DEVELOPMENT OF A DECISION SUPPORT TOOL FOR SUSTAINABLE LAND MANAGEMENT TECHNOLOGIES IN THE UPPER TANA CATCHMENT: A CASE STUDY OF EMBU COUNTY, KENYA

PAUL MATHAIYA KAHIGA

MASTER OF SCIENCE

(Environmental Engineering and Management)

JOMO KENYATTA UNIVERSITY OF

AGRICULTURE AND TECHNOLOGY

2016

Development of a Decision Support Tool for Sustainable Land Management Technologies in the Upper Tana Catchment: A Case Study of Embu County, Kenya

Paul Mathaiya Kahiga

A thesis submitted in partial fulfilment for the Degree of Master of Science in Environmental Engineering and Management in the Jomo Kenyatta University of Agriculture and Technology

2016

DECLARATION

This thesis is my original work and has not been submitted for a degree in any other University.

Signature……………………………………………. Date……………........…………

Kahiga, Paul Mathaiya

This thesis has been submitted for examination with our approval as university supervisors.

Signature…………………………......…....…………….Date….....………........……

Prof. John. M. Gathenya (PhD)

JKUAT, Kenya

Signature……………………………………………. Date………………………

Prof. Patrick. G. Home (PhD)

JKUAT, Kenya

Signature……………………………………………. Date………………………

Dr. Jane. W. Wamuongo (PhD)

KALRO, Kenya

DEDICATION

I dedicate this work to my late mother, Mrs Lydia Wanjiku Kahiga and my lovely late sister Elizabeth Murugi Kahiga who both passed on through a tragic road accident when I was out of the country. I respect the time that the Lord gave us to be with them. They were a strong pillar and foundation of my academic excellence.

ACKNOWLEDGEMENT

I would like to express my sincere gratitude to my supervisors Prof. John. M. Gathenya, Prof. Patrick. G. Home and Dr. Jane. W. Wamuongo for their excellent professional guidance from the time of formulation of the proposal, field work and writing of this thesis. Special thanks to Mr. Mathias Gurtner, the World Overview of Conservation Approaches and Technologies (WOCAT) specialist and Dr. Hanspeter Liniger, the WOCAT coordinator from the University of Berne Switzerland, Centre for Development and Environment (CDE). They took their valuable time in training me and my research assistants about the WOCAT methodology and also occasionally accompanied me during the field work.

Walking with the Lord throughout this study period has indeed given me the hope and strength of facing the future with confidence. Completion of this study was enabled by the support, consultation, advice, and assistance of numerous personalities of whom I highly appreciate. I thank the Director, Kenya Agricultural and Livestock Research Organisation (KALRO) for giving me an opportunity to work on a vocational employment because it was during this time that I got the rare opportunity to pursue my post graduate studies. I appreciate the World Agroforestry Centre (ICRAF) through the Pro-Poor Rewards for Environmental Services in Africa (PRESA) project and the Food and Agricultural Organisation (FAO) through the Swedish International Development Agency (SIDA) for their partial financial assistance.

Many thanks to my friend and mentor, Major Nickson Odhiambo Kosi from the Kenya Defence Forces Technical College (KDFTC) who assisted in the development of the Decision Support (MATSIM) Tool. My able research assistants, Timothy, Andrew, Gethi and Mwangi together with my data analysts Silvia and Joel who were very instrumental in data collection and analysis. I also acknowledge in a special way, the Centre Director, KALRO-Embu, Dr. Njoka who provided the training venue and Mrs. Catherine Gethi for her excellent facilitation. Many thanks to my key informants, the District Agricultural Officers (DAO) for Embu West, Embu North and Mbeere South districts and their respective frontline Agricultural Extension Officers (AEO) for their wonderful facilitation during the field work. My sincere appreciation also goes to my classmates Timothy Njehia, Wycliffe Nyang'au, Sitienei Kibet and Martin Kiogora.

Many thanks to my family members who really encouraged me to press on even when the going became extremely tough. My dad, Mr. Joseph Kahiga together with my brothers and sisters, Christine Muthoni, Moffat Kuria, David Muhia and Dorcas Waitherero, were indeed a strong pillar of encouragement. They supported me financially and gave me the comfort that I needed throughout the long journey. To every person who has not been mentioned but in one way or the other, contributed directly or indirectly to the success of this academic work, I will always be eternally grateful for your abiding love and support. May the Almighty God bless you.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FORMS

LIST OF FIGURES

LIST OF PLATES

LIST OF APPENDICES

ABBREVIATIONS

ACZ	Agro-Climatic zone
AEO	Agricultural Extension Officer
AEZ	Agro-Ecological Zone
ASALs	Arid and Semi Arid Lands
CDE	Centre for Environment and Development
DAO	District Agricultural Officer
DBMS	Database Management System
DSS	Decision Support System
DST- MATSIM-Tool	**D**ecision **S**upport **T**ool-**MAT**haiya **SIM**ulation **Tool**
EIS	Executive Information Systems
FAO	Food and Agricultural Organisation
FESLM	Framework for Evaluating Sustainable Land Management
GLASOD	Global Assessment of Soil Degradation
IBSRAM	International Board for Soil Research and Management
ICRAF	World Agroforestry Centre
ISCO	International Soil Conservation Organisation
KARI	Kenya Agricultural Research Institute
KDFTC	Kenya Defence Forces Technical College
KSS	Kenya Soil Survey
LUT	Land Use Type

MEA	Millennium Ecosystem Assessment
NGOs	Non-Governmental Organizations
SIDA	Swedish International Development Agency
SLM	Sustainable Land Management technologies
SPSS	Statistical Package for Social Scientists
SSA	Sub Saharan Africa
SVM	Support Vector Machine
SWC	Soil and Water Conservation
UTaNRMP	Upper Tana Natural Resource Management Project
WOCAT	World Overview of Conservation Approaches and Technology
WRMA	Water Resources Management Authority

ABSTRACT

Several Sustainable Land Management (SLM) technologies have been identified as most promising land management options and if adopted by farmers, they would contribute to increased land productivity, increased ecosystem services and improved adaptation to climate change. Since the Upper Tana catchment consists of varying agro-ecological and socio-economic conditions, different technologies would be suitable under different conditions. In order to derive maximum benefits, there is a need to up-scale these already identified SLM technologies. One important step towards up-scaling of these technologies is development of a decision support mechanism in order to assist the farmers and catchment managers identify the most suitable SLM technologies. This study aimed to develop such a decision support tool by identifying and documenting successful SLM technologies and evaluating the factors contributing to their success. Data on SLM technologies was collected using both primary and secondary sources. Non-probability sampling strategy was employed during the study to determine the sample size. A questionnaire survey administered to purposefully selected households was used to identify the most common practiced SLM technologies. The results were then analysed using Statistical Package for Social Scientists (SPSS) software. The World Overview of Conservation Approaches and Technologies (WOCAT) methodology was used to document the identified SLM technologies. The framework uses three detailed questionnaires for the analysis of technologies. For the purpose of this study, questionnaire on SLM technology (QT) was used and twenty five SLM technologies were documented. The identified technologies were categorized as agronomic, vegetative, structural and management technologies. Among the structural technologies that were identified, bench terraces (33%) and fanya juu terraces (30%) were the most common while grass strips (57%) were the most practiced vegetative technologies followed by boundary trees (26%). Agronomic technologies comprised of manuring (45%), zero tillage (2%), composting (16%), mixed cropping (8%) and contour cultivation (13%). Land use change, rotational grazing, change of management intensity, change of timing of activities and cut-and-carry were the most practiced management technologies but in varied percentages. The main factors influencing the choice of SLM technologies were; extent of land degradation, slope and climate. The study revealed that government extension services play a major role in information dissemination on SLM Technologies. The WOCAT framework was used in documenting the identified SLM technologies. In order for farmers and other catchment managers to know and assess the suitability of different SLMs for adoption and up-scaling within the catchment, a computer based Decision Support (MATSIM) Tool was developed by the use of Microsoft Access. Apart from the basic user interface, a built-in database of SLM technologies that was documented and presented using a standardized WOCAT template was developed. The tool was developed to assist the land users and watershed managers within the catchment in decision making on SLMs suitable for enhancing eco-system services and climate change adaptation. The tool offers a practical approach that if adopted will facilitate processes in which farmers and other catchment managers may share, select and decide on the most appropriate SLM solutions for their land. The tool has a built-in technical manual that further assists the user on how to operate the tool. The tool is scalable and can be adopted for any other catchment by simple manipulation of the catchment's biophysical parameters.

CHAPTER ONE

INTRODUCTION

1.0 Background

SLM measures are essential in addressing problems of land degradation and associated poverty and food insecurity. It is an integrated process of improving land management while alleviating poverty, promoting local development, and sustaining the flow of ecosystem goods and services from the land (Hurni, 2000). Maintaining ecosystem functioning is a prerequisite for Sustainable Land Management (SLM) which harbors great potential for preservation and enhancement of ecosystem services in all land use systems (Assessment of Millennium Ecosystem [AME], 2005). Degradation of water, soil and vegetation, as well as greenhouse gas emissions contributing to climate change can be limited by SLM practices that not only conserve natural resources but also contribute to yield increase. According to Scherr and Sthapit (2009), improved land management does not only enrich the landscapes and enhance food security but also helps to “cool” the planet by cutting greenhouse gas emissions and storing carbon in soils and in vegetation. Soil erosion is a worldwide environmental problem that degrades soil productivity and water quality, causes sedimentation of reservoirs and increases the probability of floods (Ouyang & Bartholic, 2001).

Liniger and Schwilch (2002) reported that there has been a considerable focus on studying and documenting soil degradation in the past. However, a comprehensive presentation of SLM practices, and Soil and Water Conservation (SWC) in particular, has not yet been undertaken. Wealth of knowledge and information on SLM exists, but the challenge is to collect this information and make it available for exchange of know-how between land users and SLM specialists, technicians, agricultural advisors, planners, coordinators and decision makers (Bossio & Geheb, 2008). Much of the local knowledge on SLM is not documented and is inaccessible.

It is imperative therefore that the knowledge be shared especially with other land users working in similar areas, seeking to accomplish similar tasks.

The ecosystem services provided through Sustainable Land Management are of three different types, namely 1) provisioning (food, fresh water, wood and fiber and fuel), 2) regulating and supporting (climate regulation, flood and disease regulation and water purification), and 3) cultural/ social services (aesthetic, spiritual, educational and recreational). Implementing such paradigms as 'sustainable development' and 'conservation-effectiveness' has exposed potential conflicts between 'conventional' and 'environmentally-sensitive' objectives of natural resource management. Often encountered conflicts include: (a) enhancing food production, by using intensive inputs, while also controlling soil degradation and water pollution, and (b) selecting land uses and management practices to simultaneously counter several forms of degradation; e.g. reducing runoff and erosion by maximizing water infiltration while also preventing groundwater contamination by leached agro-chemicals (El-Swaify, 1998). Such conflicting phenomena can be averted by adopting a credible decision support system for selecting sustainable land management practices. Local soil knowledge is an important source of information when designing SLM strategies. Local people's insights, perceptions, and management strategies are often attuned to local soil conditions and can offer guidance for realistic land management practices (Antoinette, 1999).

Appropriate soil and water conservation technologies are those which offer for a given production situation an optimal solution for using the land for sustainable and productive agricultural purposes. Appropriate technologies should not be capital-intensive and they should use local resources and the existing labour force in an optimal way (Simpson, 2009). Before introducing a new technology it is necessary to check whether local soil and water conservation measures already exist and why and how farmers apply these technologies. If such technologies exist and continue to be applied by farmers, then, provided they have not been introduced and maintained by legal force and state authority, they can be considered successful and on investigation will be found to provide tangible benefits. Understanding the reasons why farmers use such technologies is the key to the successful introduction of any new technology, which must at least match and preferably improve on the benefits to be obtained from the existing ones (Simpson, 2009).

This study focused on sustainable land management technologies that are practiced in the Upper Tana Catchment. It involved identification of these technologies with the assistance of the Ministry of Agriculture's (MoA) extension officers in the Embu County. The exercise assisted in impact evaluation and documentation of these technologies at farm level. Understanding the basics behind their success in specific farms would enhance their adoption by providing useful information on expected costs, benefits and challenges. The information was documented in a database after which a Decision Support (MATSIM) Tool was developed to assist farmers and catchment managers in choosing appropriate SLM technologies in their lands.

1.1 Problem statement

The Upper Tana Catchment is one of Kenya's most important natural resource base. However unregulated deforestation and expansion of cultivation practices into marginal soils have resulted in significant reservoir siltation, reduced ecosystem function, and more erratic downstream flows (Jacobs, Angerer, Vitale, Srinivasan & Kaitho, 2007). It faces severe challenges to meet increasing water demands due to poverty and population growth (Githui, Mutua, & Bauwens, 2009). Previous soil erosion studies in this catchment (Ongwenyi, Kithiia, & Denga, 1993; Brown, Schneider, & Harper, 1996) and reservoir sedimentation studies (Wooldridge, 1984) indicated that the reservoirs could have lost between 10 and 30 percent of their storage capacity in 30 years. The services that generally depend on these water facilities may be threatened in the near future (Hunink, Niadas, Antonaropoulos, Droogers, & De Vente, 2013). Other studies by Herrero *et al*. (2013) point out that the Upper Tana catchment may in addition suffer serious consequences due to climate change and that rainfall variability will be greater in the future. In addition, Beneah, Muya and Roimen (2011) associated the current decline in biodiversity with land use and management conversion and utilization trends in Embu County. Soil erosion in the Upper Tana Catchment is in most cases the result of a lack of soil cover by crop or mulch (Wilschut, 2010). This can be attributed to poor farming methods. Putting more land under cover will result in a higher infiltration rate, lower evaporation, lower runoff values and consequently, less soil erosion (Wilschut, 2010). Poor land management leads to soil erosion which eventually leads to siltation in the river and reservoirs. According to Kitheka, Obiero and Nthenge (2005), most of the sediments transported by the river are associated with soil erosion due to poor land use activities in the Tana River Catchment.

Masinga reservoir, one of the main reservoirs within the Upper Tana Catchment is experiencing high rates of siltation due to accelerated soil erosion in the catchment occasioned by rapid deforestation (Saenyi & Chemelil, 2002). The reservoir which was designed for hydropower generation, public water supply and irrigation is faced with severe sedimentation. The storage capacity of the reservoir is fast declining due to high rates of sedimentation. The dam was designed with a siltation rate of three million metric tonnes per year, but by 1988, eight years after operation began, the siltation rate had more than tripled to ten million tonnes per year and the reservoir capacity reduced by 6% (Bobotti, 1998). By the year 2000, annual sediment loading had increased to over 11 million cubic meters, nearly four times, reducing the design capacity by more than 15%. At this rate, the lifespan of the dam will be drastically reduced (Saenyi & Chemelil, 2002). There is need, therefore, to devise SLM strategies at the catchment level to minimize the siltation rate. It is anticipated that identification, evaluation, documentation of SLM technologies and development of a decision support tool for SLM technologies within the Upper Tana Catchment will enhance scaling up of SLM technologies which will eventually lead to increased land productivity, ecosystem services and improved adaptation to climate change.

1.2 Significance of the study

The Upper Tana Catchment provides water for about 50% of the population of Kenya (IFAD; UNEP; GEF, 2004). It is therefore of crucial importance that water and soil resources in this catchment are maintained or improved (Wilschut, 2010).

The Tana River is utilized for hydro-power by the Kenya Generating company (KenGen), which is the Kenya's main energy company (KenGen, 2005, 2008). Five major reservoirs have been built on the upper reaches: Kindaruma in 1968, Kamburu in 1975, Gitaru in 1978, Masinga in 1981, and Kiambere in 1988. Together, these provide three quarters of Kenya's electricity and regulate the river flow (Bobotti, 1998; Nippon, 2013).

Sustainable Land Management involves soil, water, and vegetation adequately supporting land-based production systems for current and future generations. Its key principles are: productivity, security and protection of natural resources, economic viability, and social acceptance. Despite numerous local and global efforts, desertification and land degradation persist (Schwilch, Bachmann & Liniger, 2009). Degradation of the natural resource base, coupled with high rates of population growth and food insecurity, is a major development problem not only in Kenya but in the Arid and Semi-Arid Lands (ASALs) of Sub-Saharan Africa (SSA). In recent decades, cropland has encroached steeper slopes, conservation measures are mostly absent, and soil erosion is widespread (Jacobs *et al.*, 2004). This calls for sound SLM practices in the entire catchment in order to safeguard this vital resource base. The current pressure on land resources in this catchment will necessitate the development of sustainable land management systems. The process of developing such systems requires that methods are available to easily assess sustainability.

1.3 Objectives

1.3.1 Main objective

To develop a Decision Support Tool (DST) for Sustainable Land Management Technologies in the Upper Tana Catchment.

1.3.2 Specific objectives

1) To identify successful Sustainable Land Management technologies in the Upper Tana Catchment.

2) To document the identified Sustainable Land Management technologies using the World Overview of Conservation Approaches and Technologies framework.
3) To develop a Decision Support Tool (DST) for selecting the appropriate Sustainable Land Management technologies for the Upper Tana Catchment.

CHAPTER TWO

LITERATURE REVIEW

2.1 Sustainable Land Management

Sustainable development is that development which meets the needs of the present generation, without compromising the ability of future generations to meet their own needs (World Commission on Environment and Development [WCED], 1987). It has three dimensions: economic growth, equity and protection of the environment. SLM is imperative for sustainable development and is especially critical in the merger of agriculture and environment through maintaining long term performance of the ecosystem functions (land, water, biodiversity) and increasing productivity (quality, quantity and diversity) of goods and services, and particularly safe and healthy food (http://www.fao.org/nr/land/ sustainable-land-management/en/). SLM should address sustainable development through the protection, enhancement and use of natural assets, thus breaking the vicious cycle of land degradation and poverty (Hurni, 1997). Sustainable land management entails the foundation of sustainable agriculture, and a strategic component of sustainable development and poverty alleviation, and seeks to harmonize the often conflicting objectives of intensifying economic and social development, while maintaining and enhancing the ecological and global life support functions of land resources (Mwangi, 2007; Dumanski, 1997).

According to Grubb (1993), the UN Earth Summit that was held in Rio de Jenairo in 1992 described SLM as the use of land resources, including soils, water, animals and plants, for the production of goods to meet changing human needs, while simultaneously ensuring the long-term productive potential of these resources and the maintenance of their environmental functions. On the other hand TerrAfrica (2007) describes SLM as the adoption of land use systems that, through appropriate management practices, enables land users to maximize the economic and social benefits from the land while maintaining or enhancing the ecological support functions of the land resources. The World Bank (2007) defines SLM as a knowledge-based procedure that helps integrate land, water, biodiversity, and environmental management to meet rising food and fiber demands while sustaining ecosystem services and livelihoods. Within the context of WOCAT, SLM is defined as the use of land resources, including soils, water, animals and plants, for the production of goods to meet changing human needs, while simultaneously ensuring the long term productive potential of these resources and the maintenance of their environmental functions (Liniger & Critchley, 2008). Improper land management can lead to land degradation and a significant reduction in the productive and service functions of watersheds and landscapes.

SLM encompasses other established approaches such as soil and water conservation, natural resources management, integrated ecosystem management and involves a holistic approach to achieving productive and healthy ecosystems by integrating social, economic, physical and biological needs and values. (http:// www.fao.org/nr/land/sustainable-land-management/en/). It consists of objectives and issues that are economically viable, environmentally sound and socially acceptable. It requires the consideration of discrepancies in spatial and temporal scales and an understanding of the intricate interdependence of economic, social and environmental factors (Campbell, 1995). An evaluation methodology that comprises these issues is very important for assessment of sustainable land management systems. Sustainable agriculture needs to protect the natural resource base, prevent the degradation of soil and water; conserve biodiversity; contribute to the economic and social well-being of all; ensure a safe and high-quality supply of agricultural products; and safeguard the livelihood and well-being of agricultural workers and their families (http://www.nda.agric.za/docs/Policy/SustainableDev.pdf).

Scherr and Yadav (1996) suggests that decline in reserves of quality arable land result from the significant loss of agricultural land through degrading land management practices. According to FAO (2008), SLM is crucial to minimizing land degradation, rehabilitating degraded areas and ensuring the optimal use of land resources for the benefit of present and future generations. Its application requires collaboration and partnership of the land users, technical experts and policy-makers in order to ensure that the causes of the degradation and corrective measures are properly identified, and that the policy and regulatory environment enables the adoption of the most appropriate management measures. According to Reij and Steeds (2003), improved land management leads to higher crop yields, farmers can achieve and reap more benefits by leaving strips of natural vegetation to terrace the slopes; the strips enrich the soils. The ill-effect of land use on the environment and environmental sustainability of agricultural production systems have become an issue of concern and inappropriate land use leads to inefficient exploitation of natural resources, destruction of the land resource, poverty and other social problems (Ruiee, Werahai & Aree, 2004). It enables smallholders to gradually improve their production capacity and begin generating additional income. In turn, this stimulates local economies and produces a compounding effect which progressively brings the cycle of rural poverty and resource degradation under control (Karl, Steiner, & Slaats, 1998).

The current enormous pressure on land resources particularly in the developing countries necessitates the need for development of SLM systems (Rod *et al.,* 2000). These pressures arise from population growth (Pinstrup & Pandya, 1994), the need to improve on current standards of nutrition (Borlaug & Dowswell, 1994), and dwindling reserves of quality arable land (Alexandratos, 1995). According to Templeton and Scherr (1999), the relationship between population growth and resource quality on hills and mountains was influenced by rainfall (mainly by affecting crop-product choice, risks of soil degradation, and land use intensity), topography (by affecting the spatial distribution of production systems), and soil characteristics (through crop choice, cropping frequency, and input use). Many case studies have shown that the rate of adoption of soil fertility, soil conservation, and water management practices is low in Sub-Saharan Africa (SSA), although substantial numbers of farmers use particular practices (Pretty *et al.,* 2006). There is potential to pursue several critical objectives synergistically through promotion of SLM in SSA, helping to mitigate and adapt to climate change while reducing land degradation, conserving biodiversity, and reducing poverty and food insecurity (Pender, 2008).

In developing countries, agriculture is the dominant user of environment and natural resources; it has the greatest impact on the sustainability of ecosystems and their services, and accounts directly and indirectly for a major share of employment and livelihoods in rural areas (Mahendra *et al.*, 2008). According to UN thematic group 7 of the sustainable agriculture and food systems, investing in sustainable agriculture is one of the most effective strategies for achieving critical post-2015 development goals related to poverty and hunger, nutrition and health, education, economic and social growth, peace and security, and preserving the world's environment. The group believes that it is possible to eradicate extreme poverty, hunger and undernourishment by 2030 and sustain food security without irreversibly damaging the world's natural resources, even in a time of climatic changes and extremes. To achieve that, rising food yields must be decoupled from unsustainable utilization of water, energy, fertilizers, chemicals and land. Kenya is highly vulnerable to climate variability (Geertsma, Wilschut, & Kauffman, 2010). The El Niño/La Niña phenomena caused severe flood events in 1997/98 and a prolonged drought, resulting in costs estimated at $820 billion and $2.8 billion respectively (Mogaka *et al.*, 2006).

According to Notter, MacMillan, Viviroli, Weingartner, and Liniger (2007), climate change scenarios predict an increase in flood flow and decreasing low flows, therefore action is needed. Use of mulch and other crop residues contributes to adaptation in situations where precipitation is erratic and of higher intensity. The plant biomass absorbs the energy of falling raindrops allowing rainwater to gently flow to the soil surface where it infiltrates into soil that is porous and undisturbed (Derpsch *et al.*, 1991). In areas of erratic and low rainfall coupled with increasing temperatures, crop residues will protect the soil, reducing the soil temperature and, hence, water loss due to evaporation, both important factors for optimum for plant growth (Derpsch *et al.*, 1991). According to a study that involved quantifying potential Soil Organic Carbon (SOC) sequestration rates for different crops by West and Post (2002), it was found out that enhancing crop rotation complexity can sequester an average of 20 ± 12 g C/m2/yr and SOC accumulation can continue over many years, reaching a new equilibrium in approximately 40 to 60 years.

2.2 Sustainable Land Management in the Upper Tana Catchment

Agriculture remains the backbone of the Kenyan economy and central to its development strategy (http://www.feedthefuture.gov/country/kenya). It is the single most important sector in the economy, contributing approximately 25% of the GDP, and employing 75% of the national labour force (Republic of Kenya, 2005). In Kenya, the agriculture policy forms part of the process of incorporating principles and objectives of sustainable development into the ethos of the agricultural sector. Unsustainable land management that leads to decline in agricultural productivity in the Central Highlands of Kenya has largely been associated with high population density, deforestation and intensive cultivation of steep slopes without effective conservation measures (Gachene, Mbuvi, Jarvis & Linner, 1997).

Even though substantial work has been done in Central Kenya with a view of introducing and educating farmers on SLM practices such as agroforestry and biomass transfer using *Tithonia diversifolia*, *Leucaena trichandra,* and *Calliandra calothyrsus* coupled with proper management and application of manure and inorganic fertilizers, Mugendi *et al*. (1999) conducted socio-economic studies to evaluate adoption of these SLM technologies which showed low adoption rates. The reasons given for this trend have been varied but have mainly revolved around socio economic factors such as gender, benefits of a technology, farmers' resource endowments and biophysical aspects of farming such as slope of land and farm/plot size. In the Upper Tana Catchment, increasing destruction of the forest cover, inappropriate land use practice in farm lands and overgrazing in the pastoral lowlands have triggered an increasing soil erosion menace that contribute a higher sediments load to the Tana and its tributaries. Plate 2.1 shows a toppled river bank as a result of poor maize cultivation practice along a riparian zone of a Tana River tributary. As can be seen, the tributary has substantial sediment load depicting unsustainable land management in the upstream

Plate 2. 1: Massive sediments and toppled banks of a tributary of River Tana

With increasing soil erosion, land productivity has declined causing even more vulnerable areas to be opened for cultivation, a process that has undermined the ability of the land to hold rainwater, increasing fluctuation in the river regime- flood flows coupled with depressed base flows in the dry season, which impair water supply (Place *et al.,* 2004). Ultimately and as shown in plate 2.2 accelerated soil erosion has not only affected the on-site production but also the chain of hydroelectric power schemes in downstream areas (Westerberg & Christianson, 1999; Schneider, 2000).

Plate 2. 2: Sediments at the upstream of the Masinga Reservoir

However, a variety of already applied conservation measures exist at the local level even though they are not adequately recognised, evaluated and shared, either by land users, technicians, researchers, or policy makers (Schwilch *et al.*, 2009). Likewise, collaboration between research and implementation is often insufficient (Schwilch *et al.*, 2009). Mati (2005) has identified several SLM technologies (plate 2.3, 2.4 and 2.5) that are commonly practiced. They include terracing, grass strips and vegetative buffers, contour bunds, trash lines, fanya juu terraces, stone lines, bench terraces, conservation tillage, minimum tillage, stubble mulch tillage, ridging and tied ridges, trench farming, silt borrowing and trapping, gully control and utilization and contour ploughing.

Plate 2. 3: Bench terraces (Mati, 2005)

Plate 2. 4: Grassed water way (Mati, 2005)

Plate 2. 5: Retention ditches

Studies in the Upper Tana Catchment have revealed that basin-wide implementation of tied ridges terracing would not only improve productivity in the uplands but also reduce sediment inflow to the Masinga reservoir by about one million tons annually (Dijkshoorn *et al.*, 2010). This would be a most economical way to extend the life of the reservoir. Also, the systematic adaptation of mulching would lead to a reduction in non-beneficial soil evaporation, which is more than 100 million m^3 per year. This water would be available for productive use in the Upper Tana Catchment but would also be added to the total amount of water in the catchment. Enhancement of groundwater recharge through the different practices could improve the usage of the natural storage capacity in the basin by about 20%. This would mean less competition for surface water, more regular flow and better groundwater availability (Dijkshoorn *et al.*, 2010).

According to Knoop *et al.* (2012), different strategies for SLM implementation were proposed in the Upper Tana Catchment. The first being introduction of measures to reduce landslides and soil erosion, coupled with techniques to maximize retention of soil moisture and infiltration to groundwater. The second strategy that they propose is to develop a surface storage either by creating a wetland or small surface storage facilities. This can be achieved by implementation of such strategies like tied ridges, terracing, and specific recharge measures. The third strategy is to preserve groundwater quality at the major springs to potable standards through protection of springheads and control of polluting discharges from urbanization, agro-based factories and agricultural land-use in their capture zones. The final strategy as proposed by Knoop *et al.* (2012) is to reduce non-beneficial evaporation, i.e. minimize the water that is lost to the atmosphere without being used. This can be achieved by improving land cover and also by measures such as mulching and windbreaks. These measures will also affect the micro-climate, influence soil temperatures, and prolong the growing season.

There are other natural resource management programmes that have been working in this catchment. They include Upper Tana Natural Resource Management Project (UTaNRMP) funded by International Fund for Agricultural Development (IFAD) and GoK, Green Water Credits (GWC) project which is an environmental reward system that promotes sustainable land and water management by farmers, so that land and water degradation diminish and both water quantity and quality increase. The GWC program is supported by IFAD. There is a need for investment in documenting and evaluating SLM best practices and in assessing their impact on ecosystem services. Scattered knowledge about SLM in the Upper Tana Catchment needs to be identified, documented and assessed in a thorough and interactive review process that involves the joint effort of land users, technical specialists, and researchers. Once documented, this knowledge should then be made available for land users and decision-makers in order to provide a basket of options for decision-making at different levels. By so doing, the concept of sustainable agriculture and catchment development can be realized.

2.3 Decision Support Systems (DSS)

The concept of Decision Support System (DSS) is broad and has been defined by many authors from different fields (Druzdzel & Flynn, 1999). The common thing is that all DSS have a component of decision making process which is an integral part of many professions where decisions are made. It is a cognitive process which selects the best course of action from various multiple alternatives. Even though Adela and Lungu (2012) suggest that definition of DSS varies depending on the evolution of information technologies and, of course, on the point of view of those who issue such a definition, Keen (1980) suggested that it is impossible to give a precise definition including all the facets of the DSS. According to Power (1997), the term Decision Support System remains a useful and inclusive term for many types of information systems that support decision making and the DSS belong to an environment that revolves about database research, artificial intelligence, human-computer interaction, simulation methods, software engineering, and telecommunications (Power, 2002).

Sandeep and Thapliyal (2012) define DSS as a class of information which is computerized and supports the activities of decision making while Turbman (1998) defines a DSS as an interactive, flexible, and adaptable computer based information system, developed especially for better decision making as it supports the solution of a non-structured management problem. The system uses data (internal and external) and models, providing a simple and easy-to-use interface, thus, allowing the decision maker control over the decision process. The DSS offers support in all decision process's stages. For Sprague and Carlson (1982) a DSS comprise a class of information system that draws on transaction processing systems and interacts with the other parts of the overall information system to support the decision-making activities of managers and other knowledge workers in organizations. Moore and Chang (1983) on the other hand defines DSS as extendible systems capable of supporting ad hoc data analysis and decision modeling, oriented toward future planning, and used at irregular, unplanned intervals. Little (1970) defines a DSS as a model-based set of procedures for processing data and judgments to assist a manager in decision-making.

