About the Volume

Sustainable Land Management in Dry Lands of Kenya: Improving land productivity through participatory research and technology transfer book is designed to provide an understanding of the various levels at which SLM issues are scientifically, socially and economically addressed. It also draws the attention of the importance of conserving the environment especially in agro-pastoral production systems of Kenya. Emerging challenges on climate change and opportunities in SLM including case studies make this book a valuable resource for researchers, postgraduate students, policy makers and NGOs practitioners.

The introduction chapter in this book gives an overview of the SLM Project actvities. Five themes are covered in this volume. The first theme 'Resource Inventory on Sustainable Land Management: Case Studies' presents four case studies from different parts of Kenya where use of RS, GIS and PGIS have been emphasised as important tools for monitoring natural resources. The second theme is on 'Enhancing dry land cropping through upscaling of soil and water conservation'. The six chapters under this theme mainly concentrate on the use of tillage for enhanced soil moisture conservation and water conservation for increased smallholder land productivity. The third theme on 'Adaptation to climate change and variability in agropastoral production systems' outlines the challenges being experienced due to climate change in these fragile agro-pastoral production systems. Two chapters covering rehabilitation of rangelands are given under the third theme on 'Rehabilitation of degraded lands through afforestration, agroforestry and natural regeneration' The last theme on 'Policy and Institutional frameworks supportive of SLM' emphasises the importance of having conducive SLM policies. It is expected that researchers, farmers and development practitioners and students will find this volume useful.

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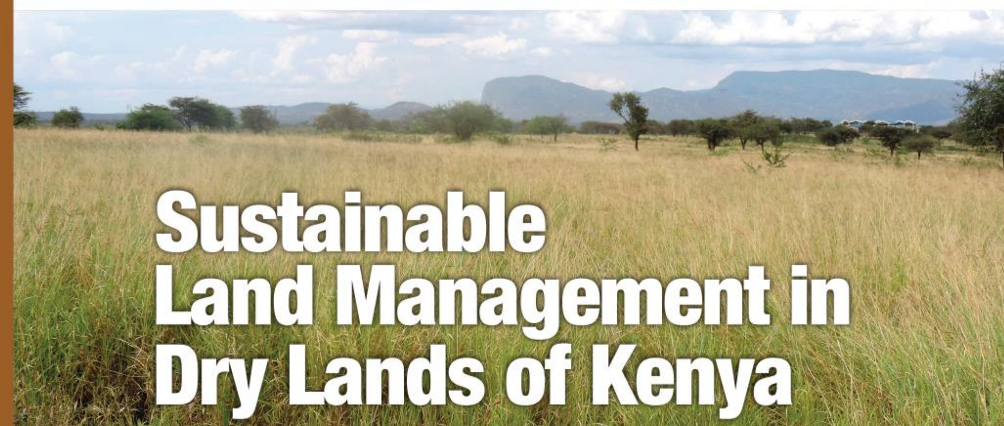
Sustainable Land Management in Dry Lands of Kenya

Zeinabu Khalif • Charles KK Gachene • Patrick Gicheru • David Mwehia Mburu • Christopher Gatama Gakahu



Sustainable Land Management in Dry Lands of Kenya

Improving Land Productivity through Participatory Research and Technology Transfer

SLM Agro-Pastoral Project Kenya

Edited by: Zeinabu Khalif • Charles KK Gachene • Patrick Gicheru • David Mwehia Mburu • Christopher Gatama Gakahu

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Foreword

The increasing degradation of ecosystems and the growing impacts of climate change urgently call for a change in the way we manage our natural resources. Without drastic changes in the way Kenya uses her land, the country will not be able to sustain both subsistence and national economies. Experts warn of the collapse of entire ecosystems and landscapes at current levels of degradation exacerbated by climate change. If the current condition continues unabated, there will be less food and clean water, and ultimately, significantly worse conditions for the nation's poorest people.

Expanding human needs, services and resources from land is creating competition and conflicts that contributes to more land degradation. To meet the increasing human needs in a sustainable manner, a more effective and efficient utilization of land and land resources must be found. This will require review of policies related to land management together with supporting integration and mainstreaming of sustainable land management (SLM) into national planning processes and implementing land management approaches, techniques and technologies. The United Nations Development Programme (UNDP) helps Kenya strengthen capacity to address land degradation challenges at national and community levels. This is realized through promoting technologies and innovations, sharing best practices, providing policy advice and linking partners through projects – such us " Mainstreaming SLM in Agro-pastoral Production Systems of Kenya" that help communities build sustainable and resilient livelihoods.

Past and contemporary researches in Kenya have generated substantive knowledge on possible causes of land degradation and also made proposals on approaches and practices for sustainable land management. However this knowledge, technologies and innovations have not been fully utilized because of poor linkages among stakeholders. UNDP as the global knowledge network promotes learning, knowledge sharing, exchange of experiences and best practices amongst stakeholders at local and national levels. This publication is a consolidation of papers from diverse studies that were presented at the first national sustainable land management conference. The conference was held under the auspices of Mainstreaming SLM in

Agro-pastoral Production system of Kenya project. The conference brought together scientists, postgraduate students, policy makers and development practitioners who shared their knowledge and experiences on SLM in key thematic areas.

At the conference, these stakeholders shared research findings, lessons learned, successes and failures of past technology transfer initiatives. The conference was a melting pot for latest case studies, profiles of projects, statistics and data. New tools for recent scientific research together with innovative approaches, practices for sustainable land management were also shared.

Therefore, I am honoured to present a book on SLM at a time when major changes and reforms in land use are taking place in Kenya. It is our hope that this book will bolster to Kenya's commitment to manage land in an equitable, efficient, productive and sustainable way as enshrined in the new constitution.

Nardos Bekele - Thomas

UN Resident Coordinator and UNDP Resident Representative

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Special thanks to the authors of the book chapters who put tireless efforts in ensuring that all the milestones and deadlines for their chapters were met. To Dr. Christopher Gakahu and Prof. Jesse Njoka for having agreed to be key note speakers during the conference. Others deserving praise for providing logistic support in the production of this book are Leonard Odini, Barbara Ombasa, Solomon Karuri, Bernard Ouma and Juliet Muchaho, all working in the SLM coordination office, and Lucy Kinyua, University of Nairobi. Last but not least, the editors acknowledge their gratitude to the farmers and agro-pastoralists whose resources, including land and time were used in the course of carrying out the case studies published in this book.

List of Abbreviations and Acronyms

AAP	African Adaptation Programme
ACZ	Agro-Climatic Zone
AEZ	Agro- ecological Zone
AISP	Agricultural Input Subsidy Program
ANOVA	Analysis of variance
APRP	Agricultural Productivity Research Project
ASALs	Arid and Semi- Arid Lands
AUC	Area Under Curve
CBNRM	Community Based Natural Resource Management
CDKN	Climate and Development Knowledge Network
CDM	Clean Development Mechanism
CEM	Climate Envelope Modelling
CER	Certified Emission Reduction
CIAT	International Centre for Tropical Agriculture
COMESA	Common Market for Eastern and Southern Africa
DAAD	German Academic Exchange Service
DANIDA	Danish International Development Agency
DEAP	District Environment Action Plan
DFID	Department for International Development
DFI	Direct Foreign Investment
DST	Decision Support Tool
ECCM	Edinburgh Centre for Carbon Management
ECOTRUST	Environment Conservation Trust
ETM	Enhanced Thematic Mapper
FANTA	Food and Nutrition Technical Assistance Project
FAO	Food and Agriculture Organization
FEWSNET	Famine Early Warning System Network
GARP	Genetic Algorithm for Rules –Set Prediction
GDP	Gross Domestic Product
GHG	Green House Gases
GIS	Geographical Information System
GoK	Government of Kenya
GPS	Global Positioning System
HHS	Household Hunger Scale

HI	Harvest Index
HWC	Human Wildlife Conflicts
IAASTD	International Assessment of Agricultural Knowledge, Science and Technology For Development
ICRAF	International Centre for Research in Agro Forestry
IDRC	International Development Research Centre
IPCC	Intergovernmental Panel on Climate Change
IR	Infiltration Rate
IUCN	International Union for Conservation of Nature
KARI	Kenya Agricultural Research Institute
KEFRI	Kenya Forestry Research Institute
KFSSG	Kenya Food Security Steering Group
KMD	Kenya Meteorological Department
KWS	Kenya Wildlife Service
LACIE	Large Area Crop Inventory Estimate
LCC	Land Cover Change
LC	Land Cover
LR	Long Rains
LTRFC	Lower Tana River Forest Complex
LTS	Land and Timber Services
LUT	Land Use Types
LU	Land Use
LULCC	Land Use and Land Cover Change
MDG	Millennium Development Goals
MEA	Millennium Ecosystem Assessment
MEWNR	Ministry of Environment, Water and Natural Resources
MoA	Ministry of Agriculture
MTP	Medium Term Plans
NAMA	Nationally Appropriate Mitigation Actions
NAP	National Action Programme
NASA	National Aeronautical Space Administration
NCCAP	National Climate Change Action Plan
NCCRS	National Climate Change Response Strategy
NDVI	Normalised Difference Vegetation Index
NGO	Non Governmental Organization
NOAA	National Oceanic and Atmospheric Administration
NUE	Nutrient Use Efficiency
PBIBD	Partially Balanced Incomplete Block Design

PES	Payment for Ecosystem Services
PGIS	Participatory Geographical Information System
PRESA	Pro- poor Rewards for Environmental Services in Africa
ROC	Receiver Operating Characteristic
REDD	Reduced Emissions from Deforestation and Degradation
RFE	Rainfall Estimate
ROI	Regions of Interest
RS	Remote Sensing
RUFORUM	Regional Universities Forum for Capacity Building in Agriculture
SEI	Stockholm Environmental Institute
SIDA	Swedish International Development Agency
SLM	Sustainable Land Management
SOC	Soil Organic Carbon
SRES	Special Report Emission Scenario
SR	Short Rains
SSA	Sub Saharan Africa
SPSS	Statistical Package for Social Science
SUA	Sokoine University of Agriculture
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNFCC	United Nations Framework Convention on Climate Change
UNPF	United Nations Population Fund
UN	United Nations
USA	United States of America
USDA	United States Department of Agriculture
WAP	Weeks After Planting
WC	Water Conservation
WMO	World Meteorological Organisation
WOCAT	World Overview of Conservation Approaches and Technology
WRI	Water Resources Institute
WRMA	Water Resources Management Authority
WRUA	Water Resource Users Association
WUE	Water Use Efficiency
WWF	World Wide Fund for Nature

Introduction

Sustainable Land Management in the Dry Lands of Kenya: Issues and Challenges

Nearly all our needs; wood for fuel and shelter, food, water,and other products come from the land and renewable resources on it. This reality is critical for Kenya whose land is the most strategic resource and natural capital that form the backbone of the country's subsistence and national economies. The question is: will the land and these resources be able to sustainably support the growing population? There is increasing scarcity of water, loss of productive agricultural land, forests, woodland, and grazing lands. Today, land use change in most cases denote negative change. These changes are mainly driven by population increase, economic growth and new technology alongside man's inappropriate uses and extractive management regime. The urgency to "develop" continue to damage and degrade landscapes and deplete natural systems that sustain renewable resources.

Drylands are home to pastoral and agro pastoral communities and wildlife. The lands are characterized by spatial and temporal rainfall variability and ecological fragility, which weakens the land's ability to revert to original condition after degradation. Land degradation denotes reduction of resource potential caused by one or a combination of processes acting on land, such as soil erosion by wind and/or water; deterioration of the physical, chemical and biological or economic properties of the soil; and long term loss of natural vegetation. A more comprehensive definition of land degradation is the aggregate diminution of the productive potential of the land, including its major uses (rain-fed, arable, irrigated, rangeland, forest), its farming systems and its value as an economic resource.

In the arid and semi – arid areas of Kenya (ASALs), land degradation is attributed to various factors. Some of the major factors include high population growth, government policies and inappropriate development models. The growing population has resulted to increased pressure on pockets of fertile land as more pastoralists sedentarize due to poverty or the need to access social amenities i.e. schools. Livestock losses due to droughts or cattle rustling have also resulted to more people engaging in charcoal production. There is evidence of vegetation degradation due to forest clearing, uncontrolled logging, selective harvesting and loss of canopy cover, invasive species, and uncontrolled fires. The situation is aggravated by climate variations and change.

The reality is that land is being degraded at increasing rates despite the fact that ecological, sociological and biophysical causes of land degradation being known. There is an urgent need to put in place the proper mix of current knowledge, techniques and approaches to help us understand the limited potential of land to sustainably produce products of value to people and to nature in general.

The concept of sustainable land management is still evolving but with a common understanding that land production systems must aim for environmental sustainability. This requires information and knowledge on the structure, function and dynamics of the land and landscapes. In addition, there is a need to know the political, fiscal, technological and policy constraints and challenges that would affect realization of full benefits of sustainable land management.

Sustainable land management (SLM) is the adoption of land use systems that through appropriate management practices can enable pastoralists, farmers and other land users to have maximum economic and social benefits from the land while maintaining or enhancing the ecological functions of the land resources. Ensuring long-term productive potential of the land resource is critical to SLM. Considering that ASALs cover a significantly large area in Kenya, a large proportion of this area is affected by various levels of land degradation.

Knoweldge gap is one of the key issues that undermine SLM in the drylands. This is despite the fact that research institutions and universities have been undertaking studies and publishing on SLM. The knoweldge gap in ASALs are attributed to indequate extension services, poor infrastructure and high level of illiterary. This gap can be addressed by enhancing linkages between research institutions and extension services as well as improving extension services in the remote areas.

The SLM Project: An Overview

The Sustainable Land Management (SLM) project aims to address the above challenges using two approaches: firstly, by supporting review of policies related to sustainable land management and mainstreaming SLM in all national planning processes. Secondly, by implementating sustainable land use community level initiatives in the pilot districts (now sub-counties) using Farmer Field School (FFS) approach to up-scale best-bet technologies for sustainable land management in ASALs.

Since the launch of the project in January 2012, SLM project continues to undertake various interventions to curb land degradation in selected sites located in pilot sub-counties . The project sites are located in Mbeere North in Mbeere Sub-County of Embu County, Kyuso in Mwingi Sub-County of Kitui County, Narok North Sub-County in Narok County and Dadaab Sub-County in Garissa County. The interventions in each site took into consideration aspects such as the levels and spread of land degradation, type of agro-ecological zone and current land use systems. Below, we highlight some of the key issues and the achievements of the SLM project.

Mbeere North

Mbeere Sub-County covers a total area of 2,092.5 km² with an estimated population of over 200,000. The soils vary but are generally strongly weathered and low in fertility with widespread soil erosion in the project sites. Although Kiang'ombe hill has global environmental significance because of its endemic plant species, most of the hill has been allocated to individuals. The remaining part of the hill continues to be threatened because of the traditional practice of slash and burn cultivation. The Mbeere community has not been known to embrace soil conservation and very few soil conservation structures had been established in the landscape before intervention by SLM project.

The project has used holistic approach to curb land degradation and enhance environmental protection in Mbeere North. This includes sensitization of the community on issues of land degradation and forming eleven Farmer Field Schools (FFS) around the Kiang'ombe hill. The schools offer training on various SLM technologies and also support in exchange visits of farmers and field days which act as extension and knowledge sharing forums. Through SLM project support the plant species on Kiang'ombe hill have been mapped and inventoried, over 50,000 trees have been planted on the degraded hill sides. The project has also supported pasture re-seeding, established SLM Award Scheme for FFS as well as the primary and secondary schools to promote SLM innovations and, to recognize champions of sustainable land management innovations. To date a total of four springs have been rehabilitated and four water troughs constructed. The project has also supported livelihood diversification by promoting beekeeping, drought resistant crops and improved livestock breeds. Post-harvest technologies were also promoted to reduce loss of crop yields.

Plate 1 Measures implemented to alleviate water shortage at Gachuriri by construction of a Sand dam and a water kiosk from the rehabilitated Kivue spring at Kiangombe hill in Mbeere North.

Plate 2 A half orange kilns for sustainable charcoal production at Njiga and distribution of Alpine dairy goats for local breeds improvement at Kandutu in Mbeere North.

Communities have been trained and currently adopted soil and water conservation structures on their farms. The community members have been sensitized on energy efficient technologies such as improved house hold cook stoves. The project has also established and trained Charcoal Producers Association and trained their members on all aspects of efficient and sustainable charcoal production technologies.

Kyuso

Kyuso is located in Mwingi Sub-County of Kitui County, which is predominantly covered by grassland interspersed by savanna vegetation. The soils are of low fertility and prone to erosion. The climate is hot and dry for the greater part of the year with erratic rainfall that normally ranges between 400 mm and 800 mm per year, with the short rains more reliable than the long rains. The main livelihood activities are marginal mixed farming, agro-pastoralism, stone quarrying, sand harvesting and petty trade. There is high level of de-forestation due to massive charcoal production driven by high level of poverty.

SLM project activities are mainly in sites around Kyuso, Kamwongo, Tseikuru, Itivanzou, Kavaani and Mulangoni areas. The SLM interventions include establishment and training of FFS, rehabilitation of Itivanzou gullies, support rain water harvesting in Itivanzou primary and secondary schools, establishment of 3 tree nurseries with over 15,000 tree seedlings, planting of trees in degraded areas and in schools and other public institutions.

Plate 3 A woman digging soil and water conservation stuctures and sisal planted as a measure to rehabilitating Itivanzou gully in Kyuso.

Plate 4 An established tree nursery at Kavaani and tanks for rain water harvesting in Itivanzou secondary schools in Kyuso.

There has also been support to water projects including digging a water pan in Itivanzou, 2 shallow wells and 1 sand dam. FFS in the area involves training on soil and water conservation. The FFSs members are also given incentives to establish terraces on their farms. Other support includes provision of improved livestock breed and drought resistant crops to FFS.

Narok North

Narok North Sub-County is situated in the south-western part of the country. The sub-county has two distinct zones - the highland zone above 2300 m and the lowland zone between 1000 m and 2300 m above sea level. Much of Narok North is in transition from pastoralism to agro-pastoralism. Previous communal land has been sub-divided and fenced hence livestock movements are restricted. The Suswa hill area is severely eroded with some of the gullies reaching depths of over 25m and widths of over 30m.

Plate 5 Community participate in digging soil and water conservation structures to control the Suswa gullies in Suswa and rehabilitation of degraded land through pasture re-seeding in Ewaso Ngiro, Narok.

Plate 6 Established water retention ditches for rehabilitation of the Suswa gully in Narok.

The soils are stratified with hard pans underlain by loose silty loam strata that is readily eroded. The area is densely bushed with T. camphoratus being the dominant tree species. Over the years, the land continues to be depleted of ground cover making it susceptible to soil erosion. Due to increased poverty, the community has also resorted to cutting down indigenous tree species for charcoal production. Recently, Narok has been identified as one of the hot spots of environmental concerns in Kenya, due to the massive production of charcoal with a ready market both locally and in the adjacent urban areas.

To combat land degradation in Narok, the SLM project has undertaken diverse activities including mapping of vegetation species in Narok and rehabilitation of over 250 ha of gullies in Suswa in partnership with KARI, UoN, KEFRI and JKUAT. The activities involved the establishment of numerous soil and water conservation structures such as water retention ditches, terraces, cut –off drains, semi – circular bands, water pans, check dams and planting of trees in degraded areas. The project also supported establishment and training of over 120 FFS members on SLM practices including sustainable charcoal production; pasture establishment and adoption of drought resistant crops and improved livestock breeds. Another activity has been disease surveillance done along the stock route to control disease breakouts and vaccination of over 5,000 units of poultry. SLM supported tree planting in schools and established SLM award to promote environmental protection.

Dadaab

Dadaab Sub-County is situated about 100 km north of Garissa township. The area receives an average annual rainfall of about 350 mm year-1. The pastoral livelihood is affected by frequent droughts which reduces pastures and fodder leading to massive livestock deaths. The place experiences flooding occasionally causing both human and livestock losses. Over the years, Dadaab has experienced massive environmental degradation due to high population of refugees. This has led to opening up of pastoral areas for refugee settlement and cutting down of trees and shrubs to provide firewood for the refugees and host communities. The high demand for firewood has led to further push into pastoral lands to harness firewood. The area suffers from under development because of persistent insecurity caused by inter-clan conflicts and recently, terrorist attacks.

Plate 7 Abakaile Primary school tree demonstation plot and Bahuri FFS meeting under trees planted at household level in Dadaab.

Some of SLM achievements include establishment and training of Pastoral Field Schools (PFS), establishment of demonstrations sites to train community on sustainable farming practices; establishment of tree nurseries and support to planting of medicinal and fruit trees; promotion of drought resistant crops; pasture establishment, improving livestock breeds; support to veterinary services, livestock disease surveillance along the stock routes; energy saving jikos; support to rehabilitation of a livestock market facility; establishment of slaughter slabs to reduce hides/skin damage, training on flaying and skin/hide treatment and support to peace building to facilitate access to pasture and water sources especially during dry seasons/droughts.

Plate 8 Beekeeping at Abakaile and distribution of energy saving jikos in Dadaab.

In addition to the above activities, the project is also supporting post graduate research and review of curricula in partnership with the University of Nairobi.

Implementation of the project activities will continue over the next two years. It is envisaged that more positive results and impacts will be achieved towards sustainable land management in the targeted sub-counties.

This publication is a consolidation of papers from diverse studies that were presented at the first national sustainable land management conference. The conference was held under the auspices of Mainstreaming Sustainable Land Management (SLM) in Agro-pastoral Production system of Kenya project. The conference brought together scientists, postgraduate students, policy makers and development practitioners who shared their knowledge and experiences on sustainable land management in key thematic areas.

Theme I

Resource Inventory on Sustainable Land Management: Case Studies

Chapter I

The Disappearing Forest: A Case Study of Trends in Land Use and Land Cover Changes of the Threatened Lower Tana River Forest Complex, Coastal Kenya

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Abstract

The main cause of land use and land cover changes (LULCC) is through changes in the way human beings use and manage their land resources. One of the most vulnerable natural resources most threatened by human beings is the forest. This study investigated trends in LULCC in the Lower Tana River Forest Complex (LTRFC) using Remote Sensing (RS) and GIS technology. The forest is located in the Kenya Coastal lowland and is of considerable value for both biodiversity conservation and local livelihoods. Analysis was carried out using multi-temporal images and field based studies, with a view to understand the dynamics of land use and land cover changes, especially deforestation and associated agricultural developments activities from 1995 to 2004. During the 9 years period, significant changes occurred in areas under the forest and agriculture. In 1995, the major land use and land cover was forest (7185.51 km^2), grassland (7010 km^2) and agriculture (243.87 km^2). The land use and land cover change was quite dynamic within the 9 year period. The forest cover decreased from about 7185.52 km^2 in 1995 to 1852.6 km^2 in 2004, a 74.2 per cent loss. On the other hand, the area under agriculture increased considerably by almost ten times, from 243.87 km^2 in 1995 to 2346.65 km^2 ha in 2004, a 862.25% gain. This means that most of the area previously under forest was lost to cultivation. Therefore there is need for proper land use planning and community awareness on the implications of this land use and land cover changes. It is also prudent that the forest management stakeholder in the area come together to collectively participate in the conservation of Lower Tana River Forest Complex.

Key words: Remote sensing, geographic information system, land use and land cover change, forest cover.

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Introduction

Land use (LU) is defined as the manner in which human beings utilize the land and its resources (e.g. for agriculture, forestry, etc.), while land cover (LC) is the ecological state and physical appearance of the land surface (e.g. forests or grasslands). It has now been recognized that the main cause of land cover change (LCC) is through changes in the way human beings use and manage their land (MEA 2005). As people labour to meet their daily needs, they are subjecting forests, wetlands, woodlands and grasslands to the highest rates of change, whose impact is, in most cases, always negative (Reij et al. 2005).

The forest is an important resource with wide range of benefits. However these natural resources are threatened by human population growth and increased economic activities. This is mainly due to the growing demand for forest products such as timber for building and burning of charcoal in addition to clearing forest land for agricultural expansion (Enfors and Gordon 2005). The benefits include offsetting air pollution, protection of the soil against erosion, providing habitat for a wide range of animal and tree species and recreational opportunities. Worldwide forests have been disappearing at an alarming rate, with an estimated 86% of the original forest cover already lost by 1993. It is even more alarming in Kenya where area under forests has declined rapidly. It is estimated that only 6.9% of the total land area is under forests (Wahungu et al. 2005). Reports by FAO (2005) and MEA (2005) further indicate that each year close to 13 million ha of forest is lost due to deforestation, particularly in the tropics, mainly as a result of conversion to agricultural land. What is even more worrying is that forests have completely disappeared in 25 countries and another 29 have lost more than 90% of their forest cover (FAO 2005 and MEA 2005). Under such conditions, it is very highly unlikely that such countries will achieve the forest cover target of Millennium Development Goals No.7. Furthermore and according to Okello and Ngigi (2012), a combination of economic and social development factors, such as levels of agricultural productivity, settlement and climatic variability together determine the rates of deforestation.

Kenya is a largely agrarian economy, where close to 90% of its population rely heavily on agriculture for livelihood needs leading to varying, and mostly, negative impacts on its forests. However, these impacts and changes have not been well documented and quantified, particularly for important natural and unique tropical forests such as Lower Tana River Forest Complex (LTRFC). This forest occurs along the mouth of Tana River, and is of considerable value for both biodiversity conservation (with several threatened animal and plant species) as well as for local livelihood activities. The purpose of this study was to monitor land use changes in LTRFC using remote sensing and Participatory Geographic Information Systems (PGIS) technology in mapping of LTRFC, which is located in the Coastal lowland, Kenya. Resource inventory of LTRFC using PGIS has been reported elsewhere in this book.

The changes in land use and land cover due to either natural or human activities or both can be observed using remotely sensed data at very high spatial, spectral and temporal resolutions. Over the years, remote sensing has emerged as the most useful data source for quantitatively measuring land use and land cover changes at the landscape scale. Researchers have now recognized the potential of remote sensing (RS) and geographical information systems (GIS) as effective tools in detecting land use and land cover change thus helping decision makers to develop effective land management plans (Ermias 2006). Remote sensing and GIS-based change-detection studies can, therefore, be utilised to provide information on how much, where and what type of land use and land cover change has occurred over a given period of time. According to Ermias (2006) satellite remote sensing provides cost-effective, multi-spectral and multi-temporal data, and turns them into information valuable for understanding and monitoring land development patterns and processes for building land use and land cover data sets. Studies further find that multi-temporal analysis of satellite imagery is effective for change detection because there is a high correlation between spectral variation in the imagery and land cover change.

Methods

Assessing trends in land use and land cover changes of Lower Tana River Forest Complex

Information on land use and land cover changes and their causes may provide a better understanding of trends in land use, and play a vital role in the formulation of policies and programmes required for development planning (Kathumo 2011; Kathumo et al. 2012; Baaru 2011). In addition, understanding the function and structure of landscapes, in terms of human impacts, also requires the integration of biophysical and socio-economic knowledge. This study was part of a larger project which also involved an assessment of socio-economic conditions of local households against land use and cover changes in the study area (Okello and Ngigi 2012).

Land use and land cover changes in the Lower Tana River Forest Complex (LTRFC), were analysed from multi-temporal images and field based studies, with a view to understand the dynamics of deforestation and associated agricultural developments activities from 1995 to 2004. The aim of the study was to use remote sensing to assess the changes in land use in the LTRFC and to use the generated information and images to sensitize the local communities on the need and benefits of forest conservation in order to promote sustainable management of this unique forest.

The study area which covers 17644 km^2 was selected because of its uniqueness and the alarming rate at which this rare forest is disappearing. According to Wahungu et al (2005), it is rare in Kenya to have a lowland evergreen riverine tropical forest. Wahungu et al (2005) further indicate that the flora in the LTRFC is quite diverse and comprise a mix of western and central Africa rainforest species and eastern and coastal forest endemic species, with at least 10 rare woody plant species. Indeed in 1976, the Kenya Government had to gazette part of the forest as a National Reserve to protect the riverine fringe and two very highly endangered primates; the Tana River red colobus *(Colobus badius rufomitratus)* and Tana River mangabey *(Cercocebus galeritus galeritus)* from extinction.

The main focus was to determine patterns of change within the major land use and land cover types, namely forest, agricultural, shrubland and grassland. The time period investigated was from 1995 to 2001 and 2001 to 2004. The land use and land cover classification therefore discriminated these four classes. To detect changes in land use and land cover, MODIS 2001, MODIS 2004 and Africa Land Cover 1995 landsat maps were used to assess land use and land cover changes over a 6 and 9 year period in LTRFC. The years with least cloud cover were 2001 and 2004. Due to the resolution of the imagery, it was difficult to display the built up areas as well as the riverine forest along the Tana River. Once the images were classified (supervised classification), Change Detection Module on ENVI software was used in order to acquire the land cover change for the years 2001 and 2004. The 1995 raster data was run through supervised classification and the results run through the change detection module to get the land cover change for the years 1995 – 2001.

The dates of the images were purposively chosen to avoid uncertainties and were acquired within the same season (dry period) in a year. This is to avoid temporary land cover evident in wet season. Cloudiness was also a factor that was considered especially in the area of study.

Landsat map examination

Using Global Positioning System (GPS), points of areas (training areas) corresponding to each land use class (i.e. forests, grassland, cultivated land, and bushland) were taken. The descriptions below (Table 1) were used to identify each of the four classes.

Table 1 Identification and description of land use classes in LTRFC

Land Use classes	Description
Forests	Indigenous trees
Cultivated land	Crop land
Grassland	Grasses, scrubland, pastureland
Bushland	Very sparse vegetation

Analysis of landsat maps was done using ENVI 4.7 software. Cursor location/ value (geographical position) for identified training areas from defined Regions of Interest (ROI) was ascertained and each class was allocated the color that matched that land cover on the landsat map. Maximum Likelihood classification was used. The method assumes that the statistics for each class in each band is evenly distributed and calculates the probability that a given pixel belong to certain class. The training points were as uniform in color as possible and their location maintained for the two images to ensure that correct pixel identified the correct class.

Change detection

Thematic change detection for Landsat TM and Landsat ETM+ was established using ENVI EX. This was done by selecting two images of the same scene, with same number of classes and same names at different times. The software identifies differences between the images and with a resultant classification image. Thematic change vectors created during classification were saved to a shape file; while statistics on image change was saved as thematic change statistics and opened in a Microsoft excel spreadsheet. The results were then examined and analyzed for land use change.

Results and Discussion

Land use changes between 1995 and 2004 in Lower Tana River Forest Complex

The major land cover conversions were from forests and grasslands to agricultural and shrubland. During year 1995, the major land use/land cover was forest (7185.51 km^2) followed by grassland (7010 km^2). Of the land use types investigated, cultivated land was the least occupying only 243.87 km^2 by 1995. The land use/land cover change under cultivation was quite dynamic within the 9 year period having covered an area of 2346.65 km^2.

The forest cover decreased from about 7185.52 km^2 in 1995 to 1852.6 km^2 in 2004, a 74.2% loss. Within a period of only six years (1995 to 2001), the land under forest had declined by more than a half, from 7185.51 km^2 to 2699.53 km^2, a 62.4% loss. On the other hand, the area under agriculture increased considerably by almost ten times, from 243.87 km^2 in 1995 to 2346.65 km^2 in 2004, a 862.25% gain. This means that most of the 7185.51 km^2 of forest was lost to cultivation. Agricultural expansion is by far the leading land use change associated with deforestation especially in Africa (Reij et al. 2005). With agricultural expansion being the major driver of deforestation in the area, the findings in this study are similar to those from other parts of the world (Enfors and Gordon 2007; Reij et al. 2005). Other drivers of deforestation in the LRTFC include food security, improved security, lifestyle change and pressure from upcountry immigrants (Okello and Ngigi 2012).

Apparently, area under shrubland also increased from 3204.62 km^2 in 1995 to 9894.76 km^2 in 2004, a 208.77% gain. Trends in land use and land cover change also show that there was a loss of 49.36% of the area under grassland from 1995 to 2004 (Table 2). It is clear that most of the areas under forest and grassland were converted for agricultural use. The gain in area under shrubland may be an indication of some of the area under cultivation probably having been abandoned and left as fallow, perhaps due to loss of inherent soil fertility.

Table 2 Changes in the major land use and land cover classes within Lower Tana River Forest Complex between 1995 and 2004

Land use / land cover type	Area (km^2)		Change	
	1995	2004	Absolute	Percent
Forest	7185.51	1852.6	-5332.91	74.2
Agricultural	243.87	2346.65	+2102.78	862.25
Grassland	7010	3549.99	- 3460.01	49.36
Shrubland	3204.62	9894.76	+ 6690.14	208.77

Figures 1, 2 and 3 also show that most of the land use and land cover changes were experienced between 1995 and 2001, that is, within a span of six years. However, the 2001 and 2004 maps show that decline in forest cover from 1995 was more pronounced in the south eastern part of the area.

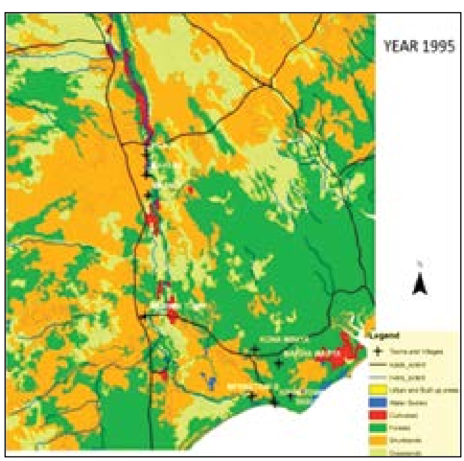

Figure 1 Land use 1995

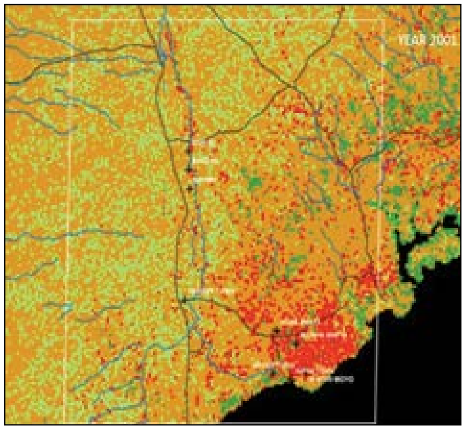

Figure 2 Land use 2001

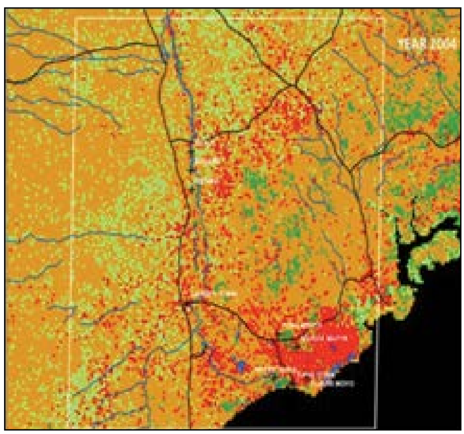

Figure 3 Land use 2004

The area coincides with heavily populated towns and villages such as Mpeketoni, Kipini, Shauri Moyo, Kona Mbaya and Maisha Mapya as well as along the Tana River banks where Garsen town, Baomo, Makere and Wenje villages are located. Indeed land use and land cover in 2001 indicates that a lot of forest had been cleared giving way to agricultural activities. This was especially more pronounced in the eastern part of the study area. Whereas Kona Mbaya and Maisha Mapya villages were surrounded by forest in 1995, this was not the case six years later. The same trend was observed along the Tana River banks where literally the forest along the river bank had disappeared. By 2004, the area under cultivation had expanded to the south western part of the area and north east of Wenje village.

This systematic trend in the clearing of forest from the river banks to the hinterland was expected. People tend to settle in areas especially where water is or may not be limiting. Once settled, clearing of land for agricultural activities then commences where trees are felled to clear the land for cultivation, providing construction materials such as timber and for charcoal burning. Similarly, the study area was characterised by farmers of low socio-economic conditions, and as alternative sources of income are very few and most of the employment is on farms with low wage returns. Opening the forest for cultivation and land degradation is still continuing at an alarming rate. A study carried out by Okello and Ngigi (2012) in the same area reported that most of the farmers resulted in agricultural activities to meet household and for economic gains. Allison and Hobbs (2004) reported that in the Western Australian agricultural region, land use and land cover changes and ensuing natural resource degradation are rooted in the economic, demographic and social changes that link variables in the ecological system to those in the social system.

Resource mapping by the local people and researchers using participatory GIS (PGIS) (Kathumo et al. 2012) and observations undertaken during the field work in 2011 and 2012 corroborated the image classification analysis results for the period under investigation and revealed the destruction of LTR Forest Complex. Field surveys and observations in 2011 revealed that illegal harvesting of trees for timber, charcoal and for boat construction had nonetheless, been going on. This is despite the fact that the communities are aware of the numerous services the forests provide (Okello and Ngigi 2012). Luoga et al. (2002) noted that people carry out activities that degrade forests / woodlands because of the high economic benefits they obtain from these activities. They further pointed out that the community often sees little immediate economic gain from conserving forest / woodland resources or assuring their sustainable utilization. There were numerous signs of illegal pitsawing, even in the so-called ‘nature reserve’ where no harvesting is allowed. The area is also not far from Lamu Town which is expected to experience high economic growth due to the newly launched multi million dollar Lamu Port – South Sudan – Ethiopia – Transport Corridor (LAPSSET) project. This makes the study area to continually attract a big population in search of forest resources that will cater for this transport corridor project. This threat is no doubt real. Another important factor is the nearness to Malindi and Mombasa towns, which are major tourist centers. These could be cited as some of the factors responsible for the current invasion of the Lower Tana River Forest Complex as evidenced by increasing agricultural activities.

Further lack of or increases in prices of agricultural inputs such as fertilizers may also lead to an increase in areas under cultivation, probably resulting in more deforestation as the local population encroaches the more fertile soils in the forest. Okello and Ngigi (2012) showed that most of the farmers hardly utilize farm inputs such as fertilizers and lack of this encouraged forest clearing for crop cultivation, resulting in significant deforestation. The increasing agricultural expansion mainly in the southern and north eastern parts as compared to the northern western part of the study area may be due to other factors such as differences in soil types. A notable increase in shrubland was observed between 1995 and 2004. The gain was mainly at the expense of grassland and forest cover (Table 2). A study carried out by Gathaara et al. (2010) on adoption and opportunities for improving soil and water conservation practices found comparable results in Kathekakai Settlement Scheme, Machakos County. Changes were observed across all land use/cover types.

Other studies (MEA 2005) have reported side effects of an expanding human population including habitat destruction for farming activities, human settlement, and pollution (MEA 2005), usually associated with how people use and manage land. However, attempts are been made to reverse the rising trends in the invasion of the forest. For instance, in Baomo sub location, seven community based organization have been formed to conserve the National Primate Forest (Okello and Ngigi 2012). In addition, there are other forest management regimes in the area, namely, private, community, Kenya Wildlife Service and the Kenya Forest Service.

Conclusion and Recommendations

It is evident that land use change has taken place in the Lower Tana River Forest Complex at a very high rate and within a very short period of time (1995 to 2004). The main drivers of the forest invasion are food security, migrants to the area and clearing of forest in search of forest products such as timber for construction and charcoal. During interviews with farmers and focus group discussions, it was reported that cutting down of trees was a rampant activity in the area to give way to land development, provide fuelwood and for building materials. In particular, spatial extent areas under forest and grassland had a downward trend while areas under cultivation and bushland had an upward trend over the 9 year period. Most of the changes in land use/cover were associated with increase in population, and a 'free for all' land owership attitude. It seems as if new settlers are at liberty to use the land in whichever way is deemed best to them as evidenced by the local's terminology, namely, *'ujikatie'* or cut for yourself and proximity to Tana River. This trend is expected to continue especially for cultivated and built-up areas noting that population for the area is on an increasing trend. The current human activities have been associated with negative land use changes especially forest disapperance and loss of vegetation. Unless firm measures are taken by the relevant authorities, it is just, but a matter of time, for this forest to disappear. A loss of 62 % of forest cover within such as a short period of time is a clear indicator of the rate at which the forest is disappearing. It is through community awareness that this trend can be minimised. One way of creating awareness is through participatory GIS. Again, changing the land tenure policy may result in proper utilisation and minimising the expansion of agricultual land. To halt the current extensive cultivation, the locals, with the assistance of the government should instead intensify agriculture in the already cleared land. Intensification can be in form of providing inputs such as certified seeds and fertilizers. This will minimise further expansion into the forest in search of fertile land soils. It is also prudent that the forest management stakeholders in the area come together to collectively participate in the conservation of Lower Tana River Forest Complex.

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Chapter 2

Is Lower Tana River Forest Complex and Ecosystem Under Threat of Total Destruction? Evidence from Participatory GIS

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Abstract

Participatory Geographical Information System (PGIS) has been used widely to empower and convince communities of the importance of conserving land resources in order to minimize undesirable effects of future land use changes on natural resources. The objective of this study was to use participatory GIS to map forest resources in the Lower Tana River Forest complex (LTRFC). The aim was to create awareness among local communities about effects of the current state of decline of the forest on the quality and quantity of the ecosystem, and to educate them on the importance of conserving the forest. Resource change mental maps showing the extent and distribution of land use and land cover within four selected villages were drawn on manila papers for the years 1970, 1990 and 2011. Ground-truthing of major physical features within the mapped area was done using GPS. Photos of the mental maps were taken and geo-referenced using ArcGIS software. Areas under each land use and land cover change were determined using on screen digitizing and their percentage changes determined for the period between 1970 and 2011. Significance levels were determined using Chi-square test. PGIS community forums were then carried out in the four villages to discuss the PGIS mental maps with regard to land resource changes over the years, resultant benefits and undesirable effects associated with the changes. Agriculture was the main land use in the area, followed by settlement and lastly natural forest. Changes in forest cover and area under agriculture were significant ($P<0.05$) for the period between 1970 and 2011 in two of the four studied villages. Areas under settlements did not change significantly. The reduction of forest cover and expansion of agricultural land were attributed to human

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activities such as illegal logging, cultivation, charcoal burning, overgrazing, and encroachment. These land cover and land use changes were associated with benefits like availing land for settlement and cultivation. These benefits were however outweighed by undesirable effects such as reduced rainfall amounts, higher temperatures, human-wildlife and human-human conflicts. The communities were convinced on the importance of conserving the forest and recommended; afforestation, agro-forestry, and use of organic manure, crop rotation and stopping deforestation as the way forward in conserving the forest.

Key words: Participatory GIS, mental maps, land resources, forest, Tana river.

Introduction

The Lower Tana River Forest Complex (LTRFC) in coastal Kenya represents lowland evergreen riverine tropical forest types which are rare in Kenya and probably in Africa, and whose unique biodiversity is widely recognized. The flora is quite diverse and comprises a mix of pan-African species of Western and Central African rainforest species and Eastern and Coastal forest endemic species, with at least ten rare woody plant species. Part of this forest was gazetted for protection by the Kenya Government in 1976 as a National Reserve and to also protect the highly endangered primates namely, the Tana River red colobus *Colobus badius rufomitratus* and Tana River mangabey *Cercocebus galeritus galeritus* from extinction (Wahungu et al. 2005).

Conserving the Complex has both ecological and economic benefits. Over the years, the complex has experienced considerable demographic pressures. Its use has been unsustainable, with charcoal burning, pole cutting, and felling of large trees for building canoes being of particular concern. In addition, the complex is surrounded by agricultural and grazing land and a trend toward forest conversion at an unsustainable rate in recent years. Given the current human growth and immigration trends to the Lower Tana River area, the demand for forest products is set to increase tremendously in the future thus putting even more pressure on the remaining forest land (Wahungu et al. 2005; Owino et al. 2008). This study dealt with the application of Participatory Geographic Information System technology (PGIS) in mapping of the LTRF complex. PGIS uses bottom-up approach as opposed to top-down approach in ordinary GIS. It is defined as a continuum starting from community mobilisation to project planning and design, choice of mapping methods and technologies, visualisation of different technologies in diverse ethno–cultural and agro ecological environments and finally putting the maps to work in the domains of ownership identity building, self determination, spatial planning and advocacy (Harris and Weiner 1998). PGIS assumes that communities are socially differentiated, and as a result, differential access to resources may simultaneously empower and marginalize certain community members. The PGIS meth¬odology acknowledges this social and political reality, and thus employs a framework that accommodates such disenfranchised members of society. As a result, local community perceptions and experiences are integrated into an expert-designed and operated GIS (ordinary GIS) as mental maps, oral narratives, and social histories (Harris and Weiner 1998). Therefore PGIS methodology employed in this study integrates ordinary geospatial information technologies and remote sensing, with community participatory methods. Perceptions and experiences of local communities are integrated into ordinary GIS database as layers of information. PGIS is mainly for community empowerment while ordinary or traditional GIS (top-down approach) emphasize the production of spatial data to facilitate official decision-making.

Most of the GIS work in Kenya uses the ordinary GIS which has not been effective in transforming the attitudes of the communities with regard to forest conservation and management. The recent surge in the implementation of GIS projects in local and indigenous communities around the world provides clues on how the forces of technological change, advocacy, and public expectation have reshaped the course of GIS development and the power relations that define its research and applications. As GIS has continued to play an expanded role in the way scientists analyze spatial data, manage natural resources, view and understand spatial phenomena, the empowerment of underprivileged groups has emerged as a popular field of GIS research and applications. The practice is the result of a spontaneous merger of participatory learning and action methods with geographic information technologies (Rambaldi et al. 2005).

Few organizations and individuals have applied PGIS for different purposes in Kenya. iMAP Africa (2009) used various methods including PGIS to carry out a study on urban planning in Kibera slums in Nairobi. They applied a combination of digital cartography, satellite and aerial photo interpretation, GPS transect walk and mental mapping exercises. The study mapped the social amenities like health facilities, schools, and housing and other social-economic activities. The study concluded that PGIS, if appropriately utilized, could exert profound impacts on community empowerment, innovation and social change by enabling communities to demand the provision of public facilities and amenities. This is particularly the case where PGIS places control of access and use of culturally sensitive spatial information in the hands of the community. PGIS practice can also protect traditional knowledge and wisdom from external exploitation.

ERMIS Africa (2007) used PGIS to map resources rights of communities threatened with extinction in Kenya namely, the Ogiek, Sengwer and Yiaku. This landmark study which aimed to validate land and resource rights, involved a combination of tools and methods such as sketch maps, Participatory 3D Models (P3DM), and aerial photographs, global positioning system (GPS), satellite imageries and Geographic Information Systems. The study found that the three communities differ significantly in their cultural backgrounds including places of worship, ancestral origin, and traditions that make them distinct. This study further aimed at promoting cohesion among the three communities and to improve natural resources management.

VACID-Africa (2010) also used PGIS to map farmers growing mukau (Melia volkensii) in Kibwezi District of Makueni County in Kenya. The study also aimed at mapping the natural resources that are found within mukau growing areas and to promote natural resource management in the area. The outcome was a map showing mukau growing areas and also a map showing the various natural resources that exist in the area. The study found that there is still a major skill gap in the use of PGIS and suggested the need for training in PGIS.

Another important study was the work of Weiner and Koto (2006) in Athi River industrial area. This study addressed two objectives namely, the effect of socio-spatial exclusion on the fringe of urban resources and the planning of urban settlements. This study used PGIS to assess social and political inclusion of the communities in urban fringe on urban planning. The study generated maps of urban locations, settlements, roads, and other social amenities in the area. It also found evidence of socio-spatial exclusion of marginalized communities in urban planning. The study recommended the need for deliberate efforts by the government to involve all communities in urban planning for social cohesion and for the purposes of political inclusion.

