vermiculite (8%), illite (6%), gibbsite (6%)
Mindu-Lugala hills (Units M4, L1)	S	E	grSL-SCL	5.5-6.5	0.3-0.8	0.03-0.06	2.0-3.0	Tr	7.0-10.0	70-95	kaolinite (55%), illite (35%), smectite (10%),
Mzinga-Bigwa piedmont slopes (Units P2, P3),	VD	W	C	6.0-7.5	0.2-0.60	0.03-0.05	0.4-1.0	Tr	6.0-10.0	80-100	kaolinite (85%), illite (8%), gibbsite (6%), smectite (1%)
Mindu-Lugala piedmont slopes (Unit P4)	VD	E-W	LS-SL	6.0-7.0	0.3-0.4	0.04-0.08	0.7-1.4	Tr	8.0-14.0	80-100	kaolinite (50%), smectite (16%), illite (34%)
SUA-Kingolwira peneplains with undulating slopes (Units L2, L3)	D-VD	W	SC-C	4.5-6.5	0.3-0.7	0.04-0.05	1.2-1.8	Tr	10.0-12.0	25-45	kaolinite (78%), illite (10%), smectite (7%), mica-vermiculite (5%),
Tungi-Mkonowamara peneplains (Units L4, L5, L6)	MD-D	E-W	LS, SL-SCL	4.5-5.5	0.3-0.5	0.04-0.08	1.0-1.5	Tr	9.0-11.0	30-40	kaolinite (48%), smectite (20%), illite (32%)
Valleys with river terraces and floodplains (Units V1, V2)	VD	MW-P	L, CL-C	6.5-8.0	0.6-1.6	0.06-0.10	8.0-9.0	5-37	20.0-30.0	75-80	kaolinite (40%), smectite (26%), illite (30%), gibbsite (4%)

S=Shallow, MD=Moderately deep, D=Deep, VD=Very deep.E=Excessively drained, W=Well drained, MW=Moderately well drained, P=Poorly drainedtr=trace

Appendix 4: Existing and proposed land use on each land mapping unit

LAND MAPPING UNIT	EXISTING LU (%)		PROPOSED LU (%)		TOTAL AREA OF LAND MAPPIN UNIT (km2)
1	Built Up	22.85	Settlements	45.74	20.7
	Agriculture	61.07	Conservation Agriculture	49.78,	
	Close Woodland	0.04	Agroforestry	4.49	
	Open Woodland	15.29	Forest	0	
	Forest	0.75			
2	Built up	2.24	Settlements	6.87	21.30
	Agriculture	71.8	Conservation agriculture	46.29	
	Closed Woodland	1.30	Agroforestry	46.42	
	Open Woodland	24.66	Forest	0.41	
	Forest	0			
3	Built Up	8.17	Settlements	0.67	14.53
	Agriculture	65.21			
	Closed Woodland	0.68	Conservation Agriculture	84.46	
	Open Woodland	24.74	Agroforestry	11.32	
	Forest	1.20	Forest	3.54	
4	Built Up	0.34	Settlements	4.34	7.65
	Agriculture	63.30	Conservation Agriculture	10.11	
	Close Woodland	0			
	Open Woodland	32.86	Agroforestry	3.83	
	Forest	3.50	Forest	81.72	
5	Built Up	0	Settlements	0.47	2.12
	Agriculture	61.60	Conservation Agriculture	5.70	
	Close Woodland	0	Agroforestry	6.27	
	Open Woodland	19.09	Forest	87.55	
	Forest	19.32			