From the above definitions, it can be concluded that, some of the most important characteristics of a DSS are; uses data and models; enhances the learning process; grows the efficiency of the decision making process; offers support in the decision making process and allows the decision maker control over the entire process; offers support in all stages of the decision making process; offers support for decision makers in solving structured or unstructured problems; offers support for a user or for a group of users (Adela & Lungu, 2012).

2.3.1 History of Decision Support Systems

According to Keen and Morton (1978), the concept of DSS evolved from two main areas of research: the theoretical studies of organizational decision making done at the Carnegie Institute of Technology (CIT) during the late 1950s and early 1960s, and the technical work on interactive computer systems, mainly carried out at the Massachusetts Institute of Technology in the 1960s. Haettenschwiler (1999) suggested that the concept of DSS became an area of research of its own in the middle of the 1970s, before gaining in intensity during the 1980s. In the middle and late 1980s, Executive Information Systems (EIS), Group Decision Support Systems (GDSS), and Organizational Decision Support Systems (ODSS) evolved from the single user and model oriented DSS. In the early 1990, data warehousing and On-Line Analytical Processing (OLAP) began broadening the realm of DSS. As the millennium approached, new web-based analytical applications were introduced.

2.3.2 Classifications of Decision Support Systems

Different authors propose different classifications of DSS as outlined in the next discussion.

a) At the user-level, Hättenschwiler (1999) differentiates passive, active and cooperative DSS using the relationship with the user as the criterion. A passive DSS aids the process of decision making but cannot bring out explicit decision suggestions or solutions while an active DSS brings out such decision suggestions or solutions. A cooperative DSS allows the decision maker (or its advisor) to modify, complete, or refine the decision suggestions provided by the system, before sending them back to the system for validation. The system again improves, completes, and refines the suggestions of the decision maker and sends them back for validation. The whole process then starts again, until a consolidated solution is generated.
b) Classification of DSS had earlier been developed by Alter (1980), his idea was, decision support operations extend along a single dimension, ranging from

extremely data oriented to extremely model oriented. At one end are file drawer systems that simply provide access to data items. Real-time equipment monitors or inventory monitoring and reorders systems offers a good example. In the middle are analysis information systems with decision oriented databases and small models. For example, product planning and analysis or sales forecasts based on a marketing database. At the other end are suggestion decision support systems using logic models that suggest specific decisions for a well understood task.

c) At the conceptual level, Power (2002) differentiates Communication-Driven DSS, Data-Driven DSS, Document-Driven DSS, Knowledge-Driven DSS, and Model-Driven DSS using the mode of assistance as the criterion. A Model-Driven DSS emphasizes access to and manipulation of a statistical, financial, optimization, or simulation model. Model-Driven DSS use data and parameters provided by DSS users to aid decision makers in analyzing a situation, but they are not necessarily data intensive. A Communication- Driven DSS supports more than one person working on a shared task; examples include integrated tools like Microsoft's NetMeeting or Groove (Stanhope, 2002). Data-Driven DSS or Data-oriented DSS emphasize access to and manipulation of a time-series of internal company data and, sometimes, external data. Document-Driven DSS manage, retrieve and manipulate unstructured information in a variety of electronic formats. Finally, Knowledge-Driven DSS provide specialized problem-solving expertise stored as facts, rules, procedures, or in similar structures.

d) At the technical level, Power (1997) differentiates enterprise-wide DSS and desktop DSS whereby, enterprise-wide DSS are linked to large data warehouses and serve many managers in a company. Desktop, single-user DSS are small systems that reside on an individual manager's PC.

2.3.3 Architecture of Decision Support Systems

There are various architectures of DSS that have been suggested by different authors. Sprague and Carlson (1982) identify the following three major components; the database management system (DBMS), the model-base management system

(MBMS) and the dialogue generation and management system (DGMS). On the other hand, Marakas (1999) proposes a generalized one that is made of five parts; the data management system, the model management system, the knowledge engine, the user interface, and the user(s) themselves. According to Power (2002), academics and practitioners have discussed building DSS in terms of four major components; the user interface, the database, the model and analytical tools, and the DSS architecture and network. Hättenschwiler (1999) identifies five components of DSS: (a) users with different roles or functions in the decision making process (decision maker, advisors, domain experts, system experts, data collectors), (b) a specific and definable decision context, (c) a target system describing the majority of the preferences, (d) a knowledge base made of external data sources, knowledge databases, working databases, data warehouses and meta-databases, mathematical models and methods, procedures, inference and search engines, administrative programs, and reporting systems, and (e) a working environment for the preparation, analysis and documentation of decision alternatives.

2.3.4 Applications of Decision Support Systems in Sustainable Land Management

DSS are used in such fields like, agricultural production, banking, engineering, education, medical, business management and environmental management (Wright & Sittig, 2008). Even though there are many constraints to the successful adoption of DSS in agriculture (Stephens & Middleton, 2002), under complex and unstructured problem scenarios, the use of DSS at various levels of decision-making can be very helpful in promoting SLM. Examples of DSS that have been developed for SLM includes the IBSRAM DSS-SLM which was developed by international Framework for Evaluating Sustainable Land Management (FESLM) under the auspices of International Board for Soil Research and Management (IBSRAM) (Smyth & Dumanski, 1993). The knowledge base of the IBSRAM DSS-SLM was developed in form of SLM indicators based on this framework. It is targeted for extension workers and NGO staff in sloping lands of South East Asia, who can use it to identify constraints to sustainable land management at the farm level by analyzing farm management practices, and to suggest prescriptive measures to achieve sustainability. IBSRAM DSS-SLM assists the user to identify or pinpoint the constraints or practices that hamper the achievement of sustainable land management. Another agricultural based DSS is the DSSAT 4 package that has so far allowed rapid assessment of several agricultural production systems around the world to facilitate decision-making at the farm and policy levels since its development (Stephens & Middleton, 2002). DSS are also prevalent in forest management where the long planning time frame demands specific requirements. All aspects of Forest management, from log transportation, harvest scheduling to sustainability and ecosystem protection have been addressed by modern DSS (Igwe & Nwele, 2013).

2.4 World Overview of Conservation Approaches and Technologies

One of the reasons why soil and water degradation still persists despite many years of effort and investment in Soil and Water Conservation (SWC) measures, is that SWC knowledge often remains a local resource, unavailable to others who work in the same area (Liniger & Schwilch, 2002). World Overview of Conservation Approaches and Technologies (WOCAT) is an established global network of Soil and Water Conservation (SWC) specialists, contributing to SLM (WOCAT, 2003). The program was initiated in 1992 during the 7th meeting of the International Soil Conservation Organisation (ISCO), held in Sydney, Australia as a global network of SWC specialists contributing to Sustainable Land Management (Liniger & Schwilch, 2002; WOCAT, 2003). It was conceived as a response to the Global Assessment of Soil Degradation (GLASOD) that showed the extent and seriousness of land degradation in various parts of the world (Oldeman *et al.,* 1990). Prior to the initiation of WOCAT, sharing of existing knowledge on the use of soil and water conservation (SWC) technologies and approaches was largely ad hoc, based on personal contacts and/or the proceedings and deliberations of international workshops and conferences. WOCAT was established with the aim of making a substantial contribution to Sustainable Land Management (SLM) by facilitating local and international exchange of experience and lessons learnt (Liniger *et al.,* 2004).

WOCAT's vision is that existing knowledge of sustainable land management is shared and used globally to improve livelihoods and the environment. Within SLM, WOCAT focuses mainly on efforts to prevent and reduce land degradation through conservation technologies and their implementation approaches. WOCAT's goal is to prevent and reduce land degradation through SLM technologies and their implementation approaches. The network provides tools that allow SLM specialists to identify fields and needs of action, share their valuable knowledge in land management, that assist them in their search for appropriate SLM technologies and approaches, and that support them in making decisions in the field and at the planning level and in up-scaling identified best practices. WOCAT contributes to sustainable use of soil and water through collection, analysis, presentation and, dissemination of SWC technologies and approaches world-wide to promote improved decision-making and land management (Thomas *et al.,* 2003).

2.4.1 WOCAT data collection and documentation

WOCAT's mission is to support decision making and innovation in sustainable land management by connecting stakeholders, enhancing capacity, and developing and applying standardized methodology, involving a set of three comprehensive questionnaires, for documentation, evaluation, monitoring and exchange of SWC conservation knowledge of individual technologies and approaches, including area coverage. It has also created and maintained a global database system for storage, retrieval and dissemination of documented information (Liniger & Schwilch, 2002; Van Lynden *et al.,* 2002; WOCAT, 2003, 2004). WOCAT focuses mainly on efforts to prevent and reduce land degradation through conservation technologies and their implementation approaches (Liniger & Schwilch, 2002). The three questionnaires are;

1) Questionnaire on SLM Technologies (QT),
2) Questionnaire on SLM Approaches (QA)
3) Questionnaire on SLM Mapping (QM)

2.4.2 Identified gaps

Despite the fact that there exist several SLM technologies in the Upper Tana Catchment, there are no standard decision making criteria for selecting their suitability in a particular place. In the Upper Tana Catchment, there is no standard framework of presentation or documentation of the successful SLM Technologies that the farmers can use to determine their expected costs, benefits and challenges to be overcome while implementing and maintaining such technologies.

CHAPTER THREE

METHODOLOGY

3.1 Description of the study area

The project was carried out in Embu County within the Upper Tana Catchment. Embu County is located in the North-West of Nairobi City approximately between latitude 0^{o} 8' and 0^{o} 50' South and longitude 37^{o} 3' and 37^{o} 9' East and occupies an area of 2,818 km^{2} (World Bank, 2007; WRI, 2007). Its elevation ranges from 5199 m.a.s.l on Mt. Kenya to 400 m.a.s.l to the East of the catchment (figure 3.1) (World Bank, 2007). The main rivers are Sagana and Thiba (Geertsma *et al.*, 2010).

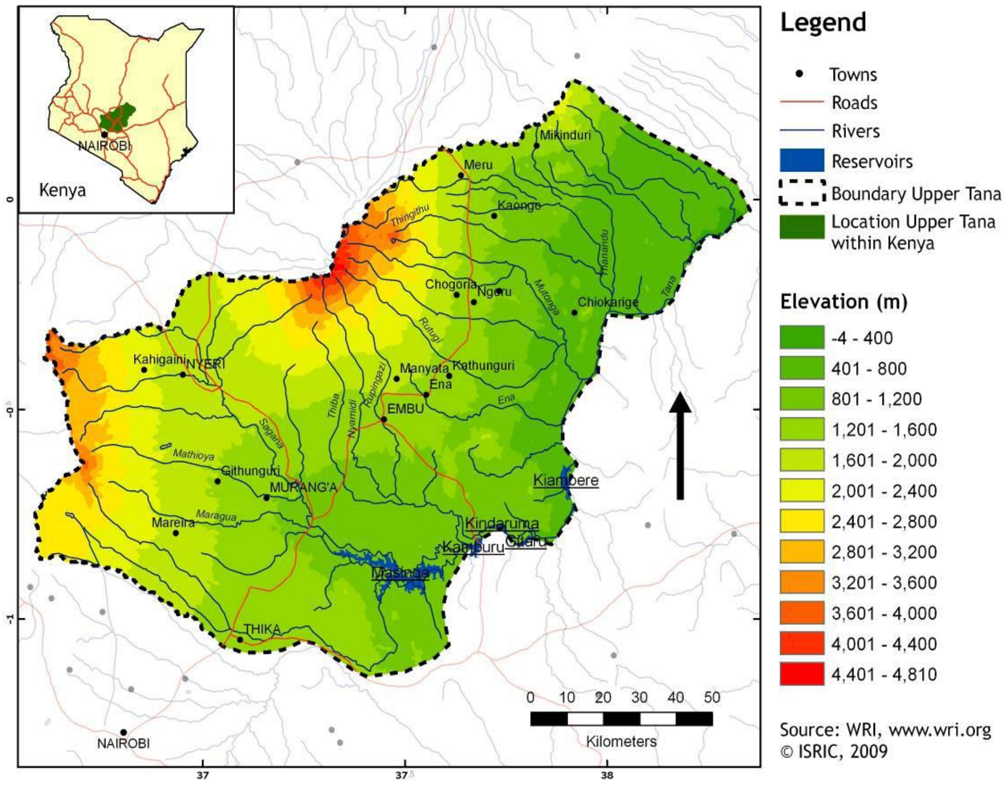


Figure 3. 1: Location and elevation of the Upper Tana Catchment, Kenya

(Source: WRI, www.wri.org, ISRIC, 2009)

3.1.1 Climate

The maximum and minimum mean annual temperatures in the basin range from 25.5 to 31.0°C and 21.0 to 24.0°C respectively (Mutua & Klik, 2007). The Upper Tana Catchment has two wet seasons and two dry seasons as a result of the Inter-tropical Convergence Zone. The long rains last from around March to June and the short rains from September to December (Hunink *et al.*, 2010). The annual precipitation at Mount Kenya and the Aberdares ranges is approximately 1800 mm (Otieno & Maingi, 2000). Within the middle elevations of 1200 to 1800 m.a.s.l, the annual rainfall ranges from 1000 to 1800 mm or slightly more, while the lower elevations of 1000 m.a.s.l, receive annual rainfall of 700 mm as shown in the spatial distribution map of precipitation (Figure 3.2). Rainfall patterns in the mountainous catchments are very heterogeneous (IFAD/UNEP/GEF, 2004; Notter *et al.*, 2007; Wambua, *et al.*, 2015). Potential evapotranspiration ranges from around 1700 mm in the low elevation savannah zone to less than 500 mm in the summit region. The areas below the forest zone have a rainfall evapotranspiration deficit. Because of this phenomenon, the high elevation forest and moorland zones provide most of the discharge of the rivers in the dry periods (Notter *et al.*, 2007; Geertsman *et al.*, 2010).

3.1.2 Hydrology and Geology

The fast-flowing perennial rivers in the Upper Tana Catchment drain on the eastern flanks of the mountains (Mount Kenya and Aberdares) into the Tana River (Knoop *et al*., 2012). The water resources of the Upper Tana Catchment provide water for 1 million ha of rainfed agriculture and 68700 ha of irrigated land (Hoff & Noel, 2007). There is increasing demand for irrigation water on the slopes of Mount Kenya, particularly to support horticulture production. Water usage in the upstream areas however affects water availability in the lower drier areas. Water is also important for electricity generation, industry and livestock (IFAD/UNEP/GEF, 2004; Mogaka *et al.*, 2006). There are seven hydro-power stations in the Upper Tana river that are operated by the Kenya Generating (KenGen) Company, of which Masinga reservoir, holding up to 1 560 million cubic metres, is the largest. According to KENGEN (2015) annual report, these reservoirs generate up to 50.7% of the country's electricity.

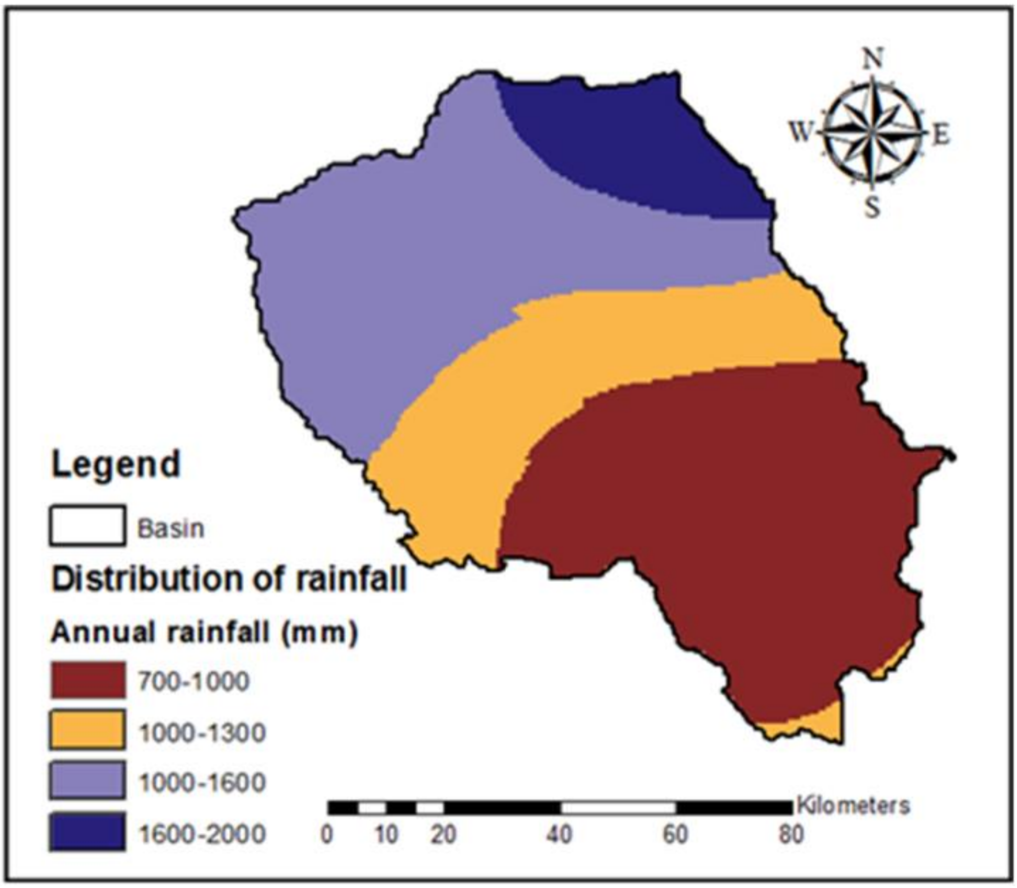


Figure 3. 2: Spatial distribution of precipitation in Upper Tana Catchment

(Wambua *et al.*, 2015)

The Upper Tana catchment can be divided into two main geological structures where by the volcanic rocks of the Cenozoic Era are found in the higher mountain areas, while in the lower areas the bedrock consists mainly of metamorphic rocks of the Mozambique belt (Veldkamp *et al*., 2012; IFAD/UNEP/GEF, 2004).

3.1.3 Land use

Main land use classes in the Upper Tana Catchment are: natural vegetation (forest, grassland and wetlands), rain-fed and irrigated agriculture (tea, coffee, maize and cereals) and rangeland (Jaetzold & Schmidt, 1983). During recent decades, the population in the higher mountain areas has increased, and formerly non-cultivated areas have been converted to agricultural lands (Muriuki & Macharia, 2011). According to Jaetzold and Schimdt (1983) the upper zone, 4000-5200 m.a.s.l is the afro-alpine zone. Between 3300 and 4000 m there is moorland. The forest zone is located between 2200 and 3000 m and comprises highly diverse indigenous forest. Below 2200 m the natural vegetation has been largely removed and the land is converted to agriculture (Panafcon, 2007). The tea zone is located between 1800 and 2200 m. The coffee zone is found below the tea zone around (1300-1800 m), although presently, many farmers are turning their coffee fields into food cropping fields. Between 1100 and 1300 m food cropping (maize, sunflower) is taking place. Below about 1100 m are the arid and semi-arid lands (ASALs) (Panafcon, 2007; IFAD/UNEP/GEF, 2004; Geertsma, *et al.*, 2010) Approximately 3.1 million people live in the Upper Tana (WRI, 2007). Figure 3.3 presents the Upper Tana Catchment's Agro Climatic Zones (ACZs) (Sombroek *et al*, 1983)

.

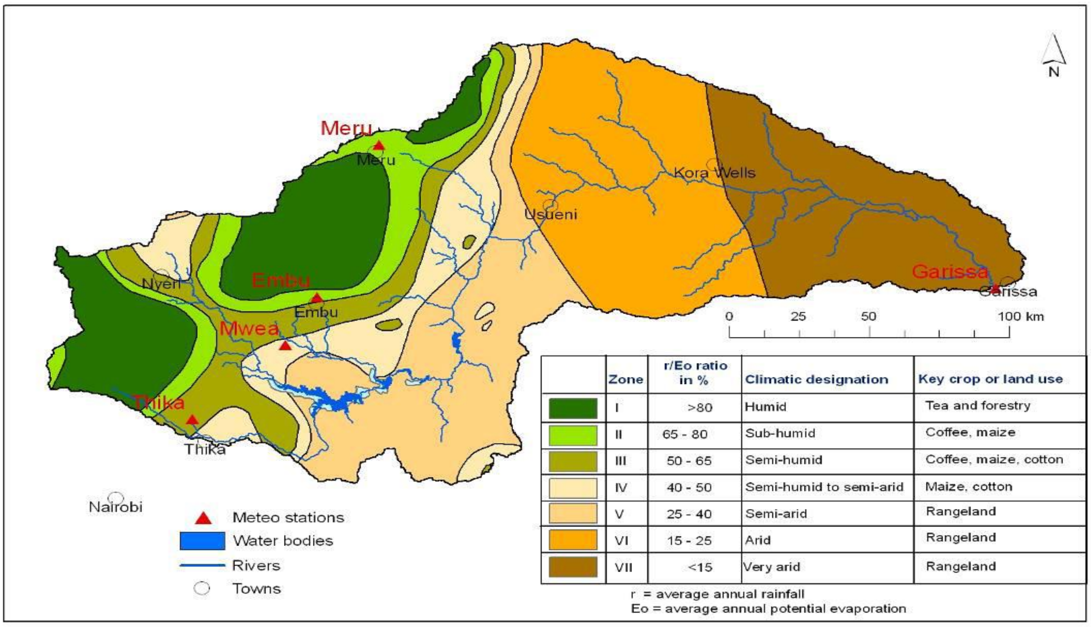


Figure 3. 3: Agro Climatic zones of the Upper and Middle Tana Catchment

(Sombroek *et al.*, 1982)

3.1.4 Dominant soil types

The dominant soil types of the Upper Tana Catchment are presented in Figure 3.4 and show a relationship with elevation. According to Hunink., *et al* (2009), the higher slopes of Mt Kenya and the Aberdare ranges are dominated by volcanic ash soils (Andosols). The middle foot slopes have mainly deep well structured nutrient rich clay soils (Nitisols). The lower foot slopes are dominated by very deep highly leached nutrients poor clay soils (Ferralsols) and by less leached soils (Cambisols and Luvisols). At lower elevations, roughly below 1000 m, Cambisols and sodic-alkaline soils (Solonetz) are the dominant soils (KSS 1996; Sombroek *et al.*, 1982).

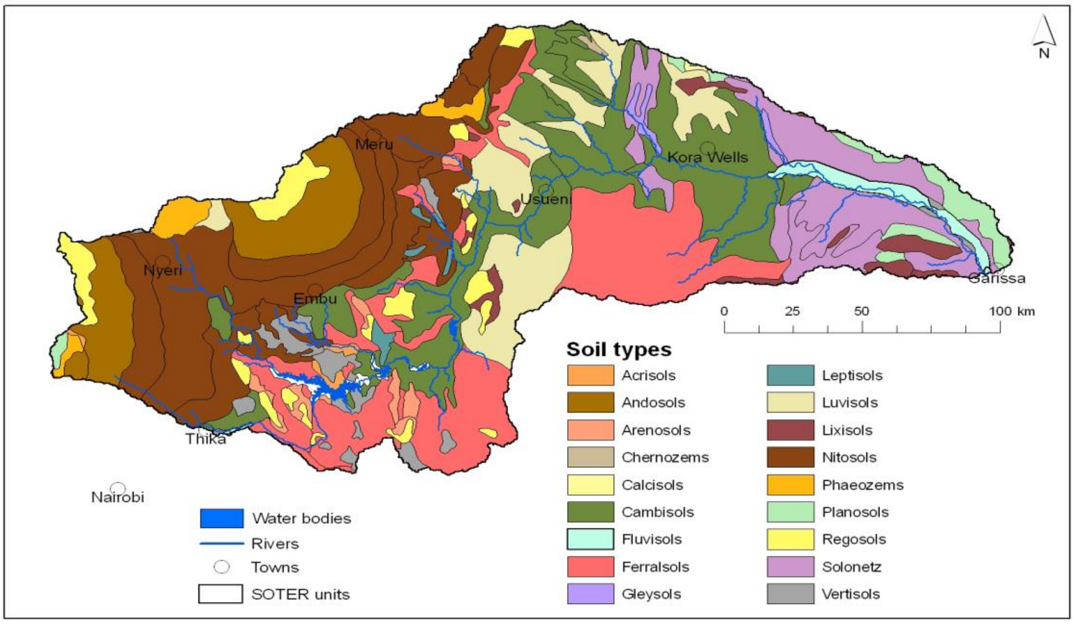


Figure 3. 4: Dominant soil types of the Upper Tana Catchment

(Source: http://www.isric.org/projects/soter-kenya-kensoter)

3.2 Identification of SLM technologies

The administrative boundaries of the Embu County cuts across varying Agro Ecological Zones (AEZs) and socio-economic conditions, from the slopes of Mt. Kenya to the dry areas of lower Mbeere South district. The project endeavoured first to identify the successful SLM technologies that the farmers have been practicing within the catchment. To achieve this objective, both convenience and purposeful survey (Patton, 2002) was carried out whereby, the basic research tool was a structured questionnaire that was administered to fifty four key informants farmers (Bernard, 2002) with the assistance of the Ministry of Agriculture (MoA) frontline extension officers. The questionnaire is presented in Appendix 1. A group of six different farmers who to the best of knowledge of the extension officers practice SLM technologies were purposely selected per AEZ for questionnaire administration along a longitudinal transect cutting across all distinct nine AEZs as shown in figure.3.5.

3.3 Agro-Ecological Zones and research design

As shown in Table 3.1, the Upper Tana Catchment has thirteen AEZs that correspond to different Land Use Types (Jaetzold & Schmidt, 1983). The identification of SLMs was confined to nine AEZs. The areas under rocks, glacier, moorland and heath land forests were not considered as they are not inhabited. They are government protected and consist of several rare forest ecosystems with high biodiversity.

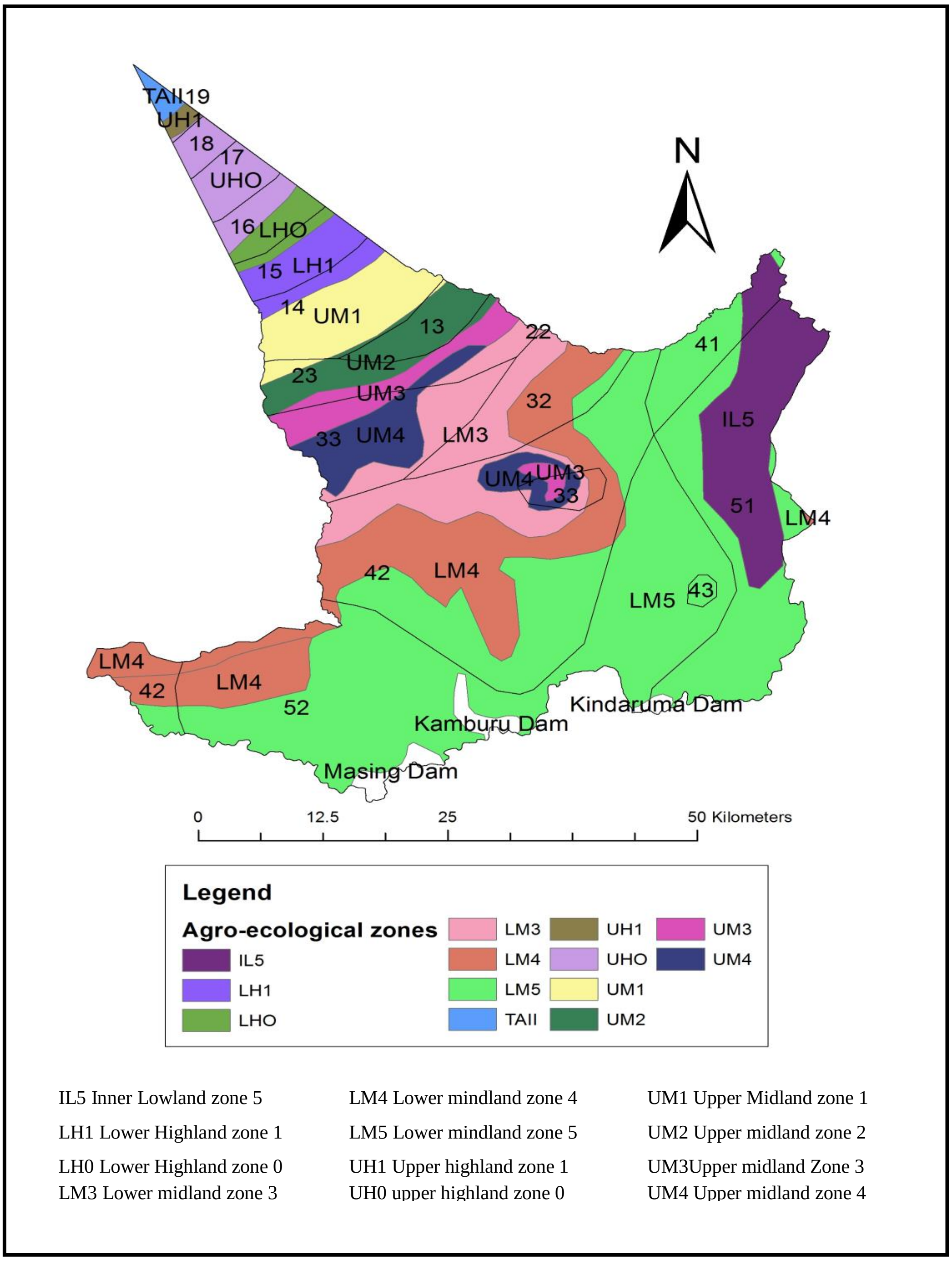


Figure 3. 5: Agro Ecological Zones and boundaries of Embu County

Table 3. 1: AEZs and main Land Use systems of the Upper Tana Catchment

No	AEZ	MAIN LAND USE SYSTEM
1	TA 0	Rocks and Glaciers
2	TA 1 + 11	Tropical Alphine, Moor and Heathlands
3	UH 0	Forest Zone
4	LH 0	Forest Zone
5	LH 1	Tea Dairy Zone
6	UM 1	Coffee-Tea Zone
7	UM 2	Main coffee zone
8	UM 3	Marginal Coffee Zone
9	UM 4	Sunflower– Maize Zone
10	LM 3	Cotton Zone
11	LM 4	Marginal Cotton Zone
12	LM 5	Lower Mid-land Live-stock-Millet Zone
13	IL 5	Inner Lowland Livestock Millet Zone

The agricultural activities within these AEZ's have a direct impact on the downstream eco-system beneficiaries. In total, the questionnaire was administered to 54 farmers with 100% response rate. The data collected was analysed using a Statistical Package for Social Scientist (SPSS) software ver.16.0.