Generally, PGIS tool is used to empower and to convince communities on the importance of conserving land resources hence minimizing undesirable effects of future land use changes on the resources. This is especially critical in the LTRF complex which is under pressure from human activities such as illegal logging, cultivation, charcoal burning, overgrazing, encroachment, poaching, flooding of contaminated water from power and lighting companies, increased human-wildlife and human-human conflicts. There have been efforts to involve the private sector, the Kenya Wildlife Service and local communities in the management of the forests. This has given rise to four forest management regimes that are fighting to save the Tana River Forest Complex from complete destruction. The regimes have been using top-down approaches in saving the forest which have not been successful. No work has been done on the application of PGIS in forest resources management in this region. Therefore, it is worthwhile to use PGIS to convince local communities on the importance of conserving the land resources so as to minimize undesirable effects of future land use changes. The objective of this study was to use participatory GIS (PGIS) to map forest resources in the Lower Tana River Forest complex in order to create awareness among local communities about the effect of the current decline of the forest on the quality and quantity of the ecosystem, and to educate them on the importance of conserving the forest.

Materials and Methods

Study site

The Lower Tana River Forest Complex is located between longitudes 39o39’36”E and 40o50’56”E and latitudes 01o22’14”S and 02o40’12”S in the Tana River County (Figure 1). The total studied area of the Lower Tana River Forest complex is 17644 km^2. It is a riverine forest in the upper part but it widens as the river enters the Indian Ocean. River Tana is the largest river in Kenya draining from Mount Kenya and Nyandarua ranges. The region has flat to gently undulating terrain with an average altitude of between 5 - 77 m above mean sea level. It experiences a bimodal pattern of rainfall with mean annual rainfall of between 400 - 1200 mm and lies in Agro-Climatic Zone IV and V (Sombroek et al. 1982). The average minimum and maximum night temperature is 22.0 and 38.5°C respectively. The soils are generally moderately deep to very deep mostly arenosols. The flora in the complex is quite diverse and comprises a mix of pan-African species of Western and Central African rainforest species and Eastern and Coastal forest endemic species, with at least ten rare woody plant species including mangroves (Owino et al. 2008). There has been an increase in the number of individuals coming from upcountry to settle in Lower Tana River forest in the last 6 years.

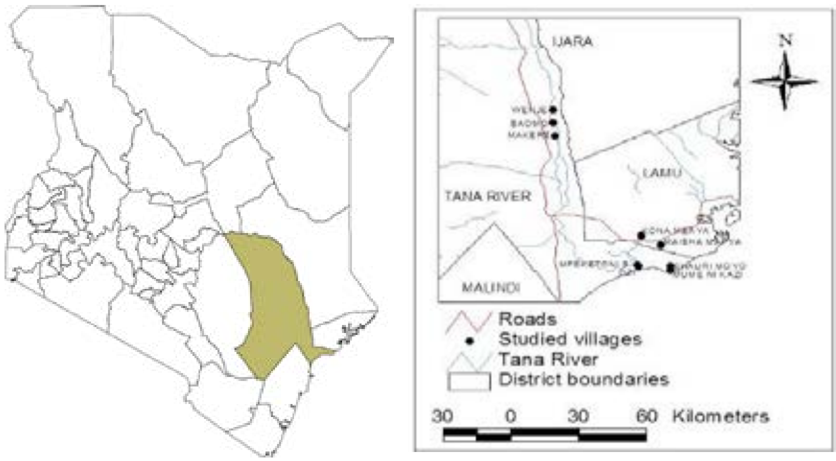

Figure 1 Location of the Lower Tana River Forest Complex

Mapping land resources using Participatory GIS

Mental maps for the years 1970, 1990 and 2011 were obtained from four villages within the LTRF complex under free prior informed consent. The villages were based on forest management regimes. The mental maps were used to assess land use and land cover changes of the forest complex as perceived by the communities neighboring the forest. The selected years of the maps were purposively chosen with an interval of 20 years considering temporal sensitivity. These villages included; Maisha masha (Kenya Forest Service management regime), Shauri moyo (Private management regime), Mpeketoni B (Community management regime) and Baomo (Kenya Wildlife Service management regime).

Twenty participants per village were selected and separated into two groups of men and women. Each group of twenty included; five old men (above 50 years), five old women (above 50 years), five young women (18 to 35 years) and five young men (18 to 35 years). The participants drew on manila papers land resource mental maps showing major land resources within each of the village for the years 1970, 1990 and 2011. The land resources targeted during the PGIS sessions included; natural forest cover, agricultural land, water bodies, settlements and roads. The community considered these as the most important resources which they depend on for their livelihood. The best three mental maps (1970, 1990 and 2011) which closely represented the reality on the ground were selected per village under the consultation of the participants and photos taken using a digital camera. The PGIS photos were then downloaded and geo-referenced using Arc GIS 9.3 software. The geo-referenced PGIS maps (1970, 1990 and 2011) were exported to Arcview-GIS software to calculate areas under different land cover and land uses (namely, forest, agricultural land and settlement). Only these three main land use types were considered because they covered 99% of the features shown in the mental maps. Changes of the main land uses and their percentages for the period between 1970 - 1990 and 1990 - 2011 were calculated. The geo-referenced PGIS maps were then printed as posters for discussions during community forums.

Participatory GIS community forums

PGIS community forums were carried out in the four selected villages. Thirty participants of the mixed gender and age were selected in each village. These included part of the twenty selected participants who participated in the prior PGIS activity. Each village discussed their own mental maps. Changes of the major land resources (forest, agricultural land, settlements and water bodies) over the years were noted. During the community forums, direct and indirect benefits and undesirable effects of these major land resource changes were discussed. The participants made recommendations for minimizing the undesirable effects of the land resource changes.

Results and Discussion

Trends in land use and land cover changes

Based on the participatory GIS, mental maps of the four villages for the year 1970, 1990 and 2011 are shown in Figures 2, 3, 4 and 5 respectively. Land use and land cover change statistics of the four studied villages are summarised in Table 1.

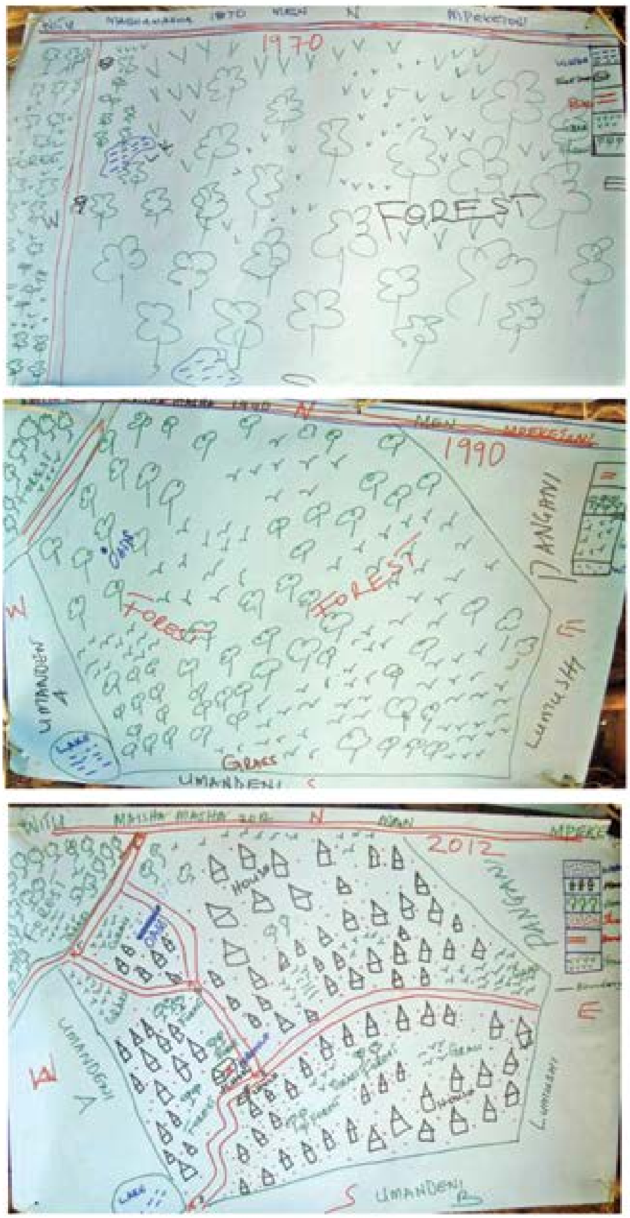

Figure 2 Maisha masha village Participatory GIS maps for years 1970, 1990 and 2011

Figure 3 Shauri moyo village Participatory GIS maps for years 1970, 1990 and 2011

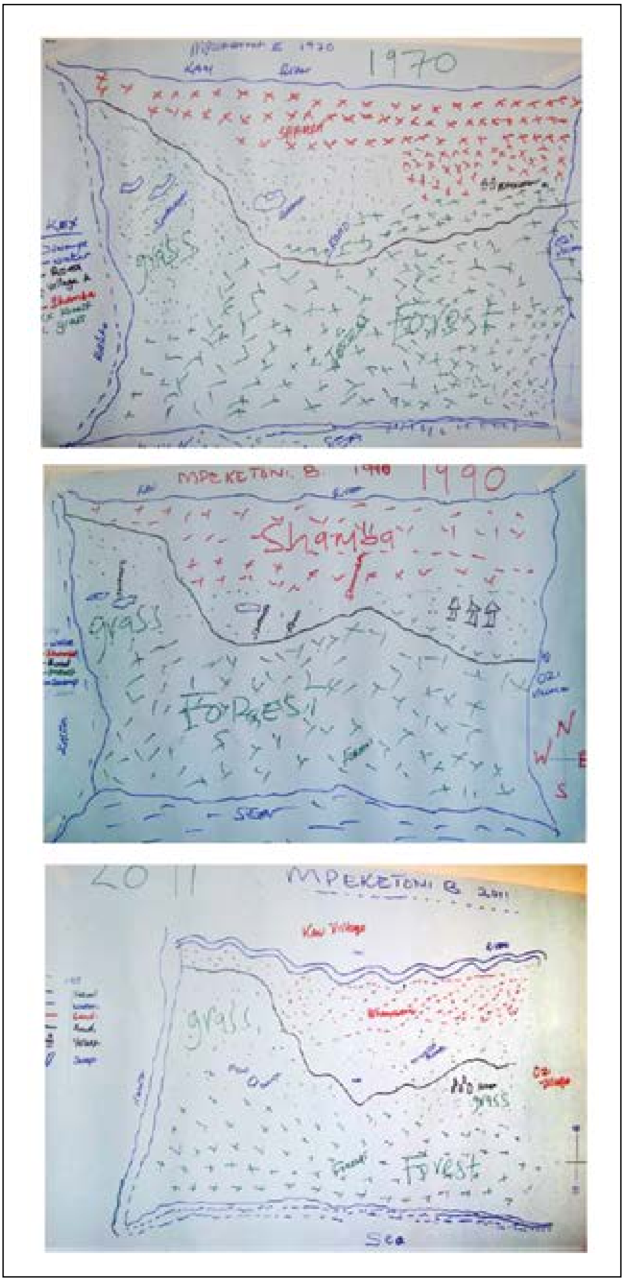

Figure 4 Mpeketoni B village Participatory GIS maps for years 1970, 1990 and 2011

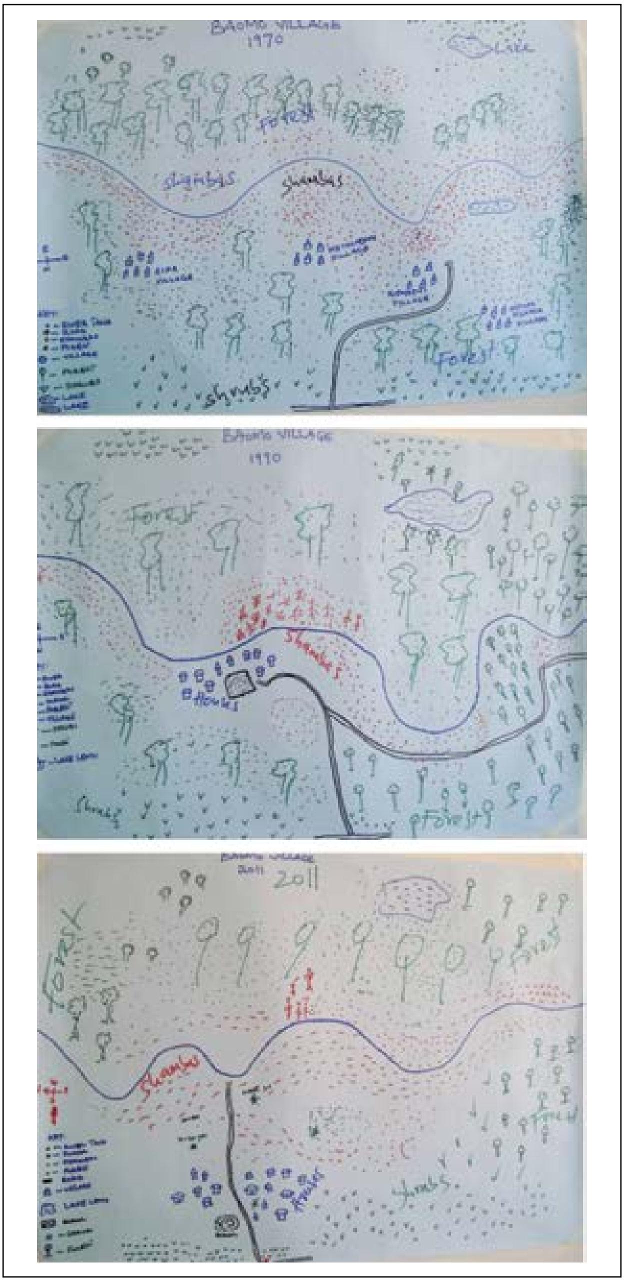

Figure 5 Baomo village Participatory GIS maps for years 1970, 1990 and 2011

Table 1 Land use and land cover change from PGIS maps

Village	Land use/ cover	1970 Area (km^2)	1990 Area (km^2)	2011 Area (km^2)	Change (1970-1990) %	Change (1990-2011) %	Change (1970-2011) %	Chi-square test		
								x2	df	P
Baomo	Settlement	2.88	3.72	5.00	+29.17	+34.41	+73.61	2.8	2	0.247
	Agricultural	36.14	41.60	42.05	+15.11	+1.08	+16.35	0.539	2	0.764
	Forest	36.91	30.61	28.88	-17.06	-30.00	-21.76	0.727	2	0.695
	Total	75.93	75.93	75.93						
Maisha Masha	Settlement	0.43	0.48	2.82	+11.63	+487.5	+555.81	1.600	2	0.449
	Agricultural	0.75	0.83	8.44	+10.67	+916.87	+1025.33	9.800	2	0.007
	Forest	11.33	11.20	1.25	-1.15	-88.84	-88.97	8.700	2	0.013
	Total	12.51	12.51	12.51						
Shauri moyo	Settlement	0.12	0.17	3.07	+41.67	+1705.88	+2458.33	1.600	2	0.449
	Agricultural	0.22	0.29	9.7	+31.82	+32244.83	+4309.09	13.500	2	0.001
	Forest	13.64	13.52	1.21	-0.88	-91.05	-91.13	11.660	2	0.003
	Total	13.98	13.98	13.98						
Mpeketoni B	Settlement	0.07	0.08	0.12	+14.29	+50	+71.43	0.000	2	1.000
	Agricultural	1.43	1.44	1.73	+0.7	+20.14	+20.98	0.500	2	0.779
	Forest	1.55	1.53	1.20	-1.29	-21.57	-22.58	0.400	2	0.819
	Total	3.05	3.05	3.05						

In Baomo village, agricultural land was the main land use covering about 55.38% of the village. Natural forest covered about 38.03%, while settlement area covered the remaining 6.59%. This was attributed to the changing livelihood systems by the community from pastoralism to crop production. Forest cover decreased by 17.06 and 30%, agricultural land increased by 15.11 and 1.08% while settlement area increased by 29.17 and 34.41% of the original area for the period between 1970 - 1990 and 1990 - 2011 respectively as shown in Table 1. The overall changes in the reduction of forest cover, expansion of agricultural land and settlement were not significant as shown in Figure 6. This is because there are very few immigrants settling in this village due to lack of enough land for cultivation and also harsh climatic conditions in the area.

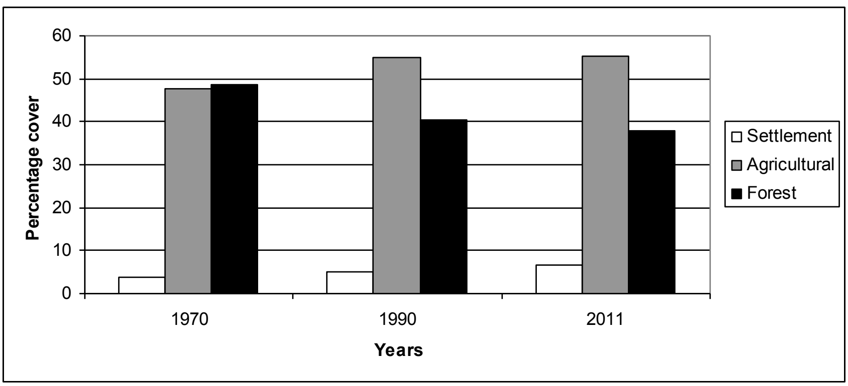

Figure 6 Land use and land cover changes of Baomo village

In Maisha masha village, agricultural land is the main land use covering about 67.47% of the village. Settlement area covers about 22.54%, while natural forest covers the remaining 10%. There is significant reduction in forest cover ($P = 0.013$) and significant expansion in agricultural land ($P = 0.007$) for the period between 1970 - 2011 as shown in Table 1. This is because of the extensive clearing of the forest for crop production by the immigrants due to availability of fertile land and suitable climate for agriculture. Settlement showed an increase from 1990 to 2011 due to migration of people to this area although it was not significant as shown in Figure 7.

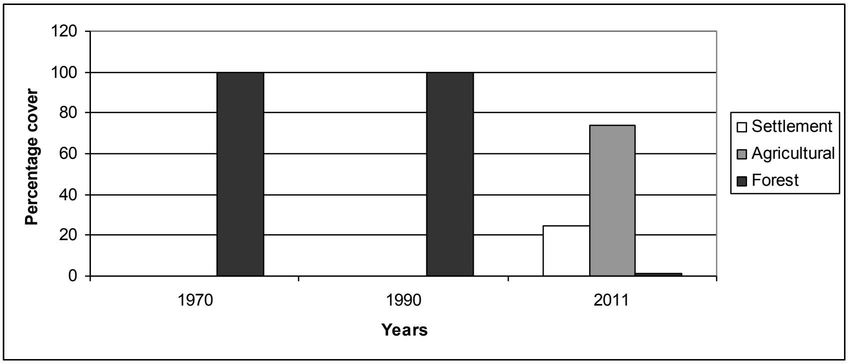

Figure 7 Land use and land cover changes of Maisha masha village

In Shauri moyo village, agricultural land is the main land use covering about 69.38% of the village. Settlement covered about 21.96%, while natural forest covers the remaining 8.66%. There is significant reduction in forest cover (P = 0.003) and significant expansion in agricultural land (P = 0.001) for the period between 1970 - 2011 (Table 1). This is because of the extensive clearing of the forest for crop production by the immigrants due to availability of fertile land and suitable climate for agriculture. Settlement showed an increment from 1990 to 2011 due to forest encroachment by people from other parts of Kenya (Okello et al. 2012), although it was not significant as shown in Figure 8.

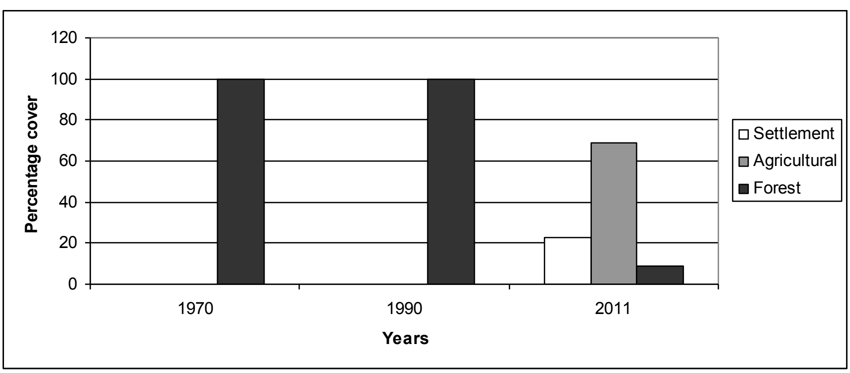

Figure 8 Land use and land cover changes of Shauri moyo village

In Mpeketoni B village, agricultural land is the main land use covering about 56.73% of the village. Natural forest covers about 39.34%, while settlement area covers the remaining 3.93%. Forest cover decreased by 1.29 and 21.57%, agricultural land increased by 0.7 and 20.14% and settlement area increased by 14.29 and 50% of the original area for the period between 1970-1990 and 1990-2011 respectively as shown in Table 1. The overall changes in the reduction of forest cover, expansion of agricultural land and settlement were not significant as shown in Figure 9. This is because there are very few immigrants settling in this village due to insecurity and the forest is managed by the community which is more effective than the other forest management regimes.

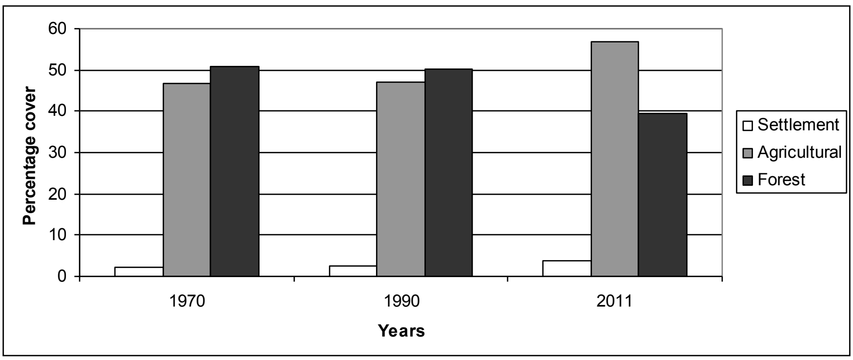

Figure 9 Land use and land cover changes of Mpeketoni B village

Participatory GIS community forums

Participants in community forums noted the following changes from the PGIS maps: (i) reduction of forest cover over time (ii) expansion of settlement (iii) reduction of river flow volume (iv) drying of water bodies (swamps) and (v) expansion of cultivated land. Accordingly, benefits associated with the reduction in forest cover and expansion of both agricultural and settlement area are summarised in Table 2. Increased food production was the major benefit because the aim of the immigrants was to clear the forest and expand agricultural land for crop production and settlement as a way to claim property rights.

Table 2 Summary of frequency of benefits by villages

Benefits	Maisha masha	Mpeketoni B	Shauri moyo	Baomo
Increased food production	✔	✔	✔	✔
Availability of settlement area	✔	✔	✔	
Increased income from the cultivated crops	✔		✔	
Reduction of destruction caused by wildlife	✔		✔	✔
Establishment of primary schools in the area	✔		✔	✔
Improved security and bargaining power		✔	✔	✔
Intermarriage between different tribes			✔	
Establishment of roads	✔			✔
Reduction of mosquitoes and diseases in the area	✔			✔
Increased pasture land		✔		
Availability of constructed wooden materials		✔		✔
Residents have the opportunity to see wild animals		✔		
Hospitals have been built				✔
Increased knowledge on farming practices				✔
More land left for cultivation as the river dries up				✔

However, the participants noted undesirable effects as a result of reduction in forest cover and expansion of agricultural and settlement area (Table 3). The major effects include low and erratic rainfall, high temperatures and reduction in water availability and river flows. This meant that the communities are aware of the possible side effects of forest destruction because forests play big role in hydrological cycle and cooling of the environment.

Table 3 Frequency of undesirable effects by villages

Benefits	Maisha masha	Mpeketoni B	Shauri moyo	Baomo
Low rainfall and high temperatures	✔	✔	✔	✔
Reduction in fish production	✔	✔		
Reduction in honey production	✔			
Invasion by Somalis in search of pasture and water	✔			
Increased of soil-borne pests	✔			
Increased human-wildlife conflicts		✔	✔	✔
Increased wind and water erosion			✔	✔
Lack of near market for their agricultural commodities			✔	✔
Insufficient schools and poor infrastructure			✔	
Lack of good hospitals and medicinal trees	✔		✔	
Lack of enough agricultural extension officers			✔	
Lack of construction materials and firewood	✔	✔	✔	
Increased theft due to high unemployment rate	✔			
Flooding of saline water in the agricultural land		✔		
Spreading of STDs		✔		
Low levels of education due to low income	✔	✔	✔	
Lack of title deeds	✔	✔	✔	
Reduction of trees used for construction of canoes				✔
Reduction of water lilies which are used as food				✔
Devastating crop damage by floods				✔
More crocodile attacks due to reduced river flows				✔
Livestock and wildlife deaths due to drought				✔
Reduction in water availability and river flows	✔	✔	✔	✔

Communities showed good understanding of their land resources and recommended provision of public facilities. This was consistent to the work of iMAP Africa (2009) who used PGIS to carry out study on urban planning in Kibera slums, Nairobi. Also, it was in line with the work of ERMIS Africa (2007) who used PGIS to map resources rights of communities threatened with extinction in Kenya. The study promoted cohesion among the threatened communities and improved natural resources management as it was with the current study.

Findings of this work were similar to the work done by VACID-Africa (2010) who used PGIS to map the natural resources that were found within mukau tree growing areas. The study intended to promote natural resource management in the area as it was in this current study. The outcome of the study was a map showing the various natural resources that exist in the area as it is the case with the current study where mental maps showing LTRF complex land resources between 1970 - 2011 were produced and discussed.

Conclusion and Recommendations

From the participatory GIS work, agriculture was seen to be the main land use in the area, followed by natural forest and the least was settlement area. Forest cover decreased and agricultural land increased significantly ($P<0.05$) for the period between 1970 and 2011 in two of the four studied villages. Settlement areas showed an increment between 1970 and 2011 although the change was not significant. The reduction of forest cover can be attributed to pressure from human activities such as illegal logging, cultivation, charcoal burning, overgrazing, and encroachment by people from other parts of Kenya in over the last 10 years.

Based on the interpretation of the mental maps by the community participants, forest cover reduced, some water bodies dried up and agricultural and settlement area expanded. These land cover and land use changes were associated with a number of benefits and also with some undesirable effects as a result of reduction in forest cover and expansion of agricultural and settlement area. Increased food production was the major benefit in the study area while, low and erratic rainfall, high temperatures and reduction in water availability and river flows, were the major undesirable effects as a result of reduction in forest cover and expansion of agricultural and settlement area in the study area.

The communities in the LTRF complex were convinced on the importance of conserving the Lower Tana River Forest complex and suggested recommendations towards minimizing the undesirable effects as a result of reduction in forest cover and expansion of agricultural and settlement areas. These recommendations included; (i) agro forestry, use of organic manure, crop rotation, afforestation programmes and stop clearing the forest to avoid nutrients depletion (ii) construction of dams and digging of more boreholes for irrigation (iii) establishment of near markets for agricultural products and improved infrastructure (iv) establishment of more government schools and health clinics and supply of electricity (v) fencing of the forest with electric fence and constructing watering points for the wild animals (vi) establishment of industries for value additions, carvings, basket making, fishing as alternative sources of livelihood. (vii) issuance of title deeds (viii) training on the best agricultural practices and human disease prevention measures (ix) employment of the locals to take care of the forest (x) enforcement of forestry act to ensure everyone plants trees (xi) compensation in case the crop damages by wild animals (xii) establishment of community sanctuaries to enable community earn income through tourism (xiii) use of appropriate alternative sources of energy other than charcoal (xiv) use of wind power as an alternative source of energy to generate electricity to replace hydropower and provide more water for agriculture and (xv) establishment of County Conservation Board for the community awareness and conservation of the forest resources. Performance of PGIS approach was considered satisfactory in mapping of land resources meaning that the communities were able to understand well their land resources in different times. Therefore, PGIS can be used in community land resources mapping thus empowering the community and convincing them on the importance of conserving them. There is need to follow on the progress of the recommended activities in the study area.

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Chapter 3

Participatory Geographic Information Systems (PGIS) for Sustainable Natural Resource Management: The Case Study of Taita Taveta County, Southern Kenya

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Abstract

Taita Taveta County is located in one of the important landscapes which act as wildlife dispersal areas. The County however, has a high population growth rate of 2.92%, which among other factors exposes the landscape to unsustainable natural resource exploitation. The management of natural resources requires the participation of local communities. This requires local communities to identify and understand resource use changes and peoples' role in the process, so as to facilitate uptake of appropriate land resource management strategies. Approaches aimed at changing local community behaviour towards natural resource use require appropriate technologies that bridge the technology and knowledge gaps between policy makers and local communities. Participatory Geographic Information System (PGIS) is an appropriate technology for analyzing land use and land cover changes and for educating local communities on the implications of land resource changes. PGIS is thus a suitable tool for evaluating and monitoring resources and for land use planning in a multi-stakeholder participant process in the management of natural resources. PGIS was used to assess and educate local communities on land use and land cover changes and to also visualize the problems associated with resource changes in Taita Taveta County. Agricultural expansion was found to be the main driving factor for land use change. Significant changes ($p < 0.05$) were observed in rain-fed and irrigated agricultural areas. Local communities were found to be knowledgeable about changes on resources and their causes. The PGIS maps developed and

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strategies proposed are an important input to decision making in appropriate land use planning and natural resource management.

Key words: PGIS, natural resource management, land use, land cover, Taita Taveta County

Introduction

The need for new approaches, information and analytical tools to integrate the multiple interests and viewpoints of stakeholders in official decision making has become an issue of concern as managers find it becoming increasingly complex. This situation has been occasioned by the lack of consensus on resource policy decisions (Walker 2002). As observed by Purnomo et al. (2004), partnerships between statutory and customary 'owners' of the resources are critical for achieving peaceful and effective resource management within communities. This has necessitated a revitalization of public participation in resource management within institutions.

The participation of local communities in natural resource management has been found to be key in effective governance of natural resources. Resource managers and local communities need to analyze resource use changes and their associated foreseeable challenges together so as to facilitate strategy setting, uptake and implementation. It has become apparent that local communities who are the custodians of natural resources within their jurisdiction play a central role in this process (Aynekulu et al. 2006).

The analysis of natural resource use changes as a means of detecting the causal factors has in most cases been done using conventional geographic information systems (GIS) and remote sensing (RS). However, this has had the challenge that the products are understood mainly by experts and policy makers but not by local communities due to technological gaps. Researchers and natural resource managers have therefore realized that this does not offer communities the opportunity to contribute to strategy setting and policy review processes. Further it does not positively influence local community's attitudes towards resource conservation. In some cases, this has been observed to lead to reluctance by local communities to implement such strategies and not to participate in all steps required in the development process (Aynekulu et al. 2006). Therefore it has become apparent that systems that are adaptable to inputs from ordinary citizens and other non-official sources are critical for holistic approaches to development while employing the ecosystem approach in natural resource management (Kyem and Saku 2009). Such systems strengthen the capacity of local knowledge in the multi-participant planning process by increasing community access to information and resources (Elwood 2002; Laituri 2002). The systems also incorporate local knowledge into national land reforms (Harris and Weiner 2002) and enable a broader and more effective participation of marginalized groups in the decision making process (Smith and Craglia 2003). Participatory approaches have also been useful in mapping areas for conservation (Bojorquez-Tapia et al. 2003; Brown et al. 2004; Kathumo and Gachene 2012).

Vernooy et al. (2000) observed that mental maps graphically represent the community's perception on how they view and use their environment. Participatory resource mapping was found to make access to information and transparency in local governance a reality. In addition, the process of making the maps and the questions raised and features chosen to be included on the maps provide information on community use, ownership and access to the resources. As observed by Nabwire and Nyabenge (2006) and Kathumo and Gachene (2012), through participatory mapping, spatial inventories of natural resources, land use rights and perceived problems can be created for more equitable and sustainable natural resource management. Hoare (2011) demonstrated that one of the most important activities for managing human-elephant conflicts is to bring stakeholders in a forum that can share information, build collaboration and advocate for new policies.

Taita Taveta County is classified as an Arid and Semi-Arid Land (ASAL) with an ecological potential for millet *(Pennisetum americanum)*, cotton *(Gossypium spp),* livestock and sisal *(Agave sisalana)* production as well as ranching. The larger part of the county is characterized by poor soils of low agricultural potential (Jaetzold and Schmidt 2005). Being on the foothills of Mt. Kilimnjaro, a small part of the county has water springs that are used for purposes of irrigation. However, this district lies adjacent to Tsavo West national park and has experienced persistent rise in the number of reported human-wildlife conflicts (HWC) for natural resources over time (Figure 1).

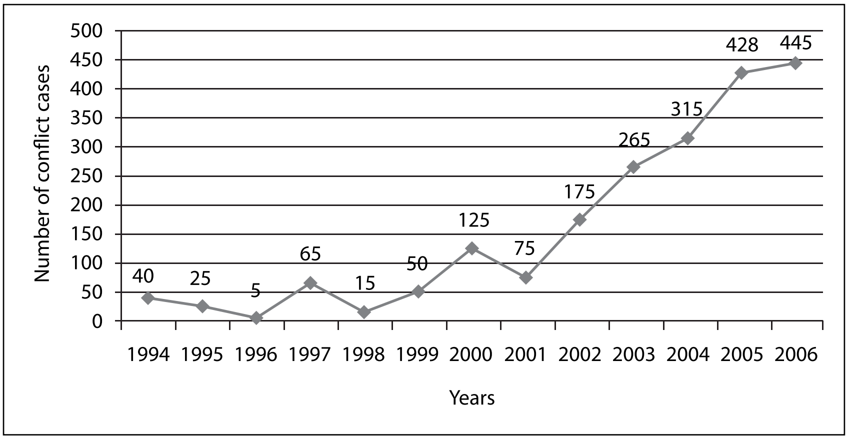

Figure 1 Trends of reported number of human-wildlife conflicts in Taita Taveta County between 1994 and 2006 (Source: Kenya Wildlife Service (2012))

Taita Taveta County is among the top six HWC hot-spots in Kenya (KWS 2012), a situation that undermines appropriate natural resource management in the county. The population growth rate is high standing at 2.92 % p.a (Government of Kenya 2009). This coupled with low rainfall exposes the county to a number of environmental challenges such as soil erosion, resource competition between people and wildlife, land fragmentation, poor crop production and land degradation (Government of Kenya 2011). In addition are social challenges of low income, unemployment and uncertainty in land ownership since part of the population are squatters. Food security in the county has been described as precarious and deteriorating in the mixed farming (rain-fed crops and livestock) zone which forms more than 75% of the county (Government of Kenya 2011). Ways are therefore needed to address these challenges so as to enhance land resource sustainability and conservation while contributing to increased food security and mitigation of HWC in the county. The purpose of this study was therefore to; analyze changes in land resources with local communities using PGIS; identify sustainable land use and management strategies for enhanced natural resource conservation; and to identify policy options for sustainable community management of land resources that can lead to reduced land degradation and human-wildlife conflicts.

Methodology

Study area

The County covers an area of 645.4 km^2 and is located between longitudes 37^0 25'E and 38^0 17'E, latitudes 3^0 15'S and 3^0 62 S (Figure 2). Almost 75% of the county is covered by agro ecological zones LM4 and LM5, areas that are suitable for cotton, sisal and millet and livestock production (Jaetzold and Schmidt 2005).

Figure 2 Location of Taita Taveta County in Kenya

Participatory GIS for community land resource mapping

Mental maps for the years 1970, 1990 and 2012 were drawn for Kitobo and Mboghoni villages in Taita Taveta County. A twenty-year interval was purposively chosen in order to cater for temporal sensitivity in land resource changes by local communities. Twenty participants from every village were selected. These were separated into two equal groups consisting of mixed gender and age. Each group of twenty was composed of five old men (above 50 years), five old women (above 50 years), five young women (18 to 35 years) and five young men (18 to 35 years). The young men and women were useful in drawing the mental maps in addition to contributing information about resource changes for the past twenty years. The participants listed and drew on manila papers land resource mental maps showing some of the land resources within each of the village for the years 1970, 1990 and 2012. The land resources included; forests, shrub lands, irrigated and rain-fed agricultural lands, sisal plantations and water bodies. Participants selected the most representative three mental maps for the years 1970, 1990 and 2012. The mental maps were used to assess land use and land cover changes as perceived by the local communities. Using a digital camera, photographs of these maps were then taken. These selected maps were used for discussions during the open forum sessions. Features that acted as boundaries and were also found within the maps drawn were mapped using Global Positioning System (GPS). These features were used for geo-referencing of the mental maps in order to analyze natural resource changes as perceived by the local community.

Participatory GIS community forums

Community forums of thirty participants per village were carried out in the two villages after the mapping exercises to discuss trends in land use and land cover changes as observed from the mental maps. Participants noted the changes of the major land resources mapped out. The undesirable effects of these land resource changes were discussed and recommendations towards sustainable land resource and human-wildlife conflicts management proposed.

Land use and land cover changes from the PGIS maps

The ground-truthing data of the geo-referenced features were used to geo-reference the year 2012 mental maps. The control points were typed in excel file and saved as delimited text. These were converted into shape files using ArcView GIS 3.2. The downloaded photographs of the mental maps were exported to Arc GIS 9.3 software for geo-referencing using the control points. The geo-referenced mental maps for the year 2012 were used to geo-reference the year 1970 and 1990 mental maps. The geo-referenced mental maps (1970, 1990 and 2012) were exported to ArcView-GIS 3.2 software. Using on-screen digitizing, areas under the different land uses and land cover were calculated. Land use and land cover change analysis of the PGIS maps for the periods between 1970-1990 and 1990 - 2012 were then computed using Excel software.

Local community perceptions on human-wildlife conflict dynamics

Information on the evolution of human-wildlife conflicts between 1970 and 2012 was gathered during the PGIS forums and amplified with data collected from the two locations using questionnaires to increase the scope of the sample size. In Kitobo location, questionnaires were administered along transects radiating from Kitobo Forest as the centre of wildlife concentration, while in Mboghoni location transects cut across the location. Four transects were covered in each location and one hundred households interviewed per location. The resultant information was discussed in relation to resource use changes as envisaged in the mental maps for the various time periods. This was intended to facilitate local communities discern their contribution to challenges associated with their own activities on natural resource degradation and therefore empower them to participate in proposing and setting up management strategies.

Data Analysis

Land use and land cover change analysis

The area of land under different land uses and land cover was used to calculate percentage changes in land use and land cover using Excel software. Overall land use and land cover change statistics were calculated. Chi-square goodness of fit was used to determine if there were significant changes in land use and land cover (Zar 1996). The questionnaires were analyzed using Statistical Package for Social Scientists (SPSS).

Results and Discussion

Trends in land use and land cover changes

Through PGIS, local communities from Kitobo and Mboghoni villages were able to demonstrate their knowledge on resource use and changes over forty-two years as shown in Figures 3 and 4 respectively. In Kitobo village, five land use and land cover types were described as shrub lands, rain-fed agriculture, irrigated agriculture, settlements and forest over the three time periods. The area covered by each of the land use/land cover types varied over the time period investigated.

As the area under rain-fed agriculture drastically increased between 1970 and 1990s, irrigated agriculture decreased giving an indication of the synchronised nature of these two land uses. Similar dynamics of the same land uses were observed between 1990s and 2012. Rain-fed agriculture is less labour intensive compared to irrigated agriculture hence the synchronised descrease in settlements and irrigated agriculture as rain-fed agriculture increased between 1970s and 1990s. Minimal changes were observed over areas under shrub lands and settlements over the three time periods. There was a major decrease in forest cover between 2001 and 2012, a time period during which irrigated agriculture showed major increase. Local community identified human population increase and commercialization of agriculture as the driving forces behind the land use and land cover changes. It was evident that through PGIS, local community in Kitobo were able to visualise how land use and land cover changed over time in addition to redistribution of human settlements in this village. Notably is the in-migration of people into this village by 2012 to tap in the irrigation potential around Kitobo Forest.

Seven land use and land cover types were described in Mboghoni village as; rain-fed agriculture, irrigated agriculture, settlements, sisal plantations, shrub lands, forests and water bodies. The area under each of these land uses and land cover was also depicted to have changed over the three time periods. Forest cover and shrub lands were the most extensive land cover type in Mboghoni village respectively while the most extensive land use type was irrigated agriculture. This shows the applicability of PGIS technology in land resource use change analysis by local communities.

Figure 3 Kitobo village PGIS maps for the years 1970, 1990 and 2012 respectively

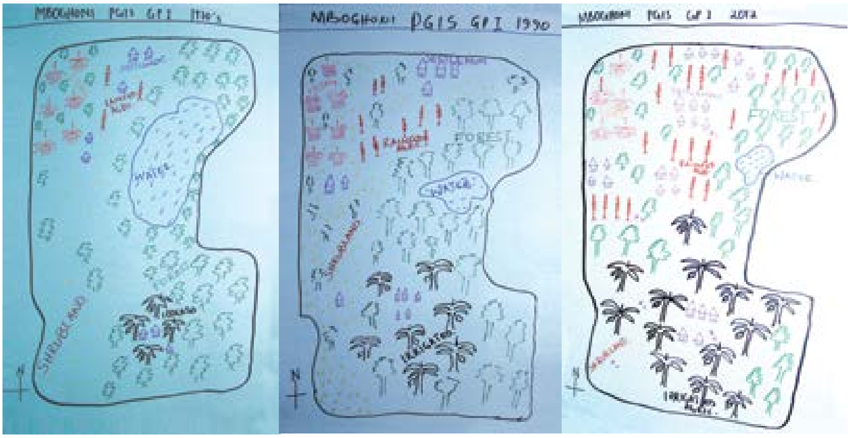

Figure 4 Mboghoni village PGIS maps for the years 1970, 1990 and 2012 respectively

The highest percentage change in land use and land cover in Kitobo location over the study period was manifested in rain-fed agriculture followed by irrigation agriculture (Table 1, Figure 5). This was an indication of the local community's desire to increase food security and commercialization of agriculture as they tapped into the irrigation around the forest which is a source of two permanent rivers. Major changes in percentage cover were observed in irrigated agriculture between 1990s and 2012.

Table 1 Percentage changes in land use and land cover in Kitobo village between 1970 –2012

Land use /land cover	1970-1990	1990-2012	1970-2012
Rain-fed agriculture	+1614.65	-53.49	+697.45
Irrigated agriculture	-75.82	+894.75	+140.53
Shrub land	-35.53	+63.45	+5.37
Settlement	- 48.03	+141.57	+25.55
Forest	-7.2	-56.15	-59.31

NB: +ve sign denotes an increase while -ve sign denotes a decrease

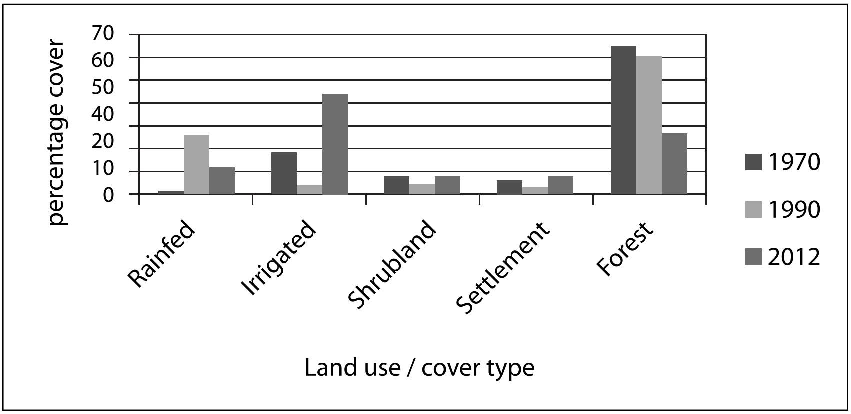

Figure 5 Percentage cover of land use and land cover in Kitobo village between 1970 – 2012

In Mboghoni, the decrease of shrub-lands and water bodies occurred throughout the time period as settlements and agriculture increased (Table 2, Figure 6). This was associated with water abstraction for irrigation purposes, as irrigated agriculture showed the highest rate of increase. This increase was associated with the decrease in shrub lands as areas under sisal plantations and forests remained stable over the three time periods.

Table 2 Percentage changes in land use and land cover in Mboghoni village between 1970 – 2012

Land use / land cover	1970-1990	1990-2012	1970-2012
Water bodies	-78.9	-29.80	-85.19
Rain-fed agriculture	+184.05	+144.10	+593.24
Shrub land	+352.8	+45.10	+557.14
Sisal plantations	-3.89	-17.20	-20.45
Shrubland	-32.41	-60.30	-73.19
Settlement	+62.55	+128.30	+271.16
Forest	+2.99	-22.90	-20.61

NB: -+ve denotes an increase while -ve sign denotes a decrease

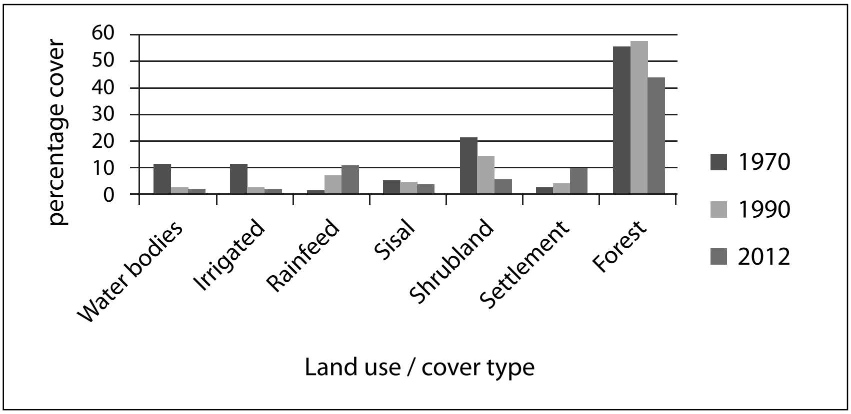

Figure 6 Percentage cover of land use and land cover in Mboghoni village between 1970 -2012

In Kitobo village significant changes in land use were observed in rain-fed agriculture (χ^2 = 7.000, df = 2, p = 0.030) and irrigated agriculture (χ^2 =11.565, df = 2, p = 0.003). Likewise significant changes in land cover were observed in forests (χ^2 = 6.04, df = 2, p = 0.049). The expansion of irrigated agriculture emerged as the only significant change in Mboghoni village (χ^2 =7.000, df = 2, p = 0.030).

Local community perceptions on human-wildlife conflict dynamics

In both locations, challenges of food security were enhanced by an increase in rodent and pest attacks, persisted crop destruction, livestock depredation in addition to post harvest losses (Figure 7). While crop destruction increased over the years in Mboghoni, it persisted in Kitobo with more than 50% of the households affected. In Kitobo, post harvest losses increased while livestock depredation persisted. The destruction of wildlife habitats for agricultural expansion creates conducive environments for the proliferation of rodent pests while destroying the ability of natural habitats to biologically control pests and diseases. In addition, it destroys wildlife habitats, setting the stage for increased competition for space and resources required by people and wildlife. This is worsened by the inability of most farmers in rural setting to afford modern methods of pest control, thus leaving them vulnerable to crop losses. Through PGIS, communities were clear on the fact that the expansion of agriculture was a driving factor leading to land resource use competition between people and wildlife. In similar studies within the Amboseli area of Kenya, Okello (2005) observed that, cultivation was considered to be more beneficial than either pastoralism or conservation, and set the scenarios for escalation of human-wildlife conflicts. Likewise Cheeseman (2001) and Okello and Kioko (2010) observed that, agricultural expansion within landscapes adjacent to protected areas destroys valuable wildlife habitats, including those preferred by wildlife and livestock during the dry season e.g., swamps, forests and riverbanks. The rate of agricultural expansion in Taita Taveta County points to the same notion; that agriculture is a more preferred land use option in the district.