3.4 Documentation of SLM Technologies

The identified technologies within the AEZs were documented using the WOCAT framework at farm level without duplication if they were also found in the subsequent AEZ's. This is a proven methodology and a tool for documentation and evaluation of soil and water conservation and management technologies; it also offers comparison of experiences.

In this case, the basic tool that was used was a comprehensive WOCAT Technology Questionnaire that consists of three main parts (Liniger & Schwilch, 2002).

1. General information
2. Specification of SLM Technology
3. Analysis of SLM Technology

All farms that were sampled were geo-referenced with the use of Geographical Positioning Systems (GPS). Apart from one-on-one interviews, other secondary data were obtained from relevant sources, these included the following: Rainfall data, Altitude, Landforms, Slope, Soil depth, Soil texture, Soil fertility, Top soil organic matter, Soil drainage/infiltration, Soil water storage capacity, Groundwater table, Water quality, Biodiversity information and population data. These are pertinent data that were filled in the WOCAT questionnaires. Other useful soil information was obtained from the Kenya Soil Survey (KSS), KENSOTER database and ISRIC Soil Information System.

3.5 Development of MATSIM Tool

The DST developed in this study is called **MAT**haiya **SIM**ulation (MATSIM) Tool. The data generated from the WOCAT-QT questionnaire was entered in the WOCAT global database for synthesis after which an inventory was created from the templates. The templates were used to create the Upper Tana Catchment SLMs database that was used for the MATSIM-Tool development. The tool was developed by the use of Microsoft Access.VBA application software. The fundamental components of the tool involved the following architecture; inventory of the best-bet SLM technologies within the catchment, decision context and the user criteria.

3.6 Main factors considered in MATSIM Tool development

According to a study done by Templeton and Scherr (1997) the relationship between population growth and resource quality on hills and mountains was influenced by rainfall (mainly by affecting crop-product choice, risks of soil degradation, and land use intensity), topography (by affecting the spatial distribution of production systems), and soil characteristics (through crop choice, cropping frequency, and input use). In order to provide reliable SLM decision support, the characteristics that constitute sustainable land use within a given agro-environmental and socio-economic conditions need to be known. An efficient way to achieve this is by identifying sustainable land-use systems, characterizing the attributes that make them sustainable and identifying criteria by which to measure the status of these attributes in other land-use systems (Gregory, 1999). The decision on what technology that would be most appropriate in a specific location in the Upper Tana Catchment depends on a number of factors. Development of the MATSIM-Tool considered the following as the most important ones; 1) Agro-climatic zones (ACZ), 2) Agro-ecological zones (AEZ), 3) Soil characteristics especially depth and drainage, 4) Land-use type 5) Topography 6) Eco-system services offered by the SLM 7) Its Climatic Extreme adaptation 8) Land Tenure 9) Gender and the SLM's characteristics.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Sustainable Land Management Technologies in the Upper Tana Catchment

This section deals with the different types of SLM technologies that are practiced by the farmers in the Upper Tana Catchment. The technologies that were identified consist of one or more conservation measures according to the following categories structural, vegetative, agronomic and management. The section highlights the technologies that the farmers consider as best with reference to their performance, factors that influenced their implementation and the source of information that the farmers depended on in order to implement these technologies in their farms. The section further discusses the adoption of these technologies per AEZ.

As shown in table 4.1, majority of the farmers interviewed across all AEZs acknowledged that they experience soil erosion in their farms. Other work done by Gachene *et al* (2015) and Baaru (2011) in Kathekakai location, Machakos County, confirms such kind of observation. Perceptions of erosion problem are found to be positively associated with the adoption of conservation practices (Santos *et al.*, 2000). It was established that in order to prevent the negative effects of soil erosion that may affect their lands or neighbor's, they have constructed various soil and water conservation structures across all AEZs even though in different percentages.

Table 4. 1 Percentage of response on occurrence of soil erosion and their mitigation measures across AEZs

AEZ	Do you experience soil erosion on your farm?		Is there run-off from your farm?		Does the runoff from your farm affect neighbours' field or drain into the river drainage?		Do you have any soil and water conservation measures constructed on your farm?	
AEZ Response	yes	no	yes	no	Yes	no	yes	no
IL5	83.3	16.7	50.0	50.0	50.0	50.0	100.0	0.0
LH1	33.3	66.7	50.0	50.0	16.7	83.3	100.0	0.0
LM3	83.3	16.7	50.0	50.0	25.0	75.0	100.0	0.0
LM4	66.7	33.3	83.3	16.7	50.0	50.0	100.0	0.0
LM5	66.7	33.3	83.3	16.7	50.0	50.0	100.0	0.0
UM1	0.0	100.0	33.3	66.7	0.0	100.0	100.0	0.0
UM2	0.0	100.0	50.0	50.0	0.0	100.0	100.0	0.0
UM3	16.7	83.3	50.0	50.0	0.0	100.0	100.0	0.0
UM4	20.0	80.0	33.3	66.7	0.0	100.0	83.3	16.7

4.1.1 Structural technologies

Even though it has been reported that the rate of adoption of soil fertility, soil conservation, and water management practices is low in SSA, substantial numbers of farmers use particular practices (Pretty *et al.*, 2006). In the Upper Tana Catchment, this study revealed that farmers have adopted various structural technologies in their farms. As shown in Figure 4.1, bench terraces (33%) and fanya juu terraces (30%) are the most practiced structural technologies. Analysis of these structural technologies per AEZ showed that bench terraces followed by graded ditches are practiced in almost all AEZs as shown in Table 4.2. Previous studies in the Upper Tana Catchment (Dijkshoorn *et al.,* 2010) showed that wide implementation of structural technologies would not only improve productivity in the uplands but also reduce sediment inflow to the Masinga reservoir by about one million tons annually which would be the most economical way to extend the life of the reservoir. Similarly, recent studies in this catchment by Knoop *et al.,* (2012) recommended bench terraces, as was found out in this study and tied ridges should be practiced in order to reduce soil erosion and at the same time encourage water infiltration.

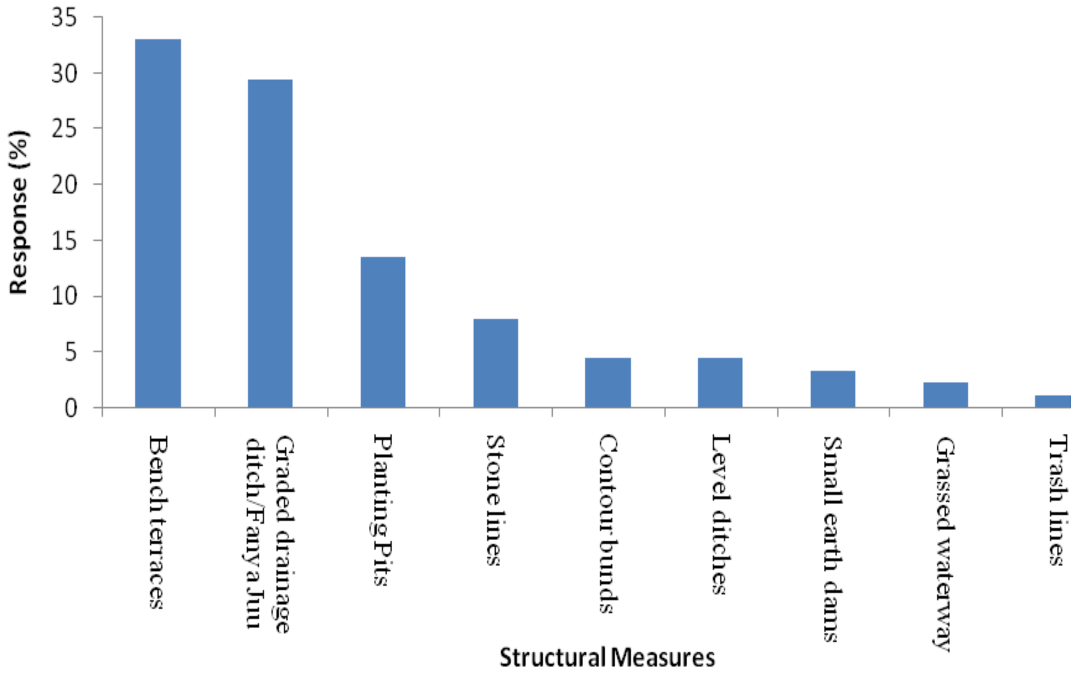


Figure 4. 1: Structural technologies adapted in the Upper Tana Catchment

Table 4. 2: Structural technologies per AEZs

	Structural technology (%)								
Agro-ecological zone	Bench terraces	Contour bunds	Fanya Juu	Level ditches	Planting Pits	Small earth dams	Stone lines	Trash lines	Grassed waterway
IL5	11.1	0.0	55.6	0.0	0.0	0.0	22.2	11.1	0.0
LH1	83.3	0.0	0.0	16.7	0.0	0.0	0.0	0.0	0.0
LM3	12.5	0.0	50.0	0.0	25.0	12.5	0.0	0.0	0.0
LM4	8.3	8.3	41.7	16.7	8.3	8.3	8.3	0.0	0.0
LM5	9.1	27.3	27.3	0.0	0.0	0.0	36.4	0.0	0.0
UM1	44.4	0.0	11.1	0.0	22.2	11.1	0.0	0.0	11.1
UM2	55.6	0.0	22.2	0.0	22.2	0.0	0.0	0.0	0.0
UM3	38.5	0.0	30.8	7.7	15.4	0.0	0.0	0.0	7.7
UM4	54.5	0.0	18.2	0.0	27.3	0.0	0.0	0.0	0.0

Best structural technologies

The study revealed that there was no major difference between the widely practiced structural technologies and their most preffered structrual technologies in their farms. This was attributed to the fact that, they could easily learn implementaion from one another and also through the extension staff. Bench terraces were the most prefered structural technology by farmers in the Upper Tana Catchment. From the interviewed farmers, 35% of them cited bench terraces as their best preferred structural technology while 30% prefer graded drainage ditches/fanya juu terraces (Figure 4.2).

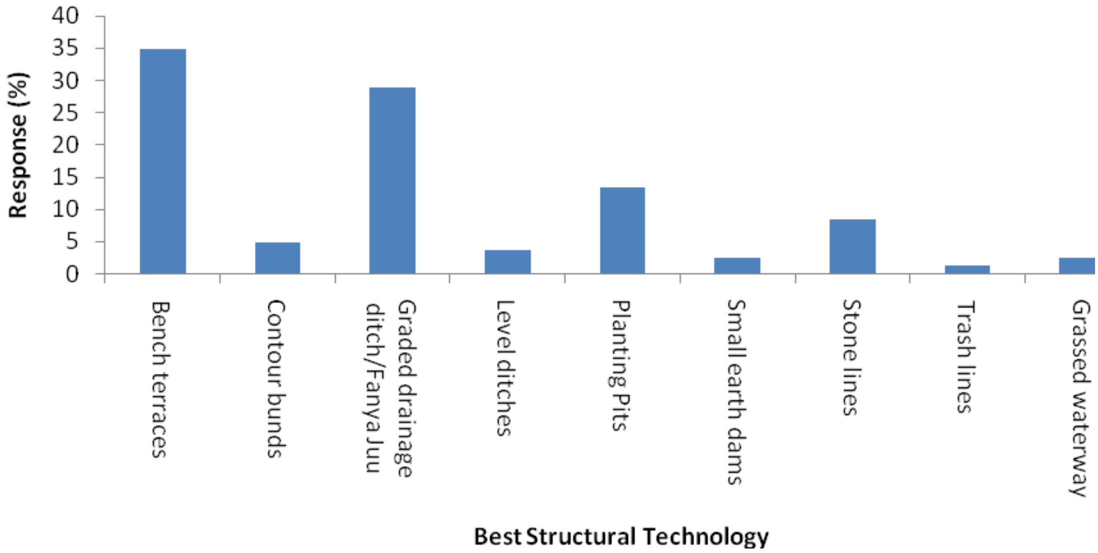


Figure 4. 2: Best structural technologies in the Upper Tana Catchment

Factors influencing the choice of structural technologies

Adoption of the structural technologies within the Upper Tana catchment was influenced by slope, climate and level of degradation. Majority (92%) of the sampled farmers cited slope as the most influencing factor on structural technology adoption as compared to climate and level of degradation (Figure 4.3). This was corroborated with a similar study that was done by Beneah *et al.,* (2011) that concluded that the farm management technologies applied in Embu and Taita study sites were dependent on the slope of the land. This was attributed to the fact that, the Upper Tana Catchment is predominantly volcanic terrain with steep slopes (Knoop *et al.,* 2012).

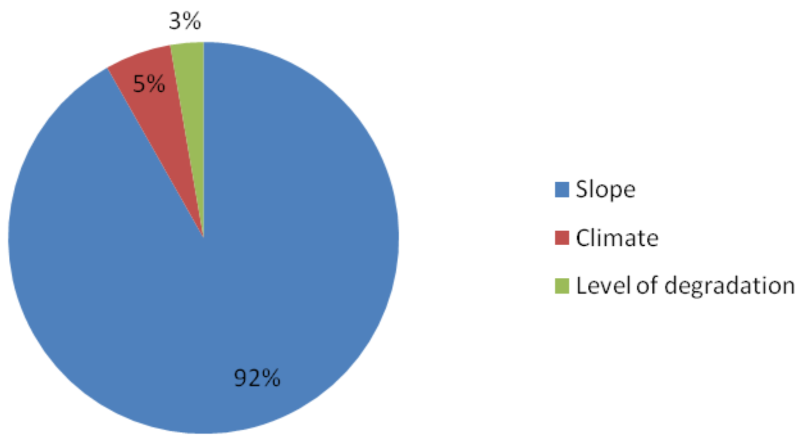


Figure 4. 3: Factors influencing adoption of structural technologies

Source of information about structural technologies

Even though Mutunga and Critchley (2002) and Mugendi *et al.*, (1999) reported that agricultural extension officers are unable to continuously and consistently follow the progress of the sustainable land management practices adoptability, this study shows a positive trend. As shown in Figure 4.4, the government extension plays a major role in information dissemination on structural technologies within the Upper Tana catchment. Wachira (2006) stated that extension services are a major source of technical information for farmers. The methodology used by the government extension officers in information dissemination is either group training (48%) or individual training. Farmers also learn from each other.

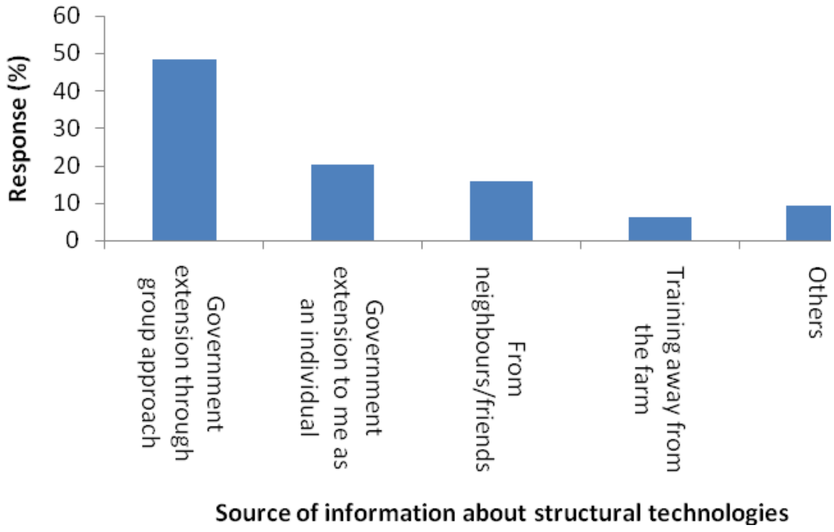


Figure 4. 4: Sources of information on structural technologies

4.1.2 Vegetative technologies

Grass strips (57%) are the most preferred vegetative technologies within the Upper Tana catchment followed by boundary tree plantings (26%) (Figure 4.5). In central Kenya, the dominant tree on the landscape is Grevillea robusta (Njuki & Verdeaux, 2001) that is used for land demarcation, source of wood and timber and to a less extent as windbreakers. The study revealed that napier grass *(Pennisetum purpureum)* is mostly used in the Upper Embu Districts while Makarikari grass (*Panicum coloratum L.*), is used in the lower parts of Mbeere District. This is so because, Makarikari grass, can withstand dry conditions than napier grass and is therefore popular in the drier Mbeere. Morgan *et al.*, (2007) suggests other suitable species like Guatemala grass, Canary grass, Oat grass, Wheat grass, and Lyme grass. As shown in Table 4.3, grass strips and boundary tree are practiced in almost all AEZ's. Woodlots are not widely practiced due to land constraints.

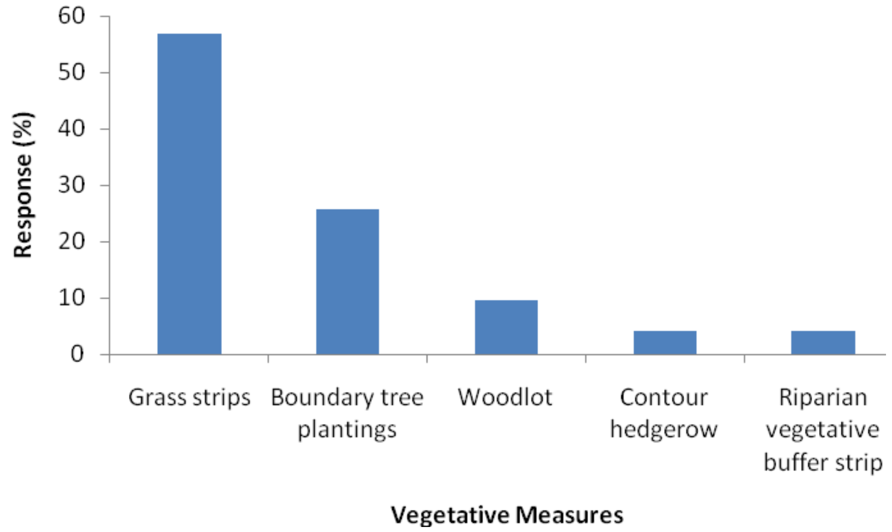


Figure 4. 5: Vegetative technologies in the Upper Tana Catchment

Table 4. 3: Vegetative technologies per AEZs

	Vegetative technology (%)				
AEZ	Grass strips	Contour hedgerow	Boundary tree plantings	Woodlot	Riparian vegetative buffer strip
IL5	40.0	0.0	50.0	0.0	10.0
LH1	83.3	0.0	0.0	16.7	0.0
LM3	33.3	0.0	33.3	22.2	11.1
LM4	57.1	14.3	28.6	0.0	0.0
LM5	71.4	0.0	14.3	0.0	14.3
UM1	62.5	0.0	12.5	25.0	0.0
UM2	57.1	14.3	14.3	14.3	0.0
UM3	66.7	11.1	22.2	0.0	0.0
UM4	54.5	0.0	36.4	9.1	0.0

Best vegetative technologies

As shown in Figure 4.6, there was no major different between the widely practiced vegetative technologies and their most preffered vegetative technologies in their farms. Just like the structural technologies, this was attributed to the fact that, the farmers implementation of these technologies was voluntary. The best vegetative technologies preferred by the farmers in the Upper Tana catchment are grass strips (51%). Fodder shrubs like *Calliandra calothyrsus* and *Leucaena trichandra* are grown in the highlands of Central Kenya (Franzel *et al.*, 2003). In addition to the dominat vegetative technologies in this catchment, promotion of these shrubs should be encouraged in the Upper Tana Catchment as they are fast growing, they fix nitrogen, and their use as contour hedgerows reduces soil erosion.

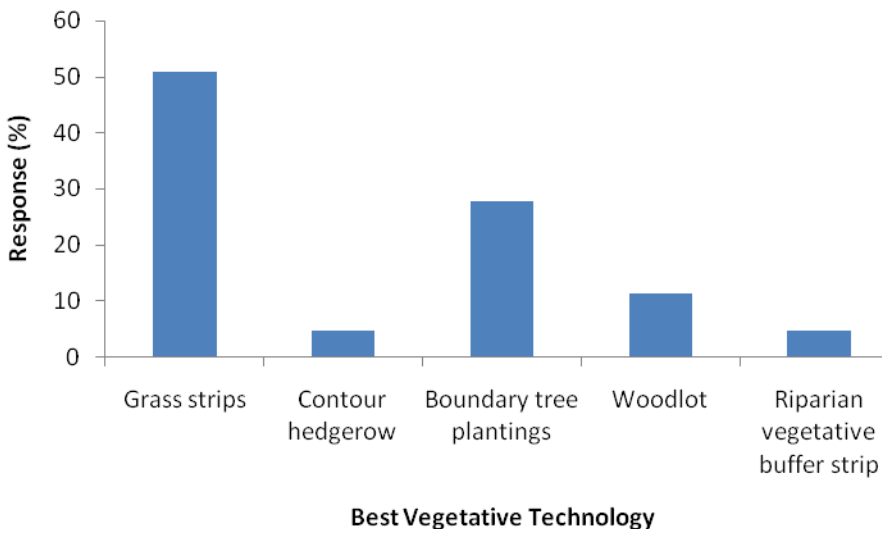


Figure 4. 6: Best vegetative technologies in the Upper Tana catchment

Factors influencing the choice of vegetative technologies

Slope (85%) was cited as the most influencing factor with climate, level degradation and others taking smaller proportions (Figure 4.7).

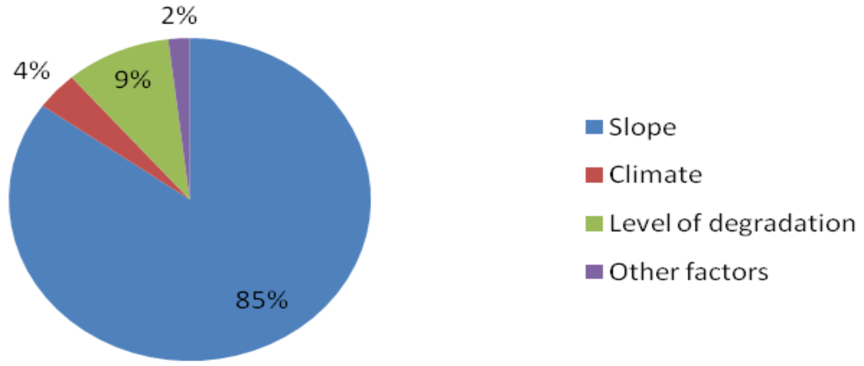


Figure 4. 7: Factors influencing adoption of vegetative measures in the upper

Tana Catchment

Source of information about vegetative technologies

Government extension in a group plays a major role in information dissemination of vegetative measures technologies within the Upper Tana catchment (Figure 4.8). Majority of the farmers interviewed (54%) cited government extension services while learning from the neighbors and friends played a minor role. This study corraborates with another one done in Central Kenya by Ouma *et al.*, (2002) who noted institutional factors influencing adoption as contact with extension agents, access to credit and membership in a farmer's group. Also Enyong (1999) reported that contact with extension agents was one of the most important factors that determined adoption. This was attributed to the fact that farmers' contact with extension agents allowed them greater access to information on the technology through greater opportunities to participate in demonstration tests (Obonyo, 2000).

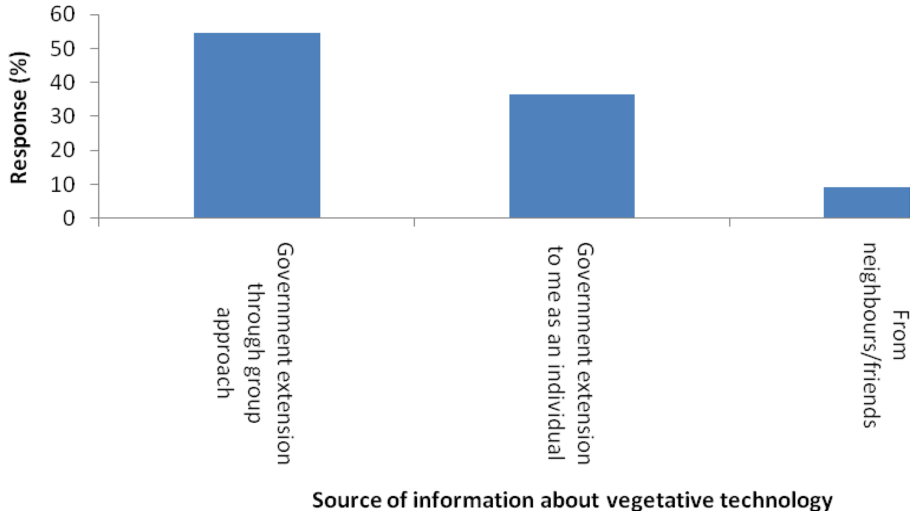


Figure 4. 8: Source of information on vegetative technologies

4.1.3 Agronomic technologies

About 45% of the agronomic technologies practiced within the Upper Tana catchment are dominated by manuring as shown in Figure 4.9 making it the most preferred agronomic technology compared to zero tillage, composting, mixed cropping, contour cultivation, mulching and green mulch. This scenario was also reflected in the analysis of technologies per AEZ with manuring and composting being practiced in all AEZs (Table 4.4).

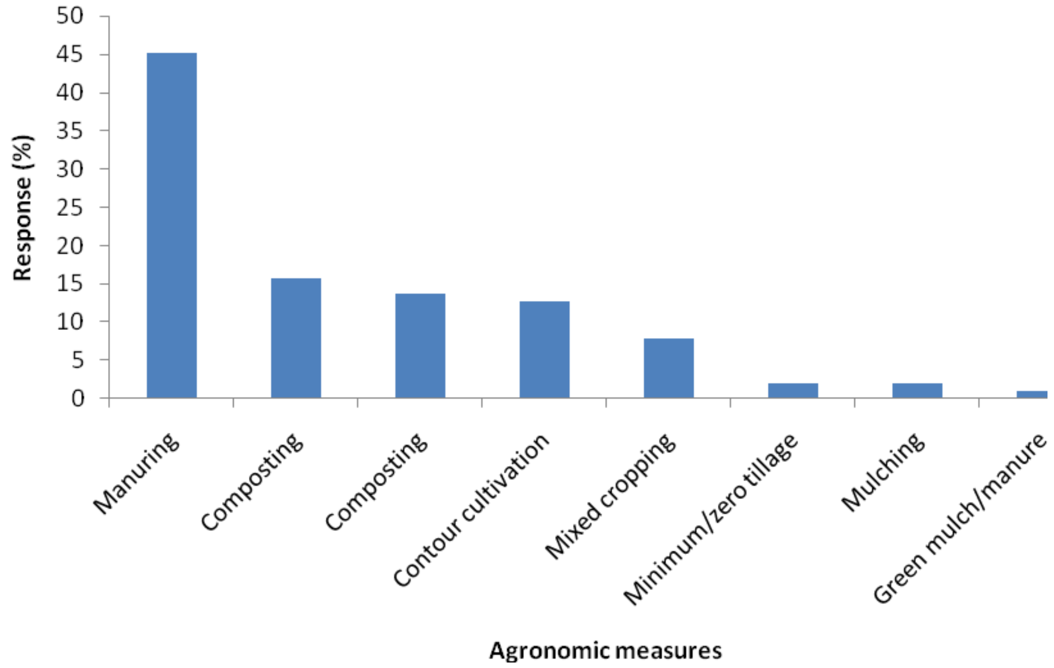


Figure 4. 9: Agronomic technologies in the Upper Tana Catchment

Table 4. 4: Agronomic technologies per AEZs

	Agronomic technology (%)							
Agro-ecological zone	Minimum/ zero tillage	Manuring	Composting	Composting	Mixed cropping	Contour cultivation	Mulching	Green mulch/manure
IL5	0.0	46.2	0.0	23.1	23.1	0.0	0.0	7.7
LH1	0.0	62.5	25.0	12.5	0.0	0.0	0.0	0.0
LM3	0.0	46.2	30.8	7.7	0.0	7.7	7.7	0.0
LM4	0.0	41.7	16.7	16.7	0.0	25.0	0.0	0.0
LM5	0.0	26.7	0.0	26.7	26.7	13.3	6.7	0.0
UM1	0.0	50.0	8.3	8.3	8.3	25.0	0.0	0.0
UM2	8.3	41.7	25.0	8.3	0.0	16.7	0.0	0.0
UM3	0.0	62.5	12.5	25.0	0.0	0.0	0.0	0.0
UM4	11.1	44.4	11.1	11.1	0.0	22.2	0.0	0.0

Best agronomic technologies

Among the agronomic technologies practiced by the farmers in the Upper Tana Catchment (figure 4.10), manuring is the best agronomic technology as cited by 43% of the sampled population followed by mixed cropping (22%), composting (14%), mulching (16%) and contour cultivation (6%).

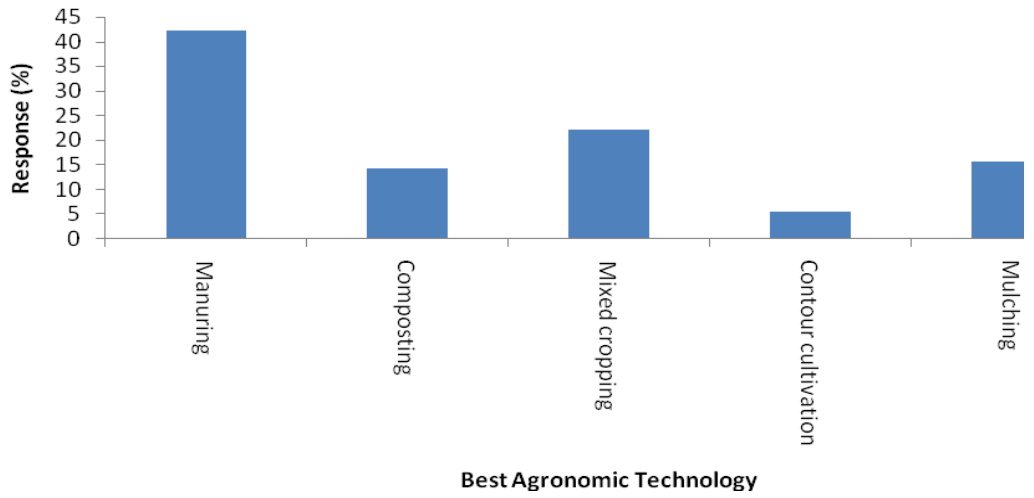


Figure 4. 10: Best agronomic technologies in the Upper Tana Catchment

Factors influencing the choice of agronomic technologies

As illustrated in Figure 4.11, level of degradation (63%) is the most influencing factor for adoption of agronomic technologies by farmers in the Upper Tana catchment. Other factors that influence the choice of agronomic technologies include, slope (22%), climate (10%) and cost of the technology (5%).

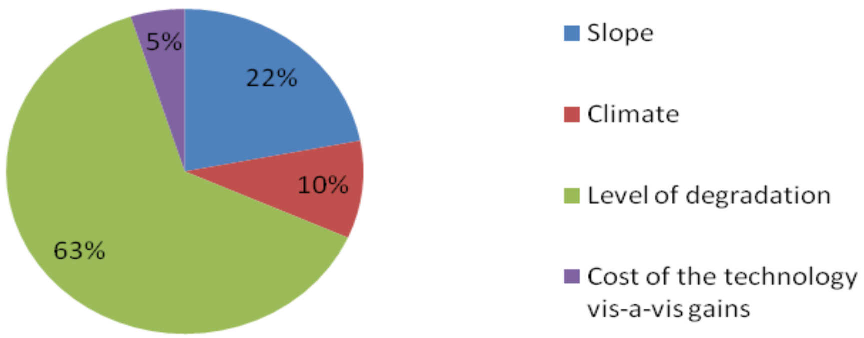


Figure 4. 11: Factors influencing adoption of agronomic technologies

4.1.4 Management technologies

Land use change (9%), rotational grazing (18%), change of management intensity (9%), change of timing of activities (27%) are the adopted management technologies within the Upper Tana Catchment with cut-and-carry being the most preferred (36%) as shown in Figure 4.12. Tarawali *et al.*, (1995) reported that proper land use management is a common practice in many parts of Sub-Saharan Africa (SSA) especially in areas where population density is high and the demand for crop land leaves very little for livestock grazing. Cut-and-carry feeding is popular with smallholder dairy schemes in parts of Kenya and Tanzania whereby the usual practice is to cultivate high yielding grass and legume species, which are then cut in rotation on a daily basis and fed to animals maintained in enclosures (Tarawali *et al.*, 1995).

As reported by Reardon (1996), shortage of arable land is one of the main challenges facing many farm households in SSA which has been exacerbated by high population growth rate and the accompanying increase in demand for food (Binswanger & Pingali, 1988). Embu County is not an exception and adoption of these varying methods of management has also been attributed to this.

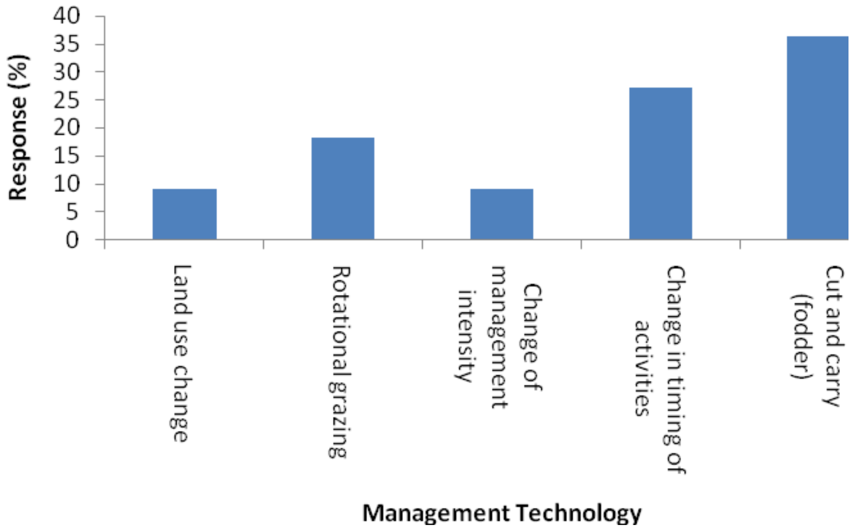


Figure 4. 12: Management Technologies in the Upper Tana Catchment

Among the sampled population per AEZs, not all farmers practiced management technologies, however among those that do, the most dominant technology was "cut-and-carry" (Table 4.5) which was found in the upper AEZs namely; LH1 (100%), UM1 (50%) and UM4 (33%). The farmers in these zones have relatively small land sizes that make it hard to have large areas for grazing. According to the Embu District Environment Action Plan 2009-2013 (GoK, 2009), the farm sizes have been declining for over 30 years. In the upper zones (tea zone), family land size varies from less than 0.2 to 1.6 ha. In the coffee zone, farm sizes vary from 0.2 to 2.0 ha. In the lower zone, family land size is variable and ranges from less than 0.1 to over 16 ha.

Table 4. 5: Management technologies per AEZs

	Managerial technology (%)				
Agro-ecological zone	Land use change	Rotational grazing	Change of management intensity	Change in timing of activities	Cut and carry (fodder)
LH1	0.0	0.0	0.0	0.0	100.0
LM3	100.0	0.0	0.0	0.0	0.0
LM5	0.0	66.7	33.3	0.0	0.0
UM1	0.0	0.0	0.0	50.0	50.0
UM4	0.0	0.0	0.0	66.7	33.3

Best management technologies

Cut and carry fodder (36%) was found out to be the best management practice for soil and water conservation among the farmers in the Upper Tana Catchment (Figure 4.13). Land use, rotational grazing, change of management intensity, change in timing activity are less preferred. According to a study done in Mwala (Machakos county), farmers had larger shares of cropped areas at the expense of grazing areas and were more likely to cut and carry fodder and restrict cattle to stalls as average farm size decreased from 17.8 hectares to 1.3 hectares (Zaal, 2004). The livestock production increased per hectare as farm size decreased because either cut-and-carry fodder and crop residues or purchased animal feed more than compensated for the loss of grazing area. The average farm size per household is 0.5ha in Embu (Ouma *et al*., 2002).

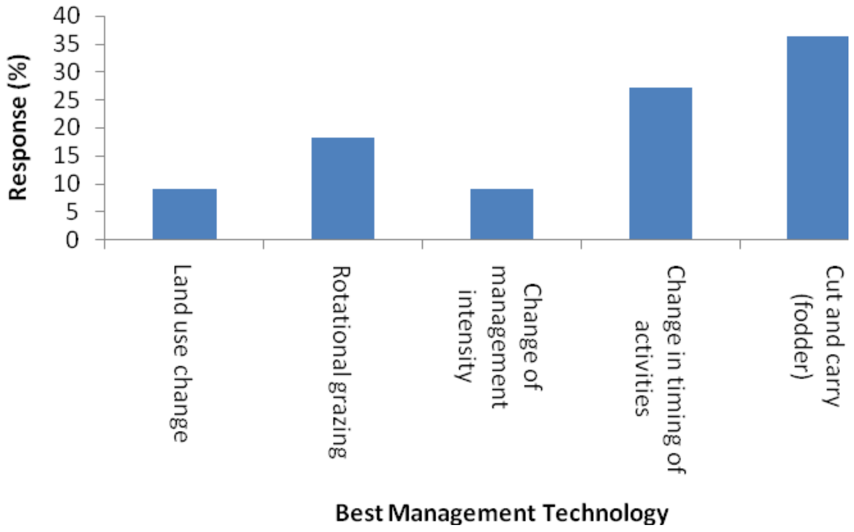


Figure 4. 13: Best management practice in the Upper Tana Catchment

Factors affecting implementation of management technologies

Management technologies adopted by farmers in the Upper Tana Catchment are influenced by climate, level of degradation and cost of the technology. Majority (72%) of the sampled farmers cited level of degradation as the most influencing factor for type of managerial technology they use in their farms for water and soil conservation (figure 4.14).

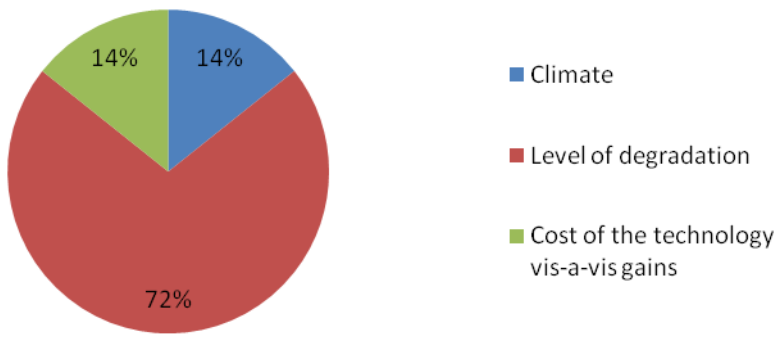


Figure 4. 14: Factors influencing adoption of management technologies

Source of information about management technologies

The use of agricultural extension officers has played a great role in dissemination of agricultural information. From 1966, in Embu, food production drastically declined and in response agriculture extension officers recommended use of fertilizers and livestock manure to improve soil fertility and food production, hence making a turning point in management of agricultural land (Beneah *et al.*, 2011). This was also confirmed from the findings of this research as shown in Figure 4.15 whereby, most (45%) of the management technology information in the Upper Tana Catchment is disseminated by government extension officers through group approach and (22%) to individual farmers while the rest gets the information from other sources.

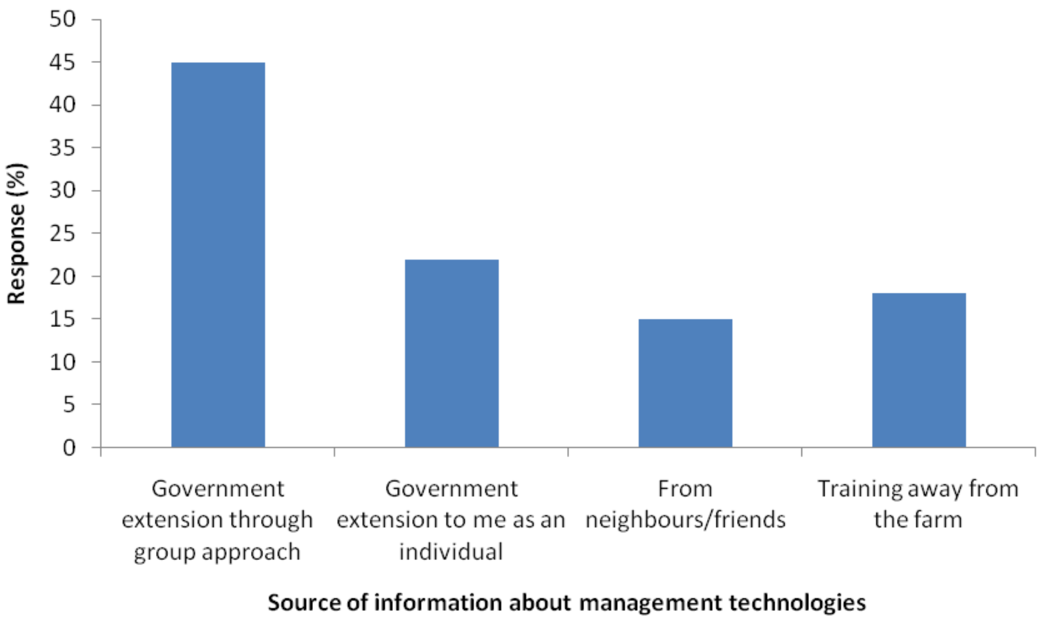


Figure 4. 15: Source of information on management technologies

4.2 Documentation of appropriate SLM Technologies

After the identification of the various SLM technologies in the Upper Tana Catchment, the most appropriate ones were selected with the assistance of the frontline agricultural extension officers for documentation. Appendix 2 shows a four page template of a synthesized stone-line technology (T_KEN660en) as documented using the WOCAT framework. The documented technologies were entered in the MATSIM tool's database and the global WOCAT database and can be accessed via the following link, (www.wocat.net) using their reference numbers or author criterion. Table (4.6) presents a summary of the documented technologies.

Table 4. 6: Documented SLMs in the Upper Tana Catchment

No	AEZ	**Identified SLM Technologies along the Upper Tana Topo-sequence**	**Conservation measure**	**WOCAT REF: Global Domain**
1.	LM5	Stone Lines	Structural	T_KEN660en
2.	LM5	Mulch	Structural	T_KEN661en
3.	UM3	Grassed Water Way (artificial)	Agronomic	T_KEN662en
4.	UM3	Trash Lines (maize stocks)	Structural	T_KEN663en
5.	UM2	Woodlot	Vegetative	T_KEN668en
6.	UM3	Maize Pits	Structural	T_KEN669en
7.	UM3	Boundary Trees-windbreakers	Vegetative	T_KEN670en
8.	LM4	Multistory Gardens	Structural	T_KEN671en
9.	UM2	Crop Rotation	Agronomic	T_KEN672en
10.	IL5	Lock and Spill Drains	Structural	T_KEN673en
11.	UM1	Coffee Agroforestry	Agronomic	T_KEN674en

12.	UM2	Raised Beds for Onions	Structural	T_KEN675en
13.	LM3	Cover crops	Agronomic	T_KEN676en
14.	LM5	Fanya Juu Terraces Makarikariensis	Structural	T_KEN677en
15.	LM4	Rotational grazing	Management	T_KEN678en
16.	LM4	Mandara Gardens	Structural	T_KEN679en
17.	UM2	RWH-Road Runoff Crop Production	Structural	T_KEN680en
18.	LM3	Artificial Wetland	Agronomic	T_KEN681en
19.	UM3	Banana Pits	Structural	T_KEN682en
20.	IL5	RHW - Rain Water Harvesting for domestic use	Structural	T_KEN683en
21.	UM3	Trashlines	Structural	T_KEN684en
22.	LM3	RWH-for Fish farming	Structural	T_KEN685en
23.	UM3	Conservation Agriculture	Management	T_KEN686en
24.	UM3	Fanya Juu Terraces – Nappier grass & sweetpotatoes	Structural	T_KEN687en
25.	IL5	Boundary Hedgerows	Vegetative	T_KEN688en
26.	LM4	Maize Zaipits-9	Structural	T_KEN689en
27.	UM1	Retention ditches	Structural	T_KEN690en

4.3 Decision Support (MATSIM) Tool

Decision Support (MATSIM) Tool for Sustainable Land Management technologies in the Upper Tana catchment was developed using Microsoft Access.VBA application software and has been compiled for the 32-bit platforms for computers running Windows 2003 and more recent windows operating systems. Apart from the basic user interface of the tool, another pertinent component of the tool is a database of SLMs that were evaluated and analyzed at field level by the use of WOCAT methodology. Every technology within the database was documented and presented using a standardized WOCAT template. The tool was developed to assist the farmers and watershed managers within the catchment in decision making on Sustainable Land Management technologies suitable for enhancing eco-system services and climate change adaptation. The tool offers a practical approach that if adopted will facilitate processes in which farmers and other catchment managers may share, select and decide on the most appropriate SLM solutions for their land.

Knoop *et al*., 2012 suggests that, in the Upper Tana Catchment, it is important to keep in mind that the SLM measures should be designed to fit the land use, slope, soil, rainfall, farming system, etc. If they are not applied in view of these specifications, Knoop *et al*., 2012 cautions that they tend to aggravate erosion and land degradation. In MATSIM-Tool the type of SLM Technology chosen follows a hierarchy as follows.

1) Agro-climatic zones
2) Agro-ecological zones
3) Land use type (Natural forest, Annual cropping, Perennial-non woody, and Agro-forestry)
4) Soil characteristics (Depth and Drainage)
5) Percentage slope
6) Ecosystem services and climate change adaptation of the SLM
7) Gender (Male, Female and Male or Female)
8) Land Tenure Systems (titled or untitled)

4.3.1 Agro-Climatic and Agro-Ecological zones of the Upper Tana Catchment

From the study area, five distinct ACZs and nine AEZs were considered in development of the MATSIM Tool according to Sombroek *et al.* (1982) and Jaetzold and Schmidt (1983) respectively. In the high altitude areas, the objective is to prevent excessive erosion while in the low altitude areas, the objective is to conserve moisture. Technologies suitable for the high altitude areas include; fanya juu terraces, bench terraces, contour bunds, grassed water ways and rain water harvesting structures. On the other hand, the technologies suitable for low altitude areas includes mulching, rain water harvesting, 9-maize pits etc.

4.3.2 Land Use Types (LUT)

The Sustainable Land Management technologies within the Upper Tana Catchment depend on the intended LUT. MATSIM Tool recognizes the following LUTs that are predominant within the catchment,

1) **Natural forest:** These are forests composed of indigenous trees, not planted by man. Mostly they are found on the Embu North district and are government protected. Technologies suitable for this LUT may include forestation and re-forestation.
2) **Annual cropping**: Land under temporary / annual crops usually harvested within one, maximally within two years (e.g. maize, vegetables, fodder crop).
3) **Perennial (non-woody) cropping:** (land under permanent (not woody) crops that may be harvested after 2 or more years, or only part of the plants are harvested like bananas.
4) **Agroforestry:** (permanent woody plants with crops harvested more than once after planting and usually lasting for more than 5 years (e.g. orchards / fruit trees, coffee, tea, fodder trees).
5) **Grazing land:** land used for animal production, grazing on natural or semi-natural grasslands, or improved or planted pastures for grazing/production of

fodder (for cutting and carrying: hay, leguminous species, silage etc) this was predominant in the Mbeere District.

4.3.3 Soil Depth

Deep soils have good drainage while shallow soils have poor drainage. Table 4.7 presents different technologies suitable for different soil depths. In sustainable land management, the objective is to improve the soil depth and in addressing this, MATSIM Tool recognizes the following categories of soil depth according to Kenya Soil Survey (KSS).

a) Very shallow (0-20)cm
b) Shallow (20-50)cm
c) Moderately deep (50-80)cm
d) Deep (80-120)cm
e) Very deep (>120)cm

4.3.4 Soil Drainage

Improving drainage on agricultural land not only enhances crop production but also has a role in soil and water conservation. Drainage is important to avoid excess water stress to the plants (www.gov.mb.ca). SLM technologies such as organic compost, manuring, mulch are used to improve soil quality and drainage. Different SLM Technologies are suitable for different categories as shown in table 4.7. The MATSIM Tool recognizes soil drainage as good, medium or poor.

Table 4. 7: Soil depth and drainage conditions suitable for implementation of SLM Technologies

Category	Description	SLM Technologies
Shallow soils	(Soil depth of ≤ 1m)	• Bench terraces • Mulching: well drained soils • Planting Pits (Zai pits): poorly drained soils • Katumani Pitting • Stone lines

Deep soils	(Soil depth of ≥ 1m)	• Contour bunds • Graded drainage ditch / Fanya Juu: enlarged ones • Mulching: well drained soils • Retention ditches: stable soils • Stone lines

4.3.5 Slope

According to Thomas (2003), conservation measures should be adapted to the slope and the land use. In the development of MATSIM Tool, the following criterion was considered. Table 4.8 presents different categories (gentle, medium and steep) that are suitable for implementation of different SLM technologies. These categories have been adopted in the MATSIM Tool.

Table 4. 8: Slope categories suitable for implementation of SLM Technologies

Category	**Percentage Slope (%)**	**SLM Technologies**	
Gentle slopes	(0-5 %):	• Contour bunds • Graded drainage ditch / Fanya Juu • Bench terraces • Small earth dams • Grassed waterways • Contour hedgerows • Trash lines	• Riparian vegetative buffer strip • Conservation tillage • Contour farming • Stone lines
Medium slopes	(5 - 25 %)	• Bench terraces • Graded drainage ditch / Fanya Juu • Grassed waterways • Contour hedgerows	• Conservation tillage • Contour farming: <10% • Stone lines • Trash lines

Steep slopes	(>25 %)	• Contour hedgerows (with a limit of 50% slope) • Conservation tillage • Stone lines

4.3.6 SLMs for Climate Change Adaptation

According to Ellen and Barry (2005), adaptation to climate is modifications to farm practices with respect to multiple (climatic and non-climatic) stimuli and conditions. The standard approach for identifying possible adaptation practices in agricultural adaptation to climate risk begins with climate change scenarios. The main objective of farmers is to promote the efficient capture, storage and utilization of rainfall through the adoption of appropriate soil and water conservation practices, the provision of irrigation, and the use of systems and practices with high use efficiency. Climate and weather risks are increasingly important in the category of factors to consider and those already following sustainable agricultural practices will be appropriate (Ellen & Barry, 2005). The adaptation of a selected SLM in the MATSIM Tool was assessed with its ability to withstand the following climatic scenarios.

1) Temperature change (positive or negative)
2) Seasonal rainfall change (positive or negative)
3) Heavy rainfall events (intensities and amount)
4) Windstorms / dust storms
5) Floods
6) Droughts / dry spells

4.3.7 Ecosystem services

Ecosystem services are the benefits that people obtain from ecosystems. Millennium Ecosystem Assessment (MEA, 2005) recognizes four categories of eco-system services: 1) Supporting e.g. nutrient cycling, soil formation and primary production;

2) Provisioning e.g. food, fresh water, wood and fiber and fuel; 3) Regulating e.g. climate regulation, flood and disease regulation and water purification; and 4) Cultural e.g. aesthetic, spiritual, educational and recreational. The suitability of a particular SLM technology within MATSIM is determined by its ability to offer a positive on-site benefit that includes production / socio-economic, socio-cultural benefits or ecological benefits as shown in appendix 3.

4.3.8 Gender (Male, Female and Male or Female).

There have been studies that have tried to link gender to adoption. Studies conducted in Ethiopia, Tanzania and Zimbabwe (Tiruneh *et al.,* 2001) revealed that gender plays a critical role in adoption of sustainable land management practices and as such cannot be ignored in development of MATSIM Tool, Women have been found to participate in lesser numbers than men, a factor that has greatly contributed to the unsuccessful implementation of SLM (Wambui., 2013). According to a study done in Machakos by Gachene *et al.,* (2015), most of the soil and water conservation activities are carried out by both men and women but the laying out of terraces is done mainly by men. From this study, it was reported that implementation of such technologies like stone-lines, fanya juu terraces and bench terraces were done by men since they have more energy unlike women.

4.3.9 Land Tenure Systems

Land tenure had two categories, titled and not titled. According to studies done in western and central Kenya by Place and Adhola (1998), security of tenure influences positively adoption of SLM hence its importance in the development of MATSIM Tool. Lee and Stewart (1983) reported that Insecurity of land tenure reduces farmers' incentives to invest in land conserving practices. Where farmers have a security of tenure, there was tendency of implementing the SLMs independently as it was evidence in the upper Embu districts as compared to the lower Mbeere south districts where some lands are communal.

4.3.10 SLM-Technologies within MATSIM Tool Framework

According to Knoop *et al.* (2012), one of the main strategies for sustainable land management in the Upper Tana Catchment is a comprehensive introduction of measures to reduce landslides and soil erosion, coupled with techniques to maximise retention of soil moisture and infiltration to groundwater. Within the framework of the MATSIM Tool, an SLM technology consists of one or more conservation measures belonging to the following categories:

Agronomic: These are measures undertaken within the cropping area for crop production purposes. They include practices such as intercropping, contour cultivation, minimum tillage, mulching and manuring.

Vegetative: These measures involve the deliberate planting of trees, shrubs, grasses etc, or retention of areas of natural vegetation (e.g. reforestation, contour hedgerows, and natural vegetative strips).

Structural: Measures which involve the construction of physical structures formed from earth, stone or masonry (e.g. graded banks or bunds, contour stone lines, level bench terraces, artificial waterways and drop structures). (Thomas *et al.,* 2003; WOCAT, 2007).

Management: These measures arise from deliberate managerial decisions taken with the intention of protecting land from erosion/improving production etc, (e.g., land use changes, area closure, rotational grazing). All these factors have been considered in building the architecture of the model.

4.4 MATSIM Tool's architecture

4.4.1 Tables in the database

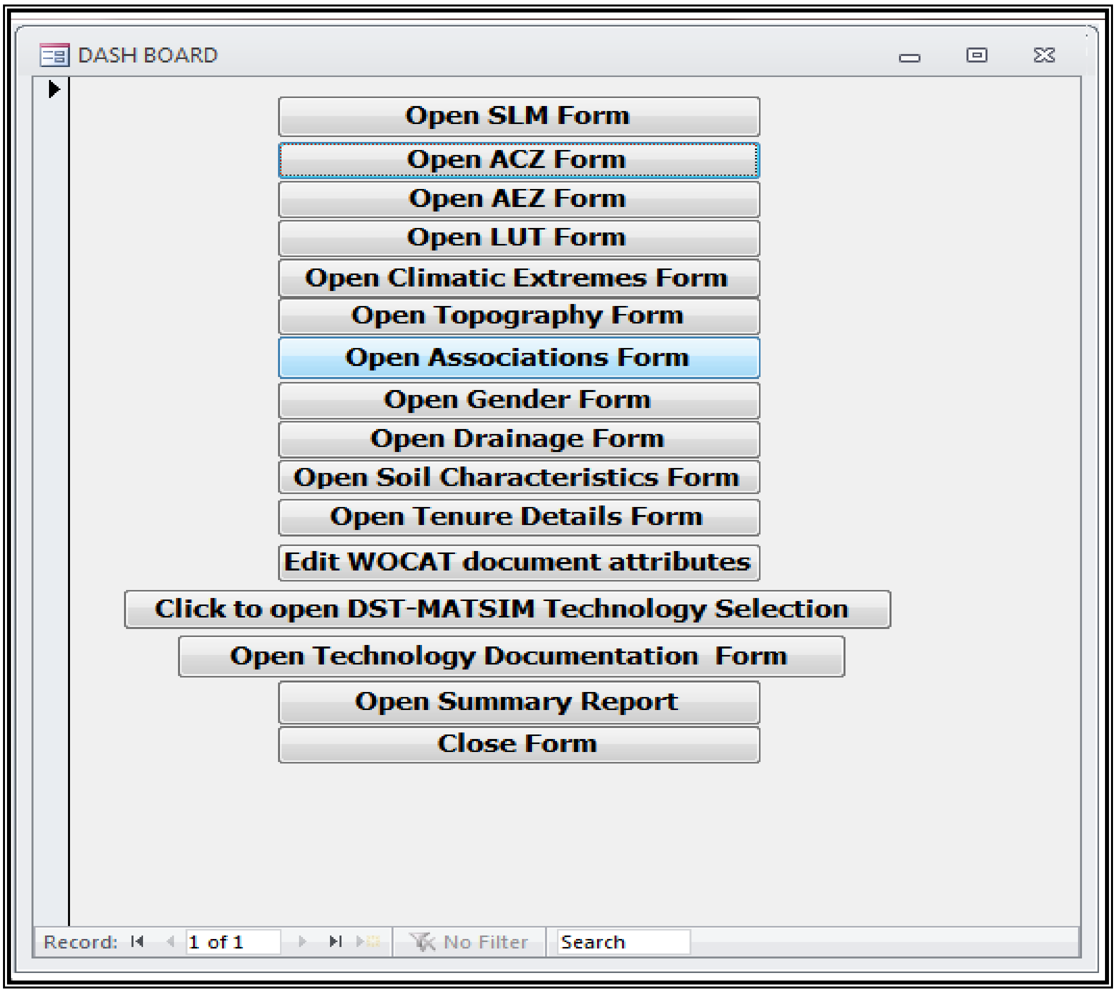
The MATSIM tool has a backend database that acts as a repository for data used by the application. The application logic processes this data into meaningful information and displays it to the user, based on various criteria selected by the user. The user uses the application output to select appropriate SLM's. The various tables and the database used to store data are listed in appendix 4.

4.4.2 Forms for adding and removing data in MATSIM Tool database

The system has several forms that assist the developers in the entry and manipulation of data in the database. The procedure for using each individual form is as outlined.

Application Dash Board Form

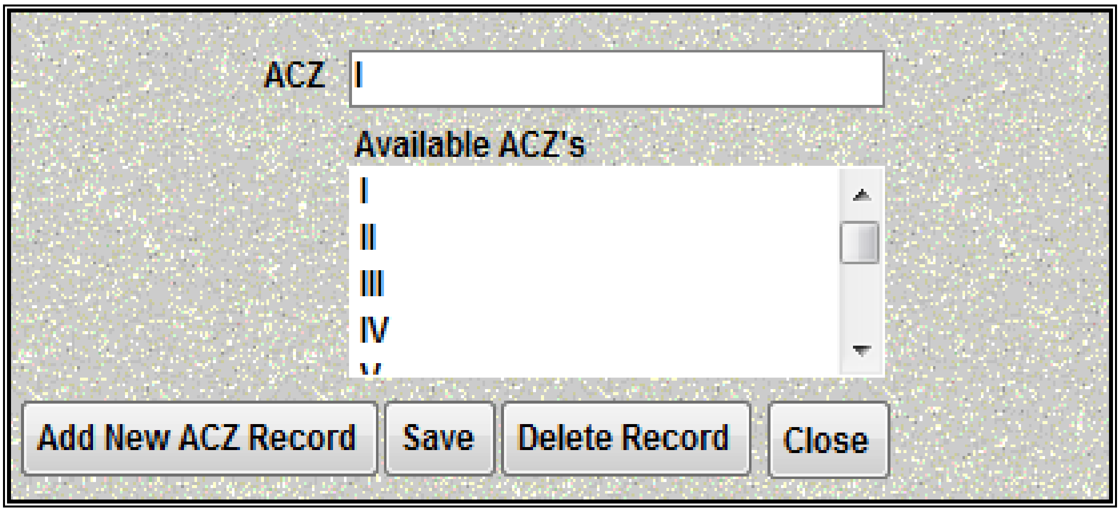
As shown in form 4.1, the Dash Board Form provides an interface from where all other forms can be called from. The forms are called by clicking on the appropriate tab on the dashboard to open the form. For example, to open the form for entering the SLMs, the user will click on the 'Open SLM form' button. After the SLM form is opened the user can then enter the SLM data into the application's database through the form.



Form 4. 1: Application Dash Board Form

Form to add new or delete existing ACZs

Form 4.2 is used to add a new or delete an existing Agro-Climatic Zone to the database. The following are the procedures that are used while adding a new or deleting an existing ACZ record in the database.



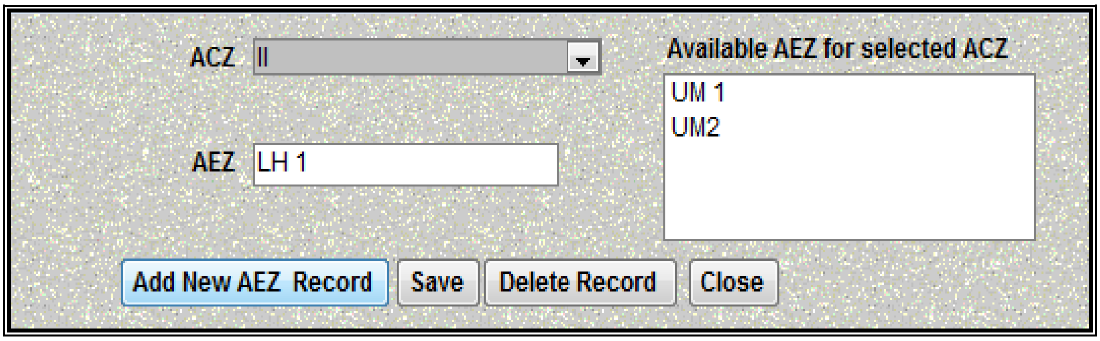
Form 4. 2: Agro-Climatic Zones (ACZ) Form

Procedure to add a new or delete an existing ACZ record in the database

1. Click on the add 'Add New ACZ Record' to add an empty record
2. Enter the ACZ in the ACZ text box.
3. Click on 'Save' to save the ACZ entry in the database.
4. To delete an existing ACZ entry click on the 'Delete Record' button.
5. To close the form, click the 'Close form' button.