Through PGIS mental mapping and community forums, local communities expressed their specific challenges as influenced by land resource use changes. The changes in land use and land cover were associated with conflicts over land and water, increased crop attacks, temperatures and environmental degradation, as well as biodiversity loss by local communities in both locations. In addition, increased insecurity due to immigrants, loss of grazing land and flooding were challenges experienced specifically in Kitobo location. Decreases in rainfall and water levels were additionally observed in Mboghoni location. PGIS in this case gave communities an opportunity to identify their own specific challenges. Such information can be used to inform natural resource managers in terms of selecting and prioritizing relevant specific strategies for specific areas and guide resource allocation.

Equipped with this knowledge, communities proposed a variety of strategies to enhance sustainable land and natural resource management (Table 3). These strategies were holistic in approach and categorized into; those aimed at preventing wildlife attacks, strategies for sustainable resource use, those addressing local community and wildlife managers' challenges and finally those addressing policy makers.

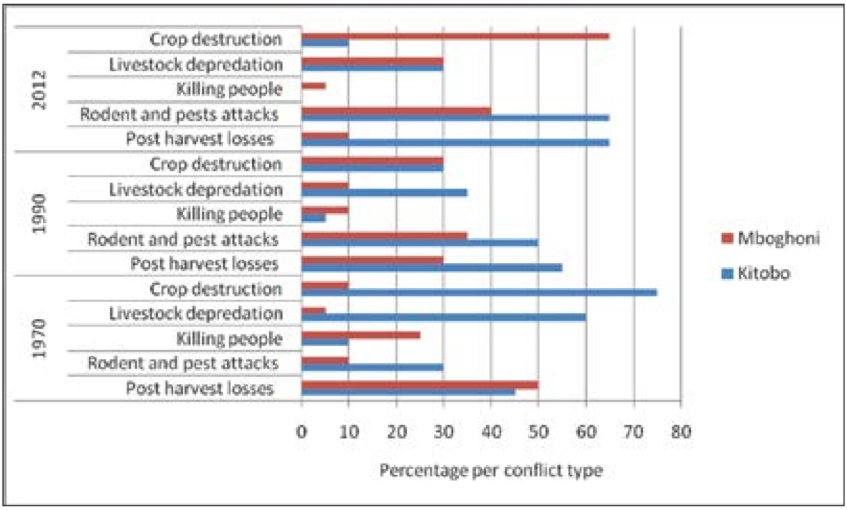

Figure 7 Local community perceptions on the dynamics of human-wildlife conflicts in Kitobo and Mboghoni locations of Taita Taveta County, Kenya

Table 3 Strategies proposed to increase resource use sustainability and reduce wildlife attacks

Strategies	Proposers	
	Kitobo	Mboghoni
Preventing Wildlife Attacks		
Fencing homesteads, farms and protected areas	✔	✔
Improvement of communication network	✔	✔
Use of scare crows	✔	✔
Proper storage of crops after harvest	✔	✔
Use of security lights to protect livestock	✔	
Sustainable Resource Use		
Eco-tourism to improve community livelihoods	✔	✔
Agricultural intensification e.g., using green houses	✔	✔
Agro-forestry to reduce demand for wood fuel, medicinal plants, and building materials	✔	✔
Water harvesting on farms and homesteads	✔	✔
Creating essential buffer zones through changes in cropping systems	✔	
Planting crops that are less edible to wildlife e.g., coconuts		✔
Reduced charcoal burning		✔
Controlling water logging in Kitobo forest	✔	

Efficient agricultural technologies		✓
Appropriate technologies to reduce demand for energy from wood		✓
Re-afforestation		✓
Use of efficient water use technologies		✓
Local Community		
Respect for wildlife laws/policies	✓	
Increase awareness about wildlife	✓	✓
Attitude change towards wildlife	✓	✓
Involving youths in wildlife conservation		✓
Community policing		✓
Establishment of community farms		✓
Wildlife Managers		
Improved dialogue between Kenya Wildlife Service (KWS) and local communities	✓	✓
Increase the amount of compensation due to wildlife damage	✓	✓
Protecting existing wildlife conservation areas /habitats e.g., Kitobo forests	✓	
Improving the quality of wildlife habitats	✓	✓
Improving water supply to wildlife in Tsavo West National Park		✓
Streamlining compensation protocols	✓	✓
Attitude change by KWS personnel towards local community claims		✓
Increase KWS personnel in Taveta district	✓	✓
Improve transport for KWS personnel in Taveta district		✓
Reshuffle KWS personnel after every two years in Taveta district		✓
Policy Makers		
Government to purchase land from Basil Criticos for the local community and issue title deeds	✓	
Clear land demarcation	✓	
Inter-sectoral coordination in natural resources management	✓	✓
Include compensation for crop damage	✓	✓
Crop damage to be assessed by ministry of agriculture		✓
Introduce small and medium enterprises (SMEs) to reduce over-reliance on crop production		✓

The above proposals point to an ecosystem approach in the management of natural resources in this County. PGIS provided a suitable approach for land resource use change analysis, strategy setting, planning and identification of compatible land use options that can lead to mitigation of human-wildlife conflicts. This strengthens the value of what natural resource managers have in the last few years called to action, i.e. bottom-up approach and community engagement in natural resource conservation. Due to the impacts of wildlife on local communities, most of them (72.3%) had a negative attitude towards wildlife. Twenty two percent of the population interviewed had a very negative attitude while only 0.3% had a positive attitude towards wildlife. The remaining 5.3% were neither negative nor positive. Therefore the impacts wildlife has on local communities influences conservation efforts. This calls for involvement of local communities to participate in natural resource conservation.

Conclusion and Recommendations

This study has established that PGIS promoted community understanding of the implications of resource use changes thus facilitating their participation in strategy setting and ownership of their contribution to environmental degradation. PGIS can be used for enhancing community awareness on the implications of the changing scenarios of land use and land cover and hence facilitates planning. Such knowledge increases local community capacity to participate in implementing strategies proposed. For approaches to win support from local communities there is need for a community participation in the proposal and planning of the strategies.

PGIS can be used to advocate for sustainable use of land resources and convince local communities to participate and uptake strategies implemented. It offers communities the opportunity to learn about resource use change, participate in their conservation and own problems irrespective of their age and level of education. PGIS has the potential to enhance transparency, empowerment, dialogue and negotiation from existing positions thus improving stakeholders' possibility of formulating sustainable natural resource management strategies in a multi-stakeholder, multi-participant process. It can have profound implications and stimulate innovation and social change in this county.

To increase crop production within this county, agricultural intensification through use of fertilizers, certified seeds and green houses, as well as training on soil and water management in areas already cleared for cultivation will be necessary to reduce further agricultural expansion and environmental degradation. There is need to address local community challenges associated with resource exploitation in this county. This calls for synergies between the relevant stakeholders in natural resource management (Ministry of Agriculture, Livestock and Fisheries, Kenya Forest Service; Ministry of Environment; Water and Natural Resources; Kenya Wildlife Service; National Environment Management Authority; Ministry of Energy and Petroleum; Ministry of Commerce and Tourism, among others), Ministry of Transport and Infrastructure, Ministry of Health, Research Institutions and local communities to effectively address the identified challenges. Such approaches will immensely benefit from PGIS technologies at the various levels of involvement.

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Chapter 4

A Multi-Stakeholder Decision Support Tool for Optimizing Sustainable Land Management Technologies: A Case Study of the Upper Tana Catchment, Kenya

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Abstract

Decision Support Tools have become increasingly important in site specific conservation practices aimed at achieving specific environmental outcomes that maximize environmental benefits. This paper presents a computer based Decision Support Tool (DST) for selecting Sustainable Land Management (SLM) technologies in the Upper Tana catchment in Kenya. It was developed using Microsoft Access VBA software. In this tool, the type of SLM technology chosen follows a specified hierarchy. The decision of the appropriate SLM technologies depends on a number of factors which the user must know in order to arrive at an appropriate decision. The tool was designed to assist farmers and watershed managers in decision making on appropriate SLM technologies suitable for enhancing ecosystem services and climate change adaptation. It has built-in technical operation manual and a database with a set of SLM technologies that have been evaluated and analyzed for their effectiveness using World Overview of Conservation Approaches and Technologies (WOCAT) framework. Every SLM technology in the set has been documented and presented using a standardized WOCAT global template. The Upper Tana catchment provides a typical example of other basins in Kenya characterized by diverse conflicting land uses which do not promote sustainable land management. Therefore, this paper presents a logical set of questions that farmers might ask in order to arrive at an appropriate sustainable land management decisions. The tool also creates a knowledge sharing platform for farmers on SLM technologies within the

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same Agro-ecological Zones (AEZs). Further the tool is useful in generating alternative decision scenarios for management of different soil types.

Key words: Decision support tool, Upper Tana catchment, WOCAT, Eco-system services, climate change adaptation

Introduction

The Upper Tana catchment is one of Kenya's most important natural resources base. However deforestation and expansion of cultivation onto marginal lands have resulted in significant siltation of rivers and reservoirs, reduced ecosystem function, and more erratic downstream water flow (Jacobs et al. 2007). 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 and Chemelil 2002). The reservoir which was designed for hydropower generation, public water supply and irrigation is losing its storage capacity due to severe siltation. The dam was designed with an expected siltation rate of 3 million t yr^{-1}, but by 1988, 8 years after operation began, the siltation rate had more than tripled to 10 million t yr^{-1} and the reservoir capacity reduced by 6% (Bobotti 1998). By the year 2000, annual sediment loading had increased to over 11.0 x 106 m^3, nearly four times more, reducing the design capacity by more than 15% (Mutua et al. 2005). At this rate, the lifespan of the dam will be drastically reduced (Saenyi and Chemelil 2002). Therefore, there is need to devise a strategy for soil and water conservation in the Upper Tana catchment in order to minimize the siltation rate. By so doing, the land users will not only reduce the rate of land degradation due to soil erosion but enhance ecosystem services within the catchment.

Soil and water management at catchment level requires integration of structural, vegetative and agronomic management measures. Topography, agro-climatic and socio-economic variation are some of the factors that determine what type of soil conservation measures a particular land area requires. This can only be possible if the land user knows the types of soils, water conservation practices and the suitability of the practices to particular geographical areas and water conservation problems. Successful SLM technologies are considered to be those that offer, for a given Land Use Type (LUT), an optimal solution for using the land for sustainable and productive agricultural purposes. They are not necessarily simple technologies. However, within the context of DST-MATSIM-Tool, the successful SLM technologies will be technologies which are not capital-intensive and which use local resources and the existing labour force in an optimal way. It should be emphasized that 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 indigenous technologies. If such technologies exist and continue to be applied by farmers, then, provided that 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. However, in the Upper Tana catchment area, getting to know the reasons why the land users apply such technologies, i.e. the production and conservation benefits they get from them, is key to successful introduction of any new technology, which must at least match and preferably improve on the benefits to be obtained from the existing ones.

Decision Support Tools (DST) for Sustainable Land Management at Catchment Level

One of the causes of the Upper Tana Catchment degradation is unsustainable exploitation of land and water resources and this has a potential for conflict among the land users. However, one of the methods of minimizing the exploitation is the use and application of sound approaches and knowledge based decision support tools. Many decision support tools (DST) are well suited to the particular problem for which they were originally designed, but generally have a fixed structure or a defined set of data processing and model connection paths, and therefore are rarely suitable to meet the needs of a new application (Argent et al. 2009).

Information technology can help a great deal in achieving sustainable land management by providing well-designed and useful tools for decision makers (Kersten et al. 2002). One element of SLM is establishing processes for improved and more straightforward adaptation of technological knowledge, increasing the testing of technologies by increasing farmers' knowledge on practical field erosion and sustainable land management (Mitiku et al. 2006). The process needs to address different issues such as unsustainable production systems, SLM options, economical and environmental impacts of land degradation.

Methodology

The DST-MATSIM TOOL for Sustainable Land Management (SLM) technologies in the Upper Tana catchment has been developed using Microsoft Access VBA software. The decision on appropriate SLM technologies to be used depends on a number of factors which the user must know in order to arrive at an appropriate decision. In this model, 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 agroforestry)
4) Soil characteristics (depth and drainage)
5) 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)

Agro-Climatic zones (ACZ) of the Upper Tana catchment

The Upper Tana catchment comprises of five distinct Agro-Climatic Zones, 1, 11, 111, 1V, V (Sombroek et al. 1982) (Table 1).

Table 1 Agro-Climatic Zones (Source: Sombroek et al. 1982)

ACZ	Climate	Land use
I	Humid	Tea and forestry
II	Sub-humid	Coffee, maize
III	Semi-humid	Coffee, maize, cotton
IV	Semi-humid to semi-arid	Maize, cotton
V	Semi-arid	Rangeland

Agro-Ecological Zones (AEZ) of the Upper Tana Catchment.

The Upper Tana catchment comprises of various Agro-Ecological Zones (AEZ) namely, UHO, LHO, LH1, UM1, UM2, UM3, and UM4 (Jaetzold and Schmidt, 1983).

Figure 1 show two overlays (ACZ and AEZ maps) of the upper Tana catchment (Embu County).

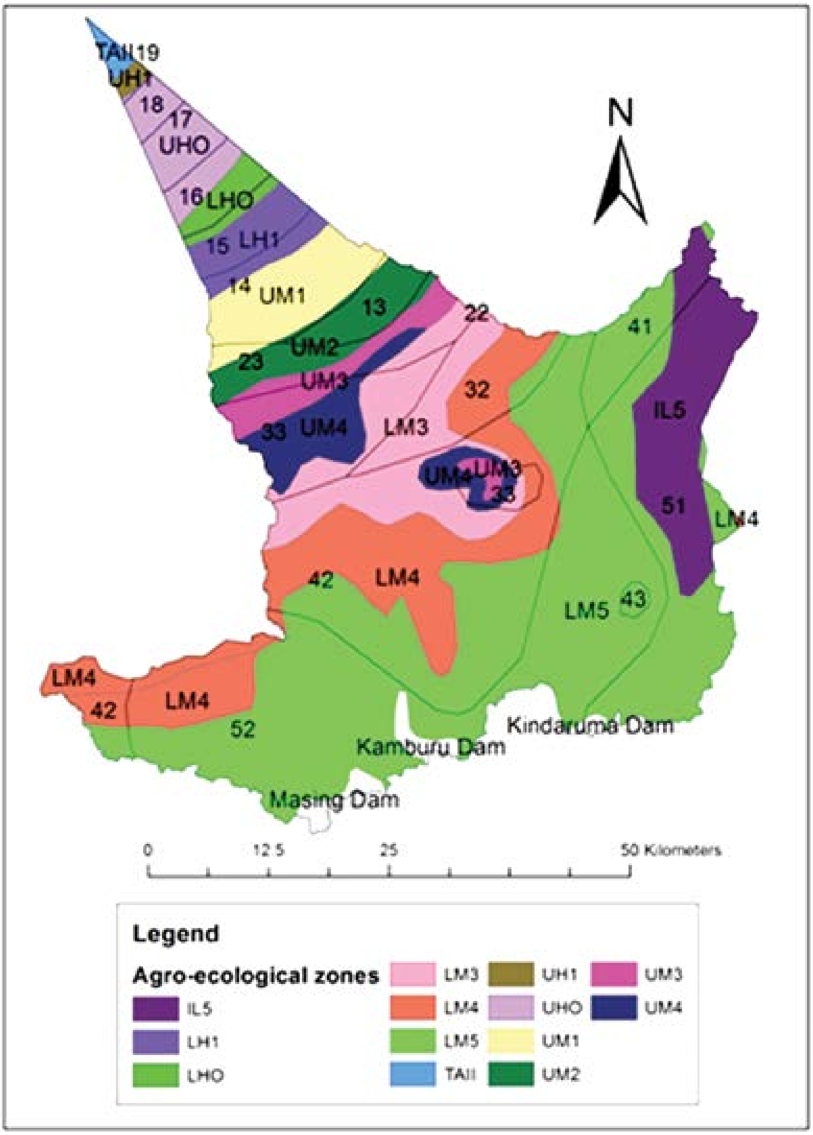

Figure 1 Agro-ecological and agro-climatic zones of Embu County

Land use type (LUT)

Sustainable land use management within the upper Tana will also depend on the intended land use type. MATSIM DST TOOL recognizes the following land use types that are predominant within the catchment:

- Natural forest: forests composed of indigenous trees, not planted by man
- Annual cropping: land under temporary / annual crops usually harvested within one, maximally within two years (e.g. maize, paddy rice, wheat, vegetables, fodder crop)
- 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 (e.g. sugar cane, banana, sisal, pineapple)
- 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)
- Grazing lands

Soil characteristics

The soils of upper AEZs are Nitisols among others. They are deep, well drained with moderate to high inherent fertility. The soil characteristics that are used by the MATSIM DST TOOL are; depth and drainage.

Slope/topography

DST-MATSIM Tool recognizes three classes of slopes namely;

- Gentle slope (0-5%)
- Medium slope (5-25%)
- Steep slope (>25%)

Ecosystem services and climate change adaptation of the SLM

The technologies have been evaluated according to their degree of resilience and vulnerability to climate change adaptation as outlined in the WOCAT framework and ecosystem services Production/ Socioeconomic, Socio-Cultural and Ecological Benefits (WOCAT 2003).

Gender

- Male
- Female
- Male/female

Tenure

- Secured / titled
- Unsecured

Data base of SLM-Technology

MATSIM DST TOOL uses the following soil conservation technologies:

- Structural measures
- Vegetative measures
- Agronomic measures
- Management measures

All these factors have been considered in building the architecture of the model. These are the important factors that will therefore be considered in decision making.

Description of the DST-MATSIM Tool

ACZ table

Purpose: Stores data concerning the ACZ's

Fields

i. CodeACZ – The primary key for the table
ii. ACZ – Holds the ACZ's

AEZ table

Purpose: Stores data concerning the AEZ's

Fields

i. CodeAEZ – The primary key for the table
ii. AEZ – Holds the AEZ's

iii. 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

Purpose: Stores data concerning the land use types

Fields

i. CodeLUT – The primary key for the table
ii. LUT – Holds the descriptions land use types

AEZ_LUT table

Purpose: A junction table linking AEZ's to Land Use that can be practiced in the AEZ

Fields

i. CodeAEZ – A foreign key referencing the primary key in the AEZ table
ii. CodeLUT – A foreign key referencing the primary key in the LUT table

LUT _SLM table

Purpose: A junction table linking SLM's to Land Use types associated with them

Fields

i. CodeLUT – A foreign key referencing the primary key in the LUT table
ii. CodeSLM – A foreign key referencing the primary key in the SLM table

SLM_CLASS table

Purpose: Stores data concerning the available SLM classes

Fields

i. CodeCLASS – The primary key for the table
ii. SLM_CLASS – Holds the name of the SLM class

SLM table

Purpose: Stores data concerning the sustainable land use management types

Fields

i. CodeSLM – The primary key for the table
ii. SLM – Holds the name of the Sustainable land use types
iii. Description – Holds a brief description of the SLM
iv. CodeCLASS – A foreign key referencing the SLM_CLASS table primary key. It links the SLMs to the SLM class they belong to

BENEFIT table

Purpose: Stores data concerning the available benefit classes

Fields

i. CodeBEN – The primary key for the table
ii. Benefit – Holds the description of the benefit class

BENTYPE table

Purpose: Stores data concerning the actual benefits

Fields

i. CodeBENTYPE– The primary key for the table
ii. BENEFIT – Holds the description of the benefit
iii. CodeBEN – a foreign key referencing the BENEFIT table primary key. It links the benefits to the benefit class they belong to

SLM_BENEFIT table

Purpose: A junction table linking SLM's to benefits that accrue from implementing the SLM's

i. CodeSLM – A foreign key referencing the primary key in the SLM table
ii. CodeBENTYPE – A foreign key referencing the primary key in the BENTYPE table

TOPO table

Purpose: Stores data concerning the topography

Fields

i. CodeTOPO – The primary key for the table
ii. Topography – Holds the description of the topography

SLM_TOPO table

Purpose: A junction table linking SLM's to topography that the SLM's can be implemented in

i. CodeTOPO – A foreign key referencing the primary key in the TOPO table
ii. CodeSLM – A foreign key referencing the primary key in the SLM table

CLIMATE table

Purpose: Stores data concerning the climatic extremes

Fields

i. CodeCLIM – The primary key for the table
ii. Climate – Holds the description of the climatic extremes

SLM_CLIM table

Purpose: A junction table linking SLM's to climatic extremes and stores the adaptability status of the SLM to the climatic extremes

i. CodeSLM – A foreign key referencing the primary key in the SLM table
ii. CodeCLIM – A foreign key referencing the primary key in the CLIMATE table
iii. Adaptability – Holds the adaptability status of the SLM to climatic extreme

CASE table

Purpose: 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

<u>*Fields*</u>

i. CaseCODE – A primary key for the table
ii. CASE_NAME – The name of the documented technology or the name of location the technology is documented in
iii. OBJECTIVE – Holds the adaptability status of the SLM to climatic extreme
iv. PHOTO_SLM_PATH – Holds the path to location of the SLM photograph on disk
v. TECHNICAL_DRAWING – Holds the path to the sketch of the SLM on disk
vi. CodeTOPO - A foreign key referencing the primary key in the TOPO table. Links the topography to the documented technology
vii. CodeAEZ - A foreign key referencing the primary key in the AEZ table. Links the AEZ to the documented technology
viii. CodeACZ - A foreign key referencing the primary key in the ACZ table . Links the ACZ to the documented technology
ix. CodeLUT - A foreign key referencing the primary key in the LUT table. Links the LUT to the documented technology
x. CodeSOIL - A foreign key referencing the primary key in the SOIL. Links the SOIL to the documented technology
xi. CodeCLIM - A foreign key referencing the primary key in the CLIMATE. Links the CLIMATE to the documented technology
xii. NOTES -
xiii. Wocatdoc_path – Holds the path to the document retrieved from the WOCAT global database
xiv. WocatREF – Holds the reference number for the documented technology in the WOCAT global reference database

<u>***SLM_CLIM table***</u>

Purpose: A junction table linking SLM's to a particular documented technology

i. CaseCODE – A foreign key referencing the primary key in the CASE table
ii. CodeSLM – A foreign key referencing the primary key in the SLM table

Form to add New ACZ

This form (Figure 2) is used to add new Agro climatic zones to the database as the need arise

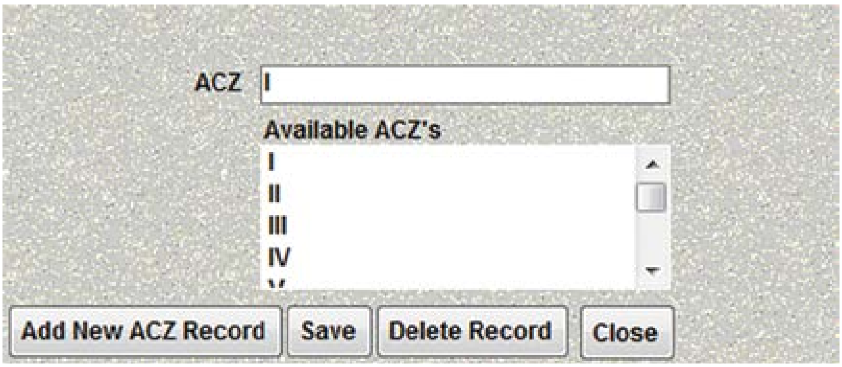

Figure 2 Form to add New ACZ

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 ACZ entry click on the 'Delete Record' button
5. To close the form, click the Close button

Form to add New AEZ

The form (Figure 3) is used to add new Agro-ecological zones entries as the need might arise.The form also enables one to view the AEZ's already within a particular ACZ

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 AEZ entry click on the 'Delete Record' button
6. To close the form, click the Close button

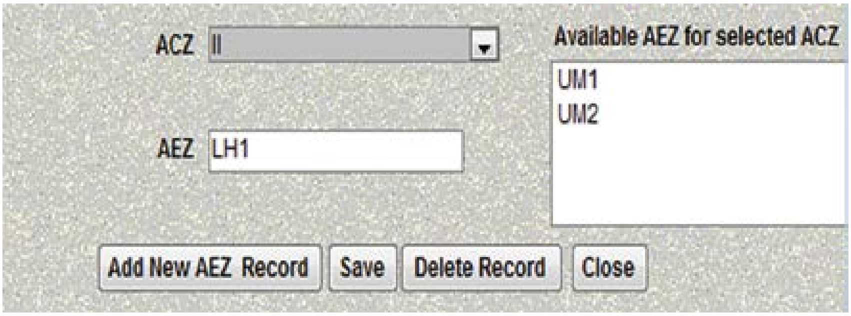

Figure 3 Form to add new AEZ

<u>*Form to Add Benefit Class to the database*</u>

This form is used to add new benefit classes to the database as need might arise

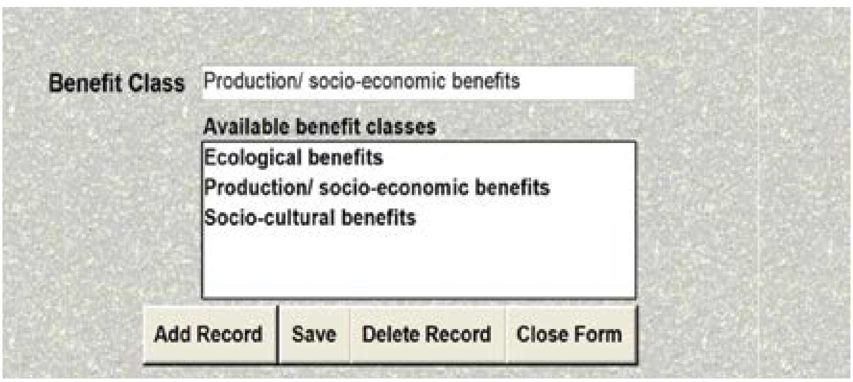

Figure 4 Form to add benefit class to the database

1. Click on the add 'Add Record' to add an empty record
2. Enter the benefit in the benefit 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

Form to add benefits the database

This form (Figure 5) is used to add new benefit data to the database as need might arise.

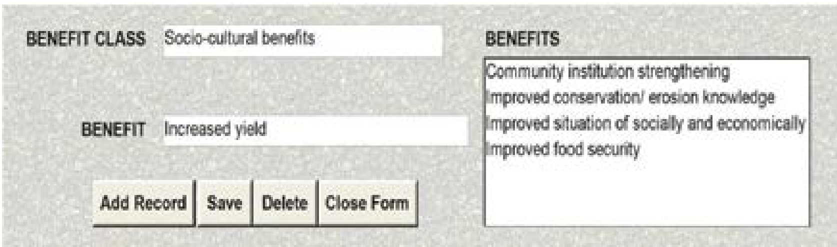

Figure 5 Form to add benefits the database

1. Select the benefit class that the benefit belongs to 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 'Add Record' 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

NB: 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 Land Use Type to the database.

This form (Figure 6) is used to add new Land Use Type (LUT) data to the database as need might arise.

Figure 6 Form to add Land Use Type to the database

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

Form to add Climate Extreme to the database

This form (Figure 7) is used to add new climate extreme data to the database as need might arise.

1. Click on the add 'Add Record' to add an empty record
2. Enter the climate in the 'climate' 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

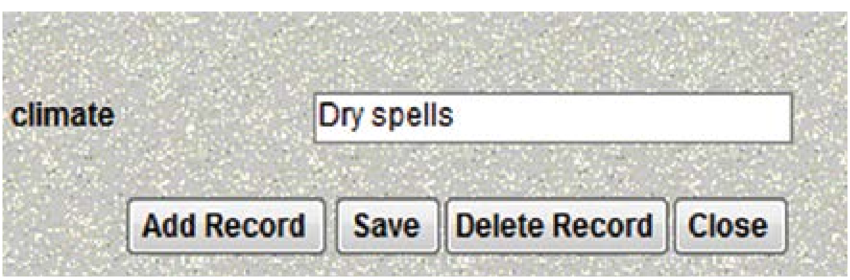

Figure 7 Form to add climate extreme to the database

Form to add topography to the database

This form (Figure 8) is used to add new topography data to the database as need might arise.

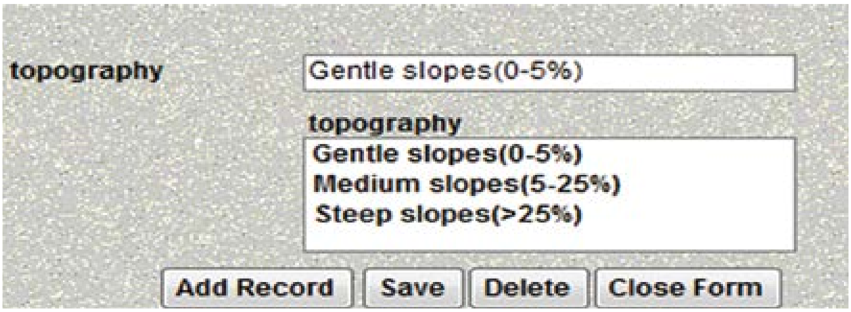

Figure 8 Form to add topography to the database

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

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

Form to add SLM technology to the database

This form (Figure 9) is used to add new SLM technology data to an existing SLM class in the database as need might arise.

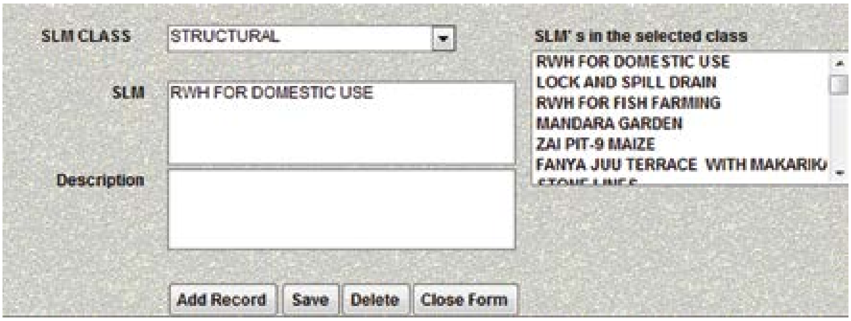

Figure 9 Form to add SLM technology to the database

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

Associating land use type with SLM

This (Figure 10) form is used to associate sustainable land use management technologies with appropriate land use types.

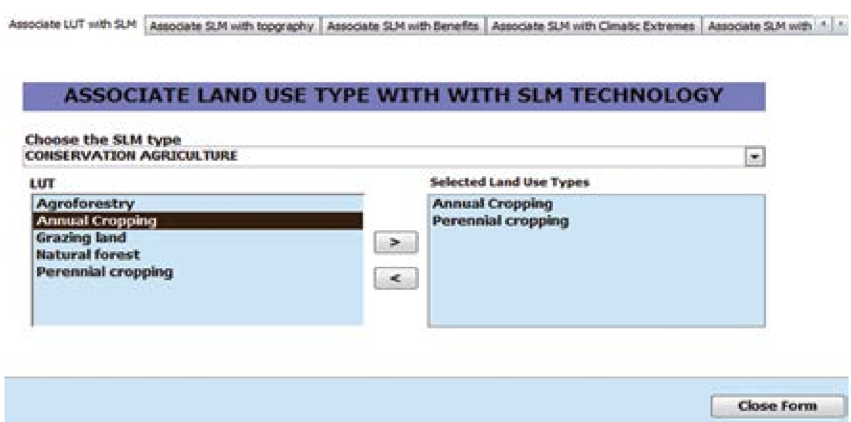

Figure 10 Associating land use type with SLM

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

Associating SLM with topography

This (Figure 11) form is used to associate SLM's with the topography that will adequately sustain SLM's appropriate land use types

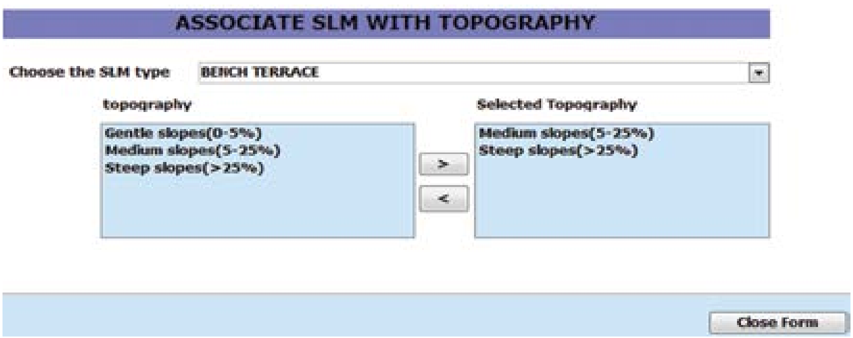

Figure 11 Associating SLM with topography

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

<u>*Associate the SLM with benefits*</u>

This (Figure 12) form is used to link the benefits that would accrue from implementing a particular SLM technology.

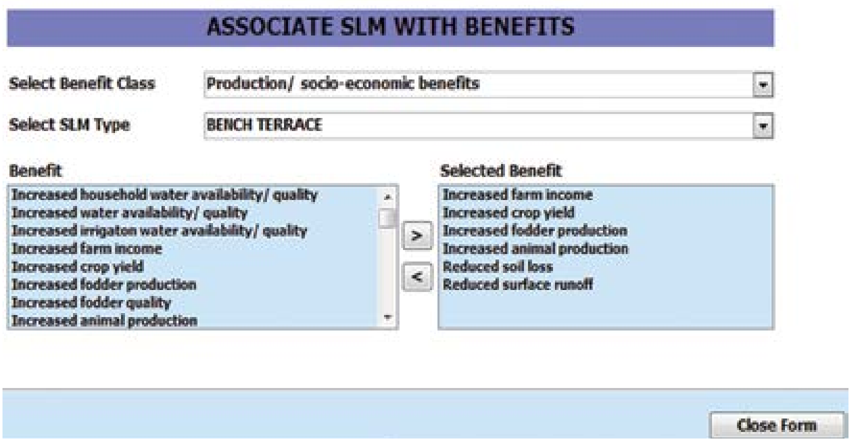

Figure 12 Associate the SLM with benefits

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

<u>*Form to associate SLM with soil characteristics*</u>

This (Figure 13) form is used to link the SLM to soil characteristics suitable for it.

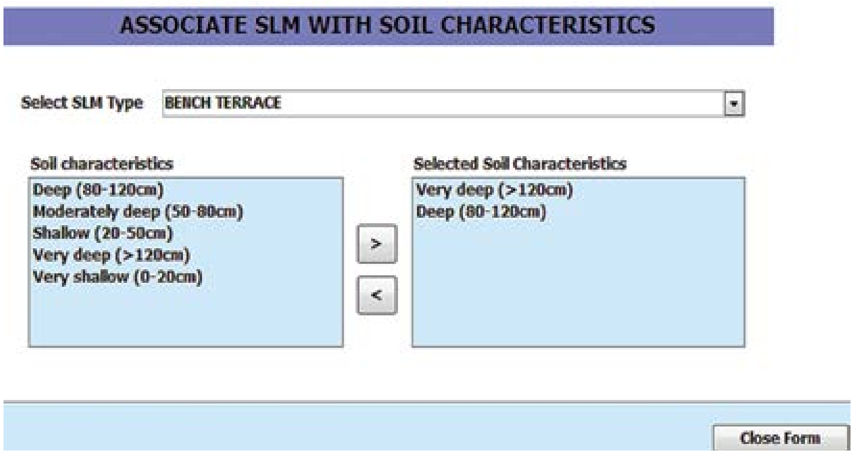

Figure 13 Form to associate SLM with soil characteristics

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

Results

Figure 14 shows the form that assists the end user to select the SLM technologies based on selection hierarchy as described earlier. Based on the agro climatic and agro ecological zones of the study area, the users are able to identify the location of their farms. The users start with selecting their particular ACZs which then populates the AEZ in those zones. Once a particular AEZ has been selected, the tool populates all the SLM technologies that can be applied in that AEZ. Further selection of LUT, SLOPE, SOIL DEPTH and SOIL DRAINAGE in that order, filters the SLMs to suit the particular selection.

Figure 14 Form to aid user in selecting suitable SLM

Clicking on a particular SLM populates the benefits list box with the benefits associated with that SLM. It also populates the climatic extremes for the SLM and its adaptability to those extremes and then loads the WOCAT documents and their reference numbers. 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 (Figure 15) has been provided on the final selection window of the DST-MATSIM Tool.

Table 2 Sample of the DST-MATSIM Tool's output for the study area

	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 (20-50 cm)	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 (50-80 cm)	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 (0-20 cm)	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 (80-120 cm)	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

Table 2 Sample of the DST-MATSIM Tool's output for the study area *(Continued)*

	UM4	Annual cropping	Gentle slope (0-5%)	Deep (80-120 cm)	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 (20-50 cm)	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 (80-120 cm)	Poor	Zai pit-9 Maize	Increased farm income, improved 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 (20-50 cm)	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 (0-20 cm)	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

Figure 15 Application manual for DST-MATSIM Tool

Conclusion

The paper presents a basic tool that can be useful in the Upper Tana catchment by the land users, policy makers and specialists to identify the appropriate SLM technologies that are applicable at farm level. The tool presents an inventory in form of a database of the successful SLM technologies that have been documented by the use of the World Overview of Conservation Approaches and Technologies (WOCAT) framework. WOCAT incorporates the use of detailed questionnaires to document, evaluate, share, disseminate, and use knowledge about SLM, and has tested it over many years (Schwilch et al. 2009).

The tool is versatile and SLM specialists can document any other suitable SLM technologies that were otherwise not documented during this study and include them in the database. The tool can also be manipulated to suite other catchments by simply including their biophysical parameters in the respective fields and forms.

The rationale behind the concept presented in this paper is that, it is possible to identify the most successful farmers in this catchment. The experience can then be used to train others by getting to know the reasons behind their success through documentation using a globally accepted methodology and using it to train others if they fall within the same agro-ecological and biophysical conditions. It has also brought about the use of technology through the use of decision support concept.

Recommendations

The DST-MATSIM-TOOL is computer based and the authors envisage that the next phase of development will be robust encompassing the use of Geographical Information System (GIS) and Remote Sensing (RS) platforms where the land user will only be required to know the geo data of his /or her farm and the tool can populate the available SLM in that AEZ at the click of the button. At advanced levels, the use of mobile technology is also possible. In order to make the tool more user friendly especially to the end user, it is recommended to have the DST-MATSIM-TOOL in paper work where a farmer can use simple logics to arrive at an appropriate decision.

Acknowledgement

The authors wish to acknowledge the World Agro Forestry Centre - International Centre for Research in Agro forestry (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.

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Theme II

Enhancing Dry Land Cropping through Upscaling of Soil and Water Conservation Technologies

Chapter 5

Factors that Influence Adoption of Soil and Water Conservation Technologies at Kathekakai Location, Machakos County

Gachene CKK[1]*, Baaru MW[2], Gathaara V[3], Onwonga R[1] and Mbuvi JP[1]

Abstract

A study on soil and water conservation technologies was carried out in Machakos County. The study identified factors that influence adoption of soil and water conservation measures (SWC) at Kathekakai location of Machakos County. Interviews were used to collect data from 62 farmers. Results show that most farmers (86%) experience serious soil erosion problem. A large number of farmers said they got information on SWC from other farmers (65%). Investment in SWC was mainly influenced by extent of land damage, slope of land and other farmers. Most farmers had witnessed reduced water damage (25%) and increased crop yield (10%) after investing in SWC. Terraces and cover crops were largely used in SWC. Training, pest, and diseases were identified as the major constraints in adoption of SWC. Lack of finances, labour, and land subdivision are other factors that were said to contribute to low adoption of SWC. The urgent need to develop control measures for termites was identified to minimize crop damage. The study also recommends that extension agents concentrate on training of selected farmers who then become trainers to other farmers.

Key words: Soil erosion, soil conservation technologies

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Introduction

Soil erosion has been identified as a major constraint in generating enough food to feed the world's escalating population (Charlotte and Slaymaker 2000). In Sub-Saharan Africa, the increasing population and diminishing land sizes coupled with the need to produce more food for the growing population has led to further land degradation through accelerated soil erosion and runoff (Ahmed et al. 2000). According to Gachene et al. (1997), one of the greatest contributory factors to the decline in soil productivity in Kenya is the high loss of fertile soil through erosion. Their results indicated that the enrichment ratio of the plant nutrients investigated was more than one, an indicator of serious loss of soil fertility.

The current agricultural practices in smallholder farms leave the soil bare during the onset of the rains resulting in severe interrill, rill and gully erosion (Khisa et al. 2002). Many researchers and extension workers have attributed this to expanded cultivation in marginal areas that are highly vulnerable to erosion, intensive cultivation of steep, long slopes and overgrazing. In certain cases land may be so badly degraded that it is abandoned by farmers (Baaru 2011).

The smallholder farmers have been slow to adopt physical conservation measures because of the high labour and capital requirements for their construction and maintenance. There is perception by farmers about wastage of land and the slow response in soil fertility improvement (Okoba 2005). According to Tenge (2005), most of the soil and water conservation measures advocated in Tanzania by extension agents are expensive and usually do not incorporate farmers' knowledge. This has made many farmers to remain largely unconvinced on the value of adopting soil and water conservation measures. High labour requirements are other concerns of farmers when deciding whether to invest in soil conservation measures (Gathaara et al. 2010; Pansak et al. 2008; Hatibu et al. 2000). Economic factors also play an important role in determining whether farmers will adopt soil and water conservation technologies. The potential to improve crop yields has been identified as a significant factor in SWC investment.

Despite several efforts to address the issue of soil erosion in the semi arid areas of Kenya (Tiffen et al. 1994), the problem of soil erosion has continued to persist. Machakos County, in particular, has witnessed much efforts being directed into soil and water conservation, funded by both governmental and non governmental organisations. The study area, the Kathekakai Settlement Scheme, which originally was a ranch, was settled in 1995. The area has continued to experience increase in population growth resulting in increased exploitation of the natural resource base. Resource mapping by the local community in the area supported by remote sensing imagery showed that there has been rapid change in land use, agriculture and settlement being the most beneficially (Figures 1). In this study, farmers indicated that there has been increased soil erosion since converting the ranch into agriculture, yet there has been very little effort to address the problem. It was thus hypothesised in this study that lack of adoption of soil and water conservation technologies is as a result of lack of perceived benefits, lack of technical knowhow and high labour and capital requirements.

The objective of this study was therefore to evaluate the factors that influence the adoption of soil and water conservation measures in Kathekakai Settlement Scheme.

1995 2009

Figure 1 Changes in Kathekakai settlement scheme (source: Baaru 2011)

Methodology

Site

The study site is located in Machakos County (Figure 2). The climate of Machakos County is typically semi-arid with mean annual temperature varying from 15 to 25º C and a total annual rainfall ranging from 400 to

800 mm. Rainfall distribution is bimodal with the long rains starting from March to May and short rains from November to early January. Short rains are more reliable than the long rains and therefore most important. The soils are mainly luvisols with low inherent fertility (Gicheru and Ita 1987). The main land use practices are crop and livestock farming. The crops grown include maize *(Zea mays)*, beans *(Phaseolus vulgaris),* peas *(Pisum sativum),* millet *(Pennisetum americanum)*, and sorghum *(Sorghum bicolor).* Cattle raring is the main activity for income generation.

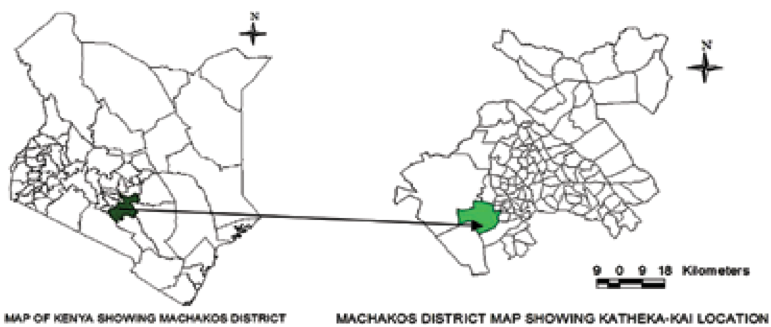

Figure 2 Location map of Machakos County and Kathekakai Location

The study was carried out in Kathekakai Settlement Scheme, in Machakos County of Kenya (Figure 2). The area, which was a ranching enterprise for nearly a hundred years, was subdivided in 1995 into individual farm holdings. Individual farmers opened-up the land (cutting trees and shrubs) for agricultural activities and other land developments. The Kathekakai Settlement Scheme continues to experience problems related to environment degradation due to the opening up of the land for cultivation and settlement. Following the sub-division of the large scale ranch, the population in the area has increased. The most significant change in land use in the area has been the conversion of commercial ranching area into small scale land holdings.

Evaluating the factors that influence the adoption of soil and water conservation measures

The study was conducted using both exploratory and descriptive designs. Qualitative research methods which allowed for generation of secondary data (qualitative information) were used at the beginning of the study. The information which helped to identify the specific study sites and also be able to generate the questions for the survey was collected from reports and field observations. This was followed with primary data collection which provided quantitative information. The data collection was conducted through a survey, involving key stakeholder discussions, individual household interviews using semi-structured questionnaires, and focus group discussions. The Ministry of Agriculture extension staff and the village elders were the main stakeholders and key informants respectively. The individual households were selected randomly on either side of the feeder roads, leaving two or three homes in between. The population size for the study consisted of six households from each of the five villages in Kathekakai location. This gave a sample population of 62 households.

Data collection

Data collection was done through various phases; i) orientation and stakeholders discussions, ii) focus group discussions, iii) individual household survey and iv) participatory rural appraisal (PRA). Excel and SPSS packages were used for data analysis.

Results

Socio-economic characteristics of the respondents

A total of 62 farmers were interviewed. Majority of the respondents (64% men and 36% women) interviewed from the five (Katilini, Ikaawani A, Ikaawani B, Weuni, and Weuni) sub-villages in Vota village were involved in farming (92%), casual labour (4%) and formal employment (2%). Most (76%) of the interviewed households are male-headed (MH), 25% male headed/female managed (MHFM) and 7% female-headed (FH). Majority of the respondents were about 48 years, with the majority (53%) having primary and 36% having secondary education respectively. The bigger proportion of the respondents depends on farming (44%), formal employment (7%) while 15% are in business among others. All the women (100%) belonged to different women groups. In 2008, 50% of the women belonged to various self-help groups compared to 15% men. These groups are involved in various activities, where financial investment/saving (36% of the self-help and 63% of the women groups) is the major activity and only 16% of the self-help and 18% women groups respectively are involved in farming activities. Table 1 is a summary of the characteristics of farmers interviewed.

Table 1 Socio-economic characteristics of respondents (N = 62)

Characteristic	Percentage (%)	Characteristic	Percentage (%)
Sex		*Occupation*	
Male	36	Farming	92
Female	64	Casual labour	4
		Formal employment	2
Leadership		Business	2
Male Headed	68		
Female Headed	8	*Farming activities*	
Male Headed/female managed	25	Crop production	45
		Livestock production	31
Age		Farm forestry	14
Mean	48		
		Contribution to income	
Land ownership		Casual labour	37
Men owned	71	Business	25
Women owned	8	Formal employment	18
Family owned	18	Sale of farm produce	11
Educational status		Remittances	9
Primary level	53		
Secondary level	36		

Farming systems

Land is mostly owned by men (71%) while 18% of the land is under family ownership. Very few women (8%) own land and this mostly happens after death of the husband. Most of the land (45%) is used for crop production, 31% for grazing/pasture land, 14% for farm forestry, 4% kitchen garden, 4% livestock keeping and 1% is used for other activities (Figure 3). The most commonly grown crops are maize *(Zea mays),* beans *(Phaseolus vulgaris)* and dolichos *(Lablab purpureus).* Other crops grown in the area include; sweet potatoes *(Lopmoea batatas),* cassava *(Manihot esculenta),* sorghum *(Sorghum bicolor),* green-grams *(Vigna radiata),* millet *(Pennisetum americanum),* garden peas *(Pisum sativum),* potatoes *(Solamum tuberosum),* banana *(Musa paradisiaca)* and pigeon peas *(Cajanus cajan).* Crop yields are below the expected average yields per acre. While this could be attributed to unfavourable climatic conditions, low inputs, use of local seed varieties for planting, change in climate and resultant changes in rainfall patterns and intensity, poor land management practices, have also contributed to current low crop yields (Gachene and Kimaru 2003). For instance, although the farmers are aware and have employed some of the soil and water conservation measure such as construction of *"fanya juu"* terraces (34%), use of farm yard manure (23%) and *"fanya chini"* terraces (17%) among other measures have not been effective, mainly because the farmers lack technical knowhow especially on how to lay out the terraces.