Form to add New or delete an existing AEZ record in the database

The form (Form 4.3) is used to add a new or delete an existing AEZ records in the database. The form also enables one to view the AEZ's that are already in that particular ACZ.



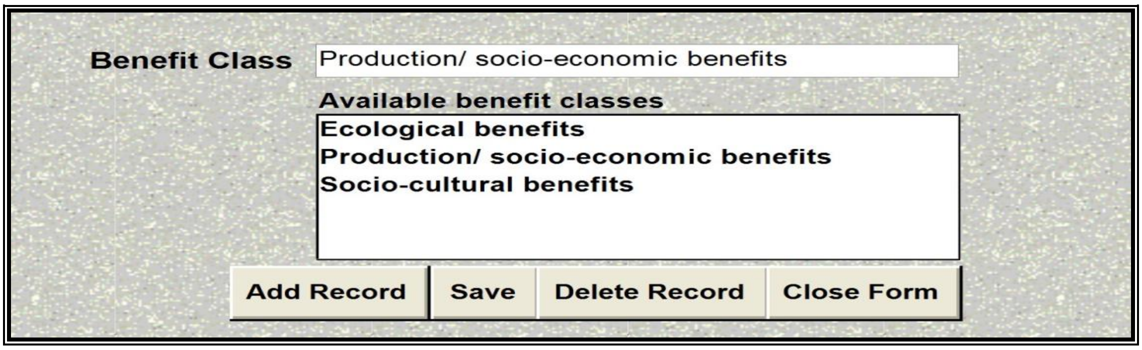
Form 4. 3: Agro-Ecological Zone (AEZ) Form

Procedure for adding a new or deleting an existing AEZ in the database

1. Select the ACZ that the AEZ belongs to from the ACZ combo box. This will populate the ‘Available AEZ’ list box with the AEZ’s in the selected ACZ.
2. Click on the add ‘Add New AEZ Record’ to add an empty record
3. Enter the AEZ in the AEZ text box.
4. Click on ‘Save’ to save the AEZ entry in the database.
5. To delete an existing AEZ entry click on the ‘Delete Record’ button.
6. To close the form, click the ‘Close form’ button.

Form to add a new or delete an existing Benefit Class in the database

Form 4.4 is used to add a new or delete an existing benefit class to the database.



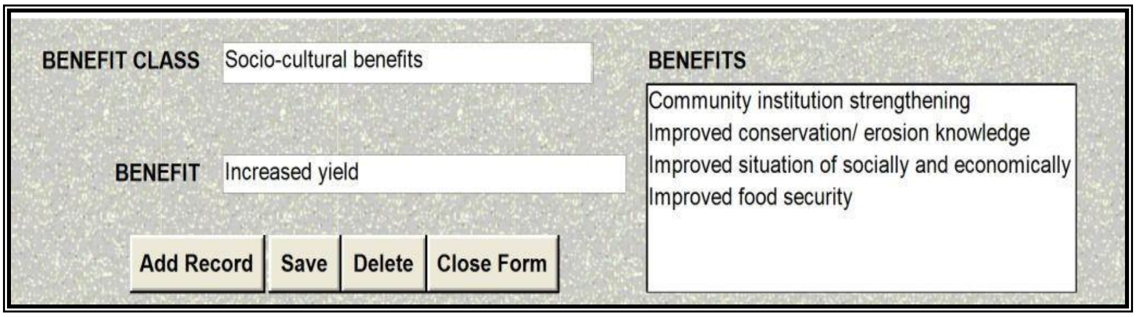
Form 4. 4: Benefit Class Form 1

Procedure for adding a new or deleting an existing Benefit Class in the database

1. Click on the ‘Add Record’ to add an empty record
2. Enter the benefit class in the benefit text box.
3. Click on ‘Save’ to save the benefit entry in the database.
4. To delete an existing benefit entry click on the ‘Delete Record’ button.
5. To close the form, click the ‘Close form’ button.

Form to add a new or delete an existing "benefits" in the database

Form 4.5 is used to add a new or delete an existing 'benefit' data to the database.



Form 4. 5: Benefit Class Form 2

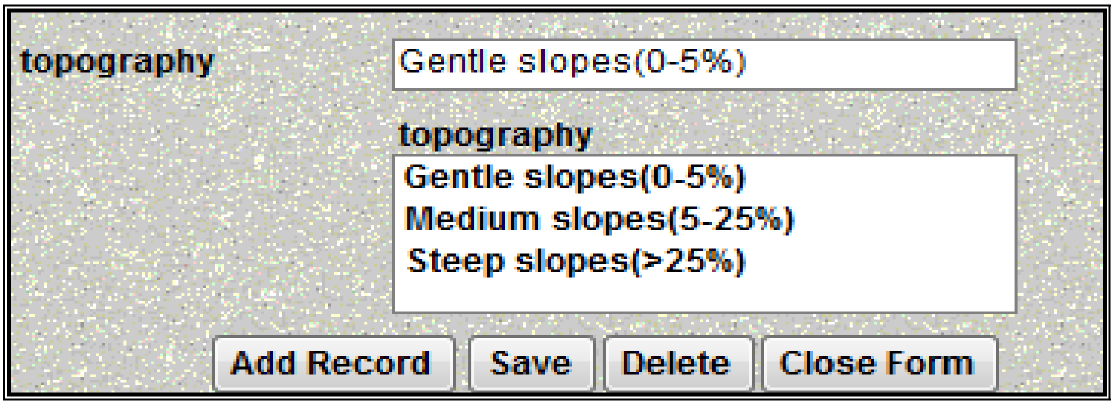
Procedure for adding a new or deleting an existing benefit to the database

1. Select the appropriate benefit class from the 'Benefit Class' combo box. This will populate the 'Benefits' list box with the benefits currently in the selected benefit class.
2. Click on the 'Add Record' button to add an empty record.
3. Enter the benefit in the 'Benefit' text box.
4. Click on 'Save' to save the benefit entry in the database.
5. To delete a benefit entry, click on the 'Delete' button.
6. To close the form, click the 'Close form' button.

The 'Benefits' list box on the right lists benefit data, belonging to the selected benefit class, that is already entered into the database.

Form to add new or delete an existing topography data to the database

The form (Form 4.6) is used to add new or delete an existing topography data to the database.



Form 4. 6: Topography Form

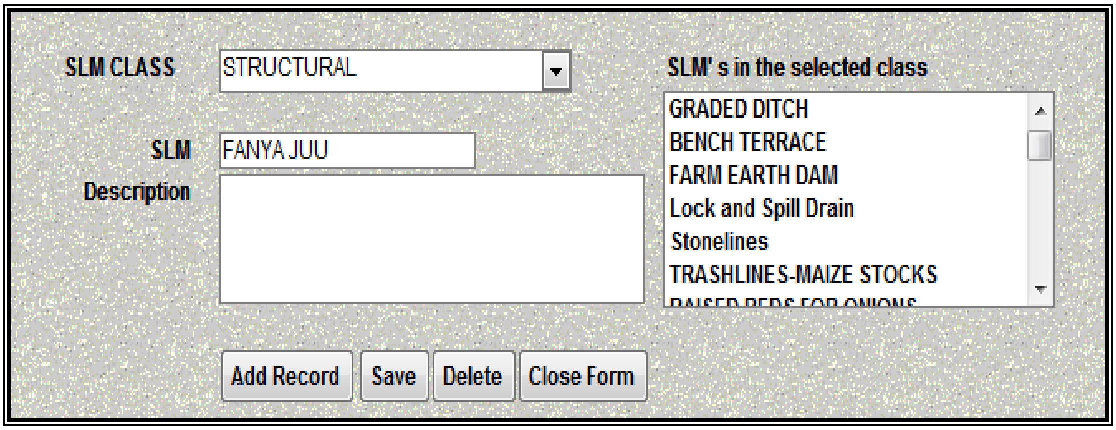
Procedure for adding a new or deleting an existing topography data to the database

1. Click on the add ‘Add Record’ to add an empty record
2. Enter the topography in the ‘topography’ text box.
3. Click on ‘Save’ to save the benefit entry in the database.
4. To delete a benefit entry click on the ‘Delete Record’ button.
5. To close the form, click the ‘Close form’ button.

The topography list box below the topography text box lists topography data already entered into the database.

Form to add a new or delete an existing SLM technology to the database

The form (Form 4.7) is used to add new SLM technology data to an existing SLM class in the database.



Form 4. 7: SLM Technology Form

Procedure for adding a new or deleting an existing SLM technology to the database

1. Select the SLM class that the SLM belongs to from the 'SLM CLASS' combo box. This will populate the 'SLM's in the selected class' list box with the SLM's currently in the selected SLM class.
2. Click on the add 'Add Record' to add an empty record
3. Enter the SLM in the 'SLM' text box.
4. Click on 'Save' to save the SLM entry in the database.
5. To delete an SLM entry click on the 'Delete' button.
6. To close the form, click the 'Close form' button.

Form to add new or delete an existing LUT data to the database

The form (Form 4.8) is used to add a new or delete an existing Land Use Type (LUT) data to the database.

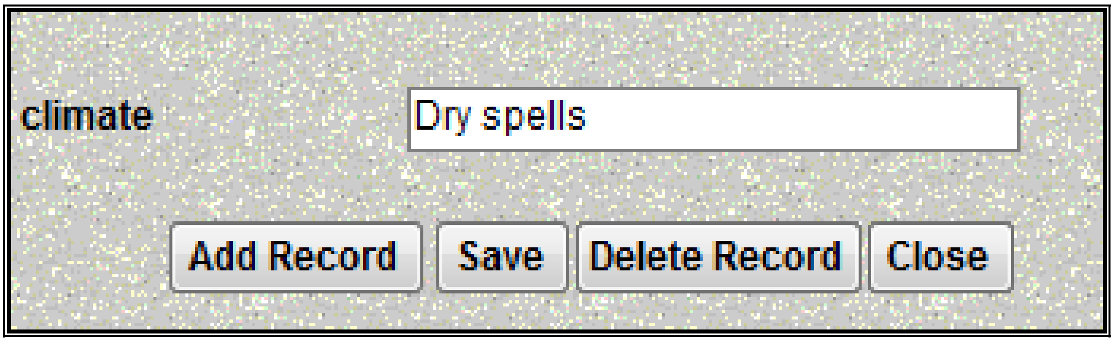
Form 4. 8: Land Use Types (LUT) Form

Procedure for adding an LUT to the database

1. Click on the add ‘Add New LUT Record’ to add an empty record
2. Enter the LUT in the ‘LUT’ text box.
3. Click on ‘Save’ to save the LUT entry in the database.
4. To delete an LUT entry click on the ‘Delete Record’ button.
5. To close the form, click the ‘Close form’ button.

Form to add a new or delete an existing climatic extremes to the database

This form (Form 4.9) is used to add a new or delete an existing ‘Climatic Data’ into thedatabase.



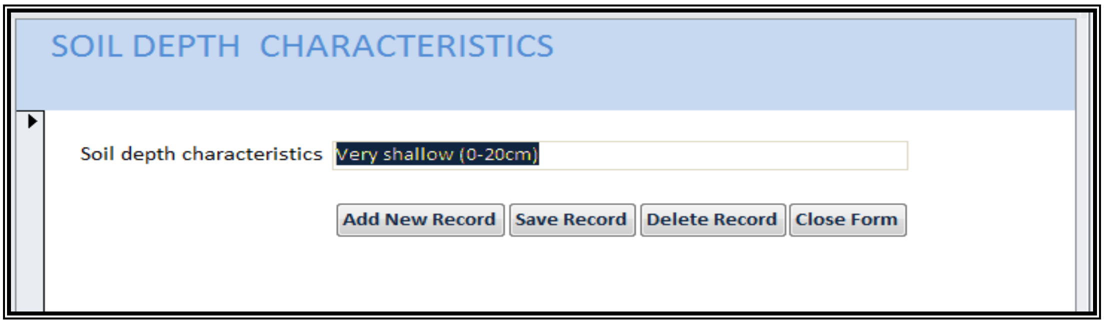
Form 4. 9: Climatic Extremes Form

Procedure for adding new or deleting an existing climate data record into the database

1. Click on the add ‘Add Record’ to add an empty record
2. Enter the climate extreme in the ‘climate’ text box.
3. Click on ‘Save’ to save the entry in the database.
4. To delete a benefit entry click on the ‘Delete Record’ button.
5. To close the form, click the ‘Close form’ button.

Form to add new or delete an existing soil depth characteristics data to the database

The form (Form 4.10) is used to add a new or delete an existing soil depth characteristic data to the database.



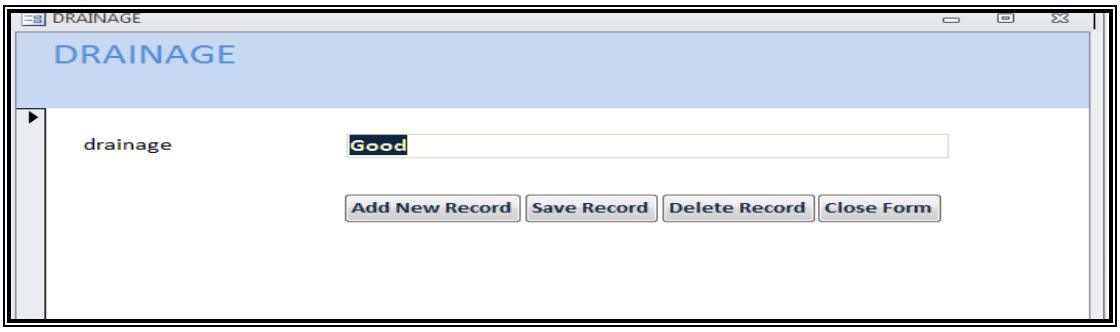
Form 4. 10: Soil Depth Form

Procedure for adding new or deleting existing soil depth characteristics

1. Click on the add 'Add New Record' to add an empty record.
2. Enter the soil depth in the 'Soil depth characteristics' text box.
3. Click on 'Save' to save the soil depth entry in the database.
4. To delete a soil depth entry, click on the 'Delete Record' button.
5. To close the form, click the 'Close form' button.

Form to add or delete an existing drainage characteristics data to the database

This form (Form 4.11) is used to add a new or delete an existing drainage characteristic data to the database.



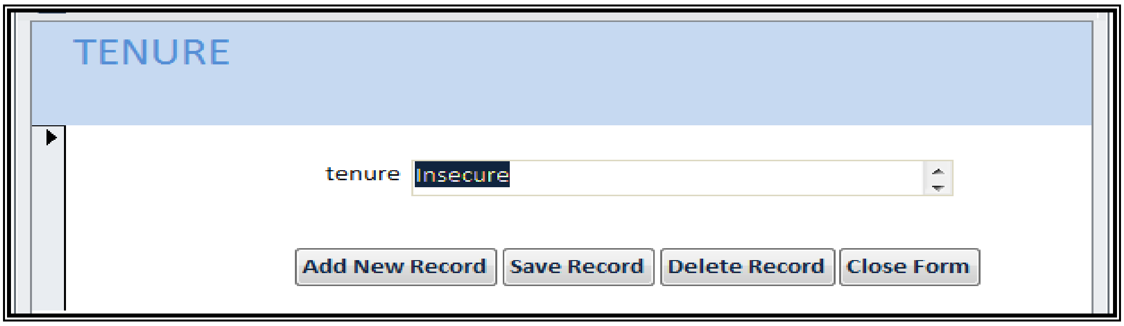
Form 4. 11: Soil Drainage Characteristics Form

Procedure for adding new or deleting existing soil drainage characteristics

1. Click on the add ‘Add New Record’ to add an empty record
2. Enter the drainage characteristic in the ‘drainage’ text box.
3. Click on ‘Save’ to save the drainage characteristic entry in the database.
4. To delete drainage characteristic entry click on the ‘Delete Record’ button.
5. To close the form, click the ‘Close form’ button

Form to add new or delete an existing Land Tenure data to the database

This form (Form 4.12) is used to add a new or delete an existing land tenure data to the database.



Form 4. 12: Land Tenure Form

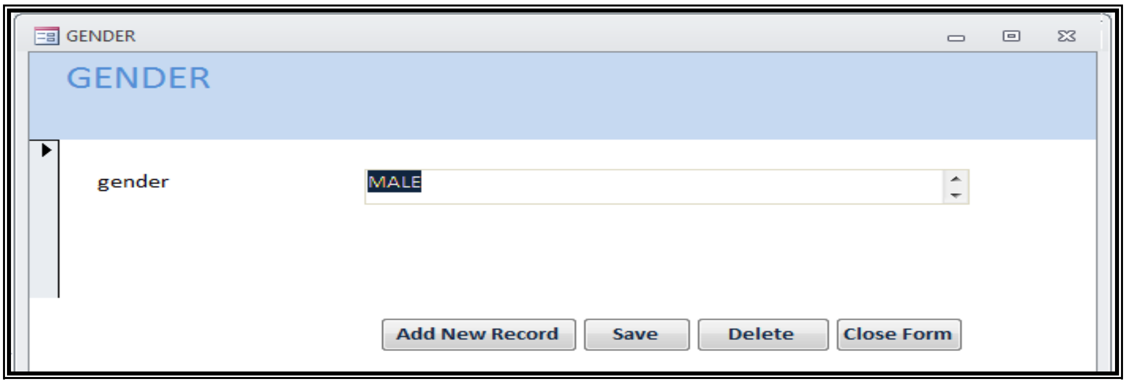
Procedure for adding new or deleting an existing land tenure data

1. Click on the add ‘Add New Record’ to add an empty record

2. Enter the land tenure in the 'Tenure' text box.
3. Click on 'Save' to save the land tenure entry in the database.
4. To delete land tenure entry click on the 'Delete Record' button.
5. To close the form, click the 'Close Form' button.

Form to add new or delete existing gender data to the database

This form (Form 4.13) is used to add a new or delete existing gender data to the database.



Form 4. 13: Gender Form

Procedure for adding new or deleting an existing gender data to the database

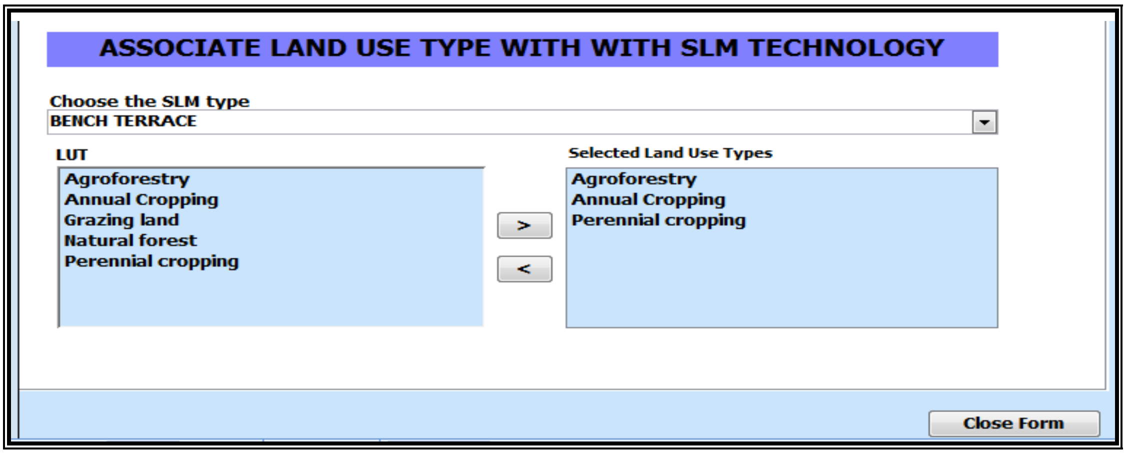
1. Click on the add 'Add New Record' to add an empty record
2. Enter the gender in the 'Gender' text box.
3. Click on 'Save' to save the gender entry in the database.
4. To delete gender entry click on the 'Delete Record' button.
5. To close the form, click the 'Close Form' button.

4.4.3 Forms for Associating SLMs with Different Biophysical Data

After all the major biophysical factors have been entered in the individual forms, the SLMs are later associated together. The following discussion shows how the association was done.

Form to associate the Land Use Type with selected SLM Technology

This form is used to associate the various land use types that have been entered in the database with respective sustainable land management technologies as shown on Form 4.14.



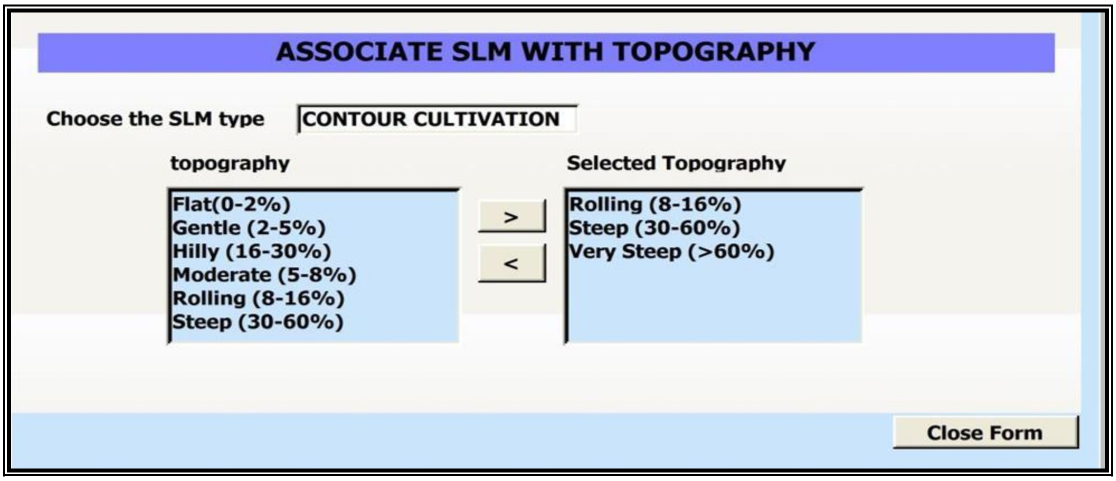
Form 4. 14: Association of LUT with selected SLM Technology

Procedure for associating land use type with SLM Technology

1. Select the SLM from the 'Choose the SLM type' combo box.
2. Select the Land use type (LUT) to associate from the LUT list box.
3. Use the > button to move the selected LUT to the 'Selected Land Use Types' list box in order to associate it with the selected SLM.
4. To dissociate the LUT from the SLM, select the LUT in the 'Selected Land Use Types' list box and use the < button to move it back to the LUT list box.
5. To close the form, click the Close form button.

Form to associate SLM with topography

This form is used to associate the various "Topography classes" that have been entered in the database with respective Sustainable Land Management technologies as shown on Form 4.15.



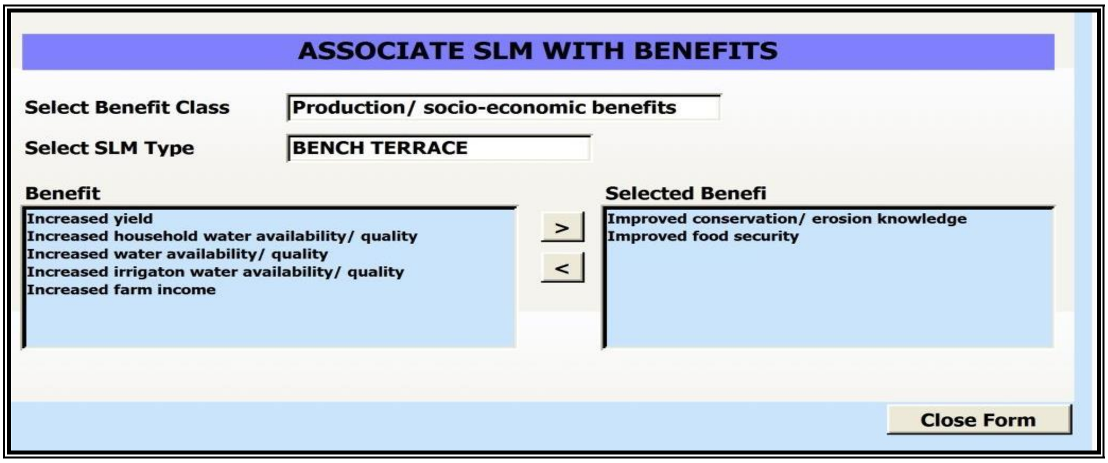
Form 4. 15: Association of SLM with Topography Form

Procedure for associating SLM with topography

1. Select the SLM from the ‘Choose the SLM type’ combo box.
2. Select the topography to associate from the topography list box.
3. Use the > button to move the selected topography to the ‘Selected topography’ list box in order to associate it with the selected SLM.
4. To dissociate the topography from the SLM, select the topography in the ‘Selected topography’ list box and use the < button to move it back to the topography list box.
5. To close the form, click the Close form button.

Form to associate SLM with benefits

This form is used to associate the various ‘Ecosystem benefits’ that have been entered in the database with respective Sustainable Land Management technologies as shown on Form 4.16.



Form 4. 16: Association of SLM with benefits Form

4.4.4 Procedure for associating SLM with benefits

1. Select the benefit class from the ‘Select Benefit Class’ combo box. The three benefit classes include

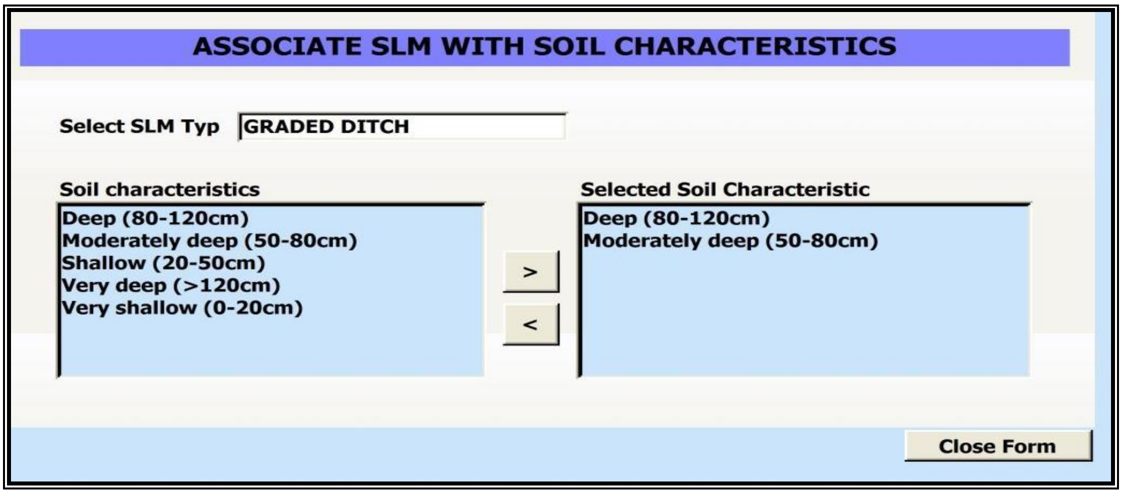
    - Production/ socio-economic benefits
    - Socio-cultural benefits
    - Ecological benefits

    Selecting the benefit class lists the benefits within that class in the ‘Benefits’ list box

2. Select the SLM to associate with the benefit from the ‘Select SLM type’ combo box. This will populate the ‘Selected Benefit’ list box with the previously associated benefits.
3. Use the > button to move the selected benefit to the ‘Selected Benefit’ list box in order to associate it with the selected SLM.
4. To dissociate the benefit from the SLM, select the benefit in the ‘Selected Benefit’ list box and use the < button to dissociate it.
5. To close the form, click the ‘Close Form’ button.

Form to associate SLM with soil characteristics/depth

This form is used to associate the various ‘soil characteristics/depths’ that have been entered in the database with respective SLM technologies as shown on Form 4.17.



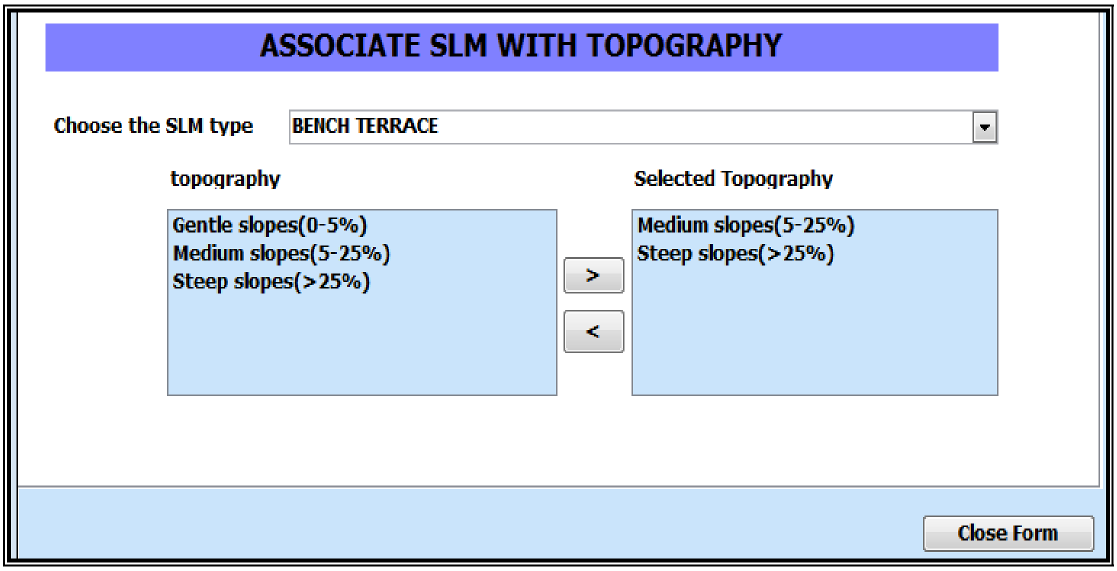
Form 4. 17: Association of SLM with Soil Depth Form

Procedure for associating SLM with soil characteristics

1. Select the SLM from the ‘Choose the SLM type’ combo box.
2. Select the soil characteristics to associate from the ‘soil characteristics’ list box.
3. Use the > button to move the selected soil characteristics to the ‘Selected soil characteristics’ list box in order to associate it with the selected SLM.
4. To dissociate the topography from the SLM, select the soil characteristics in the ‘Selected soil characteristics’ list box and use the < button to dissociate it.
5. To close the form, click the Close form button.

Form to associate SLM with topography

This form is used to associate the various ‘topography characteristics’ that have been entered in the database with respective Sustainable Land Management technologies as shown on Form 4.18.