One of the main challenges of carrying out soil conservation measures on – farm is lack of enough extension staff. Most of the farmers are thus left on their own to design and layout the structures. The net result is that most of the structures are wrongly laid out resulting in more damage of the cropped land. These poorly constructed terraces are not able to control the soil and water loss (Plates 1 and 2). The resulting loss of plant nutrients lead to poor soil fertility and subsequent poor crop performance. Some of the poorly constructed terraces have even led to more damage to the land when heavy storms are experienced. Farmers' abandonment of the traditional crops could also be contributing to the poor crop performance as most of these traditional crops, apart from being drought tolerant, also act as cover crops, thereby reducing the amount of soil and water loss.

Plate 1 A damaged and poorly laid out terrace

Plate 2 Farmers laid (left) and expert laid (right) terraces intersecting

The results of the study also indicate that majority (64%) of the farmers have planted different types of trees (agro-forestry, indigenous and fruit trees) including; grevillea (34%) among the forest trees, mango (4.9%) among the fruit trees and leucena (2.4%) among the herbaceous shrubby legumes. The purpose for forest tree planting include; wind breaking (12 %), shade (11%) and firewood (10%) while the fruit trees are mainly planted for household fruit supply and income generation. The farmers are also involved in livestock keeping of poultry, cattle including oxen and goats, under various management systems; free range grazing (41%), semi-grazing (34%) and zero grazing (19%) among others. This is an indication that farmers are actively involved in mixed farming system in crops and livestock production.

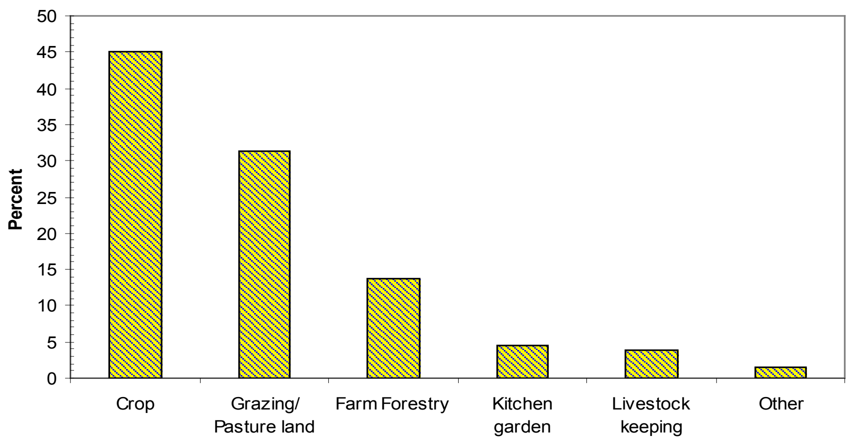

Figure 3 Distribution of land use in Kathekakai location

Soil and water conservation measures

Almost equal percentages of farmers perceive their soils to be very fertile (46%) and moderately fertile (45%) with the rest 5% and 1% who consider the soils to be very poor and poor respectively. Majority (73%) of the farmers experiences cases of soil erosion on their farms. Work done in the same area by Baaru (2011) confirmed this observation where farmers reported disappearance of the dams due to high siltation rates. According to the farmers the severity of the erosion ranges, from 11% severe, 61% moderate and 28% low cases. The farmers attributed the loss of soil and water mainly to; water run-off from the roads (32%), lack of effective soil and water conservation measures (24%) and absence of soil and water conservation measures (21%) among others (Table 2). As a way of mitigation to climate change, some farmers have adopted the use of soil and water conservation measures such as; *"fanya-juu"* terraces (34%), use of farm yard manure (23%), *"fanya-chini"* terraces / cut-off drains (17%) among others (Figure 4).

Table 2 Ranking off factors contributing to soil erosion

Contributing factor	Frequency	Valid %
Run-off from the roads	30	31.6
Lack of effective soil and water conservation measures	23	24.2
Absence of soil and water conservation measures	20	21.1
Others- not specified	7	7.4
Water from untapped roof catchments	6	6.3
Clearing of land for cultivation	5	5.3
Overgrazing	4	4.2
Total	95	100

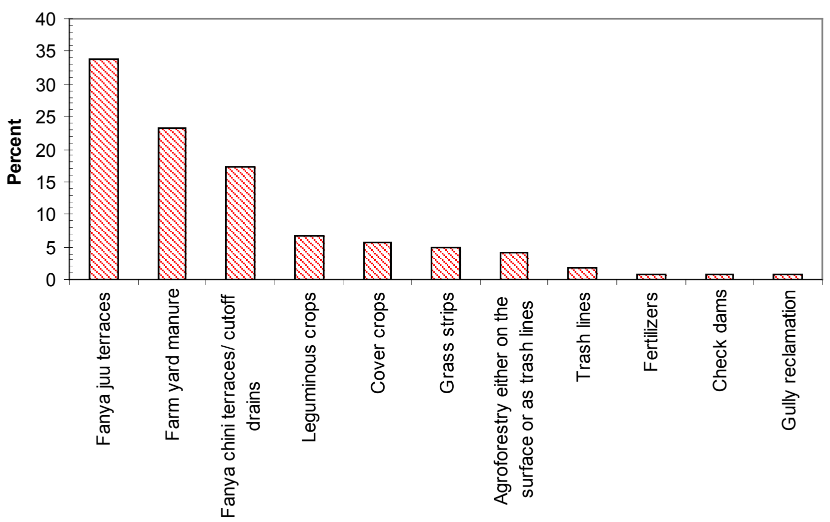

Figure 4 Percentage use of existing soil and water conservation technologies in Kathekakai sub-location

The farmers identified various measures that are used in the village and ranked them as indicated in the Table 3 below.

Table 3 Ranking of soil and water conservation measures identified by farmers

Measures		1	2	3	4	5	6	7	8	9	10	Tally	Rank
Fanya juu			1	1	1	1	6	1	1	1	1	8	1
Fanya chini				3	2	2	6	7	8	2	2	4	5
Planting trees					4	3	6	7	8	9	10	2	7
Grass strips						5	6	7	8	9	10	1	8
Destocking							6	7	8	9	10	1	8
Nappier grass on fanya juu terrace								6	8	9	6	7	2
Planting cover crops									8	9	7	5	4
Ploughing with ox plough										8	8	8	1
Contour ploughing											9	6	3
Planting sweet potato as a cover crop												3	6

The farmers identified fanya-juu and use of ox-plough as the most effective measures for soil and water conservation in the area.

The farmers indicated; lack of capital, limited technical information on soil and water conservation and lack of farm yard manure for improving the soil quality and texture as some of the limiting factors to adoption of soil and water conservation measures. Some of the other constraints that may have indirect effect on farmers' efforts to soil and water conservation includes: lack of access to appropriate seed/planting materials, inadequate and unreliable rainfall, disease and pests, drought and frost. Low market prices for farm produce discourage the farmers to undertake farming, thereby contributing to low adoption of the technologies. This agrees with the results of the household interviews and as a way of addressing these constraints, the farmers suggested to include the following; provision of loans for farming, water for irrigation, controlled market prices for farm produce, increased efforts to planting of trees to attract rains, training and capacity building on water harvesting, compositing and management of catchments areas.

But despite these efforts, the farmers still experience a lot of soil erosion problems leading to low crop yields. This was attributed to lack of technical knowhow in laying out the terraces, absence of advisory services due to lack of enough extension personnel, cultivation of steep slopes often undertaken without carrying out effective soil conservation measures. In addition, soil erosion results from poor soil management practices such as complete removal of crop residues and inadequate application of farmyard manure, that is known to improve soil structure, soil moisture retention and increased infiltration rates (Gachene and Kimaru 2003). Clearing of the initial ranch where land cultivation replaced most of the land under ranching led to and continues to cause serious erosion problems. The disappearance of the ranch to give room for cultivation was well demonstrated by the farmers during resource mapping exercise undertaken in the same area (Baaru 2011).

Status of soil erosion and soil and water conservation measures

Table 4 shows that 86% of the respondents experienced serious soil erosion. However, a majority (30%) did not know the indicators of soil erosion. A large number (10%) of those aware cited gullies and rills as the indicators for soil erosion. The most popular SWC measures were terraces and cover crops practiced by 50% and 25% of the respondents respectively. Majority (65%) of the respondents said they got information on SWC from other farmers. Still a good number (40%) said they got information from the Ministry of Agriculture while 30% used own experience to invest in SWC. Most (25%) of the respondents said that SWC had reduced water damage to the cropland, 10% had witnessed increased yield while 10% were not sure of any effect. Mainly, the used SWC measure was influenced by extent of water damage (20%), slope of land (20%) and other farmers (20%). Experts (government agents, researchers, NGO's) and increase in production influenced SWC use by 7% and 3% respectively.

Table 4 Status of soil erosion and soil and water conservation measures

Issue	Percentage		Percentage
Current situation of soil erosion		*Source of SWC information*	
Serious experience	86	Other farmers	65
Mild experience	7	Ministry of Agriculture	40

Table 4 Status of soil erosion and soil and water conservation measures *(Continued)*

No soil erosion	7	Own experience	30
Awareness on soil erosion indictors		*Perceived effect of SWC*	
Do not know 30		Reduced water damage	25
Gullies and rills	10	Improved yield	10
Damaged terraces	5	Not sure of any effect	10
Bare land	3		
Low productivity	3	*Perceived effect of SWC*	
		Bare land	3
SWC measures used		Extent of water damage	20
Terraces	50	Steep slope	20
Crop cover	25	Other farmers	20
Agro forestry	15	Experts (government agents, researchers, NGO's)	7
Preserved bush	4	Increase production	3
Sacks	4		

Constraints to SWC Investment

Data in Table 5 reveals lack of training (30%), pest and diseases (14%) as the major constraints in adoption of SWC. Termites were found to be the most serious pest affecting SWC measures (Plate 3). Lack of finances (7%), labour (5%), and knowledge on SWC (5%) are other factors contributing to low adoption of SWC. Land subdivision (4%) and grabbing of public land (4%) also influence adoption of SWC.

Table 5 Challenges in adoption of SWC

Challenge	Percentage (%)
Lack of trainings	30
Pest and diseases	14
Lack of finances	7
Labor	5
Poor soils	5
Knowledge on SWC	5
Poor relationship and harmony in family	5
Subdivision of land	4
Personalization of public land	4

(a) (b) (c)

Plates 3 Termites affecting plants used in different SWC (a) nappier grass (b) maize and (c) Grevillea tree

Gender and soil and water conservation

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. Planting of food crops on the terrace embankment and along ditches is done by women who also have the control of these food crops. While the activity profiles show that there is more or less even distribution of labour between men and women (Tables 6 and 7), the scenario changes when the issue of access and control of resources are concerned (Table 7). There is a tendency of male dominance with regard to these two aspects.

Table 6 Activity profile analysis by men

Activity	By Who			When Done
	Male	Female	Hired Labour	
Laying out of terraces	✓			During the dry season, July to September.
Digging of terraces	✓	✓	✓	During the dry season in July to September.
Land preparations	✓	✓	✓	August to September
Planting of:				
– Maize			✓	September to October
– Beans	✓	✓	✓	November to December
Sweet potatoes		✓	✓	
Cowpeas		✓		NB: Men participate in plough and planting but women plant on the embankment and in the ditch.
Pumpkins		✓		
Pigeon peas	✓	✓		
Napier grass	✓	✓	✓	
Trees- All activities	✓	✓		
Weeding of all other crops	✓	✓	✓	
Weeding for cassava and sweet potato		✓	✓	

Table 7 Activity profile analysis by women

Activity	Gender Involved			When Done
	Male	Female	Hired Labour	
Laying of terraces	✔			Dry season
Digging of terraces	✔	✔	✔	Dry season
Planting of:				
Napier grass	✔	✔	✔	Wet season
Pumpkin	✔	✔		Wet season
Cow peas	✔	✔		Wet season
Dolichos	✔	✔		Wet season
Terrace embankment		✔		Wet season
Terrace ditch	✔			Wet season
Planting trees	✔	✔		Wet season
Watering trees	✔	✔		Dry season
Maintenance	✔		✔	Beginning of every season
Purchase of seeds/ seedlings	✔	✔		Beginning of every wet season
Manure application	✔	✔	✔	
Herding	✔	✔		
Milking	✔	✔	✔	
Animal health care	✔	✔		
Sale of				
Milk		✔		
Animals (cattle)	✔			
Poultry		✔		
Sheep	✔	✔		
Farm produce	✔	✔		

Table 8 Access and control of resources

Resources	Who has access		Who has control	
	Men	Women	Men	Women
Land				
Family	✔	✔	✔	
Rented	✔	✔	✔	✔
Labour				
Family	✔	✔	✔	✔
Hired	✔	✔	✔	
Inputs				
Capital	✔	✔	✔	
Seeds/ Seedlings	✔	✔	✔	✔
Manure	✔	✔	✔	✔
Pesticide	✔		✔	✔
Water	✔	✔	✔	✔
Farm implements	✔		✔	✔
Plough	✔		✔	
Livestock	✔		✔	✔
Benefits				
Produce for food	✔	✔		✔
Produce for sale	✔	✔	✔	
Milk		✔		✔
Sale of cattle	✔		✔	
Sale of trees	✔		✔	
Income	✔	✔	✔	
Prestige		✔		

Discussion

Although sale of farm produce contributes only 11% of household income, farming is still the major activity in this area. This is an important pointer to which SWC will be used as was demonstrated by Charlotte and Slaymaker (2000). Charlotte and Slaymaker (2000) stated that when agriculture is the source of livelihood, and investing in SWC has the potential to increase yields, then the possibility that farmer will invest in SWC measures is high. Casual labor and business have the highest contribution to household income and this is an important factor in SWC investment. Investment in SWC is an expensive venture requiring both labor and finances. These two occupations would mean casual labor is available while business may provide finances needed to invest in SWC (Charlotte and Slaymaker 2000).

Although 86% of those interviewed said they experienced serious soil erosion, still a good number of them (30%) did not know the indicators of soil erosion. This may explain why most of them cited gullies and rills as these are the obvious indicators, yet erosion is most damaging in terms of water, soil and nutrient loss (Gachene et al. 1997). This is a wake-up call for experts as gullies and rills become visible after the damage is already done. The most popular SWC measures practiced in the area are terraces and cover crops. The high investment in SWC measures is justified by the fact that 92% of people engage in farming activities as indicated in Table 1. However, 65% got information on SWC measure from other farmers suggesting that farmers are not receiving as much support from the extension service as needed, which consequently could translate to low innovation adoption and technology transfer. The challenge is to have farmers equipped with the right information.

Even though 40% of respondents said they got information from Ministry of Agriculture staff, farmers own experience also played a big role in information transfer. Exchange of ideas among farmers has been found to be more frequent and efficient among farmers familiar to each other and who have similar characteristics (Murphy 1993), and hence farmer field schools (FFS) become crucial in extension services. Farmer field schools encourage peer learning and by so doing develop farmer expertise that enables them make their own crop management decisions. This approach has been shown to increase adoption rate of the technology. Dinpanah et al. (2010) reported that 63.9% of farmers who participated in FFS adopted rice production technologies compared to only 13.3% who had not participated in FFS and adopted the technology.

The extent to which other farmers own experience influenced use of SWC was found to be as important as other factors (e.g. extent of water damage and slope of land). Agwu et al. (2008) found a positive relationship between farming experience/social participation and adoption of improved technologies. The observation suggests that constant interaction and contact with fellow farmers helps them become aware of new technologies. This means that farmers are more likely to obtain information and be influenced in their farming practices and management decisions by other farmers than extension workers. However, it should be important to note that information from other farmers may be wrong and/or obsolete especially if they were not well informed.

Increase in production had least influence on adoption of SWC measures. Farmers are interested in investments that have immediate benefits. More often, SWC measures offer long term benefits and it may be important to design a range of technologies with short-term and long-term benefits. A good number (30%) of farmers identified lack of training as a major constraint to adoption of SWC measures which suggests that farmers were not receiving as much extension support as needed and consequently this may affect adoption of innovations and transfer of technologies. With minimal number of agricultural staff, it may not be possible to visit each of the farmers in this vast area. According to Mureithi et al. (2007), farmer field schools, field days and demonstration sites may become important methods of doing extension.

Termite is a significant pest that affects land productivity in this area (Plate a, b, c). Mature maize crops, grevillea and napier grass mostly used in SWC measures were infested by termites. This greatly reduces expected benefits and hence led to low adoption rate of SWC measures. Land sub-division leads to relatively small farm land. Investing in small farm constitutes a major challenge to technology adoption (Agwu et al. 2008), as it may not be cost effective. Furthermore, farmers living on public land e.g. on hills may not invest in SWC as they may be not sure for how long they will be on such land and hence feel that investing in SWC measures may not be benefit them.

Conclusion and Recommendations

The finding of this study reveal that other famers are a major source of information on improved SWC. They also greatly influence adoption of SWC. This shows that farmer to farmer extension could hasten adoption of SWC. To ensure that farmers convey the right message to their fellow farmers, extension agent will have to concentrate on training of trainers who then become the agents of technology transfer. The study also puts a challenge to researchers in pest control. Termites were found to be a great threat to adoption of SWC as they infested the crop, napier grass and trees used, and it will require that researchers develop methods of pest control.

Acknowledgment

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Chapter 6

Assessing and Monitoring Potential Agricultural Crop Production for Improved Food Security in Machakos County

Eunice W. Mwangi [1]* and Charles N. Mundia[2]

Abstract

Agricultural productivity has been a challenge to food security in Machakos County. The area is semi-arid with scanty rainfall amounts that are irregularly distributed. The objective of this study was to assess the state of land cover and land use with particular interest on agriculture land use. Eco-climatic variables are known to influence crop production, thus crop condition was assessed using normalized difference vegetation index. Rainfall amounts and distribution was analyzed to show its impact on crop production. The methodology was based on satellite data processing. Land use and land cover was derived from Landsat satellite imagery while normalized difference vegetation index was computed from SPOT vegetation satellite data. Time series analysis of biomass health and vigor for 2010 and 2011 cropping season in Machakos was analyzed. FEWSNET rainfall data was used to compute cumulative rainfall amount and average for the growing season. The analysis revealed that agriculture occupies 64% of the total land mass, and most land in high potential areas of the county is under agricultural production. During March 2011-September 2011 the region received total rainfall of 81 to 250mm. Crop condition in 2010 was better than the 2011 seasonand this could probably be attributed to decline in soil moisture content. Agriculture assessment using earth observation data is a viable technology especially when working in a relatively large area with limited resources (time/finances) or when you need to study change over time as with the normalized difference vegetation index. This study proposes use of very high resolution data to capture detailed landuse for

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crop production assessment. Long term change analysis of landcoverusing Geo information systems and Remote Sensing would further help in current and future analysis of agricultural crop production in Machakos County.

Key words: Semi-arid, remote sensing and geo information system, crop production

Introduction

Crop production in Sub Saharan Africa is low due to, among other factors, inherent low soil fertility. The soils of the Sahelian and sub-humid zones are sandy, poor in nutrients, and subject to intense erosion (KFSSG 2008), while soils of the lowland tropics are acidic, with low absorptive capacity, and poor in nutrients (FAO2009). The occurrence risk for drought is high for 66 % of the areas (FAO 2009).

The utilization of space-borne multispectral data for crop acreage and production estimation started in the 1970s with the launching of the large area crop inventory estimate (LACIE) jointly with NASA, USDA and NOAA in 1974. In India the satellite remote sensing is mainly used for crop acreage estimation of production of agricultural crops (Menon 2012).

Kenya is a country with varying climate, vegetation, topography and geology. The country's agriculture is predominantly small-scale farming (Romano 2009). Climate is the most important factor influencing soil formation. In dry areas, the soils have low organic matter mainly because rainfall is low, variable, unreliable and, poorly distributed thus leading to low vegetation cover (Apollo 1997). Agricultural sector is the mainstay of Kenya's economy; the sector directly contributes 24% of the Gross Domestic Product (GDP) and 27% of GDP indirectly through linkages with manufacturing, distribution and other service related agriculture dependent sectors (KFSSG 2008). Kenya's agriculture is mainly rain-fed and is entirely dependent on the bimodal rainfall in most parts of the country. A large proportion of the country, accounting for more than 80%, is semi-arid and arid with an annual rainfall average of 400 mm. Droughts are frequent and crops fail in one out of every three seasons.

In Machakos County, the environment and natural resources have in recent years been under threat due to increasing dependency on natural resources to meet basic needs. The natural resources in the county include land and soils, water, forestry and wildlife as well as commercial minerals. For most of Machakos County, the main limiting factors for agriculture is lack of rainfall and reliable sources of surface water. The remnants of the forest zone are now largely under cultivation, with shrubby secondary growth dominating non-cultivated areas. The county is generally dry making rain fed agriculture difficult in many areas. The situation is further aggravated by frequent droughts that affect any surplus yield in the county while affecting pastures (Machakos DEAP 2009-2013).

The County faces inadequate water for domestic, livestock, crop production and industrial use. Other characteristics include destruction of water catchment areas, persistent droughts, destruction of existing earth dams and pans, collapse of community water committees with mandate to coordinate utilization of water catchments. Climatic and human factors are causing serious threats for example that of desertification. Poor farming methods and increased population pressure on the land have led to clearing of land which was originally reserved for forests. The County has less than 2% of its area under forest (Machakos DEAP 2009-2013).

The main threats to food security in Machakos County include low amount and early cessation of rainfall, low adoption rate of drought tolerant crops, use of uncertified seeds and poor access to farm inputs especially in the low lands of the County. The main objective of this study wasto assess agricultural crop production using GIS and Remote Sensing, but more specifically to i) identify the extent of agricultural land and general land use/land cover;ii) assess seasonal crop health using vegetation indices;iii) estimate seasonal rainfall amounts and distribution and iv) map soil characteristics related to crop production in Machakos County.

Methodology

The study was based on Eco-climatic variables. The following parameters were considered: vegetation cover (type and condition), rainfall amounts and soil properties. These are the most important variables since they determine crop productivity and yield. Vegetation index and rainfall amount were assessed during the wet seasons, March–September 2010 and 2011. Field verification exercise was also conducted to obtain ground information. Main data source included: satellite imagery acquisition, interpretation and analysis. The satellite data of focus included: Landsat ETM (Enhanced Thematic Mapper), Spot Vegetation NDVI (Normalized Difference Vegetation index), Fewsnet RFE (rainfall estimate) (Table 1).

Table 1 Input data sources

Data	Image/vector type	Resolution
Land use land cover	LANDSAT TM	30m
Rainfall	FEWSNET RFE	8 km
NDVI	SPOT VGT	1 km

Data processing and analysis

The data was processed guided by the flow chart given below:

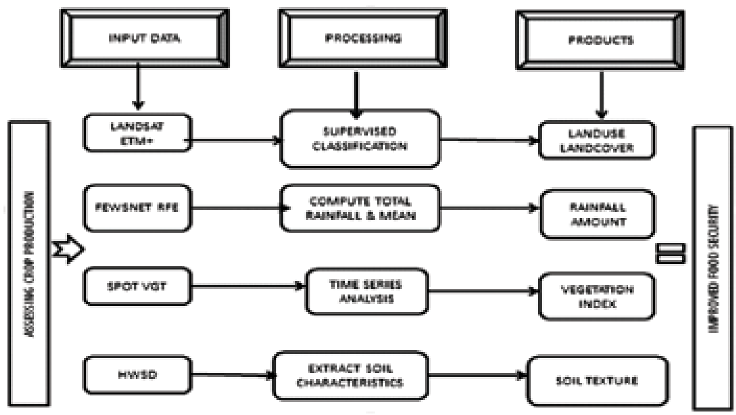

Figure 1 Data processing log-frame

Software for image analysis and interpretation included: ArcGIS, Erdas, Ilwis and Microsoft Access/ Excel. Spectral Bands 2, 3, 4 were selected to bring out the vegetation type as illustrated in Table 2. Supervised classification was done to identify the extent of agricultural land and crop type.

Table 2 Landsat image band combination

Band	Wavelength	Use in mapping
Band 2 – green	0.52-0.60	Emphasizes peak vegetation, which is useful for assessing plant vigor
Band 3 – red	0.63-0.69	Discriminates vegetation slopes
Band 4 - Near Infrared	0.77-0.90	Emphasizes biomass content and shorelines

Vegetation Index was derived from SPOT VGT NDVI (Figure 2) and a time series of the 2 wet seasons (March-September 2010 and 2011) analyzed; six sites within the study area were randomly selected for this analysis namely: Mavoko, Machakos town, Kathiani, Matungulu, Masinga and Yatta.

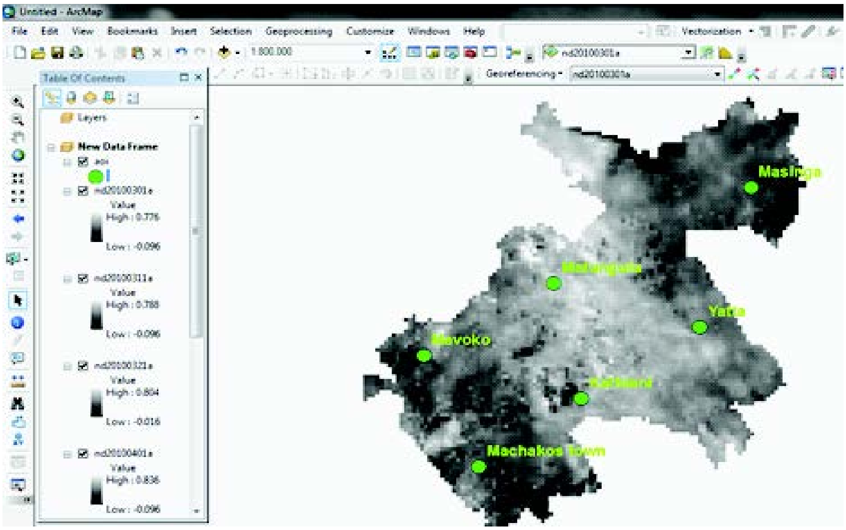

Figure 2 Processing NDVI image

Seasonal cumulative and mean rainfall amounts (Figure 3) was analyzed and their distribution mapped, besides, trend analysis was conducted to see how rainfall behaved throughout the season and its impact on crop production.

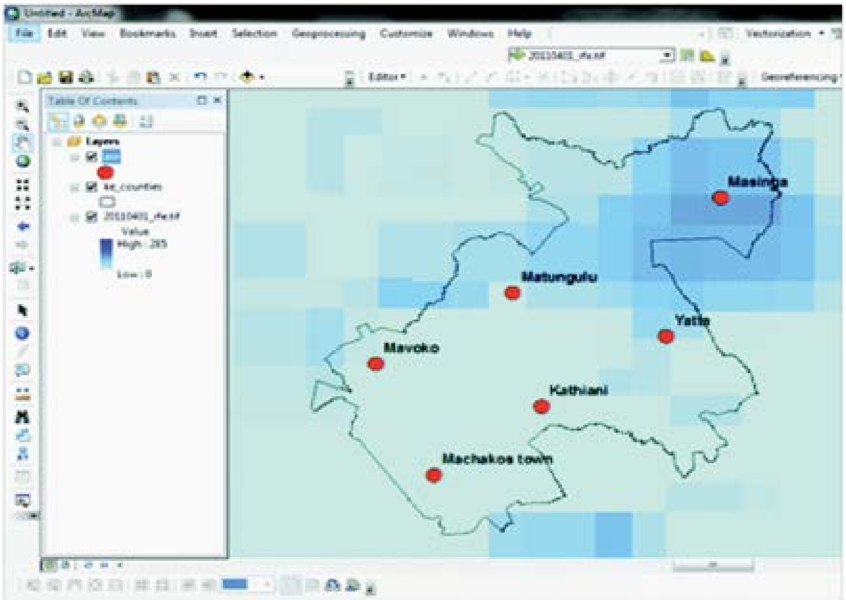

Figure 3 Processing rainfall data

Results and Discussion

The false color composite image in Figure 4 shows that the central region is highly vegetated and most agricultural activities take place in this zone. However there are some areas especially around the hill masses in Kathiani and Kangundo which though too steep for cultivation; cultivation was still going on. Agriculture is also practiced in the low potential areas (Mwala, Katangi, Yathui, Kalama, Athi River, Masinga, Yatta and Ndithini divisions). A field visit was also conducted to validate the image product and to also obtain some ground information. An Environmental Officer working in the area informed this study that soil erosion is a problem but farmers had put soil conservation structures in most of the farms. It was also observed from the field that use of fire for bush clearing in Yatta, Katangi, Mwala, Yathui and Masinga is a major environmental concern because of loss of resultant biodiversity.

Supervised classification showed that agriculture was the main land use in the study area, and that areas around Machakos town and Mavoko are drier with sparse vegetation. Out of the total area, agriculture occupies

64% which is 3942 km^2 of the total land mass (See Figures 5 and 6). The main crops grown in the area include: Cereals *(*maize *(Zea mays),* sorghum *(Sorghu* tubers (sweet potatoes *(Lopmaea batatas),* irish potatoes *(Solanum tuberosum),* cassava *(Manihot esculenta),* arrow roots *(Colossia esculenta))* and to a small extent some cash crops are grown which include: coffee *(Coffea spp.),* cotton *(Gossypium spp.),* tobacco *(Nicotiana tabacum)* and sisal *(Agave sisalana).*

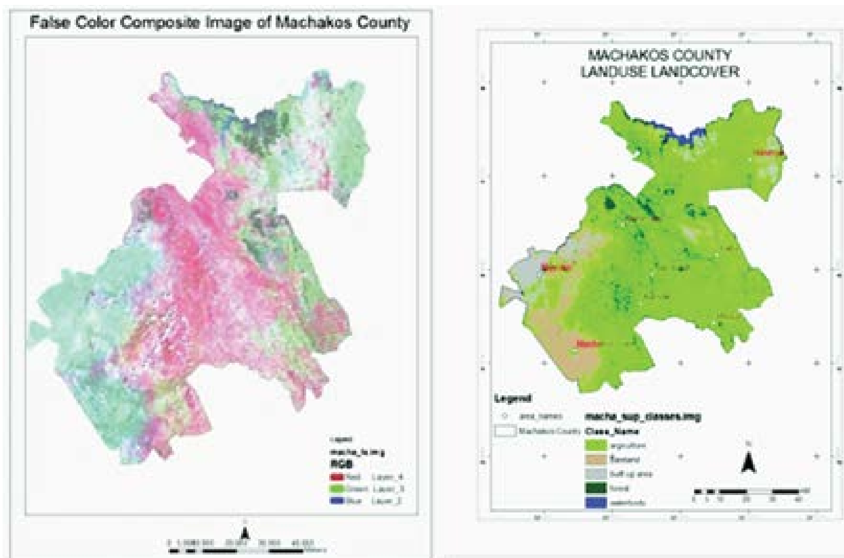

Figure 4 Land use / land cover classification

Supervised classification showed that agriculture was the main land use in the study area, and that areas around Machakos town and Mavoko are drier with sparse vegetation. Out of the total area, agriculture occupies 64% which is 3942 km^2 of the total land mass (See Figures 6 and 7).The main crops grown in the area include: Cereals(maize (*Zea mays*), sorghum (*Sorghum bicolor*), millet (*Pennisetumamericanum*)); Pulses (beans (Phaseolus vulgaris), pigeon peas (*Cajanuscajan*), cowpeas (*Vignaunguiculata*), chickpeas (*Cicerarietinum*), greengrams (*Vignaradiata*)); Root and tubers (sweet potatoes (Lopmaeabatatas), irish potatoes (*Solanumtuberosum*), cassava (*Manihotesculenta*), arrow roots (*Colossiaesculenta*)) and to a small extent some cashcrops are grown which include: coffee (Coffea spp.),cotton (*Gossypium spp.*), tobacco (*Nicotianatabacum*) and sisal (*Agave sisalana*).

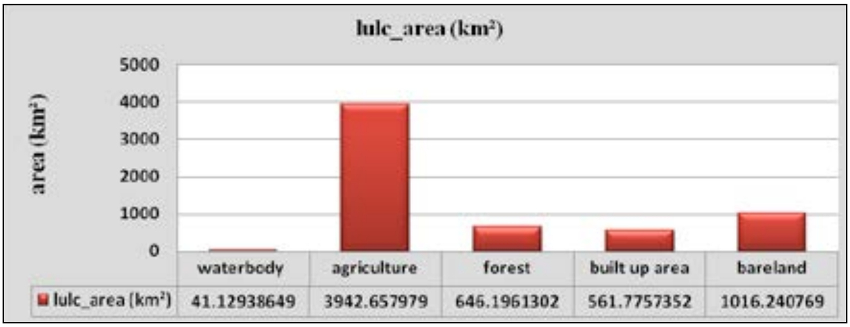

Figure 5 Machakos Land Use Land Cover (%)

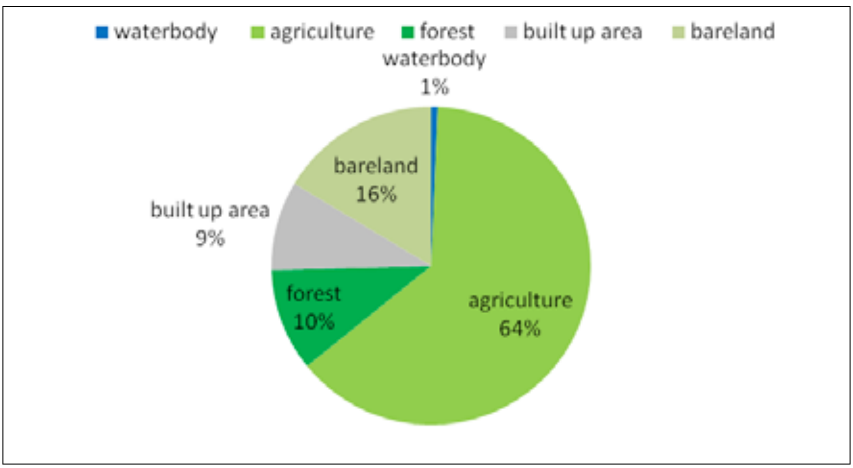

Figure 6 Machakos LULC Area Coverage

NDVI from SPOT VGT satellite data was used to monitor the trend of biomass health and vigor. NDVI is a useful product in agricultural crop assessment especially for monitoring crop health variability, identifying possible areas of poor plant stand, or for showing crop development stages.

$$NDVI = (NIR - RED)/ (NIR + RED)$$

Spatial Comparison of NDVI for the Period March-September 2010 and 2011

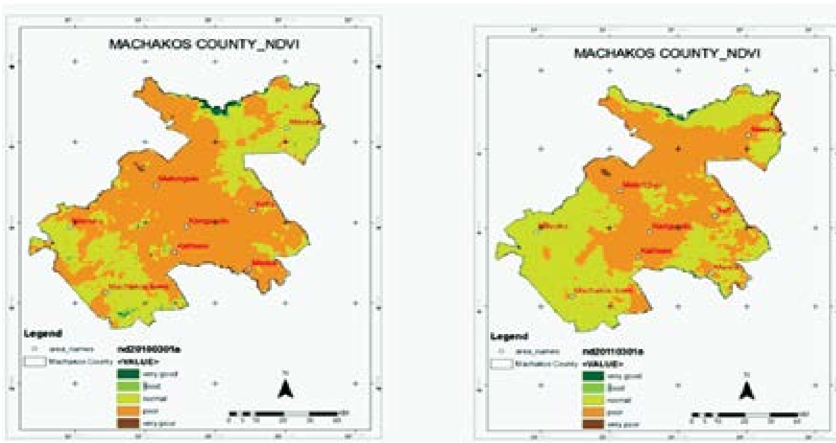

Figure 7 Machakos NDVI Maps (March 2010 and March 2011)

As shown in Figure 7, the region has NDVI value of 0.22 - 0.42 (normal) and 0.12 - 0.22 (poor) occupying almost the whole region. In 2010, 'poor' NDVI was more distributed than in 2011. This means that crop vigour/health slightly improved during this period (2010 and 2011). This could probably be attributed to an increase in crop moisture. The sites that were selected for comprehensive NDVI trend analysis of the region included Machakos town, Mavoko, Matungulu, Kathiani, Masinga and Yatta. These sites were selected based on their potential for agriculture whereby some fall in high while others in low production zones e.g. Matungulu area (Figure 8).

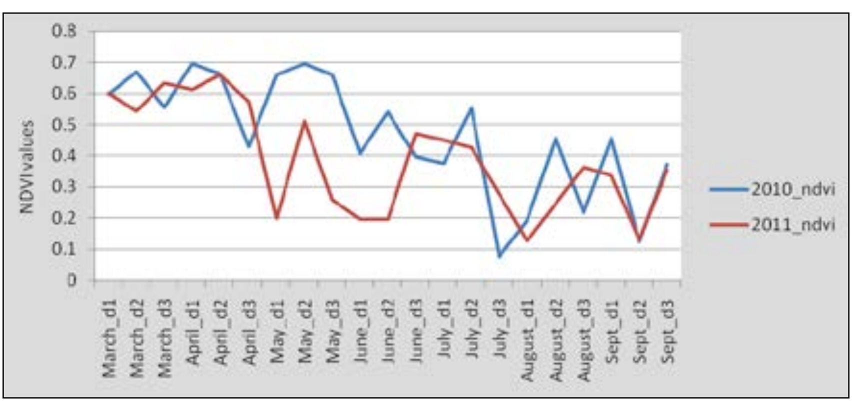

Figure 8 Matungulu NDVI Time Series, 2010-2011

Predominant crop types in Matungulu are mainly cereals and pulses. As indicated in Figure 8, there was a steady increase at the beginning of the growing season, whereby the crop began to grow then a sharp decline towards crop harvest. The difference between NDVI trend in 2010 and 2011 could be attributed to soil moisture content, nutrients, pests and diseases, whose increase or decrease could affect biomass health and maturity, as informed by NEMA official working in the area.

The results in Figure 9 shows that cumulative rainfall amount in 2010 cropping season ranged between 215 to 324 mm while in 2011 the amount was 81 to 251mm, which was lower compared to the previous year. It can therefore be argued that rainfall contributed greatly to better crop health/vigour as was witnessed earlier in the 2010 NDVI graphs. Also rainfall seem to have been evenly distributed in 2010 from the Mua Hills towards Mavoko and Machakos Town. In 2011 rainfall was scanty with little showers being experienced in Mavoko and North West Matungulu. A staff from the Kenya Meteorology informed this study that the Machakos County experiences erratic and unpredictable rains of less than 500mm annually, with short rains in October through to December and the long rains in late March to May. From the previous rainfall and NDVI figures, one can confirm this statement as it can be argued that the area receives low rainfall that is insufficient for agriculture. Agriculture production is mainly rain fed, and as been mentioned above, the county is largely semi-arid and the amount and frequency of precipitation is quite irregular. Within Iveti, Mua Hills, farmers do soil and water conservation measures. However, lack of maintenance of these structures is a big challenge. Seasonal rainfall variability greatly affects soil water availability to crops, and thus poses crop production risks.

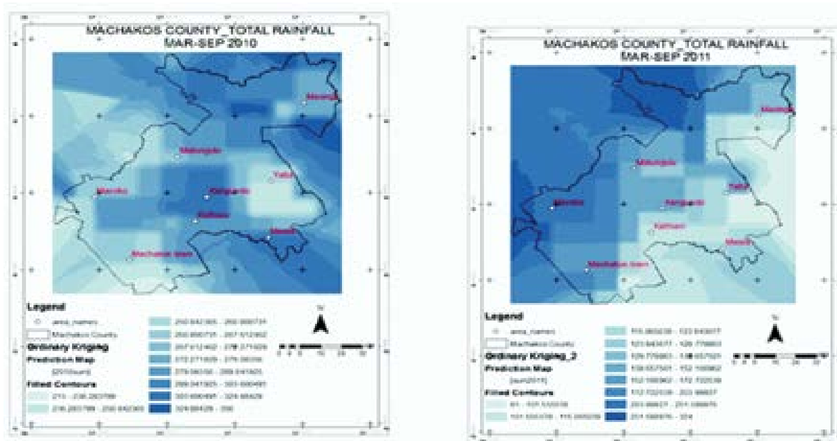

Figure 9 Total Rainfall Amounts (March-September 2010 and 2011)

Conclusion and Recommendations

Monitoring NDVI is very essential in crop assessment since the trend can be analyzed to observe when periods of dryness or drought stress are likely to occur during the growing season. These could be due to reduced soil moisture content, nutrients, or pests and diseases infestation. Vegetation index is not only useful in past and current growth assessment but also for forecasting and early warning. The area has a predominant non mechanized rain-fed agriculture as opposed to irrigated agriculture and this is therefore likely to pose a great challenge to food security. Tools such as RS and GIS would thus be useful for forecasting crop failure in such fragile ecosystems as this will lead to proper planning.

Remote sensing and GIS is a useful tool in assessing crop production especially in large areas where immediate results are needed. Spatial resolution of satellite imagery is important when details are needed. This will give room for individual crop assessment and monitoring thus giving more comprehensive and detailed results. Long term change detection (such as 10 to 30 years) of land use and land cover with keen interest on agriculture land use in Machakos would enhance understanding of current and future trends in crop production. Crop yield forecasting could also be generated from the NDVI time series analysis such as those presented in this paper together with current data on crop yield.

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Chapter 7

Tillage and Cropping Effects on Soil Water Dynamics and Crop Yields in Mwala District, Kenya

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Abstract

Soil water conservation through tillage is one of the appropriate ways of reducing soil moisture deficit in rain-fed agriculture. This study evaluated the effects of tillage practices, cropping systems on soil moisture conservation and crop yields in Machakos County in Eastern Kenya during the long rains and short rains of 2012 and 2013. Six tillage practices disc plough (DP) disc plough and harrowing (DPH), ox-ploughing (OX), subsoiling - ripping (SR), hand hoe and tied Ridges (HTR) and hand hoe only (H) and, three cropping systems namely, sole maize, sole bean and maize-bean intercrop, were investigated in a split-plot design with four replicates. Data on soil moisture content and crop growth parameters were monitored at different weeks after planting. Crop yields at end of each growing season were also measured. A three-season average showed that soil moisture content and crop yields were higher in conventional tillage practices compared to the conservation tillage practices. Long term tillage experiments are thus required at different locations, under various environmental and soil conditions to validate the study findings.

Key words: Tillage systems, cropping systems, soil moisture, semi-arid areas, crop yields.

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Introduction

Semi-arid areas are characterized by temporal and spatial variability of rainfall. In Kenya's semi-arid areas, the rainfall is usually low and unreliable (Wamari et al. 2012) and its occurrence is bimodal with two distinct rainy seasons, the short and long rains. The timing and relative lengths of each growing period varies substantially with location (Mujdeci et al. 2010; Barron et al. 2003).

Deficit of soil water in semi-arid areas is also attributed to low infiltration rates (due to surface sealing and crusting and low organic matter content) and subsequent high runoff rates (Rockstrom et al. 2003). The conservation of soil moisture in semi-arid areas requires appropriate tillage practices that not only improve rain infiltration but also conserves adequate soil moisture for plant growth (Cornelis et al. 2013). Tillage refers to different mechanical manipulations of the soil that are used to provide the necessary soil conditions favorable for crop growth. Tillage systems may be grouped into conventional and conservation tillage, depending on the kind, amount and sequence of soil disturbance. Conventional tillage systems mainly aim at weed control, residue incorporation and seed bed preparation. This also includes disruption, inversion, pulverization and mixing of soil in the tilled zone. However, conventional tillage increases the risk of soil erosion, accelerates organic matter decomposition and deteriorates soil structure (Kishor et al. 2013). The most common conventional tillage practice in semi-arid Kenya is ox-drawn mould board ploughing and hand hoeing.

Conservation tillage practices such as tied ridging, subsoiling and ripping have the potential of soil moisture retention. The practices also mitigate impact of intra-seasonal dry spells that often result in low productivity and crop failure (Manyatsi et al. 2011). According to FAO (2008), conservation tillage has positive effects on soil productivity such as enhancing infiltration and soil moisture storage. Further conservation tillage improves timing of tillage operations and spatial distribution of soil moisture at field scale, which is crucial in dryland rainfed agriculture. Although conservation tillage is highly advocated, there is strong evidence that this kind of tillage may not be good with soils prone to surface crusting and sealing, a characteristic of most of the soils in semi-arid areas of Kenya (Unger et al. 1991; Mujdeci et al. 2010). This study was conducted to quantify the comparative effectiveness of selected tillage practices in conserving soil moisture and improving crop yields in Machakos County, Eastern Kenya region.

Materials and Methods

Study site description

This study was conducted in Mbiuni Location, Machakos County, Kenya (1°15'S, 37° 25'E). The area is characterized by low, erratic and poorly distributed bimodal rainfall that makes rain fed crop production difficult. The long rains commence in mid-March and end in May while the short rains start mid-October and end late November. The mean annual rainfall for Machakos County is 596 mm (Ngugi et al. 2011). Soil chemical properties at the site (Table 1) indicates there is need to supplement the nutrients levels in the study area in order to achieve reasonable crop yield. This can be through application of mineral fertilizers, animal manures and plant residues.

Table 1 Selected soil chemical properties of the study site at 0 - 30 cm depth

Soil property	pH (H20)	pH (0.01M $CaCl_2$)	% OC	% N	K cmol kg^{-1}	Na cmol kg^{-1}	Ca cmol kg^{-1}	Mg cmol kg^{-1}	CEC cmol kg^{-1}	P ppm
	6.50	5.61	1.10	0.09	2.35	0.46	2.31	0.39	6.70	13.50

Table 2 Selected soil physical properties of the study site at 0 - 30 cm depth

Soil property	Sand (%)	Silt (%)	Clay (%)	Textural class	Bulk density (g cm^{-3})	Saturated hydraulic conductivity (Ksat) (cm hr^{-1})	Saturation (cm^3 water cm^{-3} soil)	Field capacity (cm^3 water cm^{-3} soil)	Plant available water (cm^3 water cm-3 soil)	Wilting point (cm^3 water cm^{-3} soil)
	22.00	39.00	39.00	Clay loam	1.27	0.27	0.52	0.37	0.15	0.22

Experimental design and layout

The trials were established during the long rains (LR) and short rains (SR) of 2012 and LR 2013. Six tillage practices; disc plough (DP), disc plough and harrowing (DPH), ox-ploughing (OX), hand hoe and tied ridges (HTR), hand hoe only (H) and subsoiling - ripping (SR), three cropping systems namely, sole maize, sole bean and maize-bean intercrop were investigated in a split-plot design with four replications.

Soil properties measurements

Soil moisture was monitored from time of crop emergence to the time of harvesting at depths of 0 - 20 cm and 20 - 40 cm using the gravimetric method (Okalebo et al. 2002). Monitoring of soil moisture was done at the 0 – 40 cm depth due to the high concentration of active roots at this level and less root concentration below this depth range. Saturated hydraulic conductivity (Ksat) determinations were done in the laboratory using the constant head method described by Klute and Dirksen (1982). The bulk density was determined using undisturbed core samples from each plot, which were oven dried at 1050C to a constant mass and then weighed. Bulk density was then calculated as the mass of the dry soil divided by the core ring volume. Bulk density and Ksat were determined at the beginning and at the end of every growing season.

Crop management

The dryland maize *(Zea mays L.)* variety DH 02 and beans *(Phaselous vulgaris)* (rose coco - GLP 2) were used as the test crops. These crops were planted in rows in 25 m^2 plots. The maize was planted at a spacing of 90 × 30 cm in pure stands while in the intercropping system they were planted at 90 × 60 cm. Beans were planted at spacing of 45 × 30 cm. Maize was planted in the same row but in alternating hills at the same spacing in the tied ridging plots.

Crop data measurements

In order to assess crop growth, the following maize growth parameters were collected; maize plant height, cob weights, cob lengths, maize stover yield and maize grain yield. For beans, the grain and biomass yields were measured. Final crop biomass and grain yields were determined from plants harvested in a sample area of 2 × 2 m at the centre of the plot. Ten maize plants were harvested in each plot, dried and threshed by hand, adjusting the grain to 12.5 % moisture. The harvest index (HI %) of each crop was then calculated as the ratio of the grain dry weight to the above ground plant biomass yield. The yields were calculated based on the mean experimental plot area and later adjusted to tonnes per hectare.

Statistical analysis

The soil and yield data collected were subject ed to analysis of variance (ANOVA) to evaluate the treatment effects using Genstat 14th Edition statistical software.

Results and Discussion

Moisture trends as affected by tillage practices

The soil moisture decreased over time during the growing seasons (LR 2012, SR 2012, LR 2013) at different weeks after planting (WAP) ($p \leq 0.001$). In all the seasons, the soil moisture was higher in the 20 - 40 cm than in the 0 – 20 cm depth and varied among the different tillage methods ($p \leq 0.001$). The changes in profile water content observed could be attributed to a combination of rainfall, soil evaporation, transpiration or crop water uptake (Mujdeci et al. 2010).

During the LR 2012 season, there were some significant interactions between time × depth ($p \leq 0.001$) and between time × tillage × cropping system ($p < 0.005$). Soil moisture trend in the 0 - 20 cm was in the order of HTR > DPH > H > OX > DP while in the 20 - 40 cm was in the order of HTR > OX > DPH > H > DP. At both depths, the moisture trend was HTR > DPH > H > OX > DP ($p = 0.019$). The tied ridges (HTR) had high moisture levels (15.6 %) due to the microbasin formation allowing more water storage and infiltration. These findings are supported by Guzha (2004), who found that the higher moisture was stored in ridges and this was associated with higher roughness resulting from ridge configuration (rectangular basins) that increase surface retention capacity, decrease runoff and thus improving crop growth and yields. Similar findings have been reported by Motsi et al. (2004) in Zimbabwe where tied ridges retained significantly higher moisture than conventional tillage especially during the dry months.

During the short rains (SR 2012), there were significant interactions between time × cropping system ($p = 0.003$) and time × depth ($p \leq 0.001$). There were no variations within the tillage methods ($p = 0.158$). In the long rains (LR 2013), some significant interactions were noted within tillage methods ($p = 0.003$), depth ($p \leq 0.001$), time × tillage ($p \leq 0.001$), time × cropping system ($p = 0.044$) and time × depth ($P \leq 0.001$). Soil moisture trend in the 0 - 20 cm was in the order of SR > OX > H > DP > DPH > HTR while in the 20 - 40 cm was in the order of OX > SR > H > DP > DPH > HTR. At both depths, the moisture trend was in the order OX > SR > H > DP > DPH > HTR. Contrast to the LR 2012, HTR had the lowest moisture (8.42 %) during the LR 2013. Similar findings have been reported by Gicheru et al. (1998) while working in the marginal areas of Laikipia County. They found that tied ridging conserved the lowest amount of moisture and attributed this to high evaporation losses due to increased soil surface area.

When the amount of soil moisture content for each tillage method was averaged for the three seasons, a seasonal difference was found ($p \leq 0.001$) and the trend was OX > H > DP > DPH > HTR > SR. These results showed that conventional tillage practices had the highest soil moisture content as compared to the conservation tillage methods. Rashidi and Keshavarzpour (2008) reported that conventional tillage increased soil moisture due to the effect of the primary and secondary tillage implements used which improved porosity and water holding capacity of a clay loam soil in Iran. However, Fabrizzi et al. (2005) reported an increase of soil moisture storage under conservation soil tillage due to decreases of evaporation, increases of the soil infiltration, and the enhanced soil protection from rainfall impact.

Effect of cropping systems on soil moisture trends

The soil moisture trends connote differences in the magnitude of soil moisture storage within the root zone and at different phases of the maize and bean growth under the different treatments. During the LR 2012, there was significant interaction between time × tillage × cropping system ($p = 0.005$). The sole bean (14.74 %) and the sole maize (14.71 %) had higher soil moisture than maize and bean intercrop (14.65 %). During the SR 2012, there was no significant variations of soil moisture content among the cropping system ($p = 0.684$). A time × cropping system interaction was observed ($p = 0.003$). In contrast to the LR 2012, the sole maize plots had more moisture (14.21 %) followed by bean (14.19 %) and intercrop (14.02 %) respectively. The intercrop had the lowest moisture content because of the increased plant population density per plot resulting in higher soil moisture extraction.

During the LR 2013, there was no significant variations of soil moisture among the cropping system ($p = 0.547$). However, a time × cropping system interaction was observed ($p = 0.044$). Sole bean plots had more moisture (9.48 %) followed by intercrop (9.20 %) and sole maize (9.05 %) respectively. Cropping systems that offer quick surface cover (bean and intercrop) promote soil moisture conservation by reducing evaporation and increasing infiltration (Steiner 2002). A three - season moisture average as affected by cropping showed that sole bean had higher moisture (12.80 %) followed by sole maize (12.66 %) and the intercrop (12.62 %). This confirms that increased plant population density per plot resulted in higher moisture extraction from the soil. Soil water extraction by crops is determined not only by soil water content, evaporative demand and soil physical properties but also by physiological status of the crop (Passioura and Angus, 2010).

Effect of tillage and cropping systems on soil bulk density, porosity and saturated hydraulic conductivity (Ksat)

The bulk densities of the soils ranged from 1.20 - 1.42 g cm^{-3} across the seasons ($p \leq 0.001$) which is within the acceptable range for a clay loam (USDA, 2008). Though not significant ($p = 0.508$), there were slight differences observed in bulk densities among the tillage treatments across the seasons with an average trend of DPH > HTR > H > SR > DP > OX. The high densities in DPH (1.39 g cm^{-3}) and HTR (1.36 g cm^{-3}) could be attributed to the second passes of soil manipulation (harrowing and tied ridges) to the initial tillage method of disc plough (DP) and handhoe (H). Osunbitan et al. (2005) reported insignificant changes in bulk densities due to different tillage systems in Nigeria. The seemingly no differences in bulk density among the treatments in this study could be attributed to environmental conditions (Veiga et al. 2008; USDA 2008). Moreover, bulk density is dependent on soil texture and the densities of soil minerals (sand, silt, clay and organic matter particles) as well as their packing arrangement (Brady and Weil 2008). Agbede (2006) found high bulk densities in the ploughing plus harrowing plots and attributed this to tractor wheel traffic and implement passes and lower macro-porosity and evaporation rate. However, Moreno et al. (1997) and Fabrizzi et al. (2005) found greater bulk densities under conservation tillage than conventional tillage systems.

The cropping systems did not influence the bulk densities in the three seasons (p = 0.270). On average, the intercrop had densities of 1.38 g cm^{-3}, sole maize (1.37 g cm^{-3}) and sole bean (1.35 g cm^{-3}). The differential rooting of the maize and bean crops may have contributed to decreased bulk densities in the intercrop. The plant roots are important in forming new channels in the soils thus loosening the soil. Osunbitan et al. (2005) reported that bulk density is changed by crop and land management practices that affect soil cover, organic matter, soil structure and or porosity.

Porosity values of the soils varied across the seasons ($P \leq 0.001$) and ranged from 44 - 47% during LR 2012 and 47 – 53% during SR 2012. Though not significant, (p = 0.508) soil porosity was in the order of DP > H > HTR > OX > SR > DPH. Since porosity is calculated from the relation between bulk density and particle density of soil, it is very much influenced by the soil bulk density as the particle density is not greatly altered by the agricultural manipulation. The cropping system did not show a significant (p = 0.270) influence on the porosity but sole bean and maize had higher porosity values than the intercrop.

The Ksat values varied across the season ($p \leq 0.001$) and were very slow (< 0.8 cm hr^{-1}) during LR 2012 and LR 2013, slow (0.8 – 2.0 cm hr^{-1}) in SR 2012 and LR 2013 (Landon, 1991). The Ksat mean values were 0.65, 1.41 and 0.27 cm hr^{-1} during LR 2012, SR2012 and LR 2013 respectively. Tillage did not show significant effect on Ksat values (p = 0.678) but an overall average trend of HTR > OX > DP > DPH > SR > H was noted. The low Ksat values implied low infiltration rates, low rainwater intake and probably higher runoff within the plots. Similar findings of low Ksat values in subsoiled plots than in non-subsoiled plots were observed by Karuma et al. (2011) in Machakos, Kenya. Moreno et al. (1997) found higher Ksat values in minimum tillage when compared to mouldboard ploughing and attributed this to different pore size distribution in the surface layer rather than changes in total porosity. Messing and Jarvis (1993) found lower hydraulic values in tilled soils during the growing season due to the structural breakdown and surface sealing and root growth that progressively blocked the pores. Green et al. (2003) reported that the effects of tillage on the soil hydraulic properties under different tillage treatments are not always consistent across locations, soils and experiment designs. The influence of tillage on hydraulic conductivity depends on the time of sampling, location and historical background of the field (Onstad and Voorhees, 1987; Mujdeci et al. 2010). Azooz and Arshad (1996) indicated that non stable structure of the soil structure after tillage, initial and final soil water contents, site history, time of sampling and potential for soil disturbance may result in inconsistencies in soil hydraulic conductivity, porosity and other physical properties. The pore stability and soil moisture conditions modified by tillage practices are the major features to absorb and transmit water at the time of measurement. There were no significant interactions observed among the cropping systems ($p = 0.925$).

Effect of tillage and cropping systems on crop performance

Maize height

Maize plant height varied significantly over time in all the three seasons ($p \leq 0.001$) (Table 3). The final plant heights obtained in the different treatments were greatly influenced by the amount of rainfall in a particular season and thus the soil moisture available to the crop. Plant height could be used as a measure of vegetative growth which sometimes reflects the amount of moisture available to the crops (Gicheru et al. 2004).

During LR 2012 season, the plant height was affected by tillage ($p = 0.002$), and a significant ($p = 0.014$) interaction of time × cropping system was noted. During the SR 2012 season, an interaction of time × cropping system was also observed at $P \leq 0.001$. During the LR 2012 season, tillage methods ($p = 0.002$) showed a trend of DPH > DP > OX > H > HTR while in the SR 2012, tillage, though not significant ($p = 0.246$) showed a trend where SR > DP > H > DPH > OX > HTR. The tillage trend during the LR 2013 season showed no significant ($p = 0.236$) interaction but a trend when DPH > H > DP > SR > OX > HTR was observed. The height difference could be attributed to soil moisture conservation in the former plots and moisture difference in the soil. This contrast the fact that HTR maintained higher moisture levels throughout the LR 2012 season and OX and SR during the SR 2012 and LR 2013 seasons. A probable cause of poor vegetative growth in the HTR plots was the inversion and mixing of top soil when constructing the tied ridges and this could have affected the fertility of the top soil. Khurshid et al. (2006) reported taller plants in conventional tillage plots in comparison with that of minimum tillage in Faisalabad, Pakistan.

Table 3 Maize yield parameters as influenced by seasons, tillage and cropping systems

Factor	No of cobs	Cob length (cm)	Cob weight (t ha^{-1})	Grain yield (t ha^{-1})	Biological yield (t ha^{-1})	Stover yield (t ha^{-1})	Harvest index (%)
Season (S)							
LR 2012	—	—	8.05	4.78	19.75	11.72	24.54
SR 2012	12.48	16.58	5.64	3.81	13.40	7.75	28.53
LR 2013	10.48	15.01	3.35	2.16	8.20	4.85	26.21
Tillage (T)							
H	11.06	15.84	5.45	3.51	12.76	7.31	27.67
HTR	11.12	15.22	5.03	3.23	12.76	7.72	25.58
DP	11.75	15.94	5.96	3.72	14.21	8.25	26.63
DPH	12.00	16.46	6.43	4.01	15.69	9.26	26.32
OX	11.06	15.39	5.52	3.43	13.58	8.06	25.64
SR	11.88	15.93	4.51	3.00	10.71	6.19	27.81
Mean	11.48	15.80	5.48	3.48	13.28	7.80	26.61
LSD (5 %)	0.618	0.976	1.321	0.774	3.27	2.014	2.109
Cropping system (C)							
Sole maize (M)	11.75	15.92	5.88	3.71	14.07	8.19	26.85
Intercrop (maize + bean)	11.21	15.67	5.20	3.31	12.79	7.59	26.22
LSD (5 %)	0.380	0.459	0.7551	0.4450	1.869	1.151	1.205
CV %	3.4	2.1	5.3	4.4	5.1	5.8	3.7

H = handhoe, HTR = handhoe + tied ridges, DP = disc plough, DPH = disc plough + harrowing, OX = ox-plough, SR = subsoiling-ripping, S = season, T = tillage, C = cropping system, (-) = not measured in that season

The sole maize crop had taller ($P \leq 0.001$) plants than the intercropped maize in all the seasons at the different weeks after planting (WAP). This can be attributed to no competition for water, light and nutrients with the beans (Vandermeer 1989). Increased plant height is advantageous because height is related to the final grain yield since maize stover can serve as a reservoir of labile non structural carbohydrates which are mobilized as sugars and translocated to the filling grains during post flowering period. The stems also serve as a role in maintaining the rate of grain filling against longer term effects of persistent post flowering stress such as drought (Edmeades and Lafitte 1993). This phenomenon was observed in the current study during the LR 2013 season as the maize seemed to produce very small or no maize cobs due to lack of evenly distributed rainfall during the growing season. There was too much rainfall at the start of the season and dry conditions set in which affected the growth of the crops (KMD 2013).

Cob weights

The maize cob weights were highly significantly ($p \leq 0.001$) affected by season, tillage and cropping system, season × cropping system ($P = 0.005$) and season × tillage ($p = 0.010$) as shown in Table 2. During the LR 2012 season, tillage methods showed a trend of DPH > OX > DP > H > HTR while during the SR 2012 season, DPH > DP > HTR > SR > H > OX. During the LR 2013 season, a trend of DPH > DP > H > SR > HTR > OX was observed. A three-season tillage average showed the trend of DPH > DP > OX > H > HTR > SR. These results showed that conventional tillage practices had the highest cob weights as compared to the conservation tillage.

Sole maize produced higher weights (8.51 t ha^{-1}) as compared to intercrop (7.59 t ha^{-1}), which resulted in a 10.8% decrease in cob weight by intercropping during the LR 2012 season. On average across the three seasons, sole maize produced 5.88 t ha^{-1} and the intercrop 5.20 t ha^{-1} resulting in an 11.6% decrease by intercropping. Higher yields in sole crops indicated the relative competitive effect of intercrops compared to sole cropping. The average cob weight during the LR 2012 season was higher (8.05 t ha^{-1}) compared to the SR 2012 with 5.64 t ha^{-1}. This results to a 30% decrease from the long rain season to the short rain season within the year and a 58 % decrease to the following season of LR 2013 (3.35 t ha^{-1}). Ear initiation and grain filling for maize was greatly affected by the poor rainfall distribution during the LR 2013 season (KMD 2013). Passioura and Angus (2010) stated that occurrence of drought at the grain filling stage of maize reduces the photosynthetic rate and impairs assimilate translocation in kernels leading to reduced maize grain yields.

Cob lengths

There was a seasonal effect ($p \leq 0.001$) as observed by the cob lengths (Table 2). Though not significant ($p = 0.157$), tillage showed a trend of DPH > SR > HTR > DP > OX > H during the SR 2012 season and during the LR 2013, DPH > H > DP > SR > OX > HTR. A two - season average showed a DPH > DP > SR > H > OX > HTR trend, with an average length of 15.8 cm. These results showed that the conventional tillage practices had the highest cob lengths as compared to the conservation tillage.

There were no significant ($p = 0.272$) interactions by cropping systems but sole maize had slightly higher lengths than the intercropped maize in both seasons. Sole maize had an average of 15.92 cm and the intercrop 15.67 cm. This may be attributed to the competition between beans and maize for the limiting soil nutrients. Turi et al. (2007) reported that the difference of ear length among maize genotypes is a genetic characteristic which is affected by the environment and inputs.

Maize grain and biomass yields

Grain yield is the important component of plant performance under a set of growing conditions. Any physiological or agronomic parameter at a given stage of growth would be of further use only when its effect is reflected on yield either way. Grain yield is a function of harvest index (HI) and dry matter production (Passioura and Angus 2010).

The maize grain yield was highly significantly ($p \leq 0.001$ affected by season, tillage and cropping system. A season and tillage interaction ($p = 0.03$) and cropping × season ($p = 0.004$) was also observed. During the LR 2012 season, the highest grain yield (5.35 tha^{-1}) was observed in DPH and the lowest (3.99 t ha^{-1}) in HTR. For the SR 2012 season, the highest grain yield (8.93 t ha^{-1}) was observed in DPH and the lowest (3.33 t ha^{-1}) in OX plots. During the LR 2013 season, the highest grain yield was in DPH (2.59 t ha^{-1}) and lowest in HTR (1.81 t ha^{-1}).

The biomass yields were affected by season ($p \leq 0.001$) and tillage ($p = 0.008$). During the LR 2012 season, the highest stover yield (14.44 t ha^{-1}) was observed in DPH and the lowest (10.04 t ha^{-1}) in H. For the SR 2012 season, the highest biomass (8.93 t ha^{-1}) was observed in the case of HTR and the lowest (5.72 t ha^{-1}) in subsoiling - ripping (SR) plots. During the LR 2013 season, the highest stover yield was in DPH (5.42 tha^{-1}) and lowest in OX (4.28 t ha^{-1}). There was a gradual decrease in biomass yield from the LR 2012 season to LR 2013 season and this may be attributed to the variation in rainfall which influenced soil moisture availability at the different stages of crop growth.

During the LR 2012 season, the DP plots had lower moisture levels at both soil depths but gave higher maize yields (4.92 t ha^{-1}) and above ground biomass yields (14.44 t ha^{-1}) indicating that there was efficient utilization of the soil moisture by the crops. HTR had high moisture levels due to the micro-basin formation allowing storage and infiltration but gave the lowest maize grain yields (3.99 t ha^{-1}). This contrasts the study by Gichangi et al. (2003) while working in a semi-arid highland area of Central Kenya who found that tied ridging increased maize and bean yields. Miriti (2010) while working in Makueni District also found that maize yield was higher by 55% in the tied ridging plots, which is in contrast to the findings of the current study.

During the SR 2012 season, the OX and SR plots had high moisture levels throughout the season but gave the lowest maize grain yields of 3.3 t ha^{-1} and 3.37 t ha^{-1} respectively. This is in contrast to studies done by Rockstrom et al. (2009) in Kenya and Tanzania that indicated superior maize yields with ripping tillage as compared to the conventional tillage. This difference may be partly because their studies used mulch cover which was not applied in the current study. Biamah and Nhlabathi (2003) while working over a period of four seasons in semi-arid Eastern Kenya reported that subsoiling and ridging increased maize yields and biomass by an average of 23% and 11% respectively. Although Pikul and Aase (2003) showed that infiltration was consistently greater under subsoiling compared to conventionally tilled plots with no subsoiling, the benefits of subsoiling were not obvious in the current study.

Intercropping of maize affected the grain yield and biomass yield (Table 2). The intercropping significantly ($p \leq 0.001$) reduced the three-season mean yields by 11% in maize grain and 7.3% in biomass respectively. Higher yields in sole crops indicated the relative competitive effect of intercrops compared to sole cropping. Maize yield reduction in intercropped maize compared to the sole maize reductions have also been associated with interspecies competition in mixed stands and the absence of interspecies competition in the monocrops (Vandermeer 1989). These yield variations also showed that rainfall differences in the long and short rains influenced soil moisture availability at different stages of crop growth. Although yields of maize were lower in the maize-bean intercrop, the fact that two crops could be harvested in the same plot, more than compensated for the higher yields realized in the sole maize cropping system. The intercrop system may be better and preferable to the small scale farmers due to the dual purposes of ensuring food and nutritional security, as the two crops are harvested in one season from the same land while at the same time improving soil fertility through biological nitrogen fixation by beans. The potential advantages of intercropping include over yielding i.e. improved utilization of growth resources by the crop and improved reliability from season to season (Orindi and Murrey 2005; Gitonga et al. 2008; Odendo et al. 2011).

According to GoK (2010), the average maize yield is about 2 t ha^{-1}; however, potential yields of over 6 t ha^{-1} are possible through the increased use of improved seed varieties fertilizer and crop husbandry practices. On average, the grain yield from all the treatments was 4.78 t ha^{-1} during the LR 2012 season, 3.81 t ha^{-1} and 2.16 t ha^{-1} during the LR 2012, SR 2012 and LR2013 seasons respectively. This decline in yields over the seasons could be attributed to the rainfall distribution which varied in each season. This implies that environmental factors play an important role on productivity of maize. The maize seed used was DH 02, an early maturity (80 - 90 days), dryland hybrid that is drought tolerant, resistant to stem borers and adapted to low levels of nitrogen and thus performs better in semi-arid areas such as Mwala sub-county (Kenya Seed Company 2012). Thus considering the effects of a given environmental situation to maize production is too crucial in addition to crop and soil management practices.

Maize harvest index (HI)

The HI data presented in Table 2, shows there was a seasonal difference ($p \leq 0.001$) with the highest HI in SR 2012 (28.5 %). The trend by tillage was in the order of SR > H > DP > DPH > HTR > OX. Intercropping systems produced lower yields as compared to the monocrops. This is attributed to the resource competition of water and available nutrients in the soil by the two crops. It could also be attributed to soil moisture differences between the long and short rains as influenced by the rainfall amounts. According to Maobe et al. (2010), the magnitude of the maize harvest index is not highly heritable and varies with season, management and environment. A good HI is about 40 % (Passioura and Angus 2010) and this was not achieved in this study. Failure of treatments to impact on the maize HI in the seasons could be attributed to poor distribution of rainfall at the grain filling stage. Crops that have poor water supply during grain filling may produce a large biomass but be unable to match that with a good harvest index (Passioura and Angus 2010).

Bean grain and biomass yields

The seasonal effects on bean grain yields, biological and biomass yields are shown in Table 4. The biomass yields were affected by tillage ($p = 0.046$) where the trend was in the oreder DPH > HTR > SR > OX > DP > H while for grain yield ($p = 0.057$) DPH > DP > HTR > SR > OX > H. During the LR 2012 season, the highest grain yield was observed in DPH and the lowest in handhoe (H). For the SR 2012 season, the highest grain yield was observed in the HTR plots and the lowest in handhoe (H). The mean seasonal grain yields was 0.43 t ha^{-1} during the LR 2012 season and 0.92 t ha^{-1} and 0.92 t ha^{-1} during the LR 2011 and SR 2012 season respectively. No bean yield data was recorded during the LR 2013 season due to poor rainfall distribution and prolonged drier conditions during the growing season (KMD 2013).

During the LR 2012 season, the highest biomass yield was observed in DPH and the lowest in H. For the SR 2012 season, the highest biomass was observed in the HTR and the lowest in the hand hoe (H) treatment. There was a gradual increase in biomass production from one season to the next indicative of variability in seasonal rainfall patterns.

Intercropping affected the grain yield and biomass yield (Table 4). Sole bean produced a grain yield of 0.69 t ha^{-1} and biomass of 1.9 t ha^{-1} as compared to 0.7 t ha^{-1} and 1.87 t ha^{-1} of the intercrop respectively. Yield advantages from intercropping as compared to sole cropping are often attributed to mutual complimentary effects of component crops, such as better total use of available resources (Vandermeer 1989). The greater canopy cover provided by maize-bean intercrop helps reduce evaporation, regulate the soil temperature thereby improving infiltration and therefore reduces the wastage of available water (Steiner 2002).

Table 4 Bean yield as affected by season, tillage and cropping systems (n = 2 seasons)

Factor	Bean yield (t ha^{-1})	Biological yield (t ha^{-1})	Biomass yield (t ha^{-1})	Harvest index (%)
Season (S)				
LR 2012	0.427	1.31	0.884	30.30
SR 2012	0.921	3.64	2.723	25.59
Tillage (T)				
H	0.509	1.99	1.477	25.79
HTR	0.756	2.86	2.109	28.84
DP	0.766	2.52	1.751	30.21
DPH	0.788	3.03	2.237	27.52
OX	0.646	2.41	1.765	27.39
SR	0.730	2.81	2.083	25.52
Mean	0.696	2.58	1.887	27.73
LSD (5 %)	0.3184	1.214	0.9565	6.297
Cropping system (C)				
Sole bean (B)	0.690	2.59	1.903	28.68
Intercrop (maize + bean)	0.703	2.57	1.872	26.78
LSD (5 %)	0.1786	0.6811	0.5366	3.533
CV %	23.6	20.0	19.1	8.6

H = handhoe, HTR = handhoe + tied ridges, DP = disc plough, DPH = disc plough + harrowing, OX = ox-plough, SR = subsoiling-ripping, S = season, T = tillage, C = cropping system

Conclusion and Recommendations

Soil water conservation has become an important issue during land preparation and crop growth due to climate change, effects on the amount of rainfall and the rainfall seasons. The results obtained in this study suggest that tillage methods and cropping systems have an influence on soil moisture conservation and crop yields in the semi-arid areas of Kenya. Among the tillage treatments, disc plough and harrowing (DPH) and disc plough (DP) were found to be more appropriate in improving crop yields and yield components of maize and beans. Inconsistencies in relative grain and biomass yields observed among the tillage treatments are likely to be associated with the amount of soil moisture at the time of tillage/planting, growing season and prevailing climatic conditions during the growing seasons. The inconsistencies in tillage experiments are due to the complexity of changes in soil properties caused by tillage. Therefore, it is necessary to examine the long-term effect of tillage practices at similar locations and under similar environmental and soil conditions so that more accurate generalizations can be made regarding the conditions required for sustainable tillage systems. Sustainable tillage practices are imperative for the sustainable development of our semi arid areas by enhancing their agricultural productivity and hence improve on livelihoods.

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Chapter 8

Effect of Tillage and Leguminous Trees on Soil Organic Carbon and Infiltration Rates in the Semiarid Region of Kibwezi, Eastern Kenya

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Abstract

Soil organic carbon is important in amending soil physical properties that affect rainwater infiltration into the soil. The inclusion of leguminous tree species and improved tillage practices can play an important role in achieving this. This study was carried out in Masongaleni location, Kibwezi district of the semi-arid Makueni County. The main objective was to determine the soil organic matter content and infiltration rates under different tillage practices and different leguminous tree species. The tree species were *Gliricidia sepium, Tephrosia candida* and *Faidherbia albida* while the tillage practices were: zero tillage, planting basins, ridging and ploughing. These treatments were in field plots measuring 20 m x 20 m and arranged in a Randomized Complete Block Design with three replicates. Results showed that plots with planting basins and zero tillage with *G. sepium* had mean infiltration rate of 21.88 and 16.88 cm hr^{-1} respectively. Plots under planting basins and zero tillage had significantly ($p=0.002$) higher soil organic carbon content than those under ridges and ploughing. The study recommends a combination of reduced tillage practices such as planting basins and zero tillage with tree species such as *Faidherbia albida* and short rotation tree species such as *Gliricidia sepium* instead of either tillage and tree species adopted in isolation. This is because *Gliricidia sepium* can be managed by frequent coppicing for early fertility build up while *Faidherbia albida* maintains fertility with minimum coppicing when mature. This will be beneficial for soil improvement, improved water infiltration and soil moisture content.

Key words: Infiltration, leguminous trees, soil organic carbon, tillage

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Introduction

Land is a non-renewable resource. The pressure exerted on land today to increasing population has led to degradation, a serious problem in most tropical countries. Poor and inappropriate land management practices result in rapid land degradation, massive soil loss, declining yields, deforestation, the disruption of water resources and the destruction of natural pastures (Nabhan et al. 1999). Drought, combined with the different forms of land degradation is seriously contributing to considerable decline and loss in food production thus increasing levels of food insecurity in the arid and semi-arid regions (Nabhan et al. 1999; Hernandez 2002). Decreasing rainfall in these arid regions implies worsening food shortages if the current farming practices do not improve (Nyamadzawo et al. 2013). These regions are often the most hit and vulnerable to erratic rainfall make crop production very difficult because water losses and the available water may not be adequate to sustain crop production. This calls for putting in place mechanisms that encourage water storage and conservation are put in place. Soil and water loss can seriously deplete land resources and degrade the eco-environment (Hui and Mingan 2000). Further, conservation of soil, water and nutrient through erosion control and fertility improvement should be taken into consideration in all land management systems (Young 1986).

Soil water scarcity is not only common to the arid and semi-arid regions but also in the humid tropics where poor rainfall distribution within the growing season and reduced infiltration rates lead to low moisture availability to plants, thus inducing water stress to crops (Wild 1984; Osuji et al. 2010). Conventional tillage practices based on plant residue burning and clearing usually encourages loss of soil organic matter and water. Soil organic matter is an important parameter that affects the physical, chemical and biological activity of the soil. It makes immense contribution towards the productivity of the soil. Soil organic matter contributes towards improved soil water holding capacity, provides nutrients to the soil and helps the soil to maintain good tilth, thereby improving aeration for seed germination and plant root development (Zia et al. 1994).

Water has always been the major limiting factor to improved land productivity in semi arid regions. In these areas, water capture and its conservation are important activities as they interlink nutrient cycling and primary production

(Safriel et al. 2005). The demand for water in agricultural production has been on the rise due to reduced and erratic rainfall, extra cropping seasons and farm enterprise diversification. However, opportunities of capturing and storing rain water in the soil are lost due to compacted soils leading to high water runoff. Water conservation can however be improved through soil management strategies which can be attained by practicing conservation agriculture among other agronomic practices (Gicheru et al. 2004).

Inappropriate tillage practices based on the plough and hand hoe digging lead to loss of soil organic carbon and destruction of soil structure which in turn affects soil water holding capacity and consequently plant growth (Nyamadzawo et al. 2008b; Thierfelder and Wall, 2009). Various farming activities that have been adopted in agriculture affect infiltration rates in different ways. One of the common effects is soil compaction that leads to the creation of a hard pan. Compacted soils often have low infiltration rates which accelerates rain water loss through run off. Soil organic matter is a component that can directly and indirectly affect soil productivity. Promoting improvement of soil carbon levels to turn around the falling farm productivity should be an important factor to consider.

In the dry lands of Africa, overcoming the impacts of dry spells through proper management of the soil and rainwater is important. Among the potential solutions, agroforestry, particularly practices involving multipurpose rotation legume trees and shrubs, has emerged as a low-investment option for conservation of resources and sustaining production (Narain et al. 1992; Grewal et al. 1994). Studies have shown that agroforestry practices lead to increases in soil organic carbon status of surface soil and this can be achieved by planting trees with different pruning regimes (Samra and Charan 2000; Newaj et al. 2008). Newaj et al. (2008) also observed that soil organic carbon increased by 13-16% under agroforestry production systems relative to sole tree or sole crop production systems. This is because most trees selected and used in agroforestry systems are suitable for eco- friendly conservation and rehabilitation of degraded lands. While tree-crop interactions can have both positive and negative effects on the structure and functioning of the agro-ecosystems (Garcia-Barrios and Ong 2004; Ong 1995), the interaction between legume trees and crops has produced positive results that benefit the crop and livestock components of the farm.

The inclusion of rotation legume trees on croplands can improve soil structure, infiltration and fertility through provision of leaf litter. Schroth and Sinclair (2003) concluded that litters that fall to the ground play a vital role in enriching the soil fertility through organic matter content. This is because litter fall forms an important constituent of nutrient and carbon cycling and also contributes to the formation of an important protective layer on the soil surface. This helps lessen land degradation processes thus enhancing productivity. This study aimed at examining the effect of leguminous tree species and tillage practices on total organic matter in a semi-arid region. The effect of soil organic matter, bulk density and total porosity as influenced by the tillage practices and tree species on water infiltration were also tested.

Materials and Methods

Site description

This study was conducted at Masongaleni location which is about 22 km south-east of Kibwezi town in eastern Kenya. The area falls in a semi-arid zone and experiences a bimodal pattern of rainfall; with the long rains falling in March to May and short rains in October to December (Musimba et al. 2004). The short rains are more reliable for crop production than the long rains. In total, the area receives less than 500 mm of rainfall per annum. Mean temperatures range from 20.2 to 24.6 ^{0}C but temperatures as high as 32 ^{0}C have been recorded during prolonged drought periods.

Experimental design and layout

The experimental design was a randomized complete block design with three replicates of the treatment combinations. The treatments comprised four tillage practices: planting basins, zero tillage, ridges and ploughing and three tree species: *Gliricidia sepium* [Kunth], *Tephrosia candida* DC and *Faidherbia albida* [Delile A.chev] planted in October 2009 in plots measuring 20 m × 20 m in the study site. This study was conducted between the months of February and August in 2012. Nine (9) farms located in three locations were selected. Three (3) farms per locations were used in the study.

Each tillage practice had a plot with one single tree species, replicated thrice. With four tillage practices and three tree species, this resulted in a treatment combination of twelve treatments. *Gliricidia sepium* and *Tephrosia candida* were planted in different plots at 2 m × 1 m spacing. With proper maintenance of the trees during their growth and at coppicing, this spacing results in tree population of 5,000 trees ha^{-1}. At the time of the study, not all plots had this plant population. Tree head count recorded 60-80% trees stand in the selected farms. *Faidherbia albida* trees were planted at 5 m × 5 m giving plant density of 200 trees per hectare. *G. sepium* was coppiced once a year to a height of 50 cm above the ground just before the onset of the long rain season. Light pruning of *T. candida* was done to avoid re-growth problems because the species is not known to re-grow after cutting.

Rectangular shaped planting basins with a length of about 30 - 35 cm and width of about 10 - 12 cm (based on the width of the hoes that were used during land preparation) were prepared using hand hoes to a depth of about 20 - 25 cm plot. This depth was used to help break any compacted layers below the soil surface. The basins were made in rows spaced at 70 cm (0.7 m) between rows and 50 cm (0.5 m) between basins in each row giving a total of 1143 planting basins in a 20 m × 20 m plot. Under zero-tillage, no soil disturbance was done during planting. The seeds were drilled directly into the soil using machetes or *'pangas'*. In plots with planting basins and zero tillage, the plant residues and coppiced legume tree biomass were returned on the ground as mulch. Ridges were constructed using hand hoes by splitting the ridges from the previous season. This is because farmers have always used ridges in their field from one season to another for improved soil moisture retention and erosion control, especially where ridge height was well maintained. Plant residue and coppiced tree biomass were incorporated under the new ridge.

Data collection

Soil organic carbon determination

The coppicing of tree was done just before the onset of the more reliable short rains of October - November farming season. The trees were coppiced to about 50 cm height to allow for re-growth. Light coppicing of the over grown trees was done just before the onset of the March-April long rain season. However, to allow for more biomass accumulation, coppicing was done once a year. Soil samples for total organic carbon determination were collected from quadrants of about 100 m^2 drawn in each plot. The soil samples were collected randomly from three points within each quadrant.

The sampling depth was 0 - 30 cm. The soil samples collected were used to constitute a composite sample from which three soil samples were then taken and analyzed for total organic carbon using the Walkley and Black (1934) rapid titration method.

Measurement of infiltration rate

A double ring infiltrometer method as described by Bertrand (1956) was used. Two infiltration test runs were carried out in each replicate. For plots with ridges, the measurements were done on the ridge and for planting basins, in the basin. Stover or litter was cleared from 1.5 x 1.5 m^2 area and metal rings (dimensions: 30 cm diameter of inner ring , 60 cm diameter of outer ring and 50 cm height for both rings) were driven vertically into the soil to about 15 cm so that the smaller ring was centered in the larger ring, using a mallet hammer. Both cylinders were filled with water to a height of 20 cm with a measuring rule hanging in the middle to measure changes in water levels due to infiltration. The observations for infiltration rate were carried out on the inner ring using a measuring gauge and a stop watch. A double-ring infiltrometer minimizes the error associated with lateral divergence of water. This is because water in the outer ring flows laterally while in the inner cylinder the movement of water is vertically. The water level in the outer ring forces vertical infiltration of water in the inner ring. The change in water level due to infiltration was taken at time intervals of 5, 10, 20, 30 and 45 minutes. The cylinders were refilled once the water level in the inner cylinder had dropped to about 5 cm on the measuring rule due to infiltration, and the measurement continued to be taken. The process was stopped once there was no further infiltration observed. Cumulative infiltration was calculated from adding the water infiltration readings over time.

Data analysis

The data obtained was subjected to analysis of variance, correlation and regression analysis using Genstat 13th Ed. Post hoc analysis using the LSD was used for separation of mean.

Results

Effects of tillage on soil carbon

The amount of soil organic matter under the different tillage practices are shown in Table 1. Total organic carbon significantly (P=0.002) varied under different tillage practices. Plots managed under planting basins and zero tillage had significantly higher soil organic matter than ploughed plots. Plots with planting basins had 104.9% more carbon than plots where ploughing had been done. Zero tillage plots had 121.3 and 22.7% more soil carbon compared to plots that were subjected to ploughing and ridges, respectively. On the other hand plots maintained under ridges had 69.2% more soil carbon than plots that had been ploughed while planting basins had 13.25% more soil carbon than that which was measured in ridges. Of all the four tillage practices, planting basins had the least amounts of soil carbon while zero tillage had numerically the highest amount followed by planting basins.

Table 1 Effects of tillage practices on soil total organic carbon

Tillage Practice	Soil organic carbon (%)
Planting basins	1.25a
Zero tillage	1.35a
Ridges	1.10b
Ploughing	0.61c
LSD	0.127

Means with the same superscript letter are not statistically different at P = 0.05

Effect of tree species on soil carbon

The amount of organic carbon added to the soil by the three different fertilizer tree species were significantly different (P=0.032) (Table 2). The amount of organic carbon measured under plots managed with *F. albida* was more as compared to the other two tree species. There was 3.96% more carbon in plots with *F. albida* than *G. sepium* and 15.92% more than in plots with *T. candida.* There were however no statistical differences in the amount of organic carbon measured under plots with *F. albida* and *G. sepium* and those under *G. sepium* and *T. candida. F. albida* was superior in term of organic carbon returns.

Table 2 Influence of tree species on soil total organic carbon

Tree species	Soil organic carbon %
G. sepium	1.26^{ab}
T. candida	1.13^{b}
F. albida	1.31^{a}
LSD	0.137

Means with the same superscript letter are not statistically different at P = 0.05

Interaction between tree species and tillage practices

The amount of soil organic carbon (SOC) was highly influenced by the interaction of the tree species and tillage practices (Table 3). Plots with planting basins and zero tillage had significantly higher soil organic carbon levels than plots that were managed under ridges and ploughing (p = 0.002).

Table 3 Influence of the interaction between tree species and tillage on soil organic carbon (0 - 30 cm)

Tillage	Tree species			
	Gliricidia sepium	Tephrosia candida	Faidherbia albida	Average (Tillage)
Planting basins	$1.30^{a,x}$	$1.23^{a,x}$	$1.28^{b,x}$	1.27^{x}
Zero tillage	$1.33^{a,x}$	$1.12^{ab,y}$	$1.35^{a,x}$	1.26^{x}
Ridges	$1.14^{b,x}$	$1.01^{b,y}$	$1.11^{c,xy}$	1.08^{y}
Ploughing	$1.01^{c,x}$	$0.81^{c,y}$	$0.51^{c,z}$	0.77^{z}
Average (Trees species)	1.195^{a}	1.043^{b}	1.063^{b}	
LSD		0.12		

Superscripts letters a, b and c down the column compares same tree species under different tillage practices while letters x, y and z along the row compares same tillage practice but under different tree species.

Under *G. sepium* tree cropping system, zero and planting basins practices had higher total organic carbon than plots that were ploughed. *Gliricidia sepium* had a mean of 1.195% soil organic carbon across the tillage practices and was the best performing legume tree species in terms of soil organic carbon build up with frequent coppicing. There were no significant differences in the overall mean in amount of soil organic carbon between *T. candida* and *F. albida.* Plots with planting basins and zero tillage had the highest soil organic carbon content recording 1.27 and 1.26% respectively while the ploughed plots had the least amount.

Infiltration rate

The tree species and tillage practices significantly influenced soil water infiltration rates ($p<0.01$). Infiltration rates were significantly higher in plots with *G. sepium* and planting basins recording a mean infiltration rate of 21.88 and 16.88 cm hr^{-1} under zero tillage. *T. candida* with zero tillage had 16.36 and 13.3 cm hr^{-1} with planting basins (Figure 1). The least infiltration rate and the quickest in the drop for the infiltration curves were observed under plots that were maintained under ploughing. The infiltration rates in all ploughed plots were far much lower as compared to others with similar trees species.

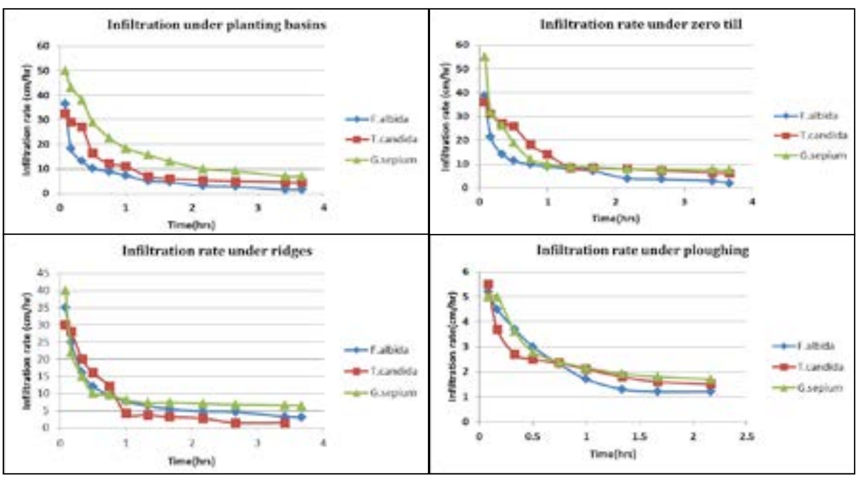

Figure 1 Infiltration rate under different legume tree species and tillage practices

Cumulative infiltration

The results showed that plots with planting basins and *G. sepium* retained 202.57 mm of water in the first 3.67 hrs. The same plot with *T. candida* and *F. albida* as the tree species had 150 and 132 mm of water after 3.67hrs respectively. On the other hand, plots with zero tillage with *G. sepium* tree species accumulated 262.5 mm. Those under zero tillage with *T. candida* and

F. albida had 173.1 mm and 150 mm respectively. On comparative terms, zero tillage plots had more water accumulation as compared to planting basins (Figure 2). Water accumulation was least in plots that had been ploughed and this was reflective of the quick drop in infiltration rate (Figure 1) that was noticed in ploughed plots. The highest amount of cumulative infiltration was in plots with *G. sepium* which had 27 mm recorded after about 2 hours and the least was in plots that had *F. albida*. As shown in Table 3, organic carbon may have played a major role in water retention and overall cumulative infiltration in these plots.

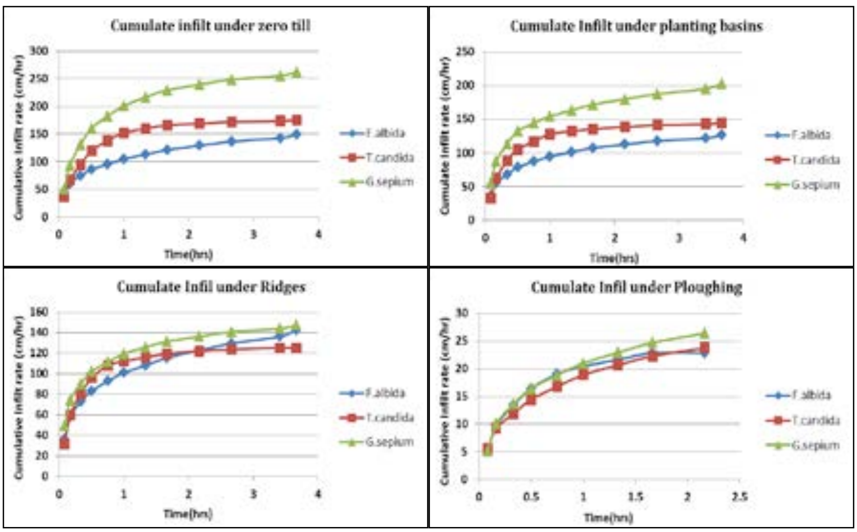

Figure 2 Cumulative infiltration rate under different legume tree species and tillage practices

Regression and Correlation Analysis

When the infiltration rate was regressed over soil organic carbon, bulk density and total porosity, soil organic carbon accounted for most of the variation in infiltration rates in the study sites. (Table 4). A correlation analysis between organic carbon and infiltration rate showed that there is a very strong correlation ($r=0.82$, $p< 0.002$) and that organic carbon accounts for about 79% ($r^2 = 0.79$) of the total variation (Table 4).

Table 4 Correlation and regression analysis of infiltration rate against organic matter, bulk density and total porosity

Soil property	r	r^2	Regression line
Organic carbon	0.82	0.79	IR=35.5+143 SOC
Bulk density	-0.67	0.62	IR=66.5-40.134 BD
Total porosity	0.73	0.7	IR=-159.56+24.7 TP

IR= Infiltration rate, SOC=Soil Organic Carbon, TP= Total porosity, BD=Bulk density

On the contrary, bulk density had a negative correlation with infiltration rate and that every unit increase in bulk density reduces infiltration by about 40.13 units. This means an increase in bulk density has a negative influence on infiltration rate in that the soil porosity reduces hence closing up the pore through which water cannot move.

Discussion

Effect of tillage practices, trees and their interaction on soil organic carbon

The increased total organic carbon observed in this study could be attributed to increased litter fall by the trees providing biomass and suitable microclimate that could have increased biological activities (Schroth and Sinclair 2003). Practices such as planting basins and zero tillage have a positive impact on soil carbon content because carbon loss from the top layers of the soil is slowed (Angers et al. 1992; Rasmussen et al. 1998; West and Marland, 2002; Kennedy and Schillinger 2006). The results confirm that bringing together the aspects of conservation tillage and agroforestry can help in enhancement of soil organic carbon and fertility.

The additions of plant material to the ground through coppicing or leaf fall play a vibrant role in enriching the soil with organic matter. The materials are decomposed and released as soil nutrients important for plant growth and development. The presence of plant litter on the ground returned as mulch also helps protect the soil surface from the direct impact of raindrops (Benkobi et al. 1993; Geddes and Dunkerley, 1999; Franzluebbers, 2002). The presence of litter on the ground also decreases the destruction of aggregates and separation of fine particles by raindrop impact thus reducing soil surface compaction and sealing which consequently prevents water losses through run-off (Morgan, 1995; Marshall et al. 1996). On the other hand, conservation tillage management with surface residue accumulation has been shown to reduce soil erosion by buffering the soil surface against rainfall impact (Langdale et al. 1992). All these play an important role in soil stabilization and easy water movement in the soil.

The results of soil organic carbon content under *F. albida* treatment shows that at 3.5 years, the trees did not accumulate sufficient biomass to alter the soil organic carbon. However, significant changes in organic carbon content and soil fertility have been observed in mature trees with results showing that nine year old *F. albida* trees supplied 150 kg ha^{-1} of nutrients and 100 kg ha^{-1} of lime to the soil (Okirio, 1992; GART, 2007). This means *F. albida* is good for long term soil fertility amendment. The results also show that *Gliricidia sepium* performed relatively well in plots that were managed under reduced tillage. There was 1.30 and 1.33 % soil organic carbon under planting basins and zero tillage respectively. The least amount of soil organic carbon was 1.04% recorded under plots that were ploughed and incorporated with T. candida tree species. *F. albida* had 1.35% soil organic carbon in zero tillage plots while the same had 1.28% in plots with planting basins and 1.11% in ridges.