Form 4. 18: Association of SLM with Topography Form

Procedure of associating and disassociating the selected SLM with topography

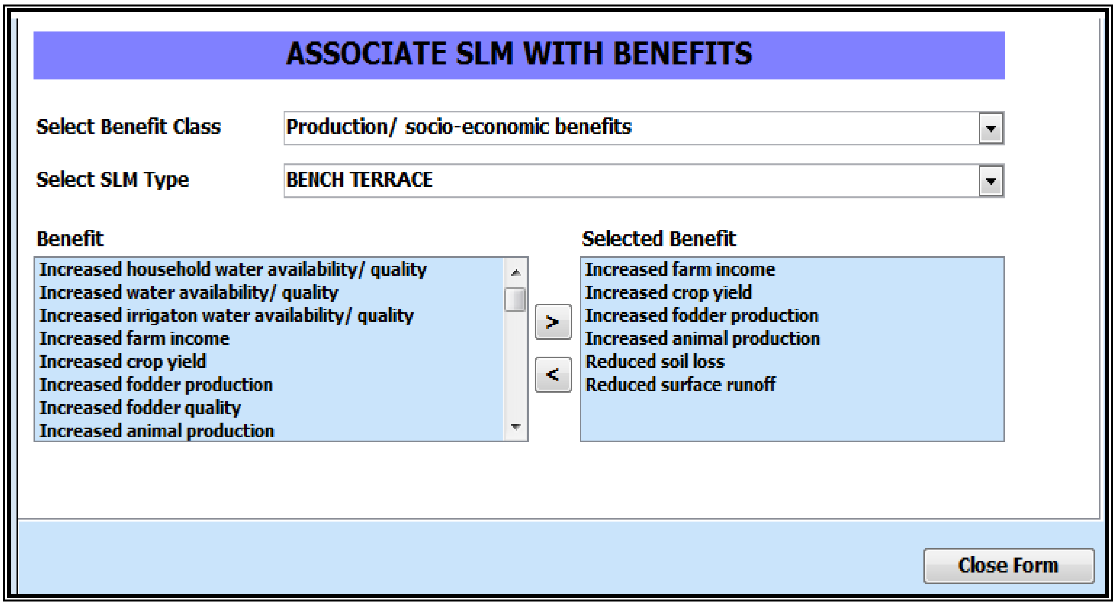
1. Select the SLM from the 'Choose the SLM type' combo box.
2. Select the 'topography characteristics' to associate from the 'topography characteristics' list box.
3. Use the > button to move the selected topography characteristics to the 'topography characteristics' list box in order to associate it with the selected SLM.
4. To dissociate the topography characteristics from the SLM, select the topography characteristics in the 'Selected topography characteristics' list box and use the < button to dissociate it.
5. To close the form, click the Close form button.

Form to associate SLM with benefits

This form is used to associate the various 'benefits' that have been entered in the database with respective Sustainable Land Management technologies as shown on Form 4.19.

Procedure of associating and disassociating the selected SLM with benefits

1. Select the SLM from the 'Choose the SLM type' combo box.
2. Select the "benefits" to associate from the 'benefits' list box.
3. Use the > button to move the selected 'benefits' to the 'benefits' list box in order to associate it with the selected SLM.
4. To dissociate the 'benefits' from the SLM, select the 'benefits' in the 'selected benefits' list box and use the < button to dissociate it.
5. To close the form, click the Close form button.



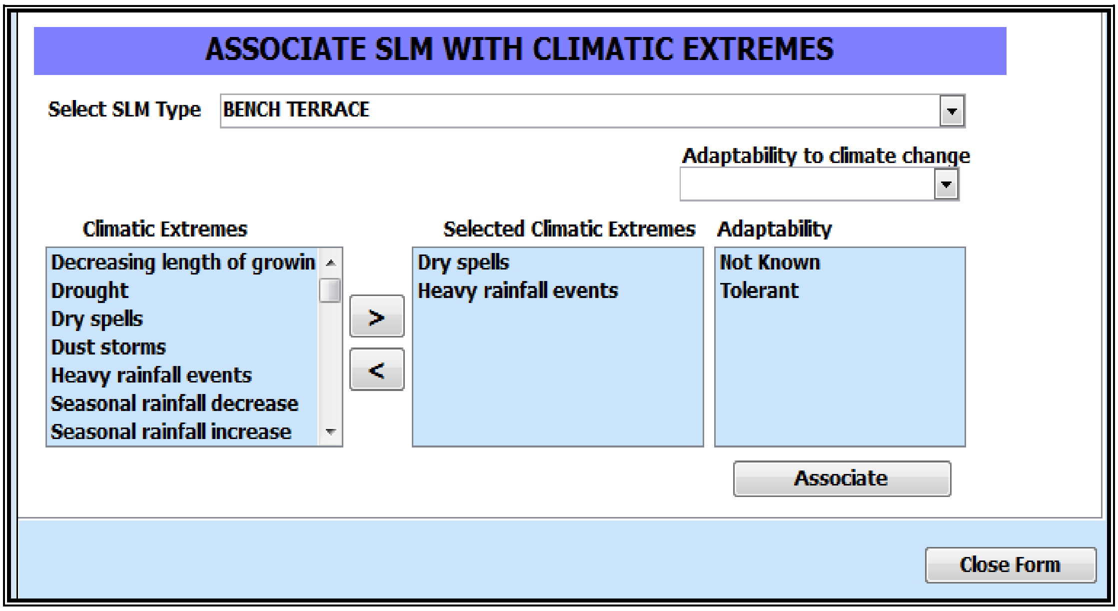
Form 4. 19: Association of SLM with Benefit Form

Form to associate or to disassociate the SLM with climate extremes

This form is used to associate the various 'climate extremes' that have been entered in the database with respective Sustainable Land Management technologies as shown on Form 4.20

Procedure of associating and disassociating the selected SLM with climate extremes

1. Select the SLM from the ‘Choose the SLM type’ combo box.
2. Select the drainage characteristics to associate from the ‘climate extremes’ list box.
3. Use the > button to move the selected ‘climate extremes’ to the ‘Selected climate extremes’ list box in order to associate it with the selected SLM.
4. To dissociate the ‘climate extremes’ from the SLM, select the ‘climate extremes’ in the ‘Selected climate extremes’ list box and use the < button to dissociate it.
5. To close the form, click the Close form button.



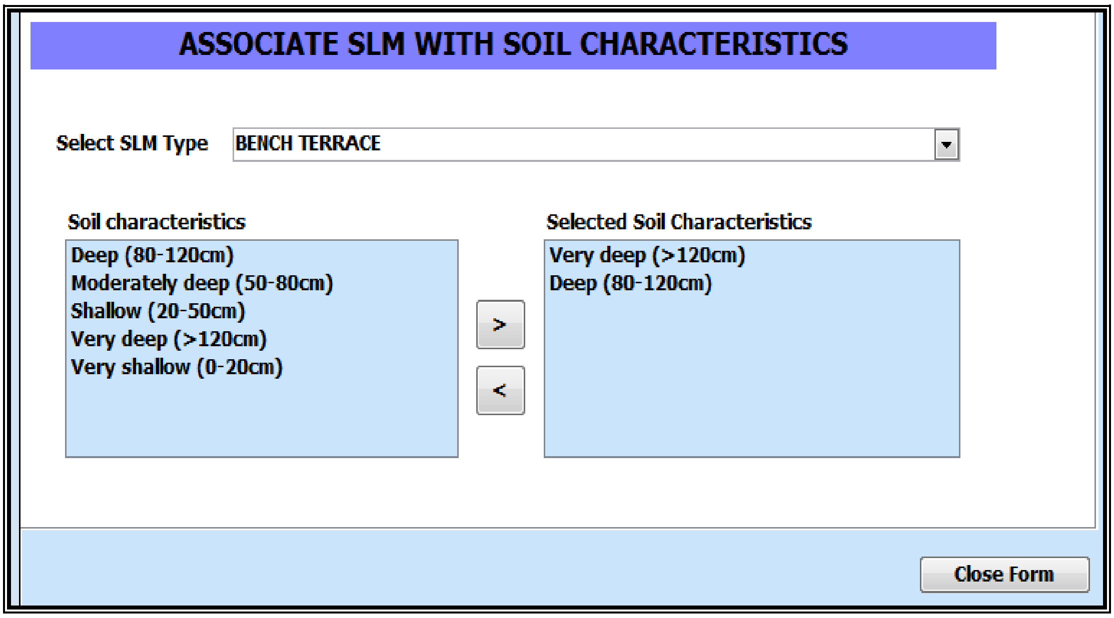
Form 4. 20: Association of SLM with Climate Extreme Form

Form to associate SLM with soil characteristics

This form is used to associate the various ‘soil characteristics’ that have been entered in the database with respective Sustainable Land Management technologies as shown on Form 4.21.

Procedure of associating and disassociating the selected SLM with soil characteristics

1. Select the SLM from the ‘Choose the SLM type’ combo box.
2. Select the ‘soil characteristics’ to associate from the ‘soil characteristics’ list box.
3. Use the > button to move the selected ‘soil characteristics’ to the ‘selected soil characteristics’ list box in order to associate it with the selected SLM.
4. To dissociate the ‘soil characteristics’ from the SLM, select the ‘soil characteristics’ in the ‘Selected soil characteristics’ list box and use the < button to dissociate it.
5. To close the form, click the ‘Close form’ button.



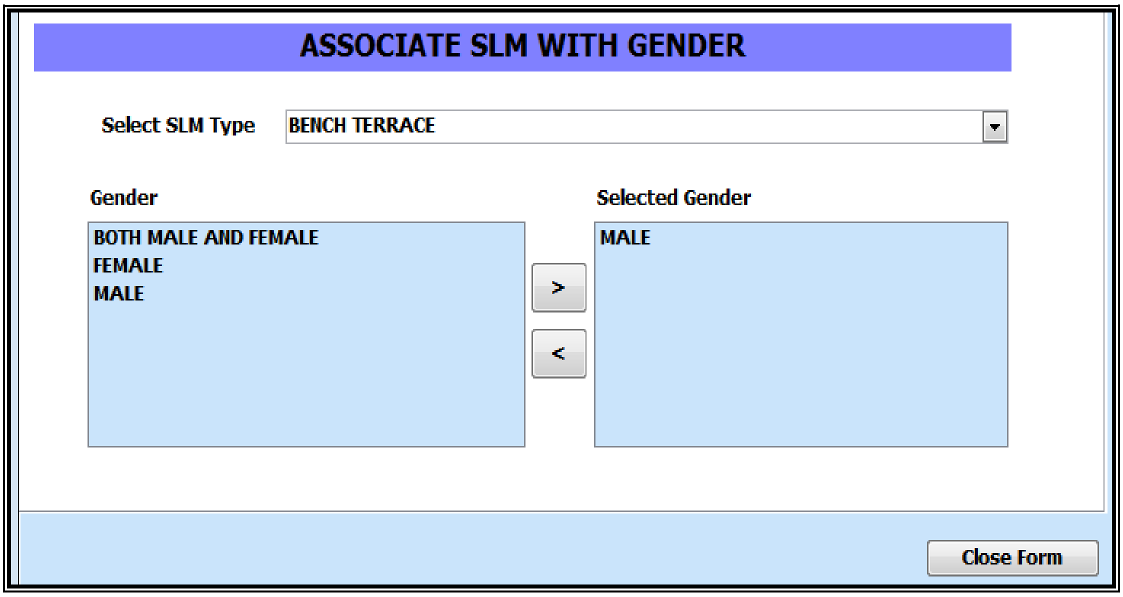
Form 4. 21: Association of SLM with Soil Depth Form

Form to associate SLM with gender

This form is used to associate the various ‘gender orientation’ that have been entered in the database with respective Sustainable Land Management technologies as shown on Form4. 22

Procedure of associating and disassociating the selected SLM with gender orientation

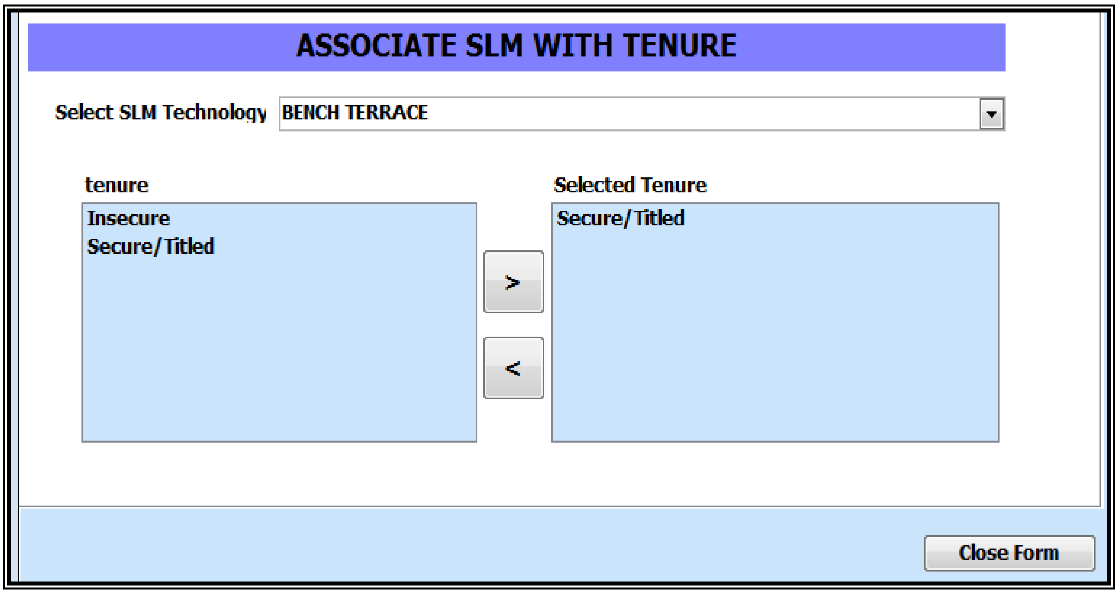
1. Select the SLM from the 'Choose the SLM type' combo box.
2. Select the 'gender orientation' to associate from the 'gender orientation' list box.
3. Use the > button to move the selected 'gender orientation' to the 'selected gender orientation' list box in order to associate it with the selected SLM.
4. To dissociate the 'gender orientation' from the SLM, select the 'gender orientation' in the 'Selected gender orientation' list box and use the < button to dissociate it.
5. To close the form, click the 'Close form' button.



Form 4. 22: Association of SLM with Gender Form

Form to associate SLM with land tenure systems

This form is used to associate the various 'land tenure systems' that have been entered in the database with respective Sustainable Land Management technologies as shown on Form4. 23



Form 4. 23: Association of SLM with Land Tenure Form

Procedure of associating and disassociating the selected SLM with land tenure systems

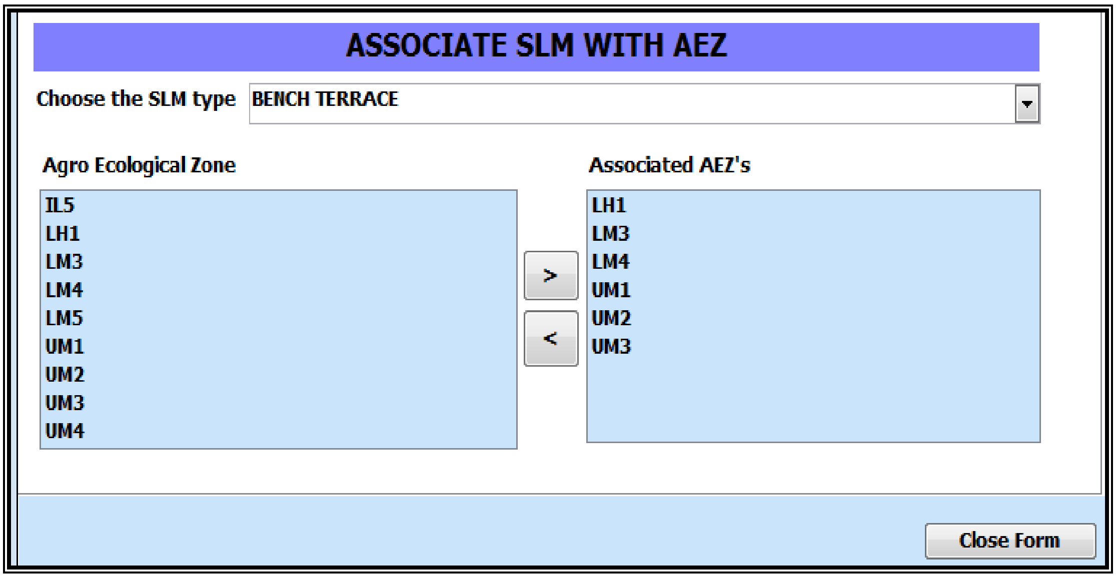
1. Select the SLM from the ‘Choose the SLM type’ combo box.
2. Select the drainage characteristics to associate from the ‘land tenure systems’ list box.
3. Use the > button to move the selected ‘land tenure systems’ to the ‘Selected land tenure systems’ list box in order to associate it with the selected SLM.
4. To dissociate the ‘land tenure systems’ from the SLM, select the ‘land tenure systems’ in the ‘Selected land tenure systems’ list box and use the < button to dissociate it.
5. To close the form, click the Close form button.

Form to associate SLM with Agro Ecological Zones

This form is used to associate the various ‘Agro Ecological Zones’ that have been entered in the database with respective Sustainable Land Management technologies as shown on Form 24

Procedure of associating and disassociating the selected SLM with Agro Ecological Zones

1. Select the SLM from the ‘Choose the SLM type’ combo box.
2. Select the drainage characteristics to associate from the ‘Agro Ecological Zones’ list box.
3. Use the > button to move the selected ‘Agro Ecological Zones’ to the ‘Selected Agro Ecological Zones’ list box in order to associate it with the selected SLM.
4. To dissociate the ‘Agro Ecological Zones’ from the SLM, select the ‘Agro Ecological Zones’ in the ‘Selected Agro Ecological Zones’ list box and use the < button to dissociate it.
5. To close the form, click the Close form button.



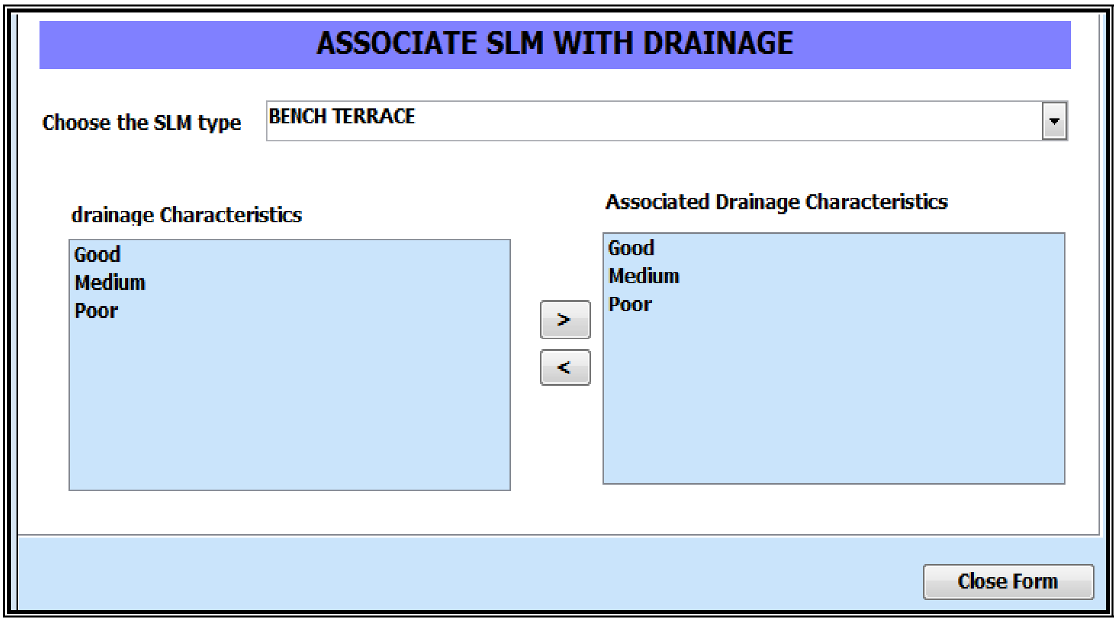
Form 4. 24: Association of SLM with AEZ Form

Form to associate the SLM with soil drainage characteristics

This form is used to associate the various ‘soil drainage characteristics’ that have been entered in the database with respective SLM technologies as shown on Form 4.25.

Procedure of associating and disassociating the selected SLMs with soil drainage

1. Select the SLM from the ‘Choose the SLM type’ combo box.
2. Select the drainage characteristics to associate from the ‘drainage characteristic’ list box.
3. Use the > button to move the selected drainage characteristics to the ‘Selected drainage characteristics’ list box in order to associate it with the selected SLM.
4. To dissociate the drainage characteristics from the SLM, select the drainage characteristics in the ‘Selected drainage characteristics list box and use the < button to dissociate it.
5. To close the form, click the Close form button.



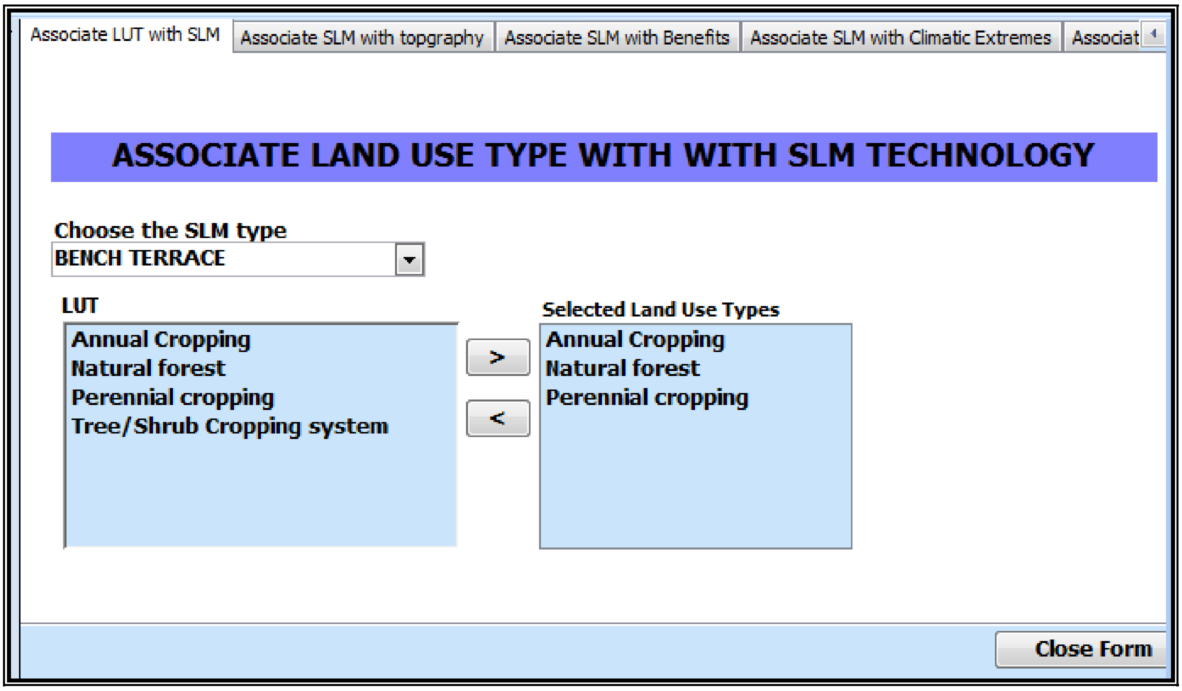
Form 4. 25: Association of SLM with Soil Drainage Form

The global (master) association form

The other parameters can be associated with the respective SLM from the global (master) association form as shown on Form 4.26

Procedure for associating SLM with other parameters

1. Choose the rest of the parameters to be associated from the list portrayed by the global/master association form 4.26
2. Select the SLM for association
3. Use the < > sign for both association and dissociation respectively



Form 4. 26: The global (master) association form

Technology documentation form

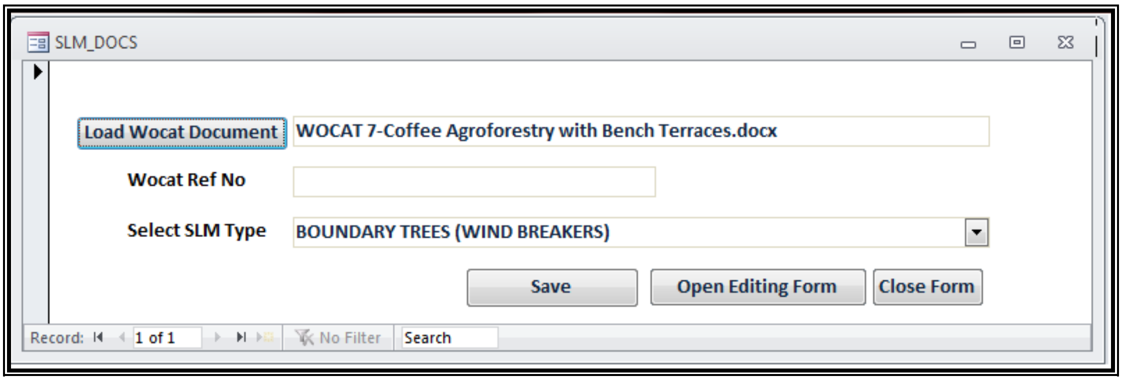
This form is used to link the document generated from the WOCAT global database to the SLM associated with the document as shown on form 4.27.

Procedure for documenting SLM technology

1. Click on the 'Load Wocat Document' button to load the Wocat document generated from the global database. This will open the file open dialog box.
2. In the file open dialog box, navigate to the location where the Wocat document is. Select the document and click 'open'.

3. Add the Wocat document reference number in the ‘Wocat Ref No’ textbox.
4. In the ‘select SLM Type’ combo box select appropriate SLM for this document.
5. Click on save to link the SLM to the Wocat document generated for it.

In order to edit the data entered, click on the ‘Open Editing Form’. This will open the ‘Edit Document attributes’ form (Form4.27) for editing purposes. Edit Document attributes is discussed in the next section.



Form 4. 27: Technology documentation form

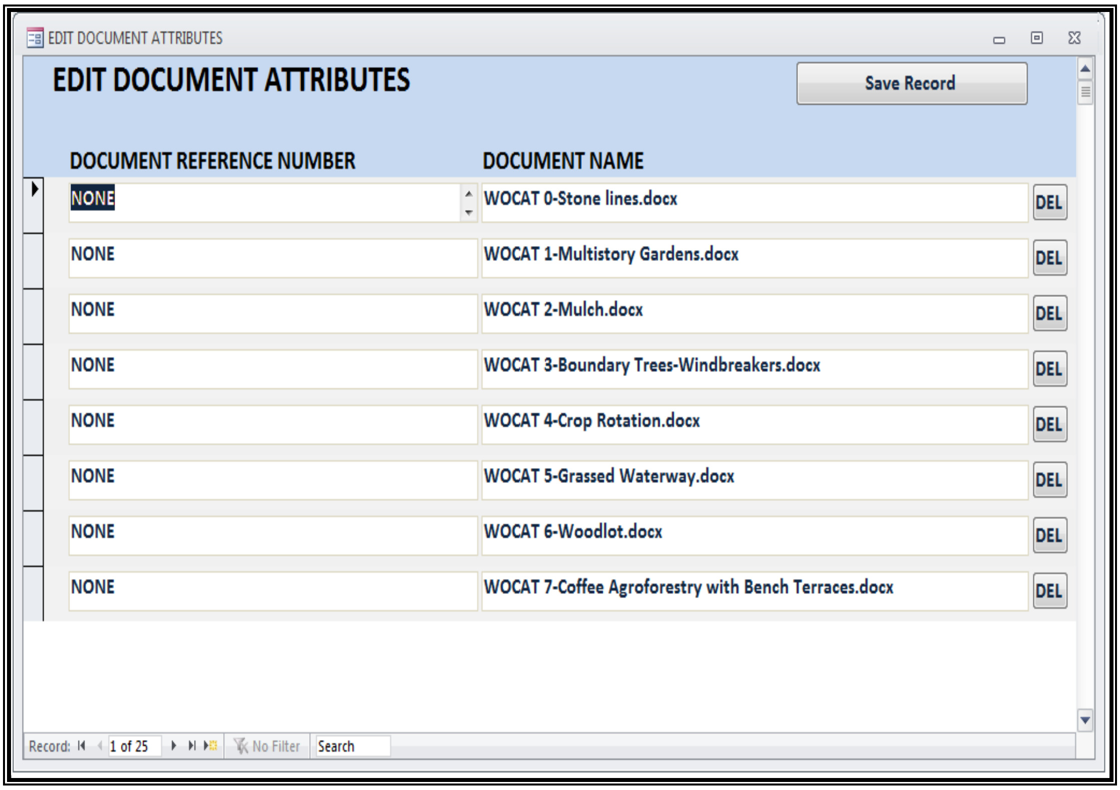
Edit Document attributes form

This form is used for editing the Wocat document attributes i.e. the Wocat reference number and Wocat document name, in case there are errors during their entry. The form is normally accessed from the technology documentation form (Form 4.27) by clicking on the ‘Open Editing Form’ button.

Procedure for editing the wocat document attributes

1. Select the attribute - the Wocat reference number or Wocat document name - that you want to edit in its appropriate row. After selecting the appropriate row, you can delete the entry from the database by clicking on the ‘DEL’ button at the end of the row as shown on form 4.28.

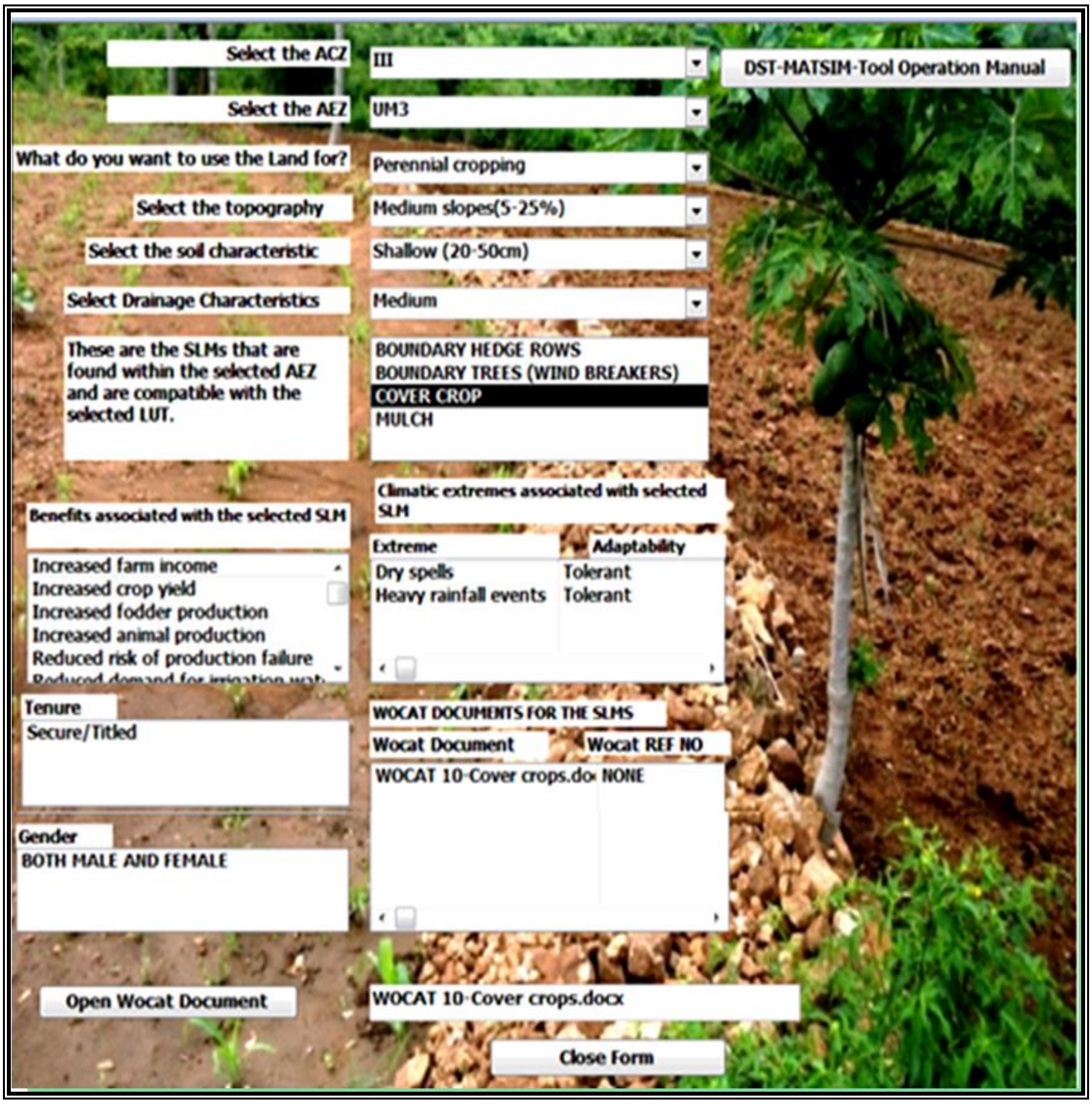
2. After editing the appropriate row, click on the 'Save Record' button at the top right corner of the page to save the changes.