More soil organic carbon accumulated in plots with planting basins and zero tillage practices than in plots that had been subjected to ridging and ploughing. These results agree with those of Gadermaier et al. (2011) who observed that soil organic carbon was higher in reduced plots than under conventional tillage under organic farming systems. They also observed that reduced tillage caused stratification of soil organic carbon, microbial properties and soil nutrients in the soil profile. High levels of soil organic matter are desirable for sustaining crop productivity (Doran et al. 1998) and maintaining the soil resource base because they are strongly linked to soil fertility (Carter, 2002). Low organic matter levels make the soil more susceptible to compaction (Wortman and Jasa 2003) thus affecting water infiltration, retention and storage.

Infiltration rates and cumulative infiltration

In plots with planting basins, the drop in infiltration rate was rapid under *F. albida* and *T. candida* species (Figure 1). The rate dropped from 36.5 cm hr^{-1} to the final rate of 3.53 cm hr^{-1} and from 32.4 cm hr^{-1} to 2.7 cm hr^{-1} respectively. High infiltration rates were observed in plots that were maintained under reduced tillage practices (planting basins and zero tillage) with tree species such as *Gliricidia sepium.* This is advantageous and shows the importance of including trees in the farming system and reducing heavy machine or hand hoeing especially during land preparation. By reducing tillage to the minimum, time spent in doing land preparation is reduced and farmers are able to save money instead of spending it on heavy duty machinery for land preparation. The use of leguminous species on the other hand can lead to reduction on the over reliance on chemical fertilizers. In areas such as the semi-arid regions of Kenya, low infiltration rates have often resulted in high water losses due to increased runoff volume. This can in the long run reduce the water storage capacity in the soil. The difference in the cumulative infiltration results observed among the treatments in this study suggests that the incorporation of trees in croplands can impact on the hydrological differences in the soils. The trees can impact on the soils' ability to infiltrate water or be prone to run-off and erosion.

Improvement of water infiltration and thus cumulative infiltration in these semi-arid soils is important. This can be achieved through agricultural practices that increase soil organic matter and reduce soil disturbance and compaction (Ahaneku 2011). The combination of reduced tillage practices and leguminous trees species resulted in increased amounts of soil organic carbon and water infiltration into the soil. The least infiltration rates were observed in conventional tillage plots which had a mean rate of 2.93 cm hr^{-1} with *G. sepium* and 2.64 cm hr^{-1} under *T. candida*.

For this area, rainfall is the main source of water on which crop production depends. Loss of water due to runoff as a result of reduced infiltration needs to be minimized. The incorporation of fast growing legume trees combined with reduced tillage practices enhance water infiltration into the subsoil and this is achieved by holding the more permeable topsoil together. Sileshi et al. (2011) in their studies concluded that the integration of legume trees into cereals croplands and supplementation with inorganic fertilizers increased rain use efficiency. Osuji et al. (2010) also observed that intensive tillage practices such as ploughing during land preparation is often accompanied by changes in the intrinsic properties such as compaction of the soil which leads to creation of a hard pan that reduces water infiltration significantly.

The results across the tree species showed that plots that had been ploughed resulted in both low infiltration rate (Figure 1) and low cumulative rate of water in the soil (Figure 2). This could be the reason for excessive runoff usually experienced in such plots. Infiltration is extremely important because it determines the amount of water that will enter a soil and dissolved chemicals or nutrients in it (Kirkham 2005). It also controls leaching, runoff, and crop water availability (Franzluebbers 2002). Thus infiltration is significant in determining soil water storage (Lampurlanés and Cantero-Martínez 2006). By reducing tillage practices to the minimum and incorporating legume tree species, greater infiltration of water into the soil profile can be achieved by slowing runoff and concentrating the water into the soil. This will result in increased soil moisture levels which ultimately result in improved moisture conditions for plant growth.

Conclusion and Recommendations

The results from this study show that fields managed under planting basins and zero tillage practices had an increase in the amount of soil organic carbon content as compared to those under ploughing and ridges. The incorporation of leguminous trees also showed capacity for improving infiltration and increasing soil available water through organic matter build up. In combining reduced tillage practices with leguminous trees, the little rain that falls in the semi-arid areas can be put to effective use by enhancing rainfall penetration into the soil and thus soil conserving adequate soil water for plant growth. To accumulate soil organic carbon, and thus fertility, farmers may choose to establish a combination of short rotation species such as Gliricidia sepium that are managed by frequent coppicing for early fertility build up with *Faidherbia albida* which maintains fertility with minimum coppicing when mature. It can therefore be recommended that lands that have deteriorated in soil fertility can be returned back to productivity if leguminous trees such as Gliricidia sepium are incorporated into reproduction system. This will contribute to organic matter build-up and improve water infiltration which will enhance faster rehabilitation.

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Chapter 9

Spatial Modeling of Sorghum Growing Areas in Kenyan Arid and Semi-Arid Lands

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Abstract

Sorghum *(Sorghum bicolor L.)* is an important African cereal crop and is listed among Africa's lost crops but is now gaining popularity as other cereals are declining in production due to adverse effects of climatic change. To promote food security, many researchers and policy makers are shifting the focus to production of sorghum. In Kenya, sorghum is primarily grown in arid and semi-arid areas whose suitability is based on climatic factors but the extent of the suitable growing areas is not known. This paper modeled the potential sorghum growing areas of current and projected to 2050 and 2080 climatic periods. The sorghum location data were downloaded from GENESYS and Kenya Agricultural Research Institute (KARI) while climate data was obtained from world climate database website. Analysis was done using MAXENT and DIVA-GIS software. The model generated an area under curve of 0.97 and the suitable areas in the future are shown to expand in both 2050 and 2080 climatic periods though not in same magnitude. The main variables contributing more than 10% of change in suitability areas in decreasing order are precipitation of wettest period, temperature seasonality, precipitation of warmest quarter, and precipitation of driest month. The generated information will guide the policy makers and stakeholders in making informed decisions with regard to the efforts of re-introduction and promotion of sorghum production in arid and semi-arid lands.

Key words: *Sorghum bicolor;* climate change, spatial modeling, arid and semi-arid lands

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Introduction

Sorghum *(Sorghum bicolor L.)* and several other cereal crops are important for food security in sub-Saharan Africa. Crop production in Kenya has been steadily declining (FAO 2013) and wheat, rice and maize is expected to decline by between 0 to -2.5% by 2020, -2.5 to -30% by 2050 and -5 to -30% by 2080 respectively compared to 1990 (Parry et al. 2004). Such declines in maize production have been linked to unpredictable rainfall and drought and adverse consequences of climate change (Meehl et al. 2007). This has led to efforts towards development of new cereal germplasm with high water use efficiency and tolerance to drought, which can withstand the effects of climate change (Twomlow et al. 2008). The newly introduced by Kenya Agricultural Institute (KARI) Gadam sorghum variety is performing well at 3880 kg ha^{-1} (Esipisu 2013) in Kitui, compared to older varieties with an average yield of 850 kg ha^{-1} in Africa and 1000 – 3000 kg ha^{-1} in eastern Kenya counties of Kitui and Machakos (Muui et al. 2013). This newly introduced sorghum variety is complementing other cereals which are failing in the face of climate change (FAO 2013).

Sorghum is relatively tolerant to drought (FAO 2013; KARI 2013) making it a primary candidate for cultivation in Arid and Semi-Arid Lands (ASALs) that are highly vulnerable to adverse effects of climate change. Further, sorghum is currently gaining popularity in Kenya due to its adaptability to different climates, failure of other crops, and its new industrial uses in beer production. Consequently many researchers and policy makers are shifting their efforts towards production of sorghum both at small-scale and large-scale levels. In Kitui, for example, farmers can only manage to supply 2080 metric tons against a demand of 40000 metric tons from East African Breweries Limited (Esipisu 2013). A large germplasm collection of sorghum comprising more than 42000 accessions has been developed (Huang 2004). As stakeholders take up the production of sorghum, it is important to map areas that are climatically suitable for sorghum cultivation at present and in the future.

A number of studies have been done on spatial species distribution modeling, using either one method or a comparison of different methods. Many studies conducted on climate change and its impacts on plant and animal communities have produced varied conclusions. KNMI (2006) used 12 models to investigate changes in precipitation using runs forced with Special Report Emission Scenario (SRES) A1B scenario. The research concluded that Kenya would experience elevated precipitation under global warming. KNMI (2007) indicated that there will be variations in climate observed in Kenya by the year 2100. The report contains different precipitation variations from different models and green house gases emission scenarios. In the north-western, northern and coastal districts an improvement in precipitation is projected in the year 2100 short rain events. Ward (2007) used DOMAIN, MAXENT and BIOCLIM to model the potential geographic distribution of six invasive ant species in New Zealand. The research concluded that unlike DOMAIN and MAXENT, BIOCLIM performed poorly with low AUC (Area Under Curve) and higher omission errors. Similar studies have been undertaken by CIAT (2011) that focused on climate change influence on tea growing areas in Kenya. This study observed that there will be a decrease in suitable tea growing areas in Kericho and Nandi districts and expansion of the same in Central Kenya districts by the years 2020 and 2050. Kigen et al. (2013) who studied climate change impact on the Grevy's zebra habitat concluded that there will be a significant habitat expansion in the year 2080 climatic period. The model's AUC was 0.984 and the key variables contributing more than 2% were isothermality, precipitation of coldest quarter, annual mean temperature, annual precipitation, minimum temperature of coldest period and precipitation of wettest quarter. A study in South East Asia on the impacts of climate change on pine distribution using MAXENT and DIVA GIS software concluded that the spatial distribution of pine will change with climate by the year 2050. The pine populations, especially in China, Cambodia and Thailand, are under threat (Zonneveld et al. 2009). They further discovered that areas with potentially new pine niches cover the Malay Archipelago. The key environmental variables in the output model were annual temperature, maximum temperature, temperature seasonality, annual precipitation and precipitation in the driest quarter.

Pearson and Dawson (2003) in their studies recommended the use of Climate Envelope Modeling (CEM) in species distribution studies. Climate Envelope Modeling (CEM) and spatial analysis tools were used in estimating the current and future distribution of sorghum growing areas. The model uses geo-referenced growing areas and nineteen climatic variables (Philips et al. 2005). Other researchers have used the Geographical Information System (GIS) in their studies and have recommended its application in similar studies (Hulmen et al. 2001). This is because GIS applications are easy to use, integrate a lot of information and do complex analyses. Outputs of GIS are maps showing sorghum suitability growing areas under different climatic conditions. Limited research on climate impacts modeling has been done in Kenya. In view of the anticipated climatic variations, this paper modeled potential areas of growing sorghum currently, and the projection for the years 2050 and 2080 with an objective of identifying areas suitable for growing sorghum. The generated information is useful in determining how climate change will affect the suitability of ASALs for sorghum production and on the regions that require special focus.

Methodology

Data sources and processing

Data were sourced from different published materials. The sorghum location data were sourced from GENESYS website (www.genesys-pgr.org) and from published material of Kenya Agricultural Research Institute website (www.kari.org). From these data, 82 geo-referenced points were selected in sorghum growing ASALs. The current, projected year 2050 and 2080 climate data with a resolution of 5 km were downloaded from Global Climate data website (www.worldclim.org). The future climate data is under CCM3 A2 carbon dioxide emission scenario and contain annual precipitation, and minimum and maximum temperature. Using DIA-GIS, climate data was used to generate other sixteen climate variables all grouped as bioclim variables. The bioclim variables are coded as BIO1 = Annual mean temperature, BIO2 = Mean diurnal range (maximum temperature – minimum temperature) (monthly average), BIO3 = Isothermality (BIO1/BIO7) * 100, BIO4 = Temperature seasonality (Coefficient of variation), BIO5 = Max Temperature of warmest period, BIO6 = Min temperature of coldest period, BIO7 = Temperature annual range (BIO5-BIO6), BIO8 = Mean temperature of wettest quarter, BIO9 = Mean temperature of driest quarter, BIO10 = Mean temperature of warmest quarter, BIO11 = mean temperature of coldest quarter, BIO12 = Annual precipitation, BIO13 = Precipitation of wettest period, BIO14 = Precipitation of driest period, BIO15 = Precipitation seasonality (Coefficient of variation), BIO16 = Precipitation of wettest quarter, BIO17 = Precipitation of driest quarter, BIO18 = Precipitation of warmest quarter and BIO19 = Precipitation of coldest quarter.

Modeling sorghum potential growing areas

Data required for modeling potential growing areas was prepared in excel and DIVA-GIS and model built in MAXENT. The climate envelopes were then mapped and categorized as low suitability (25-50%), medium suitability (50-75%) and high suitability (over 75%) areas. Maps of more than 25% suitability were generated for all the climatic periods. The robustness of the developed model was validated using cross tabulation which is one of the methods available in the Maxent software. The changes in suitability growing areas were sought and mapped using DIVA – GIS in the categories stated for each climatic period.

Results and Discussion

All the 19 bioclim variables were used in the model with 50 of the location data used for training and 10040 used to determine the MAXENT distribution (background points and presence points). Figure 1A is the omission rate and predicted area as a function of the cumulative threshold which is calculated on the training presence records and the test records. The closer the Omission on training samples line is to the predicted omission, the more accurate the generated model. In work done by (Zonneveld et al. 2009), the location data used for *Pinus kesiya* and *P. merkusii* were 46 and 50 respectively. Scheldeman and Maartenvan (2010) in their research on the influence of presence points in a model concluded that after 50 species presence point, the prediction of potential distribution was stabilized. Comparing modeling methods, regions and taxa, (Elith et al. 2006) reported a general progression of performance (least to best performing) from BIOCLIM to DOMAIN and MAXENT. Area under curve (AUC) of the receiver operating characteristic (ROC) curve (Figure 1B), is a parameter used to evaluate the predictive ability of the generated model. It measures the likelihood that a randomly selected presence point is located in a raster cell with a higher probability value for species occurrence than a randomly selected absence point.

The generated model's AUC for training data was 0.97, an excellent model as per the stated guideline (Araújo et al. 2005) with a random prediction AUC of 0.5. Apart from MAXENT being substantially superior to Genetic Algorithm for Rule-Set Prediction (GARP), Phillips et al. (2005) concluded that it also has a natural probabilistic interpretation and can be easily understood by non-experts. Their results showed that MAXENT and GARP were significantly better than random prediction when tested for omission and ROC analysis. They further concluded that MAXENT showed better discrimination of suitable and unsuitable areas of the species in the analysis of AUC.

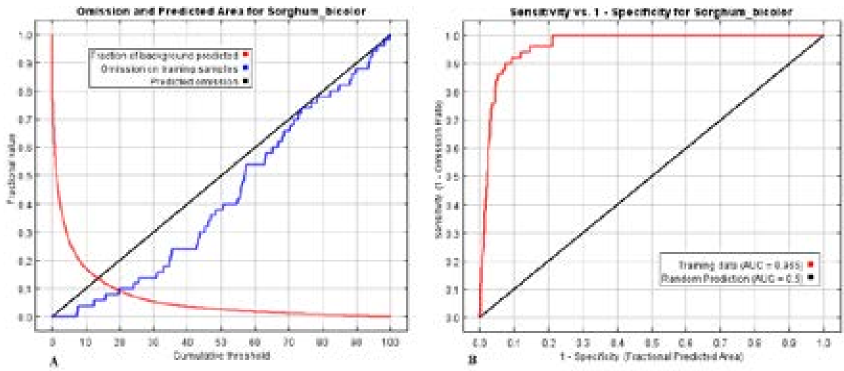

Figure 1 A and 1B The receiver operating characteristic (ROC) curve for sorghum

Change of variables with climate

The contributions of BIOCLIM variables to the model were different with the highest at 37.0 % and lowest being four variables at 0.0 %. The four variables contributing more than 10% to the model (Table 1) were BIO13-Precipitation of Wettest Period (month) (37.0%), BIO4 - Temperature Seasonality (STD * 100) (21.6 %), BIO – 18 Precipitation of warmest quarter (14.8 %) and BIO – 14 Precipitation of Driest Month (13.6 %).

As indicated in Figure 2, the Kenya's ASALs comprise a total of 27 counties 10 of which are classified as arid lands and 17 as semi-arid.

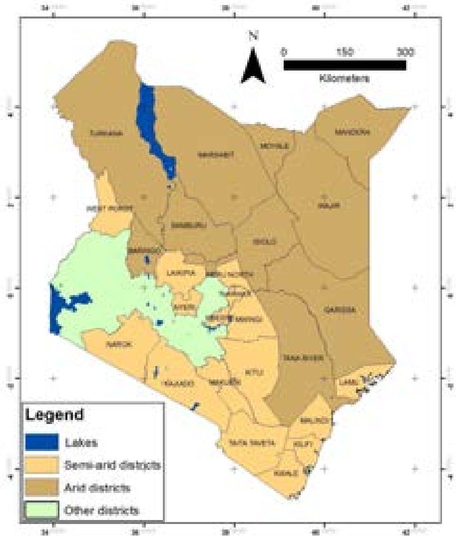

Figure 2 Kenya arid and semi-arid lands districts

Within the Kenya's ASALs, the four main BIOCLIM variables changes are summarized in Table 1. The values of all location points used in the model were averaged for each variable and differences sought in each climatic period. All the four variables are predicted to be reducing at different magnitudes in the future climatic periods where sorghum is currently growing.

Table 1 Change in the key environmental variables in current sorghum location points contributing more than 10% in sorghum suitability growing areas

Variable code	Variable title	Percent contribution	Current values	2050 Changes	2080 Changes
BIO13	Precipitation of wettest period	37.0	125.84	0.54	-21.18
BIO4	Temperature seasonality (STD * 100)	21.6	187.28	-1.76	-23.88
BIO18	Precipitation of warmest quarter	14.8	4.05	-0.21	-0.35
BIO14	Precipitation of driest month	13.6	236.09	-1.34	-5.39

Spatial analysis was also performed for the four main BIOCLIM variables (Figures 3 and 4) and their variations with climatic periods described. The results showed that the different variables change differently in the future climatic periods with some to the positive and others to the negative.

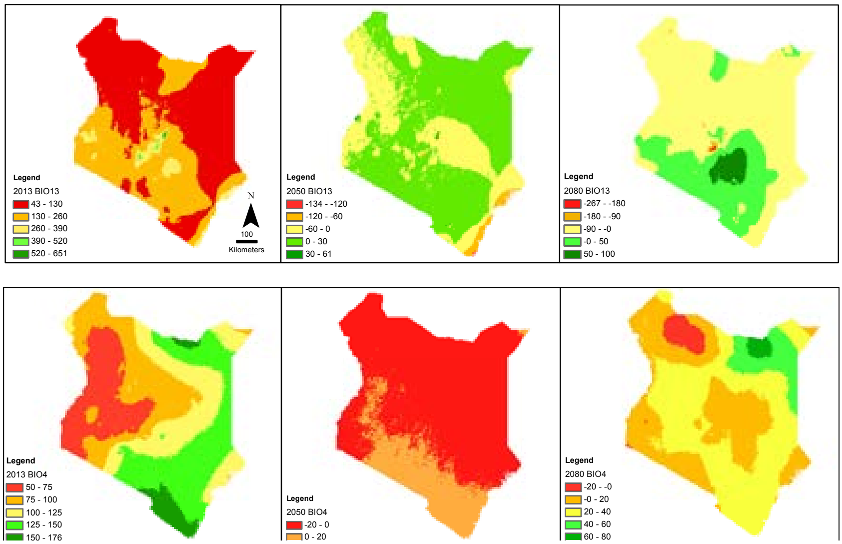

Figure 3 The current and changes in 2050 and 2080 climatic periods of BIO13 and BIO4 variables

The variable BIO13 measures precipitation in the wettest month of the year which in large parts of ASALs range from 0 mm to 260 mm in the current climatic period. In 2050 climate, BIO13 changes will be from a low of -141 mm to a high of 61 mm. Many parts of north western, eastern and coastal regions will experience changes in precipitation of slightly less than 0 mm to -141 mm. In addition, the rest of the ASAL region will receive precipitation slightly more than 0 mm to a maximum of 61 mm. There will be a reduction of as much as -270 mm and an increase of 100 mm in precipitation in the 2080 climate scenario. In this climatic period, much of the western, northern, north-eastern and coastal regions will experience precipitation variance of between 0 mm and -270 mm. An improvement in precipitation of 0 mm to 100 mm will only be received in the eastern and lower eastern regions. Majority of the ASAL districts will experience an increase in BIO13 from slightly more than 0 mm to 30 mm in 2050 climate while a reduction of between -90 mm to 0 mm will be observed in 2080 climate.

The variable, BIO4 (temperature seasonality*100) is a measure of temperature variation over the course of the year. This variable in the current climate ranges from a low of 50 in western and north-western regions then increases gradually to the eastern and southern parts of Kenya to a value of 176. Its 2050 climate values divide the country into southern and northern parts with maximum values of 20 and minimum of -20 respectively. The BIO18 (precipitation of warmest quarter) measures precipitation in the four hottest months. Much of the ASALs, especially the north-western and coastal areas, will experience declines ranging from 0 mm to -80 mm while the north-eastern parts changes are between 0 mm to 216 mm. Furthermore, the warmest quarter precipitation in 2080 climate will continue to decline in the ASALs. Most of these regions will experience declines of between 0 mm and -255 mm with a few areas receiving extra precipitation by up to 115 mm. The BIO14 variable (precipitation of driest month) is a measure of precipitation in the driest month with the entire ASALs having a value of between 0 mm and 18.0 mm with some areas in the south coast receiving up to 35.0 mm per month. Majority of ASALs in 2050 climate will experience changes of between -6.0 mm and 5.0 mm with a few areas in the south coast experiencing less precipitation by 11.0 mm. The scenario in the 2080 climate indicate that the coastal, northern and north-western parts will receive reduced precipitation by as much as -41.0 mm with the eastern and north-eastern regions having an increased rainfall by up to 20.0 mm per month.

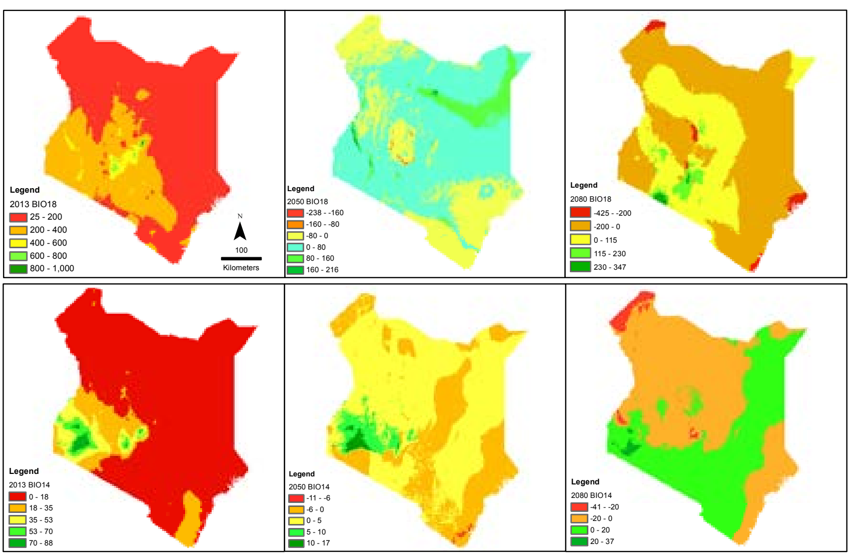

Figure 4 The current and changes in 2050 and 2080 climatic periods of BIO18 and BIO14 variables

Modeled sorghum growing suitability areas

The modeled Kenya's current sorghum growing areas of more than 25% (low) suitability in the ASALs covers mainly the semi-arid counties namely Kajiado, Makueni, Kitui, and Meru. Other ASAL counties with minimal suitable areas are in the coastal region comprising Lamu, Tana River, Kilifi, Kwale and Taita Taveta. These current modeled suitability areas are in agreement with genesis spatial data published in (GENESYS 2013). The same areas have been reported by Wortmann et al. (2006); KARI (2013); Esipisu (2013) and Muui et al. (2013) as Kenya's sorghum growing areas. The future 2050 and 2080 climate suitability areas as shown in Figure 5 indicated an expansion in the suitable sorghum growing areas. The expansion of suitable regions in 2050 climatic period will cover not only the semi-arid districts as the modeled current distribution but also new areas such as Malindi, Kilifi, Kwale and the entire Lamu districts. The new growing areas of arid lands are Tana River, Lamu, Garissa, Wajir, Marsabit and Turkana. The sorghum suitable growing areas will shrink in 2080 climate with major changes in area of coverage and level of suitability. All the districts show a reduction in level and coverage of suitability with the exception of Marsabit and Narok counties which have positive changes.

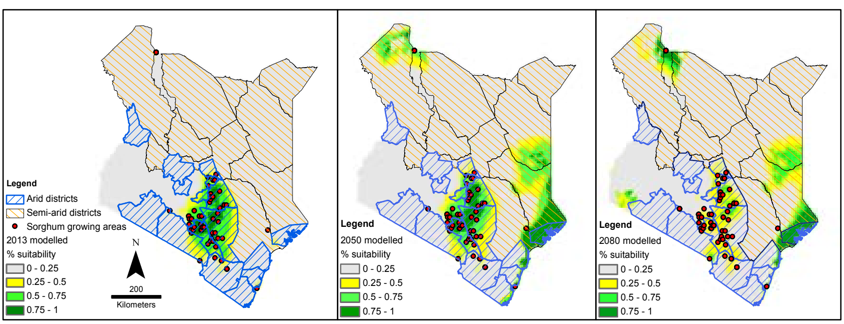

Figure 5 The modeled current, 2050 and 2080 S. bicolor potential growing areas in ASALs of Kenya

These results are consistent with studies carried out by GENESYS (2013); KARI (2013); and Muui et al. (2013). Similar studies have been done by Zonneveld et al. (2009) Kigen et al. (2013) on the impacts of climate on pine and Grevy's zebra niche respectively. They both concluded that the climate variables affected the distribution of pine and zebra both negatively and positively in their areas of study. The percentage area variations with climatic periods in each level of suitability are summarized in Table 2. The percentage changes of sorghum growing areas for the future climatic periods was calculated based on the current growing area. The 2050 climate will have a net increase in all the levels of suitability with low suitability area increasing by 130 %.

Table 2 Changes in sorghum suitability growing areas (square kilometers)

Suitability	Current area	2050% change	2080% change
Low	27,700	130	168
Medium	33,275	79	-17
High	11,500	267	71

In addition, medium suitability increased by 79% and over high suitability area changing positively by 267%. The 2080 climate affected sorghum suitability areas negatively by various degrees. There was an increase of 168% in areas of low suitability, a decrease of 17% in areas of medium suitability and expansion of high suitability areas by 71%. Parry et al. (2003) used models to estimate change in world percent cereal changes in different climatic periods. Their results showed that under SRES A2 emission scenario, percent cereal yield changes in Kenya range from 2.5 in 2020, -2.5 in 2050 and -30 in 2080.

Conclusion and Recommendations

The climate change phenomena will have varied positive changes in Kanya's ASALs sorghum growing area in the future climatic periods. The highest modeled sorghum growing areas will be in the 2050 and then decrease in the 2080 climatic periods. The model also indicated which counties to give more attention thereby assisting policy makers make informed decisions. It is recommended that the stakeholders take action as per the model output and incorporate results of the models to achieve sustainable development and utilization of Kenyan ASALs and more research be done using refined climate data.

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Chapter 10

Adoption of Water Conservation Measures Under Fluctuating Rainfall Regimes in Ngaciuma/Kinyaritha Watershed, Meru County, Kenya

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Abstract

Availability of adequate water in terms of quantity and quality affects economic growth. The aim of this study was to assess water resource conservation under fluctuating inter-annual rainfall regimes in Imenti North sub-County, Kenya. Unsustainable use of water resources has drastically affected the discharge of Ngaciuma/Kinyaritha River making some of its tributaries seasonal. This has adversely affected accessibility to adequate water for both domestic and agricultural use. The study was carried out to assess the adoption levels of water conservation practices in Imenti North. Descriptive statistics was used to analyze socio-economic parameters. Regression, correlation and Spearman's t-test were used to compare the relationship between variables. Tree planting, roof catchment and bench terraces were the major water conservation (WC) practices in use. Multiple regression analysis revealed that lack of technical knowhow could explain 83.5% variations of adoption level of WC practices. One sample t-test comparing the means of WC practices among respondents' was significant at $P \leq 0.01$. Spearman's rank test revealed a decreasing trend during the long rains (March-May) for the period 1986-2008 at $P \leq 0.05$. The disparity between the levels of adoption among water users coupled with the decreasing seasonal rainfall calls for urgent and better management of the water resources in the study area.

Key words: Rainfall, unsustainable water resource use, water conservation practices.

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Introduction

Critical discussions and negotiations on water resources have been on the international agenda and have elevated water resource to a greater global awareness. Water is a scarce resource and an essential component for human survival. This scarcity is partially linked to climate change; demand that exceeds available water resources and most importantly unsustainable use of the resource (Molle 2000). Many parts of the world, markedly the Middle East and the Sub - Saharan Africa are experiencing intense competition over limited inland water resources. This situation is serious in shared drainage basins where it has heightened political conflicts (McCartney 2000). The situation in Kenya is not any better. Kenya receives less than 647 m^3 of fresh water per capita per year, making it one of the most water scarce countries in Africa and the world (WRI 1994). Competition over water between agricultural, industrial, domestic and municipal needs has worsened, stretching the recovery of hydrological systems (Orie 1995). Kenya experiences high rainfall variability, low investment in water resources development and poor protection of the existing water resources resulting in extensive degradation (Were et al. 2006).

A basic water management challenge is to find ways to satisfy human needs while coping with climatic changes and protecting the water resource from long-term degradation. With regard to water resource management, the use of participatory approach is one of the principles of the Dublin convention (Cosgrove and Rijsberman 2000). The approach partly reflects the observation that people who inhabit an environment over time are often the ones most able to make decisions about its sustainable use. However, the vast majority of people have become passive observers, and a few people are taking decisions for everyone else. That is one of the prime reasons why the water resources are being destroyed (McLvor 2000). The real revolution in water resources management will therefore come when all stakeholders have the power to manage their own water resources. Efforts should be made to maximize productive water use. This could be by finding and stopping wasteful leaks, enhancing focused irrigation techniques, using less water-intensive industrial processes, implementing wastewater recycling, and overall conservation of water catchment areas (Mitchell et al. 2004).

Most of the people living in the rural areas tend to over-exploit their immediate environments. Cutting of trees has impacted negatively on precipitation and river systems in the Tana Catchment in which Ngaciuma/ Kinyaritha watershed, the study area is located. Some tributaries in the watershed have become seasonal due to increased land use changes and direct over-abstraction (WRMA 2008). The watershed also experiences temporal variations in water demand that creates a negative balance between demand and supply during the dry season (DAAD 2008). This study addresses the following key questions: How has been the trend in rainfall for the period 1986-2008 in the study area? What is the level of adoption of water conservation practices in the study area? Which are the constraints faced? Does accessibility and participation in local Water Resource Users Associations (WRUAs) affect adoption of water conservation practices?

Materials and Methods

Study area

Ngaciuma/Kinyaritha watershed is located within Meru County in Kenya. It is geographically bound by latitudes 37.5° E and 37.75° E and 0.04°N and 0.15° N. The watershed covers an area of 167 km^2. Climatic conditions range from humid to semi-humid. The watershed falls within Agro-ecological zones UM1, (Coffee-Tea Zone) UM2 (Main coffee Zone) and UM3 (Marginal coffee zones) (Jaetzold et al. 2007). Rainfall is bimodal with mean annual rainfall range of 1100-1600 mm and annual temperatures from of 10-30oC. The altitude ranges from 1120 - 2600 m a.s.l.

Data collection and analysis

Data was collected from primary and secondary sources. Primary sources included administering of questionnaires, focus group discussions, key informant interviews and non-participatory observations. The fieldwork was conducted between the months of June and October 2011. Secondary data included rainfall data acquired from Kenya Meteorological Department in Nairobi and Water Resource Management Authority sub-regional office in Imenti North. Before the main study, a reconnaissance survey was carried out to pre-test the research instruments and work out modalities of identifying respondents in the study area.

Descriptive statistics were used to analyze socio-economic parameters. To measure the adoption level of water conservation practices, a weighting system was used that assigned values to each conservation practice based on its importance as perceived by the respondents relative to all other conservation practices. The weighted importance score for each practice was multiplied by reported answers of implementation from respondents. Finally, respondents were categorized as “low”, “fairly low”, “fairly high” and “high” adopters based on the collective ‘adoption score’. Score ranges for low, fairly low, fairly high and high adoption categories were determined by mean and standard deviation, as follows (equation 1):

$Min < A < Mean-St.d$: A= Low
$Mean-St.d < B < Mean$: B = Fairly Low………………… (1)
$Mean < C < Mean+St.d$: C= Fairly High
$Mean+St.d < D < Max$: D = High

Trends in rainfall were analyzed using the Ms Excel software to generate graphs. Spearman rank correlation test was used to test the null hypothesis of no significant variations in trends of rainfall and stream flow for the period 1986 - 2008 in Ngaciuma/Kinyaritha watershed. Rainfall data was ordered and ranked from the lowest to highest. The differences between the rankings were computed and squared. The latter were summed up to yield $\sum \partial i^2$. The Spearman rank correlation (rs) was computed using equation 2.

$$r_s = 1 - 6\sum_{i=1}^{N} \partial i^2 / N(N^2-1) \ldots\ldots (2)$$

Where, $\partial i = k_i - I$, k_i is the rank of the series x_i and N the total number of observations. The approximate significance of r_s^2 for $N \geq 8$ and df =N-2 was calculated by computing:

$$t = rs\ \{df / (1 - r_s^2)\}^{0.5} \ldots\ldots (3)$$

Coefficient of variation was computed to compare variability of each water conservation methods adopted among the respondents. Correlation analysis was used to measure the association between dependent and independent variables. Stepwise multiple linear regression model was used to explain variations in adoption level of WC practices among respondents. Eleven independent variables: age, education level, household size, participation in WRUA conservation activities, farm size, level of information sources and channels, economic motivation, stewardship motivation, level of awareness on sustainable WC practices, attitude towards conservation practices and level of technical knowhow were fitted in the model. Backward elimination approach which involved starting with all independent variables and testing them one by one for statistical significance, deleting any that was not significant was used to fit the regression model.

Results and Discussion

Household characteristics for each zone are given in Table 1. Majority of the respondents were farmers at (83.7%). Due to unreliability of rainfall, rain-fed agriculture is no more reliable and thus majority of the farmers are practicing irrigated agriculture. Despite the perception that the study area has enough water, lack of adequate water supplies was the major hindrance to the expansion of irrigation and livestock keeping having up to 75% of mentions (Table 2). This is an indicator that Ngaciuma/Kinyaritha watershed is faced with inadequate water supplies against the perception that the watershed has adequate water.

Table 1 Summary characteristics of selected households according to agro-ecological zones

Household Characteristics	Description	Locations			
		Upper Zone	Middle Zone	Lower Zone	Average (%)
Sex (%)	Male	66	82	80	76
	Female	34	18	20	24
Education (%) level of respondents	Primary	50	48.6	54	50.9
	Secondary	26.7	20	25	23.9
	Tertiary	13.3	22.9	10	15.4
	None	10	8.5	11	9.8
Age (%)	18-36	33.3	28	21	27.4
	37-54	50	56.7	66.4	57.7
	>54	17.7	15.3	12.6	15.2
Occupation of household heads	Farmer	90	78	83	83.7
	Civil servants	6.7	12	8	8.9
	Business persons	3.3	10	9	7.4

Table 2 Major constraints limiting expansion of irrigation agriculture

Constraint	Number of times mentioned	Percentage of mentions
Land size	60	50
Water accessibility	48	40
Lack of adequate water	90	75
Market problems	6	5
Cost of farm inputs	30	25

*Note the percentages do not add to 100% because the respondents answered to more than one constraint.

Analysis of rainfall trends for the period 1986-2008 shows an inter-annual fluctuation in rainfall and declining rainfall trends both linearly and in five year moving averages (Figure 1).

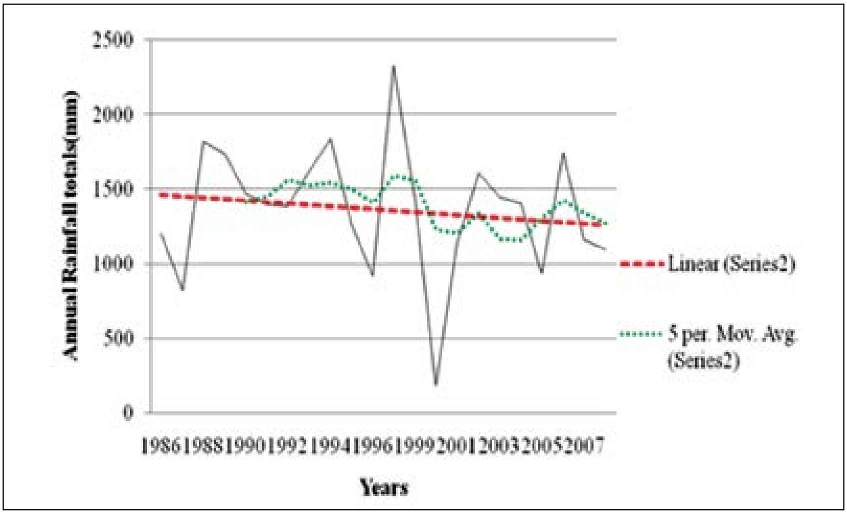

Figure 1 Inter-annual fluctuations in rainfall for the period 1986-2008

The Spearman test showed a significant decreasing ($p \leq 0.05$) trends for the long rains (March-May) for the period 1986- 2008 (Table 3). This indicates reduction in water resources as rainfall is the major source of water for rivers and ground water replenishment. This would therefore imply inadequate water supply for both domestic and agricultural uses.

Table 3 Spearman's test for annual, long (Mar-May) and short (Oct-Dec) rains

	Period	1986-2008	1986-1995	1996-2008
	Df	20	8	10
Annual rainfall	r_s	-0.22179	0.29697	-0.2940
	T	-0.9500	0.0857	-0.5620
Long rains(Mar-May)	r_s	-0.4048	0.0303	-0.2940
	T	-1.9563[a]	0.0857	0.46905
Short rains(Oct-Dec)	r_s	0.03500	0.1636	0
	T	0.1566	0.46905	0

[a] Trends statistically significant at $p \leq 0.05$.

Analysis of perceived indicators of sustainable water conservation practices; tree-planting, rainwater harvesting by use of roof catchments, bench terraces and mulching are top of the list in terms of prioritization by the respondents (Table 4). Drip irrigation according to respondents required a lot of expertise and finances to put up the systems hence the least water conservation method in Ngaciuma/Kinyaritha watershed.

Table 4 Prioritized indicators of sustainable water conservation practices

Conservation method	Mean	Standard deviation (Std)	Coefficient of Variation (CV)	Priority
Tree planting	0.670	0.140	0.209	1
Rainwater harvesting	0.767	0.161	0.210	2
Bench terracing	0.667	0.300	0.450	3
Mulching	0.500	0.225	0.450	4
Vegetative strips	0.750	0.338	0.451	5
Infiltration ditches	0.308	0.302	0.980	6
Waste water reuse	0.322	0.395	1.227	7
Fanya juu	0.256	0.376	1.469	8
Water metering	0.287	0.422	1.470	9
Drip irrigation	0.156	0.293	1.878	10

Analysis of adoption level of WC practices and the constraints (Table 5) shows the levels of adoption of water conservation practices. It could be inferred from the table that majority of the respondents fell into either fairly low or high ranking.

Table 5 Adoption level of water conservation practices by respondents

Group	Scale	Frequency	% of frequency
Group1 (low)	3.817	21	17.5
Group2 (Fairly low)	3.818-5.280	48	40.0
Group3 (Fairly high)	5.281-6.743	21	17.5
Group4 (High)	7.9	30	25.0
Total		N=120	100
Max:7.9	Min: 1.4	Mean: 5.28	Std:1.463

The community faces constraints in their efforts to adopt and to participate in water conservation practices (Table 6). However, an important finding from this study was that some of the listed adoption constraints decreased with increase in the number of water conservation practices adopted. Similar findings have been observed elsewhere (Tenge et al. 2004). Lack of capital was a major constraint. Wealth is linked to power and property rights over natural resources affecting peoples' option for adopting technology (Knox and Meinzen 1999). Those who posses a higher quantity and quality of endowment will place a higher future on medium and long term benefits produced by investment in water conservation technologies. Majority of the farmers enjoyed security of tenure having title deeds for their land, thus land tenure was not a major constraint.

Table 6 Observed constraints in relation to the number of WC practices adopted.

Adoption constraints	Frequency	Overall score (%)	Scores by number of WC practices adopted [a] (%)			
			1(n = 8)	2(n =15)	3(n=62)	4(n =35)
Lack of capital	100	83.3	41.65	24.99	8.33	8.33
Lack of technical	72	60.0	28.80	19.8	9.00	2.40
Land tenure insecurity	9	7.5	6.4	1.1	0.00	0.00
Small farm size	90	75.0	22.5	7.5	15.0	30.0
Benefit not known	8	6.7	6.03	0.67	0.00	0.00

[a]Types and numbers of adopted WC measures may have included the following measures either singly or in combination: *"Fanya juu",* bench terraces, grass strips, mulching, tree planting rain water harvesting, waste water reuse (kitchen gardens) and water metering.=

Correlation analysis of adoption level of WC practices and selective variables

Table 7 shows there is a positive correlation between adoption of WC practices and information sources as well as communication channels at P≤0.01. The positive correlation implies that as the level of information and communication channels increase, the adoption of WC practices increases and vice versa among farmers in Ngaciuma/Kinyaritha watershed. Similarly economic motivation/income level was positively correlated P≤0.01 with adoption. Sinder and King (1990) in their study on water conservation technologies adoption found that economic factors promote actual adoption by farmers. There was a positive and significant correlation (P≤0.01) between the level of awareness about the effects of water conservation practices and level of adoption. Similar finding was reported by Mahboubi (2005) in their study on factors affecting adoption behaviour of water conservation technologies in Gol watershed in Iran. Similarly the level of knowledge is positively and significantly (P≤0.01) correlated with the WC practices adopted.

Table 7 Correlation between adoption level of WC practices and selective variables

Variables	Coefficient of variation
Age	-0.033
Education level	-0.013
Household size	-0.013
Participation in WRUA conservation activities	0.126
Farm size	0.353**
Level of information sources and channels	0.460**
Level of economic motivation(Income level)	0.334**
Level of stewardship motivation	0.331*
Level of awareness on sustainable WC practices	0.136
Level of technical know- how	0.918**

* (P≤0.05) and ** (P≤0.01)

Regression analysis explaining variations in adoption level of WC Practices.

In order to explain variations in adoption level of WC practices, stepwise linear regression analysis was used. The results show that the level of technical know-how could explain 83.5% of variations in adoption level of water conservation activities among respondents (Table 8).

Table 8 Regression analysis computing variations in adoption level of WC practices

		Water conservation practice	
Description	Label	B	T
Constant		2.158	7.084**
Level of knowledge (technical know-how)	∂	0.693	18.255*
F=333.237**	R^2=0.835	R^2adj=0.832	($P \leq 0.05$) * and ($P \leq 0.01$) **

* ($P \leq 0.05$) and ** ($P \leq 0.01$)

According to the results presented in Table 8, the following model could be used to explain respondents' adoption level of water conservation practices in the study area:

$Y= 0.695\partial + 2.157$. Where Y=Dependent variable representing respondents adoption level of water conservation practices and ∂ is the level of technical know-how of the respondent.

Conclusion and Recommendations

Accelerated water resource degradation is among major constraints to agricultural production. The result of rainfall analysis indicates reduction in water resources as rainfall is the major source of water for rivers and ground water replenishment. Since adoption of many recommended water conservation measures is still minimal in many areas, paying attention to the factors which determine adoption is a priority. These factors are water conservation practices, participation in Water Resources User Association (WRUA), information sources and channels, economic motivation, level of awareness and level of technical knowhow. The factors also display positive and significant correlation with independent variable adoption. These factors interact with each other logically to influence adoption. Additionally the research provides evidence showing that the level of technical knowledge received notable support regarding water conservation practices in the regression model. The findings provided a basis for the following recommendation.

It is generally true that access to information sources and communication channels with relevant content may increase awareness about the effects and consequences of water conservation practices among farmers while providing them with required technical knowledge. By understanding the economic and environmental effects of water conservation practices, effective uptake of WC technologies may occur. Thus, provision of required information via various information sources and communication channels in order to raise farmers' awareness is suggested. Community awareness on the conservation measures should be promoted through the use of mass media. The solution is to better target extension services and improve the methods of information delivery. Whereas lack of technical knowhow is cited as a hindrance to adoption, the farmers should be made to know the practices and how best to integrate or incorporate these practices in their agricultural activities for better living and for the protection of the environment.

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Theme III

Adaptation to Climate Change and Variability in Agropastoral Production Systems

Chapter 11

Enhancing Resilience to Climate Change in Agro-Pastoral Production Systems: Lessons from the Kenya Climate Change Action Plan Development Process

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Abstract

There is irrefutable evidence that climate change has led to an increase in the frequency and severity of droughts, particularly in the Arid and Semi-Arid Lands(ASALs) of Kenya. Recognizing that climate change is a national challenge, the Government of Kenya through the National Climate Change Secretariat based at the Ministry of Environment, Water and Natural Resources formulated the National Climate Change Response Strategy (NCCRS)in2010. To implement the NCCRS, the Government of Kenya further embarked on a country-wide consultative process to develop the National Climate Change Action Plan (NCCAP). This plan will be done within 2013-2017. The county consultations were conducted under the auspices of the Kenyan component of Africa Adaptation Programme (AAP Kenya), with funding providedby the government of Japan through the United Nations Development Programme (UNDP). This paper uses primary data stratified by agro-ecological zones collected between March and May 2012 during the NCCAP county consultations. Several preliminary lessons for adaptation to climate change and variability emerge from the process. The lessons, challenges and experiences emerging revolve around: the opportunities for promoting climate change adaptation through sustainable land management, the role of climate information, and the perceptions of key players on approaches for adaptation. Results further illustrate the importance of climate risk assessment for the formulation of adaptation options at county level. It also emerges that the core causes of vulnerability, particularly in weather-sensitive agro-pastoral production systems need to be addressed first before impact-oriented adaptation efforts can be effective.

Key words: Climate change, adaptation, sustainable land management, Kenya

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Introduction

Climate change poses a serious threat to sustainable development in Kenya. The frequency and severity of droughts has been increasing in the recent past especially in the arid and semi-arid areas. According to Stockholm Environment Institute (SEI 2009), Kenya's vulnerability is set to get worse. Agriculture, tourism, health, energy, transport and water are the sectors expected to be most severely affected by climate change in the long term (SEI2009). Some of the factors that contribute to this vulnerability include:unsustainable land management practices; high levels of poverty; weak institutional capacity; insufficient disaster management capacity; limited financial resources; and a high proportion of livelihood systems that depend directly on climate sensitive natural resources.

Impacts of climate change

Kenya has in the recent past reported successive seasons of crop failure, increasing the country's food insecurity. The country's famine cycles have reduced from 20 years (1964-1984), to 12 years (1984-1996), to 2 years (2004-2006) and to yearly 2007/2008/2009, necessitating the Government's distribution of 528,341.77 metric tons (MT) of assorted foodstuffs worth KShs. 20 billion over the last five years to feed a population of between 3.5 million and 4.5 million people annually. The Ministry of Agriculture's Economic Review of 2009 indicated that the production of major crops like tea *(Camellia sinensis)*, sugarcane *(Saccharumo fficinarum)* and wheat *(Triticum aestivum)* had also declined. The ripple effect of this scenario to Kenya's economy is frightening especially when one considers the pertinent role that foreign exchange plays in international trade and investment. During 1998 to 2000, cyclic droughts cost the nation approximately $2.8 billion, mainly due to livestock loss, crop failure, forest fires, loss of aquatic life, reduced hydro power generation and water supply. At the same time the 2004 and 2005 droughts had an impact on millions of people. The 2009 droughts greatly impacted to Kenya's energy and water sectors. The greatest drought impacts were felt for the better part of 2011, during which inflation increased to 15% in July due to high food and oil prices (World Bank 2011). Additionally, climate sensitive diseases such as malaria have in the recent years begun affecting areas like Nairobi, Kericho, and even the Mt. Kenya highlands, which were previously malaria free. Increased drought spells have seen pastoralists loose thousands of cattle and millions in income. Drying of biomass and subsequent reductions on the national electricity energy production (especially during droughts and floods) continue to put further strain on Kenya's economy.

Recognizing that climate change is a national challenge, the Government of Kenya through the Ministry of Environment, Water and Natural Resources (MEWNR) formulated the National Climate Change Response Strategy (NCCRS, 2010). The NCCRS outlines the evidence and impacts of climate change in Kenya and recommends actions that the country needs to prioritize to reduce the impacts. The document also outlines opportunities presented by climate change that the country needs to aggressively pursue in order to realize vast economic gains. The recommended actions range from adaptation and mitigation measures in key sectors, to necessary policy, legislative and institutional adjustments, to ways of enhancing climate change awareness and education in the country, to necessary capacity development requirements, and ways of enhancing research and development as well as technology development and transfer in areas that respond to climate change.

To implement the NCCRS, the Government of Kenya further initiated the participatory process of developing a holistic National Climate Change Action Plan(NCCAP) to implement the strategy. The Action Plan has eight distinct sub-components which are closely linked and interrelated. It seeks to provide a harmonized approach to climate change adaptation and mitigation with a view of ensuring a climate-proof socio-economic development, anchored on a low-carbon path (GoK 2012). The process was supported by the UK Department for International Development (DFID), the Climate and Development Knowledge Network (CDKN), the Common Market for Eastern and Southern Africa (COMESA), the Danish International Development Agency (DANIDA) and the Kenyan component of the UNDP Africa Adaptation Programme. The Ministry of Environment, Water and Natural Resources was the lead agency supported by an inter-ministerial Task Force comprising of Office of the Prime Minister, Ministry of Finance, Ministry of Planning, National Development and Vision 2030, Ministry of Northern Kenya and other Arid Lands, Ministry of Agriculture and Vision 2030 Delivery Secretariat. The overarching aim of the Action Plan is to help Kenya coordinate and improve its efforts to adapt to, understand, and lessen contributions to climate change.

The Kenya Climate Change Action Plan has eight distinct sub-components described by the Government of Kenya as follows:

Sub-component 1: *Long-term National Low Carbon Development Pathway.* This is designed to facilitate mainstreaming of climate change aspects in the country's development blueprint Vision 2030 and its Medium Term Plans (notably MTP II). It also seeks to identify key elements of the country's low-carbon and climate resilient growth.

Sub-component 2: *Enabling Policy and Regulatory Framework.*This aims to review international, regional and national policy and legislative instruments relating to climate change with a view of developing a policy and /or legislative framework that promotes coherence, coordination and cooperative governance of climate change issues at the national and county levels.

Sub-component 3: *National Adaptation Plan.* Recognizing that adaptation is a priority, this sub-component aims to identify immediate, medium and long-term adaptation actions in order to develop a National Adaptation Plan.

Sub-component 4: *Nationally Appropriate Mitigation Actions (NAMAs)*. This sub-component is designed to identify and prioritize NAMAs that need to be internationally supported and enabled through technology development and transfer, financing and capacity building. This sub component also aims at addressing reduced emissions from deforestation and forest degradation (REDD+) readiness activities as well as opportunities presented by compliance and voluntary markets.

Sub-component 5: *National Technology Action Plan.* This subcomponent focuses on facilitating technology needs assessment with a view of developing a National Technology Plan that incorporates setting-up of technology innovation centres.

Sub-component 6: *National Performance and Benefit Measurement.* This sub-component will develop a national climate change measuring, reporting and verification system and performance indicators.

Sub-component 7: *Knowledge Management and Capacity Development.* This sub-component aims at addressing issues relating to institutional and technical capacity strengths and needs of the various actors ranging from government, private sector, civil society and communities. It also encompasses education, training, public awareness and networking.

Sub-component 8: *Finance.* This sub-component aims to position the country to access finances from the various sources by developing an innovative financial mechanism that includes a climate fund, investment strategy and carbon trading platform. It also aims to identify tools and incentives that would enhance private sector investments in opportunities associated with climate change.

This paper presents the outcomes of the National Climate Change Action Plan development process and offers a unique opportunity to interrogate the results from the county consultations from an interdisciplinary framework.

Methodology Framework

The National Climate Change Secretariat based at the Ministry of Environment, Water and Natural Resources conducted consultations with key stakeholders throughout the country from March to May 2012. During the consultations, stakeholders were informed of the development of the National Climate Change Action Plan and the objective of the consultations. It was clearly indicated that information gathered from the consultations would be used for the development of an Action Plan for the National Climate Change Response Strategy. Participants included district officers, representatives from youth groups, women groups, farmers and teachers. Also in attendance were consultants working on the different sub-components of the Action Plan. Table 1 summarizes the activities undertaken to consult on the Action Plan, including indications of numbers of stakeholders engaged and other outcomes.

Table 1 Summary of activities undertaken to consult on the Action Plan, including indications of numbers of stakeholders engaged and other outcomes

Method of consultation		Details	Recipients and outcomes
1.	Consultation document- National Climate Change Response Strategy (NCCRS).	1000 copies printed. Electronic version available online at http://www.environment.go.ke/wp-content/documents/complete%20nccrs%20executive%20brief.pdf	The NCCRS was highly instrumental both in creating awareness and in enhancing the understanding of climate change issues across the country.
2.	Website http://www.kccap.info/	Hosting the Action Plan county consultation workshop reports, briefs and other related documents.	The website has helped profile national efforts in combating climate change as well as providing information ontheprogress made towards finalization of the Action Plan.
3.	County Consultative meetings	The county meetings were organized by the Climate Change Secretariat of the Ministry of Environment, Water and Natural Resources (MEWNR) and enabled the government to gain the perspectives of several groups including civil society, farmers, women and the general public on climate change information and knowledge needs.	The meetings yielded animated discussions on the various issues and challenges surrounding climate change adaptation, information access, knowledge management and capacity development in Kenya.
4.	Climate change leaflets/ pamphlets	5000 copies distributed	Sent to organizations, all youth and community groups, and distributed at relevant events.

The consultative meetings were held in nine (9) counties namely; Nakuru, Eldoret, Kisumu, Kakamega, Mombasa, Nairobi, Garissa, Embu and Nyeri.

Table 2 Schedule for the nine county consultations

Province	County	Date
Rift Valley South	Nakuru	8th March 2012
Rift Valley North	Eldoret	12th-13th March 2012
Nyanza	Kisumu	19th -20th March 2012
Western	Kakamega	21st -22nd March 2012
Coast	Mombasa	19th -20th April 2012
Nairobi	Nairobi	26th -27th April 2012
North Eastern	Garissa	10th -11th May 2012
Eastern	Embu	21st -22nd May 2012
Central	Nyeri	24th -25th May 2012

During the meetings, participants were divided into working groups based on their counties. Each group was tasked with identifying and presenting on:

i. The evidence and impact of climate change;

ii. Current actions being undertaken to address or cope with climate change;

iii. The proposed actions/interventions to foster the resilience of vulnerable groups.

Results and Discussion

Evidence of climate change

The assessment captured stakeholders' perceptions and understanding of climate change, as well as notable evidences of the same. Questions asked ranged from whether the stakeholders had noticed changes in mean temperature and rainfall over the past two decades and their reasons for these observed changes. About 68%perceived mean temperature as increasing over the past 20 years, 28% as decreasing and 4% as remaining the same. Similarly, 18% perceived mean annual rainfall as increasing over the past 20 years, 62% as declining, and 20%, as remaining the same. Figure 1 depicts stakeholders' perceptions of climate change as captured during the consultations. Overall, increased temperature and declining precipitation are the predominant perceptions.

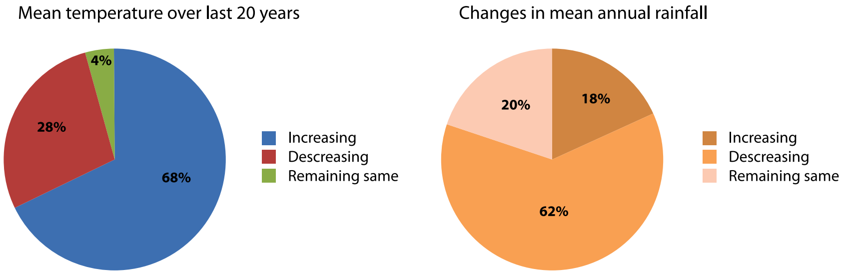

Figure 1 Stakeholders' perceptions on climate change over the past 20 years

Globally, temperature and precipitation changes are the two climatic elements that have been widely studied to provide evidence of climate change. In Kenya for instance, the Kenya Meteorological Department (KMD) has provided data of temperature and rainfall over the last fifty years. Tables 3 and 4 summarize temperature trends in different parts of the country since the early 1960s. From the tables, it can be seen that Kenya has experienced generally increasing temperature trends over vast areas, further corroborating the present findings.

Table 3 Minimum temperature trend from 1960 (Source: KMD)

Region	Trend	Magnitude (°C)
Western	Increase	0.8-2.9
Northern and North-eastern	Increase	0.7-1.8
Central	Increase	0.8-2.0
South Eastern districts	Increase	0.7-1.0
Coastal strip	Increase	0.3-1.0

Table 4 Maximum temperature trend from 1960 (Source: KMD)

Region	Trend	Magnitude (°C)
Western	Increase	0.5-2.1
Northern and North-eastern	Increase	0.1-1.3
Central	Increase	0.1-0.7
South Eastern districts	Increase	0.2-0.6

With regard to rainfall patterns, most counties reported a declining trend in the annual rainfall series over the recent years. Specifically, most counties had experienced a general decline with time of rainfall in the long rains seasons (March to May) and an increasing trend in rainfall events during the short rains period. This suggests a tendency for the short rains to extend to the hot and dry period over vast areas. In general, there is evidence of climate change related to indicators like reduced amounts of rainfall, rainfall coming late, increased temperatures, increased incidences of drought and decreased crop productivity (Table 5).

Table 5 Local indicators of climate change

Local indicators of climate change	Percentage counties
Decreasing amount of rainfall	91
Rainfall coming late in seasons	83
Increased incidence of drought	87
Increased incidence of tropical diseases e.g. malaria	65
Increased temperature	89
Outbreak of plant diseases	57
Decreased land productivity	80
Shortened growing seasons	74
Re-occurrence of food shortage	81
Decreasing number of livestock	58

According to Table 5, decreasing amount of rainfall, increased incidence of drought, increasing temperature trends and decreased crop productivity are the highest ranking indicators of climate change across the counties. Other notable evidences of climate change as reported by stakeholders included:

i. Increased wild fires both in forests and grasslands
ii. Receding natural resources particularly watering points and pasture
iii. Flash floods causing soil erosion, siltation, and reduction in soil fertility, hence reduced crop productivity
iv. Changes in migratory routes for birds.

Results of data analysis showed all counties have been adversely affected by the effects of climate change. For instance, increased heat stress on crop and livestock has led to higher night temperatures thereby affecting grain formation and other aspects of crop and livestock development. Consequently, climate change has directly increased absolute, relative and transient poverty. As is clearly evident, climate change has indeed had a devastating impact on Kenya's economy and will continue to wreak havoc in key sectors unless urgent action is taken to boost the country's resilience.

Current actions to cope with climate change

Highlighted in this section are the coping and adaptive strategies adopted by communities to manage the impacts of climate change and reduce overall vulnerability to climate shocks across the counties. The basic coping and adaptation strategies in the context of livelihood risks have been classified into a set of four analytical types: sustainable land management practices, storage, diversification and community pooling. Table 6 provides information about the distribution of different kinds and combinations of adaptation practices within the four classes across the nine counties. The evidence in the cases indicate some interesting patterns. To begin with, diversification and community pooling are predominantly the risk management approaches practiced by communities living in areas worst affected by climate change. Table 6 also suggests that the most common classes of adaptation responses are storage and diversification.

Table 6 Frequency distribution of major classes of adaptation practices across the counties

Class of Adaptation Practice	Corresponding Adaptation strategies	Frequency* (Provinces)	No. of Counties	Agro-ecological Zone
Sustainable land management practices	a. Fanya-juu b. Mulching/use of crop residues c. Crop rotations d. Conservation tillage	5	10	II, III, IV, V
Storage	a. Water storage b. Food storage (crops, seeds, forest products) c. Fodder	9	40	IV, V, VI

Diversification	a. Asset portfolio diversification b. Skills and occupational training c. Crop choices d. Consumption choices	6	32	IV, V, VI
Community pooling	a. Forestry b. Infrastructure development c. Information gathering d. Disaster preparation	3	17	V, VI
Storage and diversification	Examples of combinations of adaptation classes are drawn from the strategies listed above.			
Storage and community pooling		7	31	
Diversification and community pooling		5	44	
Diversification and storage		8	47	

It is however important to mention that the ability of income diversification strategy to buffer food security in the face of a short-run climate shock or long-run climate shift depends on the off-farm income-generating activities available, and the extent to which households can take advantage of them (Davis et al. 2007). This is especially true for Kenya where participation in lucrative off-farm activities is often limited by liquidity constraints. As such, off-farm income generation often entails lower return activities such as seasonal wage labour. The above patterns at a minimum can be taken as being informative of both the copying strategies and the constraints to adaptation. Notably, sustainable land management practices appear to be adopted mainly by farmers in the high and medium potential areas.

In summary, the current adaptation and coping strategies against the changing climate as reported by stakeholders across the counties are included (see also Table 7).

- Disease preventive measures such as use of mosquito nets, spraying of insecticides (to guard against the spread of malaria) and vaccination against water-borne diseases such as cholera and typhoid, which are often associated with flooding in Kenya.
- Promotion of zero-grazing and livestock off-take programmes. Climate change impacts have had a great toll on this particular sub-sector, with massive livestock deaths occurring, particularly during droughts. A livestock off-take programme was started to enable pastoralists to sell their livestock during droughts, to the Kenya Meat Commission, and avoid losses that would result without such programmes. In addition, farmers are also being encouraged to keep few, but high quality breeds through zero grazing.
- School feeding/relief food programmes. Relief food programmes have a long history especially in the dry counties of northern Kenya such as Turkana. This has reportedly seen increased rates of school enrolment, and may thus becited as a positive impact of climate change or a positive impact from an adaptation measure (or win-win measure as it brings about development as well as adaptation).
- Planting of drought tolerant crops. The Ministry of Agriculture, Livestock and Fisheries calls this "Orphaned Crops Programme" and targets crops such as millet, sorghum, cassava, pigeon peas and sweet potatoes, among others that have traditionally been used as Kenya's staple foods before the introduction of maize. These are now being promoted due to their fast maturity period and less water demand, especially in the face of climate change.
- Livelihood diversification options including change in eating habits (i.e. adopting new foods), fish farming, rice farming other income generating activities such as bicycle transportation and fruit-tree farming. Diversification of livelihoods cushions against climatic shocks and has been cited as a positive impact of climate change for communities dependent on one climate-sensitive economic activity such as pastoralism.

- Rationing the use of natural resources e.g. control of water use and rain water harvesting is also a coping strategy that has been adopted by almost all counties.
- Construction of dams, boreholes and other water storage infrastructure to improve water supply for agriculture, domestic and other uses. Roof-top catchment as a water-harvesting strategy is also being undertaken particularly at individual/household level in all the counties.
- Adoption of sustainable forms of agriculture like mulching, minimum tillage to conserve soil moisture and nutrients, application of organic manure etc.
- Migration of human and animals.
- Pastoralists also use supplementary feed for livestock, purchased or lopped from trees, as a coping strategy, they intensify animal disease management through indigenous and scientific techniques, and also increasingly pay for water from powered boreholes.

Finally, it is worth highlighting that majority of the stakeholders felt that the measures they were undertaking to mitigate the effects of climate change were not effective due to lack of resources at both household and community level.

Proposed interventions

In terms of future adaptation plans, the following strategies were proposed:

- Promoting the cultivation of traditional crops such as pigeon peas, cassava and sweet potatoes. For instance, the Ministry of Agriculture, Livestock and Fisheries and Kenya Agricultural Research Institute (KARI) are jointly implementing a project aimed at the conservation and sustainable use of Plant Genetic Resources for food security. The one year project is being implemented by KARI through the National Gene bank of Kenya.
- Research and development to produce improved livestock and crop varieties that can adapt to the changing climate.
- Promotion of eco-tourism, bee keeping, upland rice farming, fruit-tree farming and other forms of livelihood and economic diversification.

- Relocation and resettlement of people from forests and disaster prone areas such as areas prone to floods and landslides.
- Promotion of sustainable crop farming such as inter-cropping and organic farming and supporting farmers to initiate the same.
- Protection of water catchments, wetlands and other fragile ecosystems. The Kenyan component of Africa Adaptation Programme recently supported the rehabilitation of Lake Naivasha catchment area.
- Establishment of more weather stations for improved weather service provision.
- Improvement and modernization of infrastructure that takes into account climate change issues.
- Rehabilitation and construction of dams, boreholes and other water infrastructure in areas prone to droughts.
- Sustainable land management practices.
- Rain-water harvesting for improved livestock and crop production.
- Promotion of irrigated agriculture and other modern agricultural technologies.
- Exploitation of underground water resources.
- Enhancement of peace building initiatives to reduce resource-based conflicts.

Table 7 Current adaptation and coping strategies

Eastern

Narrative	Description
Evidence of climate change	Prolonged drought Increased temperature Increased water scarcity due to drying up of rivers and irregular rainfall patterns Extinction of some species of wildlife and plants Out-break of diseases in areas previously considered disease-free
Impacts of climate change	Crop failure due to persistent drought and floods Livestock deaths due to cyclic droughts Increased food prices due to scarcity Increase in poverty levels leading to higher crime rates

Proposed interventions	Communities across the counties are being encouraged to plant trees De-stocking to avoid over-grazing Sand harvesting has been banned Farmers growing drought-tolerant and early-maturing crop varieties Income/enterprise diversification Rehabilitation of water catchment areas Use of solar and wind energy Use of energy-saving jikos in homes and schools
Proposed interventions	Awareness creation on climate change in the whole county Rainwater harvesting Community projects aimed at protection of water sources and riparian areas Introduction and promotion of drought-resistant crop varieties Establishment of a functional meteorological station at county level Promotion of drought-tolerant breeds of livestock e.g. Borana, Zebu Adequate budgetary allocation at county level to tackle climate change issues Strengthening of farmer-research-extension linkages

Central

Narrative	Description
Evidence of climate change	Extinction of some fruit trees e.g. plum trees in Kiambu (Biodiversity loss) Landslides now common in areas like Gatundu Drying up of natural wetlands Frequent flooding Increased incidences of malaria as mosquitoes are now common Higher night temperatures Tea frosts
Impacts of climate change	Increased infant mortality due to malaria, typhoid and malnutrition Livestock deaths due to cyclic droughts Rationing of water and power due to scarcity Increase in poverty levels leading to higher crime rates Displacement of human and wildlife due to floods

Central *(Continued)*

Current actions to cope with the impacts of climate change	Afforestation Construction of water pans, gabions, dykes, dams, terraces Use of alternative sources of energy Promotion of indigenous crops Establishment and promotion of biogas pilot projects across the county Payment for Ecosystem Services (PES) Community-based natural resource management
Proposed interventions	Adoption of green technologies that reduce emission of GHGs Rehabilitation of water catchment areas Establishment of early warning systems Introduction and promotion of drought-resistant crop varieties Government subsidization of farm inputs such as seeds and fertilizer Sensitize locals on the need for community-based natural resource management through CFAs and WRUAs
Proposed interventions	Adoption of green technologies that reduce emission of GHGs Rehabilitation of water catchment areas Establishment of early warning systems Introduction and promotion of drought-resistant crop varieties Government subsidization of farm inputs such as seeds and fertilizer Sensitize locals on the need for community-based natural resource management through CFAs and WRUAs

Western

Narrative	Description
Evidence of climate change	Higher temperatures (35^0C and above) Prolonged droughts Reduced forest cover in areas with previously dense vegetation cover Frequent flooding in some areas Water scarcity Higher night temperatures Irregular rainfall patterns

Impacts of climate change	Displacement of families and destruction of property due to floods especially in Budalangi
	Outbreak of weather-related diseases
	High food process due to scarcity
	Water and power rationing
	Low agricultural productivity due to droughts
	Biodiversity loss
Current actions to cope with the impacts of climate change	Construction of water pans, gabions, dykes, dams, terraces
	Farmers practicing conservation agriculture
	Afforestation
	Rainwater harvesting
	Use of energy-saving jikos
	Growing drought-resistant and early-maturing crops
Proposed interventions	Climate Change Secretariat to be decentralized to county level
	Creation of a fund for climate change adaptation and mitigation
	Integration of climate change in the county development plans
	Development of disaster risk reduction/emergency management plans
	Community sensitization on climate friendly lifestyles/habits
	Explore existing indigenous knowledge for climate change adaptation and mitigation

Nyanza

Narrative	Description
Evidence of climate change	Receding water levels in Lake Victoria and drying up of rivers
	Unpredictable rainfall patterns
	Higher day and night temperatures
	Frequent flooding in Kano Plains, Ahero
	Some permanent rivers have now become seasonal
	Biodiversity loss and habitat change
Impacts of climate change	Emergence of new crop/livestock diseases
	Famine/droughts/ starvation/malnutrition
	High food prices due to scarcity
	Crop failure and shortage of pasture for livestock
	Displacement of families and wildlife due to floods

Nyanza *(Continued)*

Current actions to cope with the impacts of climate change	Communities practicing integrated water resource management Rehabilitation of wetlands Construction of dams Enterprise diversification (bee-keeping, small-scale "jua kali" businesses) Afforestation Growing drought-tolerant crop varieties Rainwater harvesting
Proposed interventions	Set up a climate change fund at grass-root level Integration of climate change adaptation and mitigation in to county development plans Promotion of renewable energy Promotion of drought tolerant and early-maturing crop varieties Dissemination of climate change information to farmers Protection of threatened ecosystems Documentation of best practices on climate change adaptation and mitigation

North Eastern

Narrative	Description
Evidence of climate change	Strong winds Recurrent and prolonged droughts Biodiversity loss Increasing day and night temperatures Emergence of new crop and livestock diseases Decrease in vegetation cover
Impacts of climate change	Loss of livelihoods Human-wildlife conflict Low agricultural productivity Hunger/starvation/malnutrition Conflicts over limited resources such as water points Family break-ups due to displacement

Current actions to cope with the impacts of climate change	Planting of trees/afforestation Fodder farming Construction of dams, dykes and boreholes Community sensitization on dryland farming and livelihood diversification Afforestation Growing drought-tolerant crop varieties Rainwater harvesting
Proposed interventions	Strengthening of existing Early Warning Systems Mainstreaming climate change adaptation and mitigation in to development projects Use of renewable energy Conservation agriculture Dissemination of climate change information to farmers Protection of threatened ecosystems Improved governance of community-based natural resource management Community sensitization on the need for enterprise/income diversification

Coast

Narrative	Description
Evidence of climate change	Sea-level rise in places like Ngomeni Migration of some species of fish due to rising sea-level Shifting rainfall patterns South East monsoon winds have come earlier than expected Extended dry seasons High temperatures leading to bleaching of corals
Impacts of climate change	Habitat change Degradation of coral reefs Crop failure leading to food scarcity Increased incidences of human-wildlife conflict due to scarcity of food and feed, especially in Voi and Mwatate Biodiversity loss

Coast *(Continued)*

Current actions to cope with the impacts of climate change	Establishment of tree nurseries Development of REDD+ projects Introduction of eco-jikos, eco-charcoal Planting of orphan/drought-tolerant crops such as pigeon peas, cassava Community sensitization on renewable energy Community rehabilitation of threatened ecosystems Rainwater harvesting
Proposed interventions	Afforestation Establishment of functional climate change units in every county Community sensitization on the need to conserve the environment Introduction of breed of livestock adapted to harsh weather conditions Dissemination of climate change information to farmers Establishment of water points in wildlife protected areas to reduce human-wildlife conflict Use of drought-tolerant and early-maturing crop varieties Government subsidization of farm inputs especially during seasons of drought and crop failure

Rift Valley

Narrative	Description
Evidence of climate change	Erratic rainfall patterns and habitat change especially flamingos Frequent hailstorms Less water in rivers Increasing temperature trends Change in planting seasons Frequent floods
Impacts of climate change	Increased respiratory infections due to dust Food insecurity as a result of crop failure Reduced milk production due to lack of pasture for livestock High food process due to scarcity Biodiversity loss, high energy costs, water and power rationing

Current actions to cope with the impacts of climate change	Community sensitization on climate change issues Planting of trees Growing of drought-resistant crops like millet, sorghum, cassava Enterprise diversification (bee-keeping, small-scale jua kali businesses) Community sensitization on renewable energy Enforcement of environmental laws e.g. 10% of tree cover on all farm land Rainwater harvesting
Proposed interventions	Intensify tree-planting Promotion of early-maturing and drought-tolerant crop varieties Introduction of other fodder crops resistant to harsh weather conditions Carbon trading Dissemination of climate change information to farmers Protection of threatened ecosystems Knowledge sharing on climate change adaptation and mitigation Community sensitization on the need for enterprise/income diversification

Nairobi

Narrative	Description
Evidence of climate change	Stronger winds Prolonged drought Higher day and night temperatures Flash floods Some permanent rivers have now become seasonal Biodiversity loss and habitat change Unpredictable weather patterns
Impacts of climate change	Prolonged drought cause spoor yields, inadequate water, low production of meat and milk Famine/droughts/ starvation/malnutrition High food prices due to scarcity Destruction of crops by hail storms Displacement of families and wildlife due to floods and conflicts over limited resources

Nairobi *(Continued)*

Current actions to cope with the impacts of climate change	Small-scale rain water harvesting Use of early maturing and drought-tolerant crops Rearing hardy breeds of livestock such as Zebu Enterprise diversification (bee-keeping, small-scale "jua kali" businesses) Afforestation Construction of dams, dykes, water pans Community-based natural resource management
Proposed interventions	Dissemination of climate change information to farmers Integration of climate change adaptation and mitigation in to county development plans Promotion of renewable energy Community sensitization on renewable energy Upscale tree planting programmes Protection of threatened ecosystems Enterprise/income diversification

Conclusion and policy implications

This paper presents the outcomes of the climate change Action Plan county consultations conducted between March and May 2012. The Action Plan development process represents a second milestone in Kenya's ongoing efforts to adapt to climate change after the launch of the National Climate Change Response Strategy in 2010.It indeed demonstrates how Kenya is committed both in principle and in action to combat climate change. It is hoped that this ground-breaking grand plan will steer the nation towards greater resilience in the face of climate change. Realizing this commitment will require sustained effort and cooperation from all spheres of government, the private sector, civil society, and will ultimately depend on decisions by Kenyan citizens to embrace climate-friendly lifestyles and habits.

Furthermore, agro-pastoralists and pastoralists must be empowered to manage their natural resources. As such, they urgently require the tools and knowledge to manage resources and ecosystems in the face of climate change. This should include dissemination of information to dispel the many myths of climate change and demonstrate the important role SLM can play in adapting to climate change. Farmers must also be immediately and directly assisted to adapt their management practices to build resilience to increasing climate variability and climate change through SLM practices that restore the productivity of their lands and ecosystem services.

Finally, as is clearly evident, most of the strategies adopted across the counties are effectively meant to cope with short term changes in climate; the challenge is now to develop strategies that can be used to enable future adaptation to climate change over the longer term. The need to strengthen effective coping strategies and move beyond others is therefore more urgent.

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Chapter 12

Adapting Rain-fed Agriculture to Climate Change: An Overview of Sorghum and Cowpea Production in Agro-Pastoral Areas of Eastern Kenya

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Abstract

The lower parts of Embu County in Eastern Kenya are characterized by low crop growth due to poor rainfall distribution among other factors, leading to food insecurity and increased poverty levels. Rain-fed agricultural productivity has continually declined due to unpredictable and unreliable rainfall patterns. The decline in crop productivity has been as a result of inadequate understanding of intra-seasonal rainfall variability to develop optimal cropping calendar. A study was conducted to assess the effect of various water harvesting and integrated soil fertility management technologies for enhanced sorghum *(Sorghum bicolor (L.)* Moench) and cowpea *(Vigna unguiculata L.)* productivity in Mbeere South sub-county of Embu County. A field experiment was laid out in Partially Balanced Incomplete Block Design (PBIBD) with a total of 36 treatments replicated three times. The treatments of tied ridges and contour furrows under sorghum alone and intercrop plus external soil amendment of 40 kg P ha^{-1} + 20 kg N ha^{-1} manure 2.5 t ha^{-1} had the highest grain yield of 3.1 t ha^{-1}. The soil fertility levels and water harvesting technologies differed significantly from one another ($p=0.0001$) in terms of sorghum and cowpea grain yields. Generally, all the six experiment controls had the lowest grain yields as low as 0.3 t ha^{-1} to 0.5 t ha^{-1}. Therefore, integration of 40 kg P ha^{-1} + 20 kg N ha^{-1} + manure 2.5 t ha^{-1} under various water harvesting technologies could be considered as an alternative food security initiative towards climate change mitigation for Mbeere South sub-county.

Key words: Climate change, soil amendments, semi-arid areas, Embu County

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Introduction

Agricultural productivity in semi-arid areas of Kenya has been impaired by climate change, declining soil fertility, inefficient markets, weak institutions and policies. Over 13 million of the 38 million people live below the poverty line of less than USD 1 a day (FAO 2008). Agriculture is the mainstay of the Kenyan economy contributing approximately 25% of Gross Domestic Product (GDP). The sector further provides 80% employment, accounting for 60% of the exports and 45% of the government revenue (Ragwa et al. 1998). The government of Kenya has put in place the Agricultural Input Subsidy Program (AISP) to support farmers so that they can access inputs such as inorganic fertilizers. In "Vision 2030", the government also spells out the desire to use agriculture as the vehicle to transform the country to industrialization (CAADP 2008). However, more than 80% of Kenya is arid and semi-arid areas that are characterized by erratic rainfall, high evapo-transpiration rates and fragile soils that are unsuitable for sustainable rain-fed agriculture in Kenya (Miriti et al. 2012; McCown and Jones 1992). Understanding spatio-temporal rainfall patterns has been directly implicated to combating extreme poverty and hunger through agricultural enhancement (IPPC 2007). The amount of soil-water available to crops depends on rainfall onset, length and cessation which influence the success or failure of a growing season. This is particularly important in Sub-Saharan Africa (SSA) where agricultural productivity is principally rain-fed yet crop production cannot be projected in our near future (Jury 2002).

The drier parts of Mbeere sub-county; Embu County in Kenya continue to experience elevated rainfall variations, persistent dry spells, prolonged droughts and high annual potential evapo-transpiration (2000-2300 mm $year^{-1}$) (Micheni et al. 2004). There is generally enough water for agricultural production; however, it is poorly distributed over time (Kimani et al. 2003) with 25% of the annual rain often falling within a couple of rainstorms. As a result crops suffer from water stress, often leading to complete crop failure (Meehl et al. 2007). Quite often, analyses on rainfall patterns have been based on annual averages, thus missing on characteristics of seasonal variations. Sivakumar et al. (1993) reported that, understanding the average amount of rain per rainy day is essential in assessing inter/intra seasonal variability. Evaluating mean duration between successive rain events also aids in understanding these variability (Akponikpè et al. 2008). Recha et al. (2011) noted that, most studies do not provide information on the much-needed character of within-season variability despite its implication on soil-water distribution and productivity. There has been continued interest in understanding seasonal rainfall patterns by evaluation of its variables including rainfall amount, rainy days, lengths of growing seasons and even dry-spell frequencies. Studies done by Tilahun (2006) noted high variations in annual and seasonal rainfall totals and rainy days in Ethiopia and Sudano-Sahelian regions. Mugalavai et al. (2008) analyzed onset and cessation of rainfall in Kenya and linked their variation to atmospheric, oceanic and local geographic conditions. Hitherto, the much-needed information on inter/intra seasonal variability of rainfall in Embu County is still inadequate despite its critical implication on soil-water distribution, water use efficiency (WUE), nutrient use efficiency (NUE) and final crop yield. Several recent studies have yielded little evidence on occurrence of dry spells to increase the frequency of rain water use efficiency in semi-arid areas of Africa (Stroosnijder 2009). This has been contributed by mixed crop-livestock systems being currently projected to see reduction in crop production as a result of drought throughout most East Africa regions due to climate change by 2050 (Thornton et al. 2010).

The challenge now remains on how to maximize use of every drop of rain water which falls on the ground to increase agricultural production in semi-arid areas of Embu County. The low crop production in central Kenya is also often associated with lack of appropriate farming practices that are suited to the fragile ecosystems (Bationo et al. 2004; Mbogoh 2000). Most of the smallholder farms are characterized by nutrient mining as a result of crop harvest and residue removal (Mugendi et al. 2003; Bielders et al. 2002) as well as lack of resources to invest in mineral fertilizers or very little nutrient replenishment is practiced in central Kenya (Mugendi et al. 2010). The recommendation of African Fertilizer Summit (2006) 'to increase the fertilizer use from the current 8 to 50 kg ha^{-1} nutrient by 2015' reinforces the role of fertilizer as a key entry point for increased crop productivity and attaining food security and rural well being in SSA. Alternatively most farmers cannot afford inorganic fertilizers due to their high prices (Sanginga et al. 2009; Crew and People 2004). Many agricultural systems revolve around inorganic fertilizer use rates and concentration of nutrients in manure. Inorganic fertilizers and high quality manure are often beyond the reach of most smallholder farmers in the central Kenya (Njeru et al.

2011a; Kimani et al. 2007). The soil fertility decline is as a result of a combination of processes such as high rates of soil erosion, nutrient leaching, removal of crop residues, continuous cultivation of the land without adequate fertilization and fallowing (Njeru et al. 2011b; Okalebo et al. 2006). The average annual loss in soils nutrients of 42 kg Nitrogen (N), 3 kg Phosphorus (P) and 29 kg Potassium (K) ha^{-1} in Kenya is among the greatest in Africa (Smaling et al. 1997). The rising cost of inputs has led to many smallholder farmers reducing or abandoning the use of chemical fertilizer altogether in Central Kenya (Gachimbi 2002).

Therefore, the food security situation is expected to continue deteriorating and could worsen in future if on farm rain water harvesting and integrated soil fertility technologies are not taken up quickly in semi-arid areas of Embu County. Improving agricultural productivity is crucial for resolving food crises, enhancing food security and accelerating pro-poor growth. Sorghum and cowpea are locally important food crops and household nutrition, and provide income opportunities for the most vulnerable people and women in particular. These two premium crops have potential to diversify the farming systems, adapt to spread risks and are more resilient to climatic variations and climate change. This study assessed the effect of various water harvesting and integrated soil fertility management technologies for enhanced sorghum and cowpea production in Mbeere South sub-County.

Materials and Methods

Study sites location

Figure (1) below shows map of Mbeere South sub-county in Embu county. The map also indicates the location of the study sites and surrounding towns in the sub-county.

Figure 1 Location of study site in Mbeere South sub-county

Site description

The study was conducted in Kiritiri Division, Mbeere South sub-County which lies in the south eastern slopes of Mt. Kenya. It lies between latitude 0.91672 S and 0.47330S, and between longitude 37.47680 E and 37.91238 E. The sub-county lies at 800 m a.s.l with an average rainfall of 700 to 900 mm, temperature of 21.7^{o}C to 22.5^{o}C and the soils are mainly Ferralsols (Jaetzold et al. 2007). Besides, differences in agro-ecological zones along the altitudinal gradient, agricultural systems differ from upper to lower zones. Kiritiri division is generally a low potential agro-ecologial zone. It is covered by three agro-ecological zones; the marginal cotton zone (LM4); the lower midland livestock-millet zone (LM5); and the lowland livestock millet zone (L5). The study was conducted in agro-ecological zone (LM4/5) during the long rains of 2011, 2012 and the short rains of 2011.

Experimental design

The treatments were arranged in a factorial design with each treatment being a combination of one of 3 levels of water harvesting techniques (tied ridges, contour furrows and conventional tillage/farmers practice), 2 levels of cropping systems (sole sorghum) and cowpea (M66) intercrop and 6 levels of soil fertility amendment options (control, 40 Kg P ha^{-1} + 40Kg Nha^{-1}, 40 kg P ha^{-1} + 20 kg Nha^{-1}, 40 kg P ha^{-1} + 40 kg N ha^{-1} + Manure 5 t ha^{-1}, 40 kg P ha^{-1} + 20 kg N ha^{-1} + Manure 2.5 t ha^{-1} and manure 5t ha^{-1}) thus giving a total of 36 treatments. They were laid out in a Partially Balanced Incomplete Block Design (PBIBD) with six incomplete blocks per replicate each containing six treatments, replicated 3 times making a total of 108 plots. Treatments were assigned to blocks randomly with plot size of 6 m x 4 m. The dry land sorghum and cowpea (M66) varieties were used as the test crops. A net plot of 3 m x 2 m was harvested for biomass and yield data measurements. The sub-samples were oven dried and measurements taken. All this data was subjected to statistical analysis.

Data analysis

The biophysical data on crop yield was analyzed using Statistical Analysis of Variance (ANOVA) using SAS version 8. Differences between treatment effects were declared significant at $P \leq 0.05$. Means were separated by use of Analysis of Variance.

Results

Treatment effects

The results (Table 1) underscore the scientific crop evaluation from the field experiment during long rains of 2011, 2012 and the short rains of 2011.

Table 1 Water harvesting, cropping system and soil fertility effects on sorghum yield in Mbeere South sub-county

Water Harvesting	Cropping system	Soil fertility management regimes	Total Dry Matter t ha^{-1}	Biomass + husks t ha^{-1}	Sorghum Grain yield
Tied Ridges	Sole crop	40 kg P ha^{-1} +20 kg N ha^{-1} +Manure 2.5t ha^{-1}	6.1	3.0	3.1
Contour furrows	Sole crop	40 kg P ha^{-1}+20 kg N ha^{-1} +Manure 2.5t ha^{-1}	6.1	3.0	3.1
Tied Ridges	Intercrop	40 kg P ha^{-1}+20 kg N ha^{-1} +Manure 2.5t ha^{-1}	6.1	3.0	3.1
Contour furrows	Intercrop	40 kg P ha^{-1}+20 kg N ha^{-1}+ Manure 2.5t ha^{-1}	6.1	3.0	3.1
Tied Ridges	Sole crop	40 kg P ha^{-1}+20 kg N ha^{-1}	5.9	2.9	3.0
Contour furrows	Sole crop	Manure 5 t ha^{-1}	5.9	2.9	3.0
Tied Ridges	Sole crop	40 kg P ha^{-1}+40 kg N ha^{-1}+ Manure 5t ha^{-1}	5.9	2.9	3.0
Tied Ridges	Sole crop	40 kg P ha^{-1}+40 kg N ha^{-1}	5.6	2.7	2.9
Contour furrows	Sole crop	40 kg P ha^{-1}+40 kg N ha^{-1} +Manure 5t ha^{-1}	5.6	2.7	2.9
Tied Ridges	Intercrop	40 kg P ha^{-1}+40 kg N ha^{-1} +Manure 5t ha^{-1}	5.4	2.6	2.8
Contour furrows	Sole crop	40 kg P ha^{-1}+40 kg N ha^{-1}	5.4	2.6	2.8
Contour furrows	Sole crop	40 kg P ha^{-1}+40 kg N ha^{-1}	5.2	2.7	2.7
Tied Ridges	Intercrop	40 kg P ha^{-1}+20 kg N ha^{-1}	5.2	2.5	2.7
Contour furrows	Intercrop	40 kg P ha^{-1}+40 kg N ha^{-1} +Manure 5t ha^{-1}	5.1	2.5	2.6
Tied Ridges	Intercrop	40 kg P ha^{-1}+40 kg N ha^{-1}	5.0	2.4	2.6
Contour furrows	Sole crop	40 kg P ha^{-1}+40 kg N ha^{-1}	4.9	2.4	2.5
Contour furrows	Intercrop	40 kg P ha^{-1}+20 kg N ha^{-1}	4.8	2.3	2.5

Tied Ridges	Sole crop	Manure 5t ha^{-1}	4.8	2.3	2.5
Farmers Practice	Intercrop	40 kg P ha^{-1}+20 kg N ha^{-1} +Manure 2.5t ha^{-1}	4.6	2.2	2.4
Farmers Practice	Sole crop	40 kg P ha^{-1}+20 kg N ha^{-1}	4.6	2.2	2.4
Farmers Practice	Sole crop	40 kg P ha^{-1}+40 kg N ha^{-1}	4.5	2.2	2.3
Farmers Practice	Sole crop	40 kg P ha^{-1}+20 kg N ha^{-1} +Manure 2.5 t ha^{-1}	4.4	2.1	2.3
Farmers Practice	Intercrop	40 kg P ha^{-1}+40 kg N ha^{-1}	4.3	2.1	2.2
Farmers Practice	Intercrop	40 kg P ha^{-1}+20 Kg N ha^{-1}	4.2	2.0	2.2
Farmers Practice	Sole crop	40 kg P ha^{-1}+40 kg N ha^{-1} +Manure 5t ha^{-1}	4.1	1.9	2.2
Farmers Practice	Intercrop	40 kg P ha^{-1}+40 kg N ha^{-1} +Manure 5t ha^{-1}	3.9	1.8	2.1
Farmers Practice	Intercrop	Manure 5t ha^{-1}	3.9	1.8	2.1
Farmers Practice	Sole crop	Manure 5t ha^{-1}	3.7	1.7	2.0
Tied Ridges	Sole crop	Control	1.7	1.2	0.5
Tied Ridges	Intercrop	Control	1.6	1.1	0.5
Contour furrows	Sole crop	Control	1.5	1.1	0.4
Contour furrows	Intercrop	Control	1.4	1	0.4
Farmers Practice	Sole crop	Control	1.3	1	0.3
Farmers Practice	Intercrop	Control	1.1	0.8	0.3
Means			4.5	2.2	2.3
CV			17	22.8	20.4
LSD			1.92	1.41	0.20
Test statistics			$F_{(10,843)}$=1.90; p=0.04	$F_{(10,843)}$=2.54; p=0.04	$F_{(10,843)}$=2.70; p=0.003

The result (Table 1) shows three types of water harvesting, two cropping system and six fertility amendment levels. Fertility levels differed significantly from one another ($p=0.0001$) in terms of sorghum grain yield. The total dry matter amount varied significantly among levels of cropping system and fertilizer application ($p= 0.0111$ and 0.0001) respectively. However the total dry matter amount did not vary significantly across water harvesting methods ($p=0.5333$). The sorghum biomass was significantly different among cropping system ($p=0.0020$) while water harvesting and fertility levels did not differ significantly ($p=0.3820$ and 0.0854).

Combination effect

The results further indicated that sorghum without manure application did not differ significantly in yield production with treatments that did not receive fertilizer application. However, plots that received fertilizer and no manure gave slightly higher sorghum yield as compared to plots that received manure and no fertilizer (Table 1). The highest sorghum yield (3.1 t ha^{-1}) was recorded from tied ridges under sole sorghum and intercrop cropping system with external nutrient replenishment of 40 kg P ha^{-1} + 20 kg N ha^{-1} + Manure 2.5 t ha^{-1}. The best eight treatments grain yield did not differ significantly from one another ($p<0.05$). The lowest sorghum yield (< 2.0 t ha^{-1}) was observed in treatments regarded as 'control' with neither fertilizer nor manure regardless of other interventions (water harvesting methods or cropping systems). The total dry matter and biomass were highest in tied ridges under sole cropping of soil fertility amendment of 40 kg P ha^{-1} +20 kg N ha^{-1} +Manure 2.5 t ha^{-1} (6.1 t ha^{-1}) and (3.0 t ha^{-1}) respectively.

Discussion

There were a consistently high grain biomass and total dry matter yields of 3.1 t ha^{-1}, 3.0 t ha^{-1} and 6.1 t ha^{-1} in tied ridges under nutrient replenishment of 40 kg P ha^{-1} + 20 kg N ha^{-1} + Manure 2.5 t ha^{-1}. This was an indication that 20 kg N ha^{-1} nutrient replenishment was required in all the seasons in Embu County. Studies by Mugendi et al. (2010) and Gachimbi (2002) have also reported that farms in central Kenya highlands require nutrient replenishment every season from manures, fertilizers and from crop residue return in their farms. It has also been reported by Njeru et al. (2010, 2013) and Mairura et al. (2007) that soil fertility can also be accessed through visual observation on crop performance and yield. The results in Table 1 have further shown that water harvesting technologies and soil fertility management technologies played a major role in increased crop productivity. This is in agreement with what Miriti et al. (2012) and Mucheru-Muna et al. (2009) who reported that incorporation of water harvesting and legumes can enhance crop productivity in Eastern Kenya. The results further show that tied ridges and contour furrow under intercrop of cowpea with the same soil fertility management options had lower crop yield than their sole cropping systems. This could be as a result of nutrient competition since cowpeas are heavy nutrient miners (Katsaruware and Maanyanhaire 2009) since they are associated with interspecific competition in mixed stands. The same findings have been reported by Katsaruware and Maanyanhaire, (2009) that crop yield reduction can be experienced in intercrops where they are associated with interspecific competition in mixed stands and the absence of interspecific competition in the sole cropping systems. The results further indicate that probably intercropping sorghum with cowpea depressed sorghum yields and this had an influence on crop performance. These results are in line with results on maize from Kenya (Nadar 1984) and in Tanzania (Jensen et al. 2003) where maize grain yields reduction of 46-57% and 9% occurred when maize was intercropped with cowpea due to the competition for moisture between the two crops. Alternatively, due to slow mineralization of manure which needed a number of seasons to meet the level of nutrient competition could have contributed to lower sorghum grain yields (Lekasi et al. 2003). The results by Miriti (2011) have also shown that cowpea was also a nutrient competitor for maize production in semi-arid areas of eastern Kenya. The experiment control, farmers practice, under sorghum and cowpea intercrop was the lowest in grain yield. This is in line with continuous cultivation of the same piece of land as this led to nutrient depletion and requires nutrient replenishment (Mugwe et al. 2009; Miriti et al. 2003). However, farmers are discouraged from adopting these technologies of water conservation structures as a result of labour shortage and land tenure uncertainty in their farms (Demelash and Stahr 2010). Therefore, land productivity can be improved by employing appropriate agricultural technologies which suit these semi-arid areas of Mbeere South sub-county, Eastern Kenya.

Conclusion

The results reported in the study demonstrate that there is need to incorporate water harvesting and integrated soil fertility management technologies on sorghum productivity. This nutrient replenishment of 40 kg P ha^{-1} + 20 kg N ha^{-1} + Manure 2.5 t ha^{-1} suggests that low-input and rain water management technologies are currently suitable and need to be adopted. The results have also demonstrated a very clear message to smallholder farmers, extension services and other stakeholders that there is need for nutrient replenishment on farm in every season to enhance sorghum and cowpea productivity. Therefore, integration of 20 kg N ha^{-1} + Manure 2.5t ha^{-1} under various water harvesting technologies could be considered as an alternative food security initiative towards climate change mitigation for Mbeere South sub-county, Embu County in Eastern Kenya.