Form 4. 28: Edit document attributes form

4.5 MATSIM Tool selection form

Form 4.29 assists the end user to select the SLM based on ACZ, AEZ, LUT, topography and soil characteristics (depth and drainage).



Form 4. 29: MATSIM Tool selection form

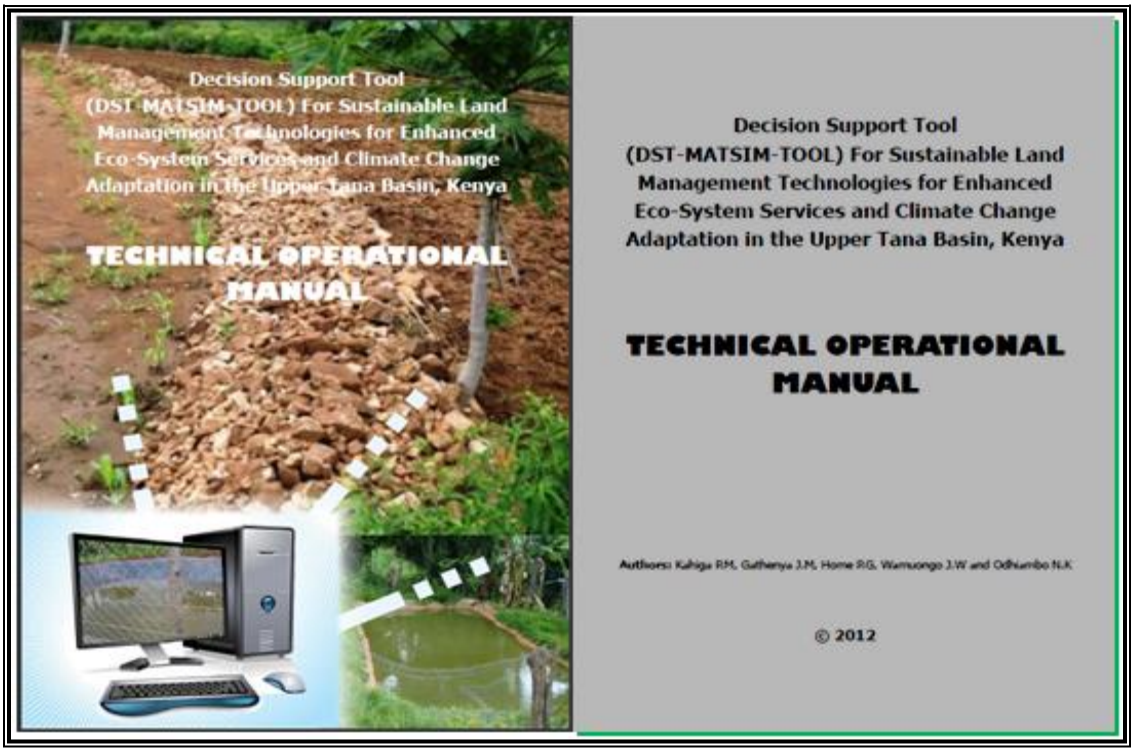
Each selection of, AEZ, LUT, Topography, Soil depth and Soil drainage filters the SLM to suit the particular selection. Clicking on the populated SLM does the following,

1. Populates the benefits list box with the benefits associated with that SLM.
2. Populates the climatic extremes for the SLM and its adaptability to those extremes
3. Loads the WOCAT documents and their reference numbers.

4. Double clicking on a WOCAT document entry in the WOCAT document list box, opens the document. Clicking once on a WOCAT document entry in the WOCAT document list box loads the document file name in the Open WOCAT text box. The file can then be opened by clicking on the Open WOCAT command button.

Application manual

A user friendly technical operation manual (form 4.30) has been provided on the final selection window of the MATSIM Tool.



Form 4. 30: MATSIM-Tool's technical selection manual form

4.6 Use of MATSIM Tool for selection of SLM technologies

The credibility of the information provided by a DST is critical to its success (McCown, 2002). The information contained in the MATSIM Tool’s database, contains the results of any search that the tool can be subjected into provided it is in the Upper Tana Catchment. It was collected in the field as a result of a consultative process i.e. it was farmer's firsthand information in consultation with the frontline extension officers, WOCAT scientists and the research assistants. Local knowledge from these farmers was identified and integrated into MATSIM Tool as an important and necessary source of information and decision-making (Gregory. 1999). Table 4.9 presents a tabular format of a sample of the MATSIM tool's output from the study area. When the user has keyed in the biophysical attributes of the farm, one is able to get the SLM compatible with the attributes, its ecological benefits, and adaptability to climate extremes, the kind of land tenure that it can be used and the gender that is most suitable to implement it. The user can also either read direct or print the PDF WOCAT document. This is achieved by either by double clicking on a WOCAT document entry in the WOCAT document list box or by clicking once on a WOCAT document entry in the WOCAT document list box which loads the document file name in the Open WOCAT text box. The file can then be opened by clicking on the Open WOCAT command button. The global WOCAT reference number can also be downloaded from the WOCAT website (*www.wocat.net)*.

Table 4. 9: MATSIM Tool's output sample from the study area

ACZ	AEZ	LUT	Topography	Soil Depth	Soil Drainage	Compatible SLM	Benefits	Adaptability To Climatic Extremes	Land Tenure	Gender
1	LH1	Perennial crop	Gentle slope (0-5%)	Shallow (20-50cm)	Medium	Conservation Agriculture	Increased farm income, Increased crop yield, Reduced risk of production failure, and Reduced demand for irrigation water	Tolerant under both Dry spells and Heavy rainfall events	Secured/titled	Both male and female
11	UM1	Annual cropping	Medium slope (5-25%)	Moderately deep (50-80cm)	Good	Cover crop	Increased farm income, increased crop yield Increased fodder production, Increased animal production, Reduced demand for irrigation water, Diversification of income sources, Increased soil moisture and Improved food security	Tolerant under both Dry spells and Heavy rainfall events	Secured/titled	Both male and female
	UM2	Agroforestry	Steep slope (>25%)	Very shallow (0-20cm)	Medium	Mulch	Reduced demand for irrigation water, increased farm income, increased soil moisture, increased soil cover, increased biomass/above ground cover, increased soil organic matter, reduced soil loss, reduced surface runoff	Tolerant under both Dry spells and Heavy rainfall events	Secured/titled	Both male and female
111	UM3	Perennial cropping	Gentle slopes (0-5%)	Deep (80-120cm)	Good	Boundary trees (wind breakers)	Increased wood production, reduced risk of production failure, increased farm income, diversification of farm income, increased product diversification, reduced wind erosion	Tolerant under dust storms and sensitive under dry spells	Secured/titled	Both male and female

	UM4	Annual cropping	Gentle slope (0-5%)	Deep (80-120cm)	Medium	Trash-lines	Increased crop yield, increased farm income, reduced risk of production failure, reduced demand for irrigation water, decreased labour constraints, increased soil moisture	Tolerant under both Dry spells and Heavy rainfall events	Secured/titled	Both male and female
1V	LM3	Agroforestry	Medium slopes (5-25%)	Shallow (20-50cm)	Good	Crop rotation	Increased farm income, increased soil organic matter, reduced soil loss, reduced evaporation, increased nutrient cycling/recharge, increased farm income, increased product diversification, reduced risk of production failure.	Tolerant under both Dry spells and Heavy rainfall events	Secured/titled	Both male and female
	LM4	Agroforestry	Gentle slopes (0-5%)	Deep (80-120cm)	Poor	Zai pit-9 Maize	Increased farm income, iproved food security, improved rainwater harvesting, increased moisture retention, reduced evaporation, reduced surface runoff	Tolerant under both Dry spells and Heavy rainfall events	Secured/titled	Male
	LM5	Annual cropping	Gentle slopes (0-5%)	Shallow (20-50cm)	Good	Mandara garden	Increased farm income, increased farm yield, reduced risk of production failure, reduced demand for irrigation water and diversification of income resources	Sensitive under dry spells and tolerant under heavy rainfall events	Secured/titled	Male
V	IL5	Grazing land	Steep slopes (>25%)	Very shallow (0-20cm)	Poor	Rotational grazing	Increased animal production, increased farm income, reduced risk of production failure, increased fodder production, reduced surface runoff.	Tolerant under both Dry spells and Heavy rainfall events	Secure/titled and insecure	male

4.7 Computer system requirement

Decision Support (MATSIM) Tool for Sustainable Land Management (SLM) technologies in the Upper Tana Catchment is a computer based tool developed using Microsoft Access VBA application software. Debugging was done in order to remove errors using the inbuilt debugger in the Microsoft Access VBA application software. The tool can be deployed on both 32-bit and 64 bit computers running Windows 2003 and more recent windows operating systems. In addition Microsoft Access 2003 or later must be installed on the target computer.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The specific conclusions drawn from this study were as follows:

1) Various successful SLM technologies were identified in the Upper Tana Catchment. Bench terraces (33%) and Fanya juu terraces (30%) are the most preferred structural technologies within the Upper Tana Catchment in varied proportions across different AEZs. Grass strips (57%) and boundary tree plantings (26%) are the most practiced vegetative SLM technologies within the Upper Tana Catchment. About 45% of the agronomic technologies practiced within the Upper Tana Catchment are dominated by manuring as compared to zero tillage, composting, mixed cropping, contour cultivation, mulching and green mulch. Land use change, rotational grazing, change of management intensity, change of timing activities and cut and carry are the adapted management technologies within the Upper Tana catchment but in varied percentages. Apart from management technologies that are mostly influenced by the level of land degradation, all other conservation measures are mostly influenced by the slope, level of land degradation and climate at less extent.
2) Irrespective of either structural, vegetative, agronomic or management SLM technologies, in total, twenty seven (27) SLM technologies were identified within the Upper Tana Catchment and documented using the WOCAT methodology.
3) The Decision Support (MATSIM) Tool for selecting Sustainable Land Management technologies in the Upper Tana Catchment was developed and can be used to assist the user in making decisions based on the information so provided using a criterion.

5.2 Recommendations

From the research conducted, the following recommendations were made.

1) Scaling out of the identified SLM technologies within the Upper Tana Catchment.
2) Making use of the WOCAT documented SLM technologies within the Upper Tana Catchment.
3) Use of MATSIM tool to inform decisions on sustainable land management within the Upper Tana Catchment

Further Research

The research conducted in this thesis has led to some useful results and conclusions on development of a decision support tool for sustainable land management in the Upper Tana Catchment, however, it has identified the following areas that need further research.

1) Further development of MATSIM Tool by combining biophysical, social, and economic data in order to help users identify the best locations for protection and restoration activities in order to maximize the ecological return on investment.
2) Further incorporation of spatial data capabilities into the MATSIM Tool to unlock its further potential.
3) Further development of MATSIM in paper work where a farmer can use simple logics to arrive at an appropriate decision.
4) Scaling out of MATSIM tool into other catchments.
5) Documentation and incorporation in the MATSIM's database of other successful technologies within the catchment that were otherwise not captured during field work.

REFERENCES

Alexandratos, N. (1995). *World agriculture: towards 2010: an FAO study*. Food & Agriculture Org.

Alter, S., & Alter, S. (1980). *Decision support systems: current practice and continuing challenges* (No. 04; HD30. 23, A5.).

Antoinette, M. G. A. (1999) *Insights and applications local soil knowledge: a tool for sustainable land management*. Society & Natural Resources, *12*(2), 151-161.

Assessment, M. E. (2005). Ecosystems and human well-being: biodiversity synthesis. *World resources institute, Washington, DC*, *86*.

Baaru, M. W., Mbuvi, J. P., Onwonga, R., Gathaara, V., & Gachene, C. K. K. (2015). Factors that influence adoption of soil and water conservation technology at Kathekakai Location, Machakos.

Bâra, A., & Lungu, I. (2012). *Improving Decision Support Systems with Data Mining Techniques*. INTECH Open Access Publisher.

Batjes, N. H. (2014). Projected changes in soil organic carbon stocks upon adoption of recommended soil and water conservation practices in the Upper Tana River catchment, Kenya. *Land Degradation & Development*, *25*(3), 278-287.

Batjes, N. H., Al-Adamat, R., Bhattacharyya, T., Bernoux, M., Cerri, C. E. P., Gicheru, P., ... & Rawajfih, Z. (2007). Preparation of consistent soil data sets for modelling purposes: secondary SOTER data for four case study areas. *Agriculture, ecosystems & environment*, *122*(1), 26-34.

Bernard, H.R. (2002). Research Methods in Anthropology: *qualitative and quantitative methods*: (3rd ed.) AltaMira Press ,Walnut Creek, California.

Bobotti, O. K. (1998). Masinga Reservoir Capacity and Sedimentation, Kenya. *A World Bank Project*

Borlaug, N. E., & Dowswell, C. R. (1994). Feeding a human population that increasingly crowds a fragile planet. World Congress of Soil Science, 15; Acapulco, Mexico; 10-16 Jul 1994: Program and information handbook. In ^ *TWorld Congress of Soil Science, 15; Acapulco, Mexico; 10-16 Jul 1994: Program and information handbook^ AMexico, DF (Mexico)^ BInternational Society of Soil Science-Mexican Society of Soil Science^ C1994* (No. 631.4 ISS. CIMMYT.).

Bossio, D., & Geheb, K. (Eds.). (2008). *Conserving land, protecting water* (Vol. 6). CABI.

Bouma, J., Droogers, P., Sonneveld, M. P. W., Ritsema, C. J., Hunink, J. E., Immerzeel, W. W., & Kauffman, S. (2011). Hydropedological insights when considering catchment classification. *Hydrology and Earth System Sciences*, *15*(6), 1909-1919.

Brown, T., Schneider, H., & Harper, D. (1996). Multi-scale estimates of erosion and sediment yields in the Upper Tana basin, Kenya. *IAHS Publications-Series of Proceedings and Reports-Intern Assoc Hydrological Sciences*, *236*, 49-54.

Brundtland, G. H. (1985). World commission on environment and development. *Environmental policy and law*, *14*(1), 26-30.Bunyasi, M. M., Onywere, S. M., & Kigomo, M. K. (2013). Sustainable Catchment Management: Assessment of Sedimentation of Masing a Reservoir and its Implication on the Dam's Hydropower Generation Capacity.

Campbell, C. A. (1995). Landcare: Participative Australian approaches to inquiry and learning for sustainability. *Journal of Soil and Water Conservation*, *50*(2), 125-131.

Chasek, P., Essahli, W., Akhtar-Schuster, M., Stringer, L. C., & Thomas, R. (2011). Integrated land degradation monitoring and assessment: horizontal knowledge management at the national and international levels. *Land Degradation & Development*, *22*(2), 272-284.

Cordell, D., Drangert, J. O., & White, S. (2009). The story of phosphorus: global food security and food for thought. *Global environmental change*, *19*(2), 292-305.

Critchley, W. R. S., & Mutunga, K. (2003). Local innovation in a global context: documenting farmer initiatives in land husbandry through WOCAT. *Land Degradation & Development*, *14*(1), 143-162.

Derpsch, R. (1991). Understanding the process of soil erosion and water infiltration. *FAO Publication*, Rome, Italy.

Dijkshoorn, J. A., Macharia, P. N., Huting, J. R. M., Maingi, P. M., & Njoroge, C. R. K. (2010). Soil and terrain conditions for the Upper Tana River catchment, Kenya, Green Water Credits Report 11/ISRIC Report 2010/09, ISRIC–World Soil Information, Wageningen.

Droogers, P., Kauffman, J. H., Dijkshoorn, J. A., Immerzeel, W., & Huting, J. R. M. (2006). Green water credits: Basin identification. *ISRIC-World Soil Information, Wageningen*.

Druzdzel, M. J., & Flynn, R. R. (1999). Decision support systems. Encyclopedia of library and information science. A. Kent. *Marcel Dekker, Inc. Last Login*, *10*(03), 2010.

Dumanski, J. (1997). Criteria and indicators for Land Quality and Sustainable Land Management. Paper presented at the SLM Workshop, Enschede, The Netherlands.

El-Swaify, S. A. (1998). Multiple objective decision making for land, water, and environmental management. In *Towards sustainable land use. Furthering cooperation between people and institutions. Volume 1. Proceedings of the International Soil Conservation Organisation, Bonn, Germany, 26-30 August 1996.* (No. 31, pp. 63-72).

Enyong, L. A., Debrah, S. K., & Bationo, A. (1999). Farmers' perceptions and attitudes towards introduced soil-fertility enhancing technologies in western Africa. *Nutrient cycling in Agroecosystems*, *53*(2), 177-187.

Erdogan, E. H., Erpul, G., & Bayramin, İ. (2007). Use of USLE/GIS methodology for predicting soil loss in a semiarid agricultural watershed. *Environmental monitoring and assessment*, *131*(1-3), 153-161.

Franzel, S., Wambugu, C., & Tuwei, P. (2003). *The adoption and dissemination of fodder shrubs in central Kenya*. Overseas development institute (ODI). Agricultural research & extension network (AgREN).

Gachene, C. K., Mbuvi, J. P., Jarvis, N. J., & Linner, H. (1997). Soil erosion effects on soil properties in a highland area of Central Kenya. *Soil Science Society of America Journal*, *61*(2), 559-564.

Geertsma, R., Wilschut, L. I., & Kauffman, J. H. (2010). *Review for the Green Water Credits Pilot Operations in Kenya*. ISRIC-World Soil Information.

Geertsma, R., Wilschut, L. I., & Kauffman, J. H. (2010). *Review for the Green Water Credits Pilot Operations in Kenya*. ISRIC-World Soil Information.

Geertsma, R., Wilschut, L. I., & Kauffman, J. H. (2010). *Review for the Green Water Credits Pilot Operations in Kenya*. ISRIC-World Soil Information.

Githui, F., Mutua, F., & Bauwens, W. (2009). Estimating the impacts of land-cover change on runoff using the soil and water assessment tool (SWAT): case study of Nzoia catchment, Kenya/Estimation des impacts du changement d'occupation du sol sur l'écoulement à l'aide de SWAT: étude du cas du bassin de Nzoia, Kenya. *Hydrological sciences journal, 54*(5), 899-908.

Gok, 2009, Republic of Kenya, Ministry of Environment and Mineral Resources, Embu District Environment Action Plan (2009-2013),

Gregory, P.J. (1999). The terrestrial biosphere and global change: implications for natural and managed systems. Cambridge University Press; Cambridge, UK: pp. 229–270.

Haettenschwiler, P. (1999). Neues anwenderfreundliches Konzept der ntscheidungsunterstützung. Gutes Entscheiden in Wirtschaft, Politik und Gesellschaft. Zurich, vdf Hochschulverlag AG**:** 189-208.

Herrero, M., Havlík, P., Valin, H., Notenbaert, A., Rufino, M. C., Thornton, P. K., ... & Obersteiner, M. (2013). Biomass use, production, feed efficiencies, and greenhouse gas emissions from global livestock systems. *Proceedings of the National Academy of Sciences*, *110*(52), 20888-20893.

Herweg, K., Steiner, K., & Slaats, J. (1998). Sustainable Land Management—Guidelines for Impact Monitoring (Workbook and Toolkit). *Centre for Development and Environment, Berne, Switzerland*.

Hoff, H., Noel, S., (2007). Quantifying water usage and demand in the Tana River basin: an analysis using the Water and Evaluation and Planning Tool (WEAP). In: Dent, D. (Ed.), Green Water Credits. ISRIC - World Soil Information, Wageningen.

http://www.fao.org/nr/land/sustainable-land-management/en/ Accessed on 08/10/2015

http://www.feedthefuture.gov/country/Kenya, accessed on 08/10/2015

http://www.isric.org/isric/Webdocs/Docs/ISRIC_Report_2010_06.pdf accessed on 08/10/2015.

http://www.nda.agric.za/docs/Policy/SustainableDev.pdf, accessed on 08/10/2015

http://www.wocat.net, accessed on 08/10/15.

https://www.gov.mb.ca/agriculture/environment/soil-management/soil-management-guide/drainage-management.html accessed on 29/04/2016.

Hunink, J. E., Immerzeel, W. W., Droogers, P., & Kaufmann, S. (2010). Green Water Credits for the Upper Tana Basin, Kenya. Phase II-Pilot Operations: Biophysical assessment using SWAT. *Green Water Credits Report*, *10*.

Hunink, J. E., Niadas, I. A., Antonaropoulos, P., Droogers, P., & De Vente, J. (2013). Targeting of intervention areas to reduce reservoir sedimentation in the Tana catchment (Kenya) using SWAT. *Hydrological Sciences Journal*, *58*(3), 600-614.

Hurni, H. (1997). Concepts of sustainable land management. *ITC journal*, 210-215.

Hurni, H. (2000). Assessing sustainable land management (SLM). *Agriculture, ecosystems & environment*, *81*(2), 83-92.

Igwe, S.A. & Nwele, A.O, (2013) The Need For Introducing Decision Support System (DSS) In Nigerian Universities Management And Administration, Information and Knowledge Management, www.iiste.org ISSN 2224-5758 (Paper) ISSN 2224-896X (Online) Vol.3, No.10, 96.

Jacobs, J. H., Angerer, J., Vitale, J., Srinivasan, R., & Kaitho, R. (2007). Mitigating economic damage in Kenya's upper Tana River basin: an application of Arc-View SWAT. *Journal of Spatial Hydrology*, *7*(1).

Jacobs, J., Angerer, J., Vitale, J., Srinivasen, R., Kaitho, R., Stuth, J., & Clarke, N. (2004). Exploring the potential impact of reforestation on the hydrology of the upper Tana River catchment and the Masinga Dam, Kenya. *Impact Assessment Group, Cent. for Natural Resource Information Technol., Texas A&M Univ., College Station*.

Jaetzold, R., & Schimdt, H. (1983). Farm Management handbook: Natural and farm management information Vol. II/B. *Ministry of Agriculture, Nairobi*.

Jaetzold, R., & Schmidt, H. (1983). Farm Management Handbook of Kenya, Volume IIC. East Kenya (Eastern and Coast Provinces). *Farm Management Branch, Ministry of Agriculture, Nairobi, Kenya*.

Karl, H., Steiner, K., & Slaats, J. (1998). Sustainable Land Management—Guidelines for Impact Monitoring (Workbook and Toolkit). *Centre for Development and Environment, Berne, Switzerland*.

Kautish, S., & Thapliyal, M. P. (2012). Concept of Decision Support Systems in relation with Knowledge Management–Fundamentals, theories, frameworks and practices. *International Journal of Application or Innovation in Engineering & Management*, *1*(2), 1-9.

Keen, P. G. (1980). *MIS research: reference disciplines and a cumulative tradition* (pp. 9-18). Center for Information Systems Research, Alfred P. Sloan School of Management.

Keen, P. G., & Scott, M. (1978). *Decisión support systems; an organizational perspective* (No. 04; QA76. 6, K44.).

KenGen, (2005). Rehabilitation / Upgrading of Hydro Power Stations. Tana Catchment Reh`abilitation Report. In: Scott and Wilson (Ed.). KenGen, Nairobi, pp 58.

Kitheka, J. U., Obiero, M., & Nthenge, P. (2005). River discharge, sediment transport and exchange in the Tana Estuary, Kenya. *Estuarine, Coastal and Shelf Science, 63*(3), 455-468.

Knoop, L., Sambalino, F., & Steenbergen, F. V. (2012). *Securing water and land in the Tana basin: a resource book for water managers and practitioners*. UNEP/3R Water Secretariat.

Lee, L. K., & Stewart, W. H. (1983). Landownership and the adoption of minimum tillage. *American Journal of Agricultural Economics*, *65*(2), 256-264.

Lefroy, R. D., Bechstedt, H. D., & Rais, M. (2000). Indicators for sustainable land management based on farmer surveys in Vietnam, Indonesia, and Thailand. *Agriculture, ecosystems & environment*, *81*(2), 137-146.

Liniger, H. P., Cahill, D., Thomas, D. B., van Lynden, G. W. J., & Schwilch, G. (2002, May). Categorization of SWC technologies and approaches–a global need. In *Proceedings of ISCO Conference 2002* (Vol. 3, pp. 6-12).

Liniger, H. P., Douglas, M., & Schwilch, G. (2004, July). Towards sustainable land management–'Common sense'and some of the other key missing elements (the WOCAT experience). In *Proceedings of International Soil Conservation Organization (ISCO) Conference* (pp. 4-9).
Liniger, H. P., Douglas, M., & Schwilch, G. (2004, July). Towards sustainable land management–'Common sense'and some of the other key missing elements (the WOCAT experience). In *Proceedings of International Soil Conservation Organization (ISCO) Conference* (pp. 4-9).
Liniger, H., & Critchley, W. (2008). 9 Safeguarding Water Resources by. *Conserving Land, Protecting Water*, *6*, 129.

Liniger, H., & Schwilch, G. (2002). Enhanced decision-making based on local knowledge: The WOCAT method of sustainable soil and water management. *Mountain Research and Development*, *22*(1), 14-18.
Liniger, H., & Schwilch, G. (2002). Enhanced decision-making based on local knowledge: The WOCAT method of sustainable soil and water management. *Mountain Research and Development*, *22*(1), 14-18.
Liniger, H., Lynden,G., Nachtergaele,F., & Schwilch,G. (2008). *Mapping land degradation and Sustainable Land Management. (QM)*. Bern, Rome, Wageningen: CDE/WOCAT, FAO/LADA, ISRIC.

Liniger, H.P., Schwilch, G., Gurtner, M., Mekdaschi, S., Hauert, C., & Van Lynden, G. (2008). WOCAT. *Une structure pour la documentation et l'évaluation de la gestion durable des terres. Technologies. Questionnaire de base. Bern*: WOCAT.

Little, J. D. (1970). Models and managers: The concept of a decision calculus. *Management science*, *16*(8), B-466.

Mahendra, M., Günther F., & Harrij.V, (2008). Food Security and Sustainable Agriculture The Challenges of Climate Change in Sub-Saharan Africa. *International Institute for Applied Systems Analysis* A- 2361 Laxenburg, Austria.

Marakas, G. M. Decision Support Systems in the Twenty-First Century, 1999.

Mati, B. M. (2006). *Overview of water and soil nutrient management under smallholder rain-fed agriculture in East Africa* (Vol. 105). IWMI.

McCown, R. L. (2002). Changing systems for supporting farmers' decisions: problems, paradigms, and prospects. *Agricultural systems*, *74*(1), 179-220.

Micale, V., Trabacchi, C., & Boni, L. (2015). Using Public Finance to Attract Private Investment in Geothermal: Olkaria III Case Study, Kenya. *Climate Policy Initiative, Venice, Italy. Available at: http://climatepolicyinitiative. org/wp-content/uploads/2015/06/150601_Final_Olkaria_ForWeb. pdf*.

Mogaka, H. (2006). *Climate variability and water resources degradation in Kenya: improving water resources development and management* (Vol. 69). World Bank Publications.

Moore, J. H., & Chang, M. G. (1983). Meta-design considerations in building DSS. *Building decision support systems*, 173-204.

Morgan, J. A., Milchunas, D. G., LeCain, D. R., West, M., & Mosier, A. R. (2007). Carbon dioxide enrichment alters plant community structure and accelerates shrub growth in the shortgrass steppe. *Proceedings of the National Academy of Sciences*, *104*(37), 14724-14729.

Mugwe, J. N., Mugendi, D. N., Nair, P. K. R., O'Neill, M. K., & Woomer, P. L. (1999). Calliandra and Leucaena alley cropped with maize. Part 1:

Soil fertility changes and maize production in the sub-humid highlands of Kenya.

Muriuki, J. P., & Macharia, P. N. (2011). Inventory and Analysis of Existing Soil and Water Conservation Practices in the Upper Tana, Kenya. Green Water Credits Report 12, ISRIC–World Soil Information, Wageningen. *Green Water Credits Report*, *12*.

Mutsotso, B., Muya, E., & Roimen, H. (2011). Conocimiento campesino, actitudes y prácticas en los sitios de trabajo de Embu y Taita antes y después de la intervención del proyecto" Below-ground biodiversity". *Tropical and subtropical agroecosystems*, *13*(1), 51-58.

Mutua, B. M., & Klik, A. (2007). Predicting daily streamflow in ungauged rural catchments: the case of Masinga catchment, Kenya. *Hydrological sciences journal*, *52*(2), 292-304.

Mwangi, A. (2007). Policies and institutions for promoting sustainable land management in dry lands through trade. *In Trade and sustainable land management in dry lands*, ICTSD Publication.

Nippon Koei (2013a) *The project on the development of the national water master plan 2030. Final Report. Volume III Part F – Tana Catchment Area.* Republic of Kenya

Njuki, J., & Verdeaux, F. (2001). Changes in land use and land management in the Eastern Highlands of Kenya: Before land demarcation to the present. *International Centre for Research in Agroforestry: Nairobi*.

Notter, B., MacMillan, L., Viviroli, D., Weingartner, R., & Liniger, H. P. (2007). Impacts of environmental change on water resources in the Mt. Kenya region. *Journal of Hydrology*, *343*(3), 266-278.

Notter, B., MacMillan, L., Viviroli, D., Weingartner, R., & Liniger, H. P. (2007). Impacts of environmental change on water resources in the Mt. Kenya region. *Journal of Hydrology, 343*(3), 266-278.

Obonyo, E. (2000). The adoption of biomass transfer technology in Western Kenya. *Unpublished MSc thesis, Kwame Nkrumah University of Science and Technology. Ghana*.

Oldeman, L. R., Hakkeling, R. U., & Sombroek, W. G. (1990). *World map of the status of human-induced soil degradation: an explanatory note*. International Soil Reference and Information Centre.

Ongwenyi, G. S., Kithiia, S. M., & Denga, F. O. (1993). An overview of the soil erosion and sedimentation problems in Kenya.

Otieno, F. A. O., Maingi, S. M., Gichuki, F. N., Mungai, D. N., Gachene, C. K. K., & Thomas, D. B. (2000). Sedimentation problems of Masinga reservoir. In *Land and water management in Kenya: towards sustainable land use. Proceedings of the Fourth National Workshop, Kikuyu, Kenya, 15-19 February, 1993.* (pp. 43-46). Soil and Water Conservation Branch, Ministry of Agriculture and Rural Development.

Ouma, J. O., Murithi, F. M., Mwangi, W., Verkuijl, H., Gethi, M., & De Groote, H. (2002). *Adoption of maize seed and fertilizer technologies in Embu district, Kenya*. CIMMYT.

Panafcon, D.C. (2007). Upper Tana Catchment Study. *World Bank* pp 333.

Patton, M. Q. (2002). Qualitative research and evaluation methods (3rd ed.) Sage. *Thousand Oaks, CA.*

Pender, J. (2012). The world food crisis, land degradation, and sustainable land management.

Pinstrup-Andersen, P., & Pandya-Lorch, R. (1994). *Alleviating poverty, intensifying agriculture, and effectively managing natural resources* (Vol. 1). Intl Food Policy Res Inst.

Place, F., & Migot-Adholla, S. E. (1998). The economic effects of land registration on smallholder farms in Kenya: evidence from Nyeri and Kakamega districts. *Land Economics*, 360-373.

Place, F., Franzel, S., Noordin, Q., & Jama, B. (2004). *Improved fallows in Kenya: history, farmer practice, and impacts*. Intl Food Policy Res Inst.

Power, D. J. (1997). What is a DSS. *The On-Line Executive Journal for Data-Intensive Decision Support*, *1*(3), 223-232.

Power, D. J. (2002). Decision Support Systems: Concepts and Resources for Managers. *Studies in Informatics and Control*, *11*(4), 349-350.

Pretty, J. N., Noble, A. D., Bossio, D., Dixon, J., Hine, R. E., Penning de Vries, F. W., & Morison, J. I. (2006). Resource-conserving agriculture increases yields in developing countries. *Environmental science & technology*, *40*(4), 1114-1119.

Reardon, T., Kelly, V., Crawford, E., Jayne, T., Savadogo, K., & Clay, D. (1996). *Determinants of farm productivity in Africa: a synthesis of four case studies* (No. 22). Department of Agricultural Economics and the Department of Economics, Michigan State University.

Reij, C., & Steeds, D. (2003, March). Success stories in Africa's drylands: supporting advocates and answering skeptics. In *Global Mechanism of the Convention to Combat Desertification*.

Ruiee, R., Werahai, N., & Aree, S. (2004). Land Evaluation for an agriculture land reform area using GIS, Ministry of Agriculture and cooperatives. *Bankok, Thailand*.

Saenyi, W. W., & Chemelil, M. C. (2002). Modelling of suspended sediment discharge for Masinga catchment reservoir in Kenya. *Journal of Civil Engineering, JKUAT*, *8*(1), 89-98.

Scherr, S. J., & Sthapit, S. (2009). Farming and land use to cool the planet. *Wordwatch Institute. State of the World*.

Scherr, S. J., & Yadav, S. (1996). Land degradation in the developing world: Implications for food, agriculture, and the environment to 2020.

Schneider, H. M., Gichuki, F. N., Mungai, D. N., Gachene, C. K. K., & Thomas, D. B. (2000). Sediment sources to Masinga dam. In *Land and water management in Kenya: towards sustainable land use. Proceedings of the Fourth National Workshop, Kikuyu, Kenya, 15-19 February, 1993.* (pp. 47-54). Soil and Water Conservation Branch, Ministry of Agriculture and Rural Development.

Schwilch, G., Bachmann, F., & Liniger, H. P. (2009). Appraising and selecting conservation measures to mitigate desertification and land degradation based on stakeholder participation and global best practices. *Land Degradation & Development*, *20*(3), 308-326.

Sifuna, D. N. (2005). Increasing access and participation of pastoralist communities in primary education in Kenya. *International review of education*, *51*(5-6), 499-516.

Simpson L.A, (2009). A Manual of Soil Conservation and Slope Cultivation, , Caribbean Agricultural Research and Development Institute (CARDI)

Mainstreaming and Capacity Building for Sustainable Land Management PIMS 3409 – Atlas Project ID 43949.

Smyth, A. J., & Dumanski, J. (1993). *FESLM: An international framework for evaluating sustainable land management* (p. 76). Rome: FAO.

Sombroek, W. G., Braun, H. M. H., & Van der Pouw, B. J. A. (1982). *Exploratory soil map and agro-climatic zone map of Kenya, 1980* (No. 551.6906762 SOM. CIMMYT.).

Sprague Jr, R. H., & Carlson, E. D. (1982). *Building effective decision support systems*. Prentice Hall Professional Technical Reference.

Stanhope, P. (2002). *Get in the Groove: building tools and peer-to-peer solutions with the Groove platform*. John Wiley & Sons, Inc.

Stephens, W., Middleton, T., & Matthews, R. (2002). Why has the uptake of decision support systems been so poor?. *Crop-soil simulation models: applications in developing countries*, 129-147.

Tarawali S.A., Tarawali G., Larbi A. & Hanson J. (1995). *Methods for the Evaluation of Legumes,* Grasses and Fodder Trees for Use as Livestock Feed. ILRI Manual 1. ILRI (International Livestock Research Institute), Nairobi, Kenya. pp. 51.

Templeton, S. R., & Scherr, S. J. (1997). *Population pressure and the microeconomy of land management in hills and mountains of developing countries* (No. 26). International Food Policy Research Institute (IFPRI).

Templeton, S. R., & Scherr, S. J. (1999). Effects of demographic and related microeconomic change on land quality in hills and mountains of developing countries. *World Development*, *27*(6), 903-918.

Thomas, D.B., Mutunga, K., & Mburu, J.K. (2003). *Soil and water conservation in Kenya as documented through WOCAT. Working Paper No. 19, Regional Land Management Unit (RELMA),* Swedish International Development Agency (Sida). Nairobi, Kenya.

Tiruneh, A., Tesfaye, T., Mwangi, W., & Verkuijl, H. (2001). *Gender differentials in agricultural production and decision-making among smallholders in Ada, Lume, and Gimbichu Woredas of the Central Highlands of Ethiopia*. Cimmyt.

Tongruksawattana, S. (2014). Climate shocks and choice of adaptation strategy for Kenyan maize-legume farmers: insights from poverty, food security and gender perspectives.

Trotter, R. T. (2012). Qualitative research sample design and sample size: Resolving and unresolved issues and inferential imperatives. *Preventive medicine*, *55*(5), 398-400.

Turban, E., Sharda, R., & Delen, D. (2011). *Decision support and business intelligence systems*. Pearson Education India.

Van Lynden, G. W. J., Liniger, H. P., & Schwilch, G. (2002). The WOCAT map methodology, a standardized tool for mapping degradation and conservation. In *Proceedings of ISCO Conference 2002* (Vol. 4, pp. 11-16).

Veldkamp, A., Schoorl, J. M., Wijbrans, J. R., & Claessens, L. (2012). Mount Kenya volcanic activity and the Late Cenozoic landscape reorganisation in the upper Tana fluvial system. *Geomorphology*, *145*, 19-31.

Wachira, S. W. (2013). An evaluation of potential sustainable land management practices to enhance watershed ecosystem services in upper tana catchment: a case study of Kirurumwe River, Ena Basin in Embu County, Kenya.

Wall, E., & Smit, B. (2005). Climate change adaptation in light of sustainable agriculture. *Journal of sustainable agriculture, 27*(1), 113-123.

Wambua, R. M., Mutua, B. M., & Raude, J. M. (2015). Spatio-temporal Drought Characterization for the Upper Tana River Basin, Kenya Using Standardized Precipitation Index (SPI). *World Journal of Environmental Engineering, 3*(4), 111-120.

WCED, U. (1987). Our common future. *World Commission on Environment and Development Oxford University Press*.

West, T. O., & Post, W. M. (2002). Soil organic carbon sequestration rates by tillage and crop rotation. *Soil Science Society of America Journal*, *66*(6), 1930-1946.

Westerberg, L. O., & Christiansson, C. (1999). Highlands in East Africa: unstable slopes, unstable environments?. *Ambio*, 419-429.

Wilschut, L. I. (2010). *Land use in the Upper Tana* (Vol. 58). Technical report of a remote sensing based land use map. Green Water Credits Report 9, ISRIC–World Soil Information, Wageningen.

WOCAT (2004): www.wocat.

Wooldridge, R. (1984). *Sedimentation in reservoirs Tana River Basin, Kenya*. III-Analysis of Hydrographic surveys of three reservoirs in June/July 1983. Part A.

World Bank, (2007). *Project appraisal document on a proposed credit in the amount of sdr 46.0 million (US$68.5 million equivalent) to the*

Government of Kenya for a natural resource management project. World Bankpp 176.

Wright, A., & Sittig, D. F. (2008). A framework and model for evaluating clinical decision support architectures. *Journal of biomedical informatics*, *41*(6), 982-990.

Zaal, F., & Oostendorp, R. H. (2002). Explaining a miracle: Intensification and the transition towards sustainable small-scale agriculture in dryland Machakos and Kitui Districts, Kenya. *World Development*, *30*(7), 1271-1287.

APPENDICES

Appendix 1: Questionnaire on SLM Practices within the Upper Tana Catchment

1.0 Soil and Water Management

1.1 Do you experience soil erosion on your farm? 1=□Yes 2=□No

1.2 Is there runoff from your farm? 1=□Yes 2=□No

1.3 Does the runoff from your farm affect neighbours' field or drain into the river drainage? 1=□Yes 2=□No

1.4 Do you have any soil and water conservation measures installed/constructed on your farm? 1=□Yes 2=□No

1.5 Based on the SLM technologies/practices you have on your farm, respond to the following.

	Technology/Practice	**1.5.1 Which do you practice? *(tick appropriate)***	**1.5.2 Which ones work well on your farm? *(Tick where appropriate)***	***1.5.3* Factors influencing uptake *(Key)***	**1.5.4 How did you learn about it? *(Key)***
Structural	Bench terraces				
	Contour bunds				
	Graded drainage ditch/Fanya				

	Juu				
	Level ditches				
	Planting Pits				
	Check dams				
	Small earth dams				
	Stone lines				
	Trash lines				
	Grassed waterway				
Vegetative	Grass strips				
	Contour hedgerow				
	Alley cropping				
	Boundary tree plantings				
	Woodlot				
	Riparian vegetative buffer strip				
	Buffer strips				
Agronomic	Minimum/zero tillage				
	Manuring				
	Composting				
	Mixed cropping				
	Contour cultivation				
	Mulching				

	Cover crops				
	Green mulch/manure				
	Intercropping				
Management	Land use change				
	Area closure				
	Rotational grazing				
	Change of management intensity				
	Change in timing of activities				
	Cut and carry (fodder)				

Key for 1.5.3: Factors influencing uptake	
1	Slope
2	Climate
3	Level of degradation
4	Cost of the technology vis-a-vis gains
5	Others
Key for 1.5.4: How did you learn about it?	
7	Government extension through group approach

8	Government extension to me as an individual
9	From neighbours/friends
	Training away from the farm
	Others

Appendix 2: Stone-line technology WOCAT Technology

Stonelines

Kenya - Miraini ya maviga

Stonelines are constructed along the contours to slow the speed of runoff, filter the soil and enhance water infiltration.

In Kenya stone lines are mostly practiced in areas that receive 200-750 mm of annual rainfall with a spacing of 15-30 m between them. They are particularly common in areas where rocks are readily available, such as Mbeere, Laikipia, Baringo, Mwingi, Kitui and Tharaka. Since the stonelines are permeable they do not pond runoff water, but instead, they slow down the speed, filter it, and spread the water over the field, thus enhancing water infiltration and reducing soil erosion. They are built in series running along the slope. In addition, the stone barrier blocks and settles down the sediments transported from the upper slopes.
They are often used to rehabilitate eroded and abandoned land. The advantages of stonelines include; slowing down the runoff thereby increasing infiltration and soil moisture. They also induce a natural process of terracing, reducing erosion and rehabilitation of eroded lands by trapping silt, they are easy to design and construct, since the stone line structure is permeable, there is no need for construction of spillways to drain the excess runoff water. When it rains, the soil builds up on the upslope side of the stonelines, and over time a natural terrace is formed. The stonelines are spaced 15-30 m apart, a shorter distance being used for the steeper slopes. Stonelines are normally suitable on gentle slopes. Slopes above 35% should be avoided. They are established in the following manner, first, the contour line are marked out with the help of a tube level or line levels. In this region, this is done with the help of the frontline agricultural extension officers. Secondly, a shallow foundation trench is dug across the slope (5-10 cm to 30 cm deep) using basic farm equipments (jembes or hoes). As shown on the above photographs, the larger stones are put on the down slope side of the trench while the smaller stones are used to build the rest of the bund. The smallest stones are used to fill the gaps and increase the heights of the bunds up to the desired level. Farmers plant fruit trees (pawpaws) as show in the photograph above on the upper part. The trees utilises the moisture and rich sediments deposited on the upper part. The stonelines can be reinforced with earth, or crop residues to make them more stable. Maintenance of stonelines is done by repairing the already damaged /fallen stoneline that may have been knocked down or disarranged by livestock or by human beings. In this case animal access needs to be limited and/or the bund should be laid out in a way that allows the annimals to pass through.
In the lower Mbeere South District where the stoneline technologies is largely practiced, unless there are stones in the individual farms, it is might be difficult to import stones from other farms as the exercise can be labor intensive. In this catchment, the Ministry of Agriculture through the front line extension officers has taken a lead role in encouraging farmers to adopt the technology especially the farms which has many stones. Most of the farmers who has practiced this technology in the Lower Mbeere South District learn from the ones who are already practicing through field days or individual initiatives.

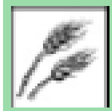
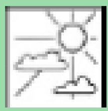
left: A landscape view of stoneline technology constructed along a contour line in Lower Mbeere South District, Kenya (Photo: Paul Kahiga)
right: Farmers constructing a stoneline technology along a contour line in the Lower Mbeere South District (Photo: Paul Kahiga)

Location: Eastern Province
Region: Mbeere South District
Technology area: < 0.1 km2 (10 ha)
Conservation measure: structural
Stage of intervention: prevention of land degradation, rehabilitation / reclamation of denuded land
Origin: Developed through land user´s initiative, 10-50 years ago
Land use type:
Cropland: Annual cropping
Land use:
Cropland: Tree and shrub cropping (before), Cropland: Annual cropping (after)
Climate: semi-arid, tropics
WOCAT database reference:
T_KEN660en
Related approach:
Compiled by: Paul Kahiga, Jomo Kenyatta University
Date: 2011-02-08
Contact person: Paul Kahiga, Jomo Kenyatta University of Agriculture and Technology, Biomechanical and Environmental Engineering Department, P.O.Box 62000-00200 Nairobi Kenya,Tel:+254720578636, Email: paulkahiga@gmail.com

Classification

Land use problems:

- Limited cultivation land due to hindrances that are brought about by the scattered stones on the land's surface. There is soil and water erosion that leads to low land productivity. (expert's point of view)
Soil erosion because of lack of soil and water conservation structures (land user's point of view)

Land use	Climate	Degradation	Conservation measure
			
Annual cropping Cropland: Tree and shrub cropping (before) Cropland: Annual cropping (after) rainfed	semi-arid	Soil erosion by water: loss of topsoil / surface erosion	structural: Bunds / banks

Stage of intervention

- ■ Prevention
- ▒ Mitigation / Reduction
- ■ Rehabilitation

Origin

- ■ Land users initiative: 10-50 years ago
- □ Experiments / Research
- ▒ Externally introduced

Level of technical knowledge

- ▒ Agricultural advisor
- ■ Land user

Main causes of land degradation:
Direct causes - Human induced: soil management
Direct causes - Natural: Heavy / extreme rainfall (intensity/amounts)
Indirect causes: poverty / wealth, labour availability

Main technical functions:
- water spreading
- sediment retention / trapping, sediment harvesting

Secondary technical functions:

Environment

Natural Environment

Average annual rainfall (mm)

- □ > 4000 mm
- □ 3000-4000 mm
- □ 2000-3000 mm
- □ 1500-2000 mm
- □ 1000-1500 mm
- □ 750-1000 mm
- ■ 500-750 mm
- ■ 250-500 mm
- ■ < 250 mm

Altitude (m a.s.l.)

- □ > 4000
- □ 3000-4000
- □ 2500-3000
- □ 2000-2500
- □ 1500-2000
- □ 1000-1500
- ■ 500-1000
- □ 100-500
- □ <100

Landform

- □ plateau / plains
- □ ridges
- □ mountain slopes
- □ hill slopes
- ■ footslopes
- □ valley floors

Slope (%)

- □ flat
- □ gentle
- ■ moderate
- □ rolling
- □ hilly
- □ steep
- □ very steep

Soil depth (cm)

- □ 0-20
- ■ 20-50
- □ 50-80
- □ 80-120
- □ >120

Growing season(s): 90 days(March-May), 90 days(October - December)
Soil texture: coarse / light (sandy)
Topsoil organic matter: low (<1%)
Soil drainage/infiltration: medium

Soil water storage capacity: medium
Ground water table: > 50 m
Availability of surface water: poor / none
Biodiversity: medium

Tolerant of climatic extremes: temperature increase, seasonal rainfall increase, seasonal rainfall decrease, wind storms / dust storms, droughts / dry spells
Sensitive to climatic extremes: heavy rainfall events (intensities and amount), floods

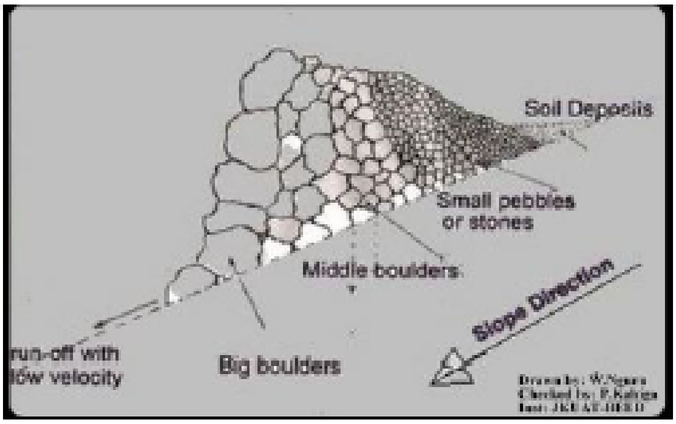
Human Environment

Cropland per household (ha)

- □ <0.5
- □ 0.5-1
- □ 1-2
- □ 2-5
- ■ 5-15
- □ 15-50
- □ 50-100
- □ 100-500
- □ 500-1,000
- □ 1,000-10,000
- □ >10,000

Land user: Individual / household, Small scale land users, common / average land users, mainly men
Population density: 10-50 persons/km2
Annual population growth: < 0.5%
Land ownership: individual, titled
Relative level of wealth: poor, which represents 80% of the land users;

Importance of off-farm income: less than 10% of all income:
Access to service and infrastructure: low: employment (eg off-farm), market, energy, roads & transport, financial services; moderate: health, education, technical assistance, drinking water and sanitation
Market orientation: mixed (subsistence and commercial)
Mechanization: manual labour, animal traction
Livestock grazing on cropland: no



Technical drawing

This is a technical drawing representing a cross-section view of how the stonelines are constructed by the emerging farmers in the lower Mbeere South District. First, a small trench is dug along an established contour line, the farmer starts arranging the stones with reference to their sizes. The bigger ones are arranged on the lower side and the small ones on the upper side as shown on the technical drawing. By so doing, the eroded soils are trapped on the upper side by the small pebbles, allowing the water to pass through at lower speed hence low erosive capacity. (W.Nguru)

Implementation activities, inputs and costs

Establishment activities

- Establish a contour line and dig up a trench upon which the stones will be arranged
- stones are collected and arranged along the established trench. The big boulders are reduced to the required sizes by the use of mattocks
- The big stones are arranged on the lower side and the rest follows with respect to their sizes on the upper side
- This formation is done per meter length. Mostly is charged 150Kshs per meter.

Establishment inputs and costs per ha

Inputs	Costs (US$)	% met by land user
Labour	87.50	100%
Construction material		
- stone	0.00	%
TOTAL	**1.00**	**100.00%**

Maintenance/recurrent activities

- Repair/Rearrange stone on stone line after a rainy seasons or when people and animals have destroyed the stone line.

Maintenance/recurrent inputs and costs per ha per year

Inputs	Costs (US$)	% met by land user
Labour	0.50	100%
TOTAL		**100.00%**

Remarks:
The system is labour intensive and hence will affect the cost of constructing the stonelines. However availability of farm equipments like wheelbarrows, mattocks or oxen will help reduce the total cost and time required for construction and maintaining the stonelines. On steep slopes, the spacing between the lines is small as compared to a relatively gentle slope. The cost applies for the year 2011 and was calculated per meter square, meter length, meter height and meter width.

Assessment

Impacts of the Technology

Production and socio-economic benefits

+++ simplified farm operations
++ increased crop yield
++ reduced risk of production failure

Production and socio-economic disadvantages

++ increased labour constraints
++ hindered farm operations

Socio-cultural benefits

+++ improved conservation / erosion knowledge
+ improved situation of disadvantaged groups

Socio-cultural disadvantages

Ecological benefits

+++ increased soil moisture
+++ reduced soil loss
++ reduced hazard towards adverse events

Ecological disadvantages

Off-site benefits

++ reduced downstream flooding

Off-site disadvantages

+++ reduced sediment yields

Contribution to human well-being / livelihoods

+++ increased food security (the yield near the stoneline is better as compared to the situation that it was before implementation

Benefits /costs according to land user			
	Benefits compared with costs	**short-term:**	**long-term:**
	Establishment	slightly positive	positive
	Maintenance / recurrent	positive	positive

Acceptance / adoption:

There is moderate trend towards (growing) spontaneous adoption of the technology. The technology is mainly practiced on the farms with stones even though the farmers admit that the task of construction is labour intensive. However, these not withstanding, the farmers do acknowledge that the technology is beneficial since they can see the results of yields from the ones who are already practicing.

Concluding statements

Strengths and → how to sustain/improve	Weaknesses and → how to overcome
The stones for constructing the technology are readily available in most of the farms. → Encouraging farmers to use the available stones to put up the technology.	Labour intensive → When constructing, always move the stones downslope by gravity instead of moving upwards.i.e start from the contours from the upper side
Stoneline technology prevents soil loss due to erosion → Modification of the technology to allow more infiltration	The technology only allows the soil to deposit on the upper side of the stoneline but water passes through. → Proper arrangement of the stones should be enhanced basing on their sizes.
No high level technical knowledge is required for construction of stoneline technology → More farmers should be encouraged to adopt the technology since they dont need a high level of technical knowledge	Increased habitats for snakes and other dangerous creatures like scorpions that hide on the stonelines → Where there creatures are prone, the farmers should be careful
Stone lines technology can be modified to prevent soil and water from running off on the side of stone line ridge → construction of side ridges	Contour profiling is challenging → Assistance from the front line agricultural extension officers
By concentrating the stones along a contour, the farmer is able to make use of the land which otherwise is not possible if the stones are scatered. → Farmers should be encouraged to learn from one another but they should also seek advice from extension officers in making the contours	
The cost of replacement of farm equipments (jembes, forks and pangas) is reduced since they arent broken by stones during land preparation →	

Appendix 3: Ecosystem services

Ecological Benefits	**Production/ Socioeconomic Benefits**	**Socio-Cultural Benefits**
• Increased water quantity	• Increased crop yield	• Improved cultural opportunities (eg spiritual, aesthetic, others)
• Increased water quality	• Increased fodder production	• Increased recreational opportunities
• Improved harvesting / collection of Water (runoff, dew, snow, etc)	• Increased fodder quality	• Community institution strengthening
• Increased soil moisture	• Increased animal production	• National institution strengthening
• Reduced evaporation	• Increased wood production	• Improved conservation / erosion knowledge
• Reduced surface runoff	• Reduced risk of production failure	• Conflict mitigation
• Improved excess water drainage	• Increased drinking / household water	• Improved situation of socially and economically

		disadvantaged groups (gender, age, status, ethnicity etc)
• Recharge of groundwater table/aquifer	• Availability / quality	• Improved food security / self-sufficiency (reduced dependence on external support)
• Reduced hazard towards adverse events (drought, floods, storms, …)	• Increased water availability / quality	• Improved health
• Reduced wind velocity	• For livestock	
• Improved soil cover	• Increased irrigation water availability/ quality	
• Increased biomass / above ground c	• Reduced demand for irrigation water	
• Increased nutrient cycling / recharge	• Reduced expenses on agricultural Inputs	
• Increased soil organic matter / below ground c	• Increased farm income	

• Reduced emission of carbon and greenhouse gases	• Diversification of income sources	
• Reduced soil loss	• Increased production area (new land Under cultivation / use)	
• Reduced soil crusting/sealing	• Decreased labour constraints	
• Reduced soil compaction	• Decreased workload	
• Reduced salinity	• Simplified farm operations	
• Reduced fire risk	• Increased product diversification	
• Increased animal diversity		
• Increased plant diversity		
• Reduced invasive alien species		
• Increased beneficial species (predators, earthworms,		

pollinators)		
• Increased biological pest / disease control		
• Increased / maintained habitat diversity		

Appendix 4: Table of MATSIM fields

Table	**Purpose**	**Fields**
ACZ table	Stores data concerning the ACZ's	1) codeACZ – The primary key for the table 2) ACZ – Holds the ACZ's
AEZ table	Stores data concerning the AEZ's.	1) codeAEZ – The primary key for the table. 2) AEZ – Holds the AEZ's. 3) codeACZ – A foreign key referencing the primary key in the ACZ table. Used to associate AEZ's to the ACZ's they belong to.
LUT table	Stores data concerning the land use types.	1) codeLUT – The primary key for the table. 2) LUT – Holds the descriptions land use types.
AEZ_LUT table	A junction table linking AEZ's to Land Use that can be practiced in the AEZ.	1) codeAEZ – A foreign key referencing the primary key in the AEZ table. 2) codeLUT – A foreign key referencing the primary key in the LUT table.
LUT _SLM table	A junction table linking SLM's to Land Use types associated with them.	1) codeLUT – A foreign key referencing the primary key in the LUT table. 2) codeSLM – A foreign key referencing the primary key in the SLM table.
SLM_CLASS table	Stores data concerning the available SLM classes.	1) codeCLASS – The primary key for the table 2) SLM_CLASS – Holds the name of the SLM class.
SLM table	Stores data concerning the sustainable land use management types.	1) codeSLM – The primary key for the table 2) SLM – Holds the name of the Sustainable land use types. 3) Description – Holds a brief description of the SLM. 4) codeCLASS – A foreign key referencing the SLM_CLASS table primary key. It links the

		SLMs to the SLM class they belong to.
BENEFIT table	Stores data concerning the available benefit classes.	1) codeBEN – The primary key for the table 2) benefit – Holds the description of the benefit class.
BENTYPE table	Stores data concerning the actual benefits.	1) codeBENTYPE– The primary key for the table 2) BENEFIT – Holds the description of the benefit. 3) codeBEN – a foreign key referencing the BENEFIT table primary key. It links the benefits to the benefit class they belong to.
SLM_BENEFIT table	A junction table linking SLM's to benefits that accrue from implementing the SLM's	1) codeSLM – A foreign key referencing the primary key in the SLM table. 2) codeBENTYPE – A foreign key referencing the primary key in the BENTYPE table.
TOPO table	Stores data concerning the topography.	1) codeTOPO – The primary key for the table topography – Holds the description of the topography.
SLM_TOPO table	A junction table linking SLM's to topography that the SLM's can be implemented in	1) codeTOPO – A foreign key referencing the primary key in the TOPO table. 2) codeSLM – A foreign key referencing the primary key in the SLM table.
CLIMATE table	Stores data concerning the climatic extremes.	1) codeCLIM – The primary key for the table 2) climate – Holds the description of the climatic extremes.
SLM_CLIM table	A junction table linking SLM's to climatic extremes and stores the adaptability status of the SLM to the climatic extremes.	1) codeSLM – A foreign key referencing the primary key in the SLM table. 2) codeCLIM – A foreign key referencing the primary key in the CLIMATE table. 3) Adaptability – Holds the adaptability status of

		the SLM to climatic extreme.
CASE table	A table used to hold limited information for the documented technologies in a particular catchment. The table basically contains data that points one to the WOCAT global database where one can get more detailed information concerning the technology.	1) caseCODE – A primary key for the table. 2) CASE_NAME – The name of the documented technology or the name of location the technology is documented in. 3) OBJECTIVE – Holds the adaptability status of the SLM to climatic extreme. 4) PHOTO_SLM_PATH – Holds the path to location of the SLM photograph on disk. 5) TECHNICAL_DRAWING – Holds the path to the sketch of the SLM on disk 6) codeTOPO - A foreign key referencing the primary key in the TOPO table. Links the topography to the documented technology 7) codeAEZ - A foreign key referencing the primary key in the AEZ table. Links the AEZ to the documented technology 8) codeACZ - A foreign key referencing the primary key in the ACZ table . Links the ACZ to the documented technology 9) codeLUT - A foreign key referencing the primary key in the LUT table. Links the LUT to the documented technology 10) codeSOIL - A foreign key referencing the primary key in the SOIL. Links the SOIL to the documented technology 11) codeCLIM - A foreign key referencing the primary key in the CLIMATE. Links the CLIMATE to the documented technology 12) NOTES - 13) Wocatdoc_path – Holds the path to the document retrieved from the WOCAT global database.

		14) wocatREF – Holds the reference number for the documented technology in the WOCAT global reference database.
SLM_CLIM table	A junction table linking SLM's to a particular documented technology.	1) caseCODE – A foreign key referencing the primary key in the CASE table. 2) codeSLM – A foreign key referencing the primary key in the SLM table.
DRAINAGE table	Stores drainage characteristics data.	1) codeDNG – A primary key for the table. 2) drainage – A field storing the drainage characteristic description.
GENDER table	Stores the gender data for the application.	1) codeDNG – A primary key for the table. 2) gender – A field storing the gender description data.
SOIL table	Stores the soil characteristics data for the application.	1) codeSOIL – A primary key for the table. 2) xter – A field storing the soil characteristics data.
TENURE table	Stores the land tenure data for the application.	1) codeTEN – A primary key for the table. 2) tenure – A field storing the land tenure description.