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Chapter 13

Strategies Used by Women to Adapt to the Effects of Climate Change in Mwala Division, Machakos County, Kenya

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Abstract

Climate change is a major threat and challenge to household food security in Machakos County where the majority of small scale farmers, mostly women, rely on rain fed agriculture. Paradoxically, since climate change disproportionately affects the poor globally, and women form the majority of the world poor, they are more vulnerable to the effects of climate change. Nevertheless, women are not just helpless victims of the vagaries of nature as they have demonstrated unique knowledge and expertise in generating appropriate adaptive strategies to combat the effects of climate change through collective action. A cross-sectional study was conducted in Mwala Division, of Machakos County Kenya, to investigate the contribution of women group participation in adaptation to climate change. A sample of 156 respondents was selected through simple random sampling, with 94 people affiliated to groups while 62 were not. The study revealed that women with strong membership to groups had more access to extension information and used appropriate adaptive strategies against climate change thannon-group members. The results also revealed that group participation had a positive and significant influence ($p<0.05$) on the level of drought preparedness and food security ($p<0.001$). The study recommended that women groups' organizational and resource capacity be enhanced to profit more households for up scaling appropriate and effective drought adaptation strategies for improved livelihoods and household food security. Information regarding various adaptive and coping strategies against climate change should be provided to women in line with their local needs and circumstances. The authors argue that women groups have the potential to contribute to access

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of information and training on climatic change adaptation technologies and consequently to also influence the uptake of those technologies by the women farmers.

Key words: Climatic change, drought adaptation, food security, group participation

Introduction

Persistent rural poverty, food and nutrition insecurity continue to be major challenges facing farmers in Sub-Saharan Africa (SSA), particularly those living in the arid and semi-arid lands (ASALs). Farmers in ASALs face many challenges in their endeavor to secure the nutrition needs of their households. The challenges include climate variability characterized by prolonged droughts and erratic rainfall, poor marketing infrastructure, limited access to credit, high costs and adulteration of inputs, reduced effectiveness of extension services, low and declining soil fertility and lack of coherent land use policies (Sanchez 2002; Belay and Abebaw 2004; Morrison et al. 2007).For women farmers, these challenges are further exacerbated by widespread gender disparities in terms of participation in decision making, asset endowment, division of labour and access to and control of inputs and outputs which disadvantage them as the custodians of household food security (Quisumbing et al. 2001; Akinboade 2005;IAASTD 2009).

Empirical evidence has shown that women are the engine that drives agriculture in developing countries especially in the SSA. They play an important role as food producers, natural resource managers, income earners, and caretakers of household food security (Quisumbinget al.2001). Globally, women produce 50% staple food, while in Africa, Asia and Latin America they produce 60 - 80% (World Bank2008), making them crucial in the achievement of household food security. Through their economic and household work, poor rural women in sub-Saharan Africa are in daily contact with the agro-ecological system as they largely depend on natural resources for livelihood and have limited income earning opportunities outside agriculture which make them even more vulnerable to climate change (UNFPA 2009). Prolonged droughts resulting from climatic change mean that the Sub-Saharan woman now walks longer distances to collect water, wood fuel and to gather food for her household as the world becomes a hotter and drier place to live in (Brody et al. 2008). This decreases the time available to undertake food production and preparation, and for participation in income generating activities. This consequently negatively affects household food security and nutritional well-being.

Climate change can be identified by changes in the mean variability of precipitation and temperature that persist for extended periods, typically decades or longer (IPPC 2012). Changes in temperature, precipitation and increases in climate variability including extreme weather related events like droughts and floods are already evident. Consequently, climate change poses a challenge to governments' efforts for poverty reduction and also threatens to undo decades of development efforts (IPCC 2010), especially in the Sub-Saharan Africa. Climate change has therefore emerge as one of the defining political and socio-economic issues of the twenty-first century, becoming a mainstream political issue that policy makers need to understand and respond to.

Climate adaptation is the process of adjustment of human systems to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities resulting from climate change. According to Richerson et al. (2001), the human race has faced climate change and also adapted to it since the species evolution. The development of agriculture was almost certainly a major adaptation to climate change. Inter-governmental Panel on Climate Change, (IPCC 2007), explains that adaptation helps farmers achieve their food, income and livelihood security objectives in the face of changing climatic and socioeconomic conditions, including climate variability, extreme weather conditions and volatile short-term changes in local and large-scale markets. Agrawal (2008) views the choice of adaptation practices as dependent on social and economic endowments of households and communities, their ecological location, networks of social and institutional relationships, institutional articulation, and access to resources and power.

However, climate change is not gender neutral but has various gender-specific impacts. Differentiated power relations between men and women, and unequal access and control over assets mean that men and women do not have the same adaptive and coping capacity; instead, women have a distinct vulnerability, increased exposure to risk and have less, coping capacity and ability to recover from climate change impacts (Masika 2002).Lack of adequate agricultural information especially on climate change adaptation, constrains the women farmers' ability to produce enough food and earn adequate income to secure their household nutritional needs (Quisumbing et al. 2001). Unfortunately, extension agencies have often failed to get timely and appropriate information to women farmers due to conflicting time schedules and illiteracy among other bottlenecks. Additionally, extension personnel do not consider men and women as separate clientele with different needs in agricultural production processes and different approaches and interventions (World Bank 2008).

Nevertheless, the rural sub-Saharan woman is not a helpless victim of the vagaries of nature but is capable of adapting and generating ingenious mitigating activities against the effects of climate change especially when she engages in a collective action through membership in women groups. History has shown that women farmers and their supporting institutions have been successful in introducing technological innovations to respond to constraints facing them in agricultural production value chains and adaptation to environmental and socio-economic challenges (Udvardy 1998; World Bank 2008; Mwaniki 2009). Citing women groups as important to technology uptake, Mwaniki (2009), noted that women groups are seen as useful entry points for testing technologies in rural areas, and are widely recognized as the grass root units through which change can be initiated and implemented, particularly with regard to family food production and nutrition. *The International Union for Conservation of Nature* (IUCN 2008), noted forming social networks as capable of helping women cope with food insecurity and climatic changes by reducing their socio-economic vulnerability while Grootaert and Narayan(2004),cited groups as important in promoting economic well-being and offering buffers against natural and policy shocks. In Machakos County, the reciprocal merry-go-round women groups locally known as "mwethya" are widely recognised for their efforts in supporting and promoting adoption of soil and water conservation measures through labour sharing (Kamar 2001).This study therefore focused on the strategies that women participating in associational groups use to adapt to the effects of climate change in Mwala Division as they may inform practices promoted by extension and development agents for climatic change adaptation across the country.

Participation of women groups in Kenya

Group participation is the involvement of individuals in specific formal or informal organizations for purpose of realizing not only utilitarian individual interests but also for attaining mutually satisfying collective interests (Amudavi 2005). The realization that they occupied a marginalized position in society motivated Kenyan women to form cooperative parties as a coping mechanism against denial to adequate access or control of productive resources (Mazingira Institute 1992). Udvardy (1998), places the origin of modern grassroots women's groups in Kenya in the post- World War II period. Discovering the power and utility of neighbourhood groups, Gikuyu women began to utilize these neighbourhood collectivities to improve their households' welfare by purchasing goods in bulk, as rotating credit or savings associations, to effect the establishment of local infrastructure (Udvardy 1998). The groups also fitted in the rallying spirit of mobilizing and organizing concept of *harambee* ('pull together'), that Kenya's first president advocated as an effective path to rural development in Kenya.

By forming groups, women farmers combine knowledge, skills and resources, and access services through collective action. The groups also enhance their bargaining power and advance claims to their rights through advocacy (World Bank 2008). Due to their versatility, women groups are increasingly being used by development and extension service agencies as entry points for testing technologies in rural areas, and as vehicles through which change can be initiated and implemented, particularly with regards to family food production and nutrition (Mwaniki 2009). As such, the Kenya Government has committed to support activities of women groups through specific policy measures in its Vision 2030 blue print (GOK 2007). One way through which the government is empowering women is through availing enterprise funds. Women entrepreneurs are encouraged to form groups and to apply for the funds with no collateral and at subsidized interest rates. A study by the Ministry of Gender and Social Services on the women enterprise fund revealed that in the year 2011, women committed 80 % of the money advanced to them from women enterprise funds to livestock farming and crop production (Omwenga 2012).

Materials and Methods

Study area

The study was carried out in Mwala Division of Machakos County in eastern Kenya (Figure 1). The Division has five locations with a population of 108,361 people and 23,868 households. The average land holding size is 0.7 ha per household (Kenya National Bureau of Statistics 2010). The Division is semi-arid with 61.4% of its population living below poverty line (KFSSG2009). The areas receives an average rainfall of 600–700mm per year, which is bimodal with the short rains being most reliable and occurring in the months of October to December and long rains in March to May. Soil is generally sandy clay and is easily eroded and leached. Maize *(Zea mays L.)* isthe major crop grown by all the households. Other crops grown in the area includebeans (Phaseolus vulgaris), cowpeas *(Vigna unguiculata),* pigeon peas *(Cajanus cajan)*, green grams *(Vigna radiata)*, sorghum *(Sorghum bicolor),* millet *(Pennisetum americanum),* cassava *(Manihot esculenta),* sweet potato *(Lopmaea batatas),* and fruit crops like mangoes *(Mangifera spp.)* and oranges *(Citrus spp.)*. Livestock kept in the area include poultry, goats, cattle, donkeys and sheep.

MACHAKOS COUNTY

Figure 1 Location of Mwala Division in Machakos County

Design and data collection

The research used a cross-sectional survey design that employed structured interview schedules to collect data. Population under study consisted of women farmers in 23,868 households in Mwala Division. Two sub–groups were studied namely; women group members from 22 groups actively involved in agricultural activities and registered by the Social Services Department and non-group members in the Division. Simple random sampling was used to select 94 women farmers from the 22 women groups that have a total membership of 540. Farmers who did not belong to any women groups and referred to as non-members were proportionately and randomly sampled according to the number of households in the locations of the Division to give a sample of 62 farmers. In addition, 10group leaders from the most active women groups involved in agricultural activities were selected for a focus group discussion to verify and strengthen data collected from the group participants. The data was analysed using SPSS package version 17 and presented using frequencies, percentages and multiple regression.

Results and Discussion

Sample's demographic characteristics

A total of 156 women farmers were interviewed. Demographic characteristics were used to describe the study sample (Table 1).

Table 1 Descriptive data for individuals interviewed(N=156)

Variable	Sub-level	Frequency	Percentage
Age	<30 years	14	9.0
	31-40 years	49	31.4
	41-50	62	39.7
	>50 years	31	19.9
Marriage	Married	117	75
	Widowed	22	14
	Single	17	11

Education	No formal education	11	7.1
	Primary	100	62
	Secondary	40	25.6
	Tertiary	8	5.1
Household size	2-4 members	42	27
	5-8 members	106	68
	>9 members	8	5
Land size (hectares)	0.1-1.0	101	64.7
	1.1-2.0	48	30.8
	>2.1	7	4.5

The respondents' age ranged between 23 and 68 years with the majority (71.1 %) falling between 31-50 years showing that the sample was fairly representative. Most (75%) of the respondents were married, 14% were widowed and 11% were single. Age has been found to influence technology uptake with the older farmers being less inclined to adopt new innovations (Ogunsumi and Ogbusuka 2009), while marital status of the respondents may influence labor availability for agricultural work. Sixty-eight percent of the respondents had medium sized households of 5-8 members, 27% had small households of 2-4 members and only 5% reported a large family of over nine members. This compared favorably with the 2009 population census which put the average household size in Mwala District at 6 (Kenya National Bureau of Statistics 2010). A majority (62%) of the respondents had primary education while 25.6% had secondary education, 5.1% had tertiary education and 7.1% had no formal education. Average household farm size for the sample respondents was 0.96 ha. A bigger household may offer more labour required in putting in place drought adaptation structures while literacy and numeracy may be instrumental in sourcing and enabling understanding of agricultural information and technologies, forming social networks and entering into contractual agreements that collectively contribute towards farmer's empowerment.

Group participation and activities undertaken

Ninety four women farmers were sampled from twenty two women groups involved in agricultural activities. Individuals made voluntary decisions to join the groups. The majority (77%) of the respondents reported that their groups had been formed through their own efforts, while 23% of respondents reported their groups as initiated by NGOs. None of the groups had been formed through government projects. According to the District agricultural officer in the area, government projects preferred working with already formed groups. Asked why, he said.

"existing groups have structures, we do not want to be seen as planting groups because we work with everyone and it may bring wrangles"

It was assumed that voluntary choice to join groups would elicit high level of participation. Although farmers participating in women groups did so on voluntary basis, membership was not automatic since members had to fulfill certain conditions. Conditions for membership as indicated by the respondents and authenticated through focus group discussions included; paying membership fee, willingness to abide by the groups' by-laws, making regular contributions agreed on by the members, ensuring attendance to group meetings and practicing the activities taught on their farms. The lowest membership fee was USD 0.6while the highest was USD 23.5. Groups that had assets or income generating activities had higher membership fee requirement. Groups also levied fines for absence and lateness to group meetings. Violation of rules enforceable by penalties included lateness or failure to attend meetings without apologies, delaying group contributions and not attending labour sharing days.

The levies and time requirements may mean that women groups are not entirely inclusive and may leave out the poorest of the poor who may not be able to pay the dues or the women in child bearing bracket who may be constrained for time. Pretty and Ward (2001), noted that requirements for effective membership suggest that not everyone may necessarily benefit from group participation. Members may need to consider certain factors like opportunity costs in term of money and time, household characteristics and personal characteristic (Katinka and Johannes 2001).

Group activities

The women groups undertook various activities including livestock rearing, crop production, seed bulking, soil and water conservation, merry-go-round and table banking as reported by the group leaders during focus group discussions and the members during interview. Table 2 summarizes reasons for group formation as reported by the respondents.

Table 2 Reasons for Group formation (N=94)

Reasons for group formation	Frequency	Percent
Social capital and merry-go-round	51	54.2
To qualify for funding	16	17.0
Promote environmental conservation	12	13.8
Enhance access to extension services	8	8.5
Enhance market access	4	4.3
Enhance negotiations and advocacy	3	3.2

The reasons cited included social capital and merry go round (54.2%), to qualify for funding (17.0%), promote environmental conservation (13.8%), enhance access to extension services (8.5%), enhance market access (4.3%) and because they enhance negotiations and advocacy (3.2%).

Farmers' perceptions of climate change

The study sought to determine the level of farmers' awareness of climate change phenomenon. The majority (98.2%) of the respondents had knowledge about climate change phenomenon and consensually noted that climate change was indeed a reality. They identified changes in rainfall patterns (starting earlier or later than expected), frequent and prolonged droughts and high temperatures as circumstantial evidence of climate change. During the focus group discussions, farmers agreed thatdry spells and droughts had always happened, but in the past they normally occurred roughly once or twice every ten years. They observed that the pattern had changed, with dry spells now occurring as frequently as once every three years. One participant explained;

"when we were young and closed school in April, we would weed for maize, nowadays, the maize is too small to cultivate because rain delayed or you

have to plant twice because the rains stopped, nowadays there are more bad seasons because the sun has increased"

These results are consistent with those of a study conducted in Kibwezi, Makueni County in eastern Kenya by Mwang'ombe et al. (2011)where 98 % of respondents reported increased dry conditions as the main unusual climatic change effect. Another study done in Kasai location in Kisau Division of Makueni County, neighbouring Machakos County, reported similar results where 97.3 % of the respondents identified increased frequency and intensity of drought, early cessation, irregular distribution, and delayed onset of rains as common problems of climatic change in the area (GoK 2009).The study shows that effects of climate change are evident in the area and the farmers have been able to identify and are concerned about them.

Source of climate and weather information

The respondents were asked to indicate sources of information they used to learn about climate and weather change phenomena (Table 3).

Table 3 Sources of climate change and weather information (N=156)

Source	Frequency	Percentage
Mass media	89	57.0
Extension providers	32	20.5
NGO	24	15.4
Local leaders	8	5.1
Church organizations	3	2.0

About three-fifths (57.0%) of the respondents cited mass media (radios, television, newspapers) as the most important information source followed by government extension providers cited by 20.5% of respondents, NGOs (15.4%), local leaders (5.1%) and church organizations (2.0%).Access to climate information and technologies for adaptation has been found to be crucial, in enabling actors to anticipate risks and adjustments to increase their resilience. GoK (2009) noted that the key to effective community based adaptation to climate change is proper utilization of weather and climate information which needs to be communicated in a meaningful way, and in a timely manner.

Effects of drought on households' livelihoods

All respondents (100%) reported that they have experienced drought in the area at some point in the past. This was in response to the question," Has your area experienced drought in the last ten years"? The respondents gave drought effects on their household as shown in Table 4.

Table 4 Effects of drought on households (N=156)

Effect	Frequency	Percent
Decrease in fresh water	150	97.4
Led to high food prices	150	97.4
Reduced crop yield	137	89.0
Reduced animal productivity	89	57.8
Increase in field and storage pest	60	39.0
Sold livestock at low price	53	34.4
Lack of casual employment	49	31.8
Death of livestock	27	17.5

The main effects of drought reported by the respondents in order of importance were; decrease in fresh water (97.4% of the respondents), high food prices (97.4%), reduced crop yield, (89.0%), reduced animal productivity (57.8%), sale of livestock at low prices (34.4%), increase in field and storage pests (39%), lack of casual employment (31.8%) and death of livestock (17.5%).

Water scarcity in the area was compounded by the fact that the rivers in the area are seasonal and the predominantly sandy soils allow percolation of water with very low retention. This was further aggravated by sand harvesting on river beds which increased during droughts and lowered the water table. Livestock prices were reported to have decreased significantly as more families disposed their stocks to buy food whose prices had skyrocketed every time there was a drought. An increase in food prices has a real income effect, with low-income households often suffering most, as they tend to devote larger shares of their incomes to food than higher-income households do (Thomson and Metz 1998). The study clearly illustrated that droughts affect demand of agricultural labour as 31.8 % of the respondents cited decrease in casual employment. This concurs with the findings of FAO (2009) report which concluded that changes in the demand for seasonal agricultural labour, caused by changes in production practices in response to climate change, can affect income-generating capacity which affects people's food access. Labour demands are often reduced when crops fail, mostly owing to such factors as drought, flood, frost or pest outbreaks, which can be influenced by climate change.

Drought adaptive measures

The women farmers were asked to indicate the adaptive measures they use in their farms against the effects of droughts. Terracing was the most common form of soil and water conservation measure used in the area with majority in both categories (97.8% of group members) and 87.3 % of non-members reporting its use (Table 5).

Table 5 Drought adaptive measures N=156)

Mitigation measure	Group members n=94	%	None members n=62	%
Terraces	91	97.8	57	87.3
Drought tolerant crops	85	91.4	51	83.6
Use of organic manures	83	89.2	49	80.3
Keeping small stocks	69	74.2	29	47.5
Retention ditches	63	67.6	30	49.2
Irrigation	16	17.2	2	3.3
Shallow wells	11	11.8	3	4.8

Terracing in Mwala region dates back to the colonial times during forceful implementation of conservation measures and continued after independence with the support of various NGOs like the Catholic Diocese of Machakos and development partners such as SIDA. Tiffenet al. (1994) reported that by 1978 evidence of terracing in cultivated land in Masii location had risen from 30 % in 1930s to 100 percent even though the percentage reduced later as more land was brought under cultivation. Kamar (2001) reported 88.5 % use of terraces in another part of Machakos. The existence of well-developed self-help groups is cited as one of the main reasons for the success of conservation activities in Machakos County, especially terracing. The District Agriculture Office in Mwala attributed the success of terracing in

Mwala to assistance given in form of "Food for Work" to various self-help groups by the Catholic Diocese of Machakos. Terraces were also favoured because the farmers could plant bananas and fruit trees inside the trench and pasture grass on the embankment leading to efficient usage of land.

Majority of the farmers grew traditional crops, which are more drought tolerant and adaptable to the dry areas. Over 91% of group participants and 83.6% of non-group participants reported planting drought tolerant crops like cassava *(Manihot esculenta)*, millet *(Pennisetum americanum)* and sorghum *(Sorghum bicolor)* due to increased incidences of erratic and unreliable rainfall. Kenya Agriculture Research Institute (KARI) in conjunction with Ministry of Agriculture (MoA) is working with some groups to promote these crops through the *Njaa Marufuku* Kenya Initiative, a Kenya government programme to eliminate hunger.

In the study area the use of manure was limited to farm yard and compost. The practice was reported in 89.2 % of group affiliated participants and 80.3 % of the non-group participants. The practice was promoted by the increased understanding of the role of manure in increasing crop production, the high cost of fertilizer and increase in the availability of manure as a result of zero-grazing. Tiffenet al. (1994), reported 66% of households in Mwala to be using manures in their farms by the 1980s.

Farmers also kept small stock as a drought mitigation measure. The indigenous chicken was the most popular small livestock kept followed by the goat. Over 74% of the group-affiliated participants kept small stock, compared to 47.5% of the non-group members. Farmers in both categories admitted that goats showed more adaptability and tolerance to climate variability than did the cattle. Other small stocks reared were sheep and rabbits.

Retention ditches were also used to harvest road runoff, collect silt and retain the water until it infiltrates into the ground. Fruit trees and bananas were planted in the ditches. A higher percentage (67.6%) of group members used retention ditches as compared to non-group members (49.2%). This could be due to the fact that construction of the ditches is labour intensive and groups have access to shared labour.

Only 17.2% of group members and 3.3%of non-group members practiced irrigation. This could be attributed to the fact that most of the rivers in Mwala are seasonal. It also suggests that the majority of women farmers in Mwala practice rain fed agriculture making them even more vulnerable to climate change effects. Shallow wells were dug on or next to dry river beds. Only 11.8% of the women group members reported having dug shallow wells compared to 4.8% by non-group members. This low number could be due to labour requirements and the few fields bordering the rivers.

Influence of participation in groups on level of drought adaptation

The level of adaptation against drought effects was measured by scoring against the practices known to enable farmers to adapt against effects of drought that were being used in the farm. A single practice got a score of one. The more the number of practices the higher the score and consequently the higher the level of adaptation. The practices had been selected after being identified by the group leaders during the focus group discussion. A multiple regression analysis was carried out to determine the influence of participation in women groups on the level of adaptation against drought effects. The influence of group participation was determined while controlling for effects of respondent's age, education level, marital status, household size and farm size (Table 6).

Table 6 Results of multiple regression analysis of group participation and level of drought adaptation (N=156)

Variables	Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	T	Sig.
(Constant)	1.585	.190		8.325	.000
Age in years	.000	.004	.008	.083	.934
Married; 1=Y 0 = N	.218	.074	.236	2.960	.004
Lower primary; 1=Y 0 = N	.096	.095	.087	1.007	.316
Secondary; 1=Y 0 = N	.209	.075	.228	2.775	.006
Tertiary; 1=Y 0 = N	-.183	.142	-.101	-1.284	.201
Household size	-.008	.018	-.035	-.450	.653
Land size in hectares	.026	.022	.099	1.171	.243
Group membership; 1=Y 0 = N	.202	.065	.246	3.125	.002

Dependent Variable: The level of adaptation against drought effects, Adjusted R-square =.138, Regression ANOVA; F-statistic = 3.7378.

The results show that group participation has positive influence on level of drought preparedness when age, education, household size, marital status and farm size are held constant (t=3.125, $p<0.05$). Marriage and secondary education also had a positive and statistically significant influence on the level of drought mitigation and preparedness. Age, household size, farm size, primary education and tertiary education were found not to significantly influence the level of drought mitigation and preparedness. Predictor variables together with group participation explain about 13.8 % of the variation in level of preparedness and mitigation against drought in the derived model. F-value for the model was statistically significant at 3.738; df=9. This implies that the influence of group participation on the level of mitigation against drought was statistically significant (F=3.738, $p<0.05$). The positive influence of participation in groups on the level of preparedness in drought mitigation could be because social networks provided through participation in groups play substantial role in adoption of agricultural technologies, acting as conduits for financial transfers that may ease farmers' credit constraints, provide information about new technologies, and facilitate cooperation among farmers to allow the costs and benefits of adoption to be shared. Some of the adaptive and mitigative measures are labour intensive.

Pooling of labour among group members, where women access to reciprocal labour on rotating basis, has been documented as one of the main reasons for the success of conservation activities in Machakos, especially terracing (Kamar 2001).In a study done in the Nile basin of Ethiopia, Deressa et al. (2008), found farm income, access to crop and livestock extension services, availability of information on temperature and rainfall variability, social capital and access to credit to have a positive and significant impact on the likelihood of usingsoil conservation measures, changing planting dates, and using irrigation.

Household food security status

The study sought to determine if participation in women groups was correlated with food security status of the respondents' household. Household hunger scale (HHS) developed by FANTA was adapted to assess food security. The scale consists of three items and three frequencies, with a continuous scale score of a minimum of 0 and a maximum possible score of 6. A categorical measure with 3 categories of household hunger was used. Scores 0-1 classified as little to no household hunger, scores 2–3 moderate household hunger while scores 4-6 classified as severe household hunger. The results are presented in Table 7.

Table 7 Status of household food security

Type of membership	Household hunger scale			
Category	Food secure	Moderate Food secure	Severe food Insecure	Total
Group Member (n)	29	47	18	94
%	30.9	50.0	19.1	100
Non-member (n)	10	27	25	62
%	16.1	43.5	40.3	100
Total sample	39	74	3	156
%	25.0	47.4	27.6	100

The results indicate that household food insecurity is still a challenge in Mwala Division. However, individuals belonging to groups reported a higher household food security status than did non-group members. Among the food secure respondents, the study revealed that over a third (30.9%) of the group-affiliated participants outweighed the 16.1% of the non-group participants. About half (47.4%) of the respondents reported moderate food security while 27.6 % were found to be severely food insecure.

Further, a hierarchical multiple regression was run to determine the influence of participation in women groups on food security. Results are reported in Table 8.

Table 8 Multiple regression coefficients of explanatory variables on household food security (N=156)

Independent Variables	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	3.137	.457		6.862	.000
Age in years	-.018	.006	-.232	-3.002	.003
Marital status	-.077	.047	-.111	1.622	.107
Education level	-.205	.058	-.264	3.526	.001
Land size in hectares	-.166	.034	-.355	-4.837	.000
Household size	.112	.029	.268	3.932	.000
Group membership	.216	.101	.145	2.128	.035

Dependent Variable: Household food security, Adjusted R-square = .349, Regression ANOVA F-statistic 4.529, t= 2.128, p= 0.035.

The results showed that the level of food security at the household level was positively influenced by participation in women groups (when age, education level, marital status, household size and farm sizes are held constant). This positive influence could imply that groups are relevant for dissemination of agricultural extension services and provide information about new technologies, and also facilitate cooperation among farmers to allow members to tap the benefits of economies of scale. The implication could also be that women group activities had direct influence on the household food security. This study's findings agree with household-based studies by Narayan and Pritchett (1997) who found that both formal and non-formal groups had positive association with household welfare including food security in rural Tanzania. Similar findings were reported by Placeet al.(2004) who found participation in groups to substantially influence household welfare in central Kenya.

Conclusion and Recommendations

The study concluded that social networks measured by participation in groups increase access to agricultural productive resources, awareness of climate change and access to training on drought adaptive measures. Furthermore, women groups facilitated the ability and formed a fora to pool resources by the farmers for common good. Government extension providers and non-governmental organizations gave most support to groups rather than individual farmers to the advantage of group participants. However, despite the positive aspects noted, the women groups were not wholly inclusive. The very poor and therefore most vulnerable of the society were observed to be left out due to the requirements of group participation. This could have negative implication on the very vulnerable members of society because it seemed to deny them common resources like extension services since most extension officers were likely to work with groups and not individuals. Bringing participation requirements down to a level where the poorest can afford and timing meetings to accommodate members within child bearing bracket could be a step toward increasing inclusiveness in women groups in the study area.

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Chapter 14

Effects of Climate Change and Coping Strategies in Isiolo County: The Case of the Borana Pastoral Women

Anastasia W. Kagunyu[1]* and Joseph G. Wanjohi[2]

Abstract

The overall objective of this study that was conducted in Isiolo County was to investigate the level of awareness of Borana pastoral women on climate change and the coping strategies they use. Data collection methods included: use of semi structured questionnaires, key informants interviews, and focus group discussions. Quantitative data was analysed with SPSS software and presented in frequencies and percentages. The study indicated that the Borana pastoral women have been affected greatly by climate variability and as a result have come up with coping strategies as mitigation measures. The study results also indicated that the livelihoods of the Borana pastoralists have been affected greatly leading to displacement, poverty and food insecurity. In addition their workload and climate related diseases have also increased. Various coping strategies applied by the pastoralists included, small scale farming, business, working for others for pay and searching vegetables for their families. The study findings revealed that the coping strategies utilized by the women were only for survival. This study therefore recommends that the government and other actors need to assist the Borana women to come with adaptive strategies which are affordable and appropriate for arid and semi-arid lands.

Key words: Borana women, climate variability, coping strategies

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Introduction

According to Babugura et al. (2010) climate variability and change will mostly affect the poorest countries and communities. The impacts of global climate change are not only physical and economic, but also social and cultural, thus jeopardising environmentally based livelihoods in many areas of the world. Climate change impacts are differently distributed among regions, generations, age, class and between gender (Omolo 2010). Climate variability is gender neutral implying that it affects both women andmen but women are more vulnerable.The reason for this is that in many cases, communities interact with their physical environment in a gender-differentiated way. It is evident that women have different positions and faces different challenges from men in coping and adapting to climate change. In some of the livestock keeping societies women provide labour for the various tasks related to livestock but may or may not control the process of decision making, particularly over the disposal of animals and animal products (Omolo 2010).

Women, as the majority of the world's poor, are the most vulnerable to the effects of climate change (Dankelman et al. 2008). When poor women lose their livelihoods, they slip deeper into poverty due to the increase in inequality and the marginalization they suffer because of their gender. As a result, climate change presents a very specific threat to women's security (Dankelman et al. 2008,). Women are also more prone to effects of climate variability due to their gender based roles which are culturally defined (Omolo 2010). The impact of climate variability has increased gender vulnerability leading to changes in the roles of women and men, with additional burden on women. Climate variability impact is dependent on issues such as wealth, technological power, access to information, all of which are major problem areas for women. Despite the importance of recognizing gender-related differences, both the United Nations Framework Convention on Climate Change and the Kyoto Protocol fail to place more emphasis on this issue (Mutimba et al. 2010). The poorest populations and marginal groups are impacted the most; nevertheless, there can be a differential effect on men and women as a consequence of their social roles, inequalities in the access to and control of resources, and their low participation in decision-making (Mutimba et al. 2010).

The International Union for Conservation of Naturereport (IUCN, 2007) indicates that women are likely to suffer more than men whenever there are natural disasters. The report further indicates that in 1991 the cyclone disaster which took place in Bangladesh killed 140,000 people and 90% of those who died were women. The Hurricane Katrina which took place in the USA affected many African-American women than their male counter parts (IUCN, 2007). These impacts prompted this study which aimed at trying to investigate the effects of climate variability and adaptive strategies utilized by the Borana pastoral women in Isiolo County. This paper focused on the following specific objectives: to assessthe level of understanding of climate variability by the Borana women; to establish ways by which the Borana pastoral women are being affected by climate variability; and to establish the coping strategies which are being applied by the Borana pastoral women.

Materials and Methods

Study sites

Isiolo County is occupied by pastoral and agro- pastoralists Borana, Somali, Turkana, Samburu, Rendille, and Ameru communities. This study focused on the Borana community because it is the largest community in Isiolo County.

Sample size and data collection methods

To get the respondents the researcher visited the senior chief of the area who assisted in identification of the areas occupied by the Borana community. Three villages were identified and selected purposively since they were the areas occupied by the Borana community alone. The villages were Kambi Odha, Kambi Mbule and Kambi Garba. A total of 195 women were interviewed, that is, 65 women from each village.

Data collection methods

Three methods of data collection were applied: household interviews with the help of semi-structured questionnaires, focus group discussions and key informant interviews. Two focus group discussions were held and each group had about 10 participants aged above 45 years and they were selected purposively. The issues discussed Borana women understanding of climate variability, effects of the variability and the coping strategies they applied. Key informant interviews were also conducted. A total of 12 key informants were interviewed, including local chiefs, Government departmental heads, and programme coordinators from NGOs working in the area.

Data processing and analysis

This study collected both qualitative and quantitative data. Qualitative data derived from focus group discussions and key informant interviews were presented in discussions. Quantitative data derived from the household interviews were edited, coded and analyzed using Statistical Package for Social Science (SPSS) software version 20.

Results and Discussion

Back-ground Characteristics of Borana Pastoral Women

Figure 1 below shows that the ages of the respondents ranged from 20 to 60 years. Seventeen per cent of the respondents were between 20–30 years, 35% were between 31-40 years, 22% were between 41-50 years, 18% were between 51-60 years and 8%were 61 years and above.

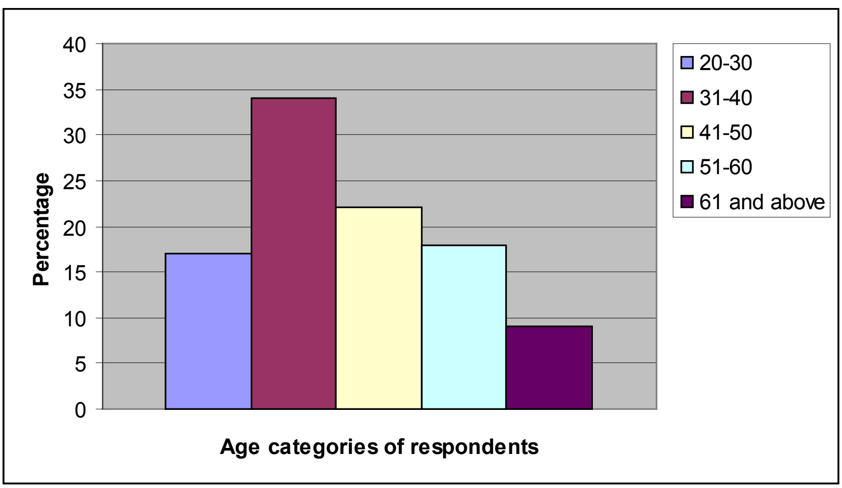

Figure 1 Age categories of respondents

Educational background of the respondents

Figure 2 below shows the level of education of the respondents. Over half (65%) of the respondents had no education at all; this was followed by 21%

who had primary education. On the other hand, 9% of the respondents stated that they had secondary education while,5% of the respondents indicated that they had attained college or university education. This category included any respondent who had joined a post-secondary institution. The findings suggest that the level of education was generally low. Undoubtedly, low levels of education in the study area made the Borona women depend a lot on subsistence livestock keeping, a sector which is highly impacted by climate variability and climate change.

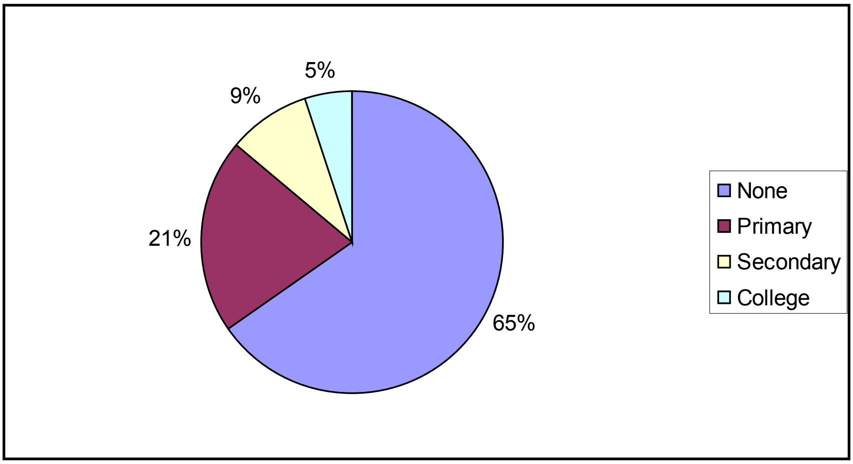

Figure 2 Education level of respondents

The Borana women understanding of climate variability

The findings suggested that the Borana women in Isiolo County are aware of climate variability. Figure 3 below presents respondents' experiences associated with climate variability. Among the respondents, 51% had experienced prolonged droughts whereas, 26% experienced rainfall shortage. In addition, 11% of the respondents stated that there were changes in rainfall patterns and seasons, 9% had witnessed floods and *El Niño* rains, 3% had experienced violent storms. Focus group discussants revealed that there has been reversal in rainfall patterns. According to them the long rains used to occur in the month of April but for the last 20 years they occur in the month of October, although sometimes they might come late or even fail. Further rainfall is erratic, and when it comes most of it is spread over a few days or hours causing erosion and flooding.

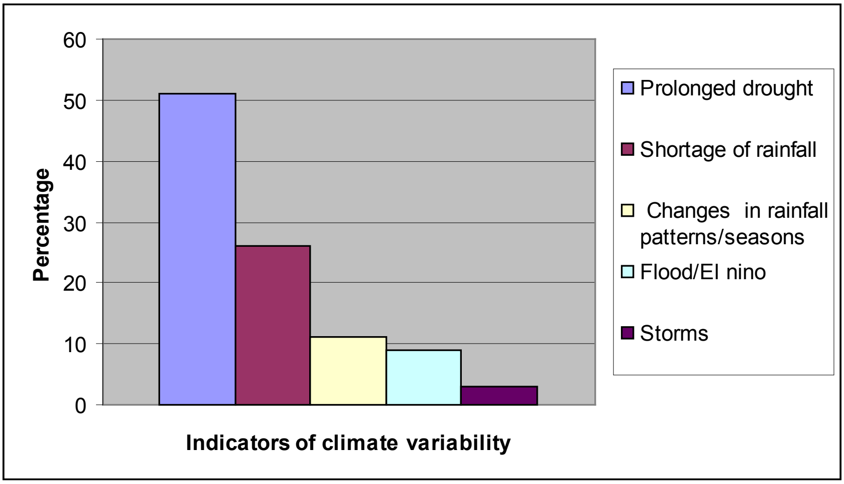

Figure 3 Respondent experiences of climate variability

Effects of climate variability on the socio–economic wellbeing of the Borana Pastoral Women

The study findings indicate that climate variability has affected the livelihood of the Borana women to a great extent. Nearly 100% of the respondents answered in affirmative when asked whether climate variability has affected their social and economic status. The respondents said that their well-being has been affected in three ways as shown in Figure 4 below. Thirty six per cent stated that climate variability had contributed to the death of livestock, which was the major economic activity of the community as a whole. Droughts had caused instability in the livestock population through increased mortality and reduced birth rates due to decreased forage and water availability. Thirty three per cent of the respondents stated that climate variability brought displacements since men moved with their livestock in search of water and pasture leaving women, the elderly and children behind. Lastly, 31% of the respondents stated that poverty had become rampant among the Borana women as a result of massive loss of livestock.

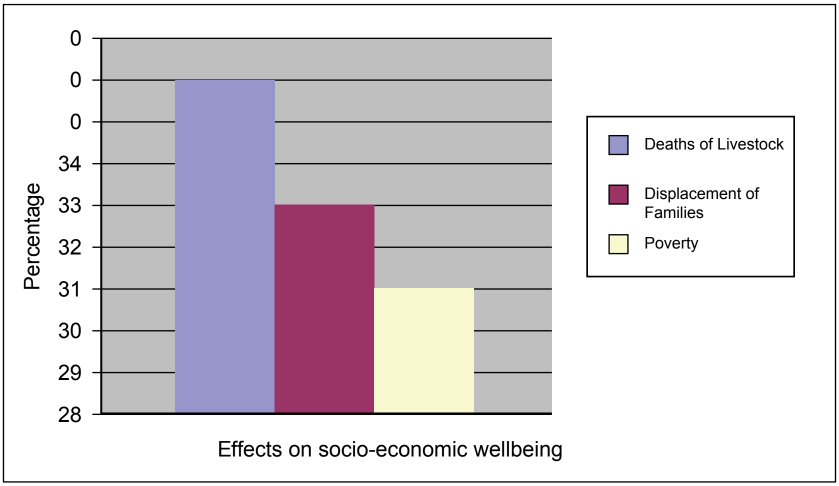

Figure 4 Effect of climate variability on the socio-economic well-being of respondents

Food insecurity

The study findings indicated that climate variability had caused food insecurity. Figure 5 below demonstrates that 49% of the respondents rely on food relief, 28% said that food has become scarce, while 23% indicated that the available food is of poor quality. Key informant participants were in support of this information as they indicated that food insecurity has led households of the Borana community to change from eating their staple food meat and milk to eating other foods such as maize, beans, rice, pasta, chapati and githeri among others.

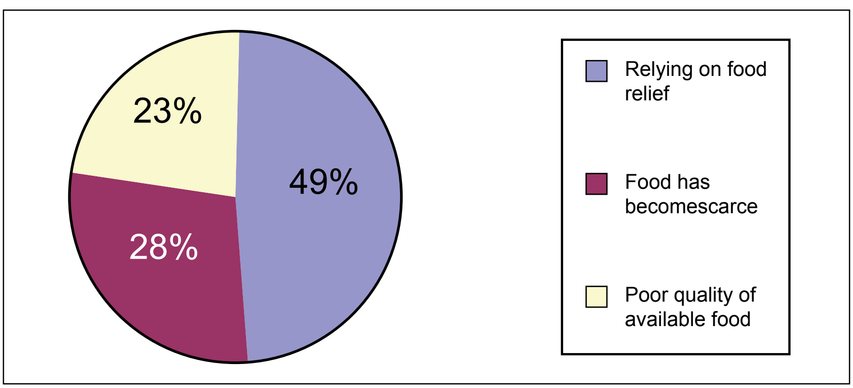

Figure 5 Food insecurity as a result of climate variability

Human Diseases

This study also revealed that climate variability has led to increased human diseases. Figure 6 below shows that more than a third (36%) of respondents said that malaria had become very common, 20% mentioned TB and HIV/AIDS, 21% stated that there were new diseases and gave an example of Rift Valley fever. Twelve percent of the respondents indicated that diseases related to food deficiency (malnutrition) such as *kwashikor* and *marasmus* had increased. Lastly, 11% of the respondents stated that pneumonia had become more rampant than it used to be before. Other diseases mentioned by key informants included typhoid, amoebiosis, fever, common cold, diarrhoea and dysentery. Occurrence of these diseases in the family increased the burdens of women and their responsibilities as they are the main caretakers and also bread winners.

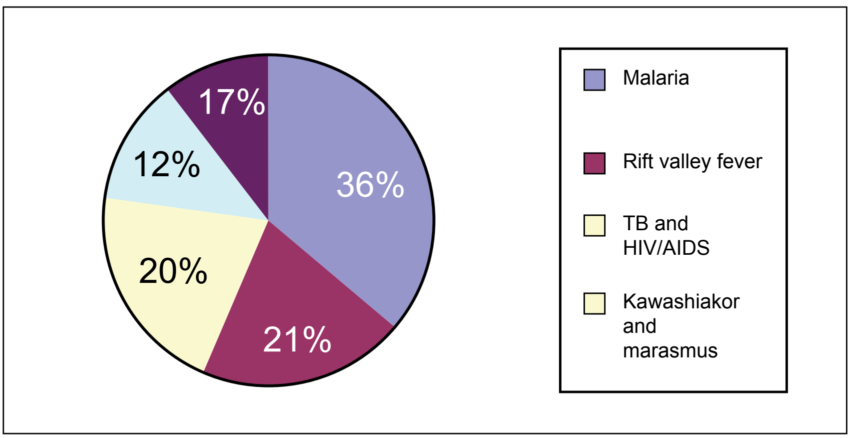

Figure 6 Climate variability related human diseases

Effects of climate variability on gender-based roles

The study findings suggest that climate variability has increased the workload of women. According to the respondents climate variability had brought environmental changes that affect accessibility to basic necessities such as water, food and wood fuel which are women's role to fetch. Focus group discussants held similar views that women had many activities to attend to such as looking for family food and its preparation, searching for fuel, childcare and income-generating activities such as small-scale farming and business. It was also indicated that many able bodied men who have lost their livestock due to droughts have moved to urban areas to look for jobs leaving their wives behind. The implication for this is that women perform their roles and that of their husbands.

Coping strategies of Borana Pastoral Women

The findings of this study suggest that climate variability has made the Borana women to come up with alternative livelihoods. Traditionally, pastoralism was a full-time occupation and everyone from an early age was engaged in livestock production. However, climate variability has made the Borana pastoral women look for alternative ways of getting income. According to the results of this study, 36% of the respondents stated that they engaged in causal labourand 28% said that they have turned to small-scale farming. Twenty four per cent haveengaged in small-scale businesses. Lastly, 12% of the respondents indicated that they have joined salaried employment. All the alternative livelihoods are summarized in Figure 7.

Field observations revealed that many households had kitchen gardens while others were operating small kiosks. This finding suggests that due to the social pressure brought by climate variability, Borana women have sought alternative livelihoods outside the pastoral context in order to minimize the negative effects. Apart from salaried employment which can be sustained, some of the activities which the women engage in are only for survival and are not sustainable. For instance rain-fed small-scale farming and small businesses are not sustainable. A woman hardly cultivates 2 hectares of farmland per season, and productivity is poor due to weather and poor agricultural practices. This study shows that because of increased anxiety and future uncertainties, Borana women pastoralists are diversifying *en masse,* but most of the available options are *ad hoc*, short-term and unsustainable. Consequently serious planning on other medium and long-term options is seriously needed.

Information gathered from focus group discussions and key informants stated that some women doubled their roles by working as house helps in Isiolo town during the day and attending to their families at night. The extra workload make women work for longer hours than men.

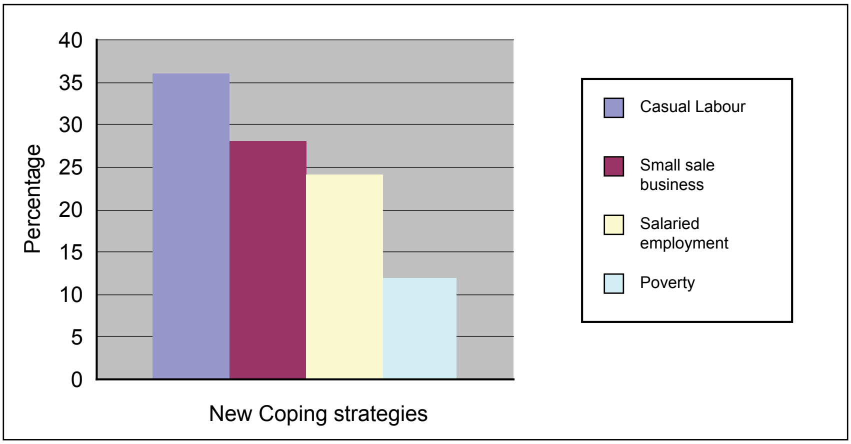

Figure 7 Alternative sources of livelihood of respondents

Searching for wild edible plants by pastoral women as a coping strategy

Wild fruits, vegetables and roots were occasionally used as food with some being available during the drought period while others were collected before the onset of the drought. The collection of these natural foods is mainly done by women and children. The products were relied on during times of crisis as a mitigation measure against food shortage. The fruits that were mentioned included Deka *(Grewia tembensis),* Mader *(Cordia gharat spp.)* Qurqura *(Zizyphus mauritiana),* Jaj jab *(Berchemia spp.),* Ogomdi *(Grewia villosa),* Kamunde*(Lannea alata spp.)* others such as mader (Cordiagharat) produced edible fruits and also their gum was chewed during the drought period. Urbu*(Acacia tortilis)* pods were boiled and eaten during the drought period. Some of the plants such as Iddihiddi *(Solanum scabrum)* produced vegetables and fruits eaten during droughts. Other wild vegetables eaten as revealed during focus group discussions include Sumalele *(Mormodica trifoliolata)*which is boiled in water, and mixed with salt to form porridge. Ng'orondo *(Cyphostemma nierrense)* plant also contributed to survival during drought. A majority (81%) of the respondents said that the distance travelled by women in search of food and water resourcesis longer than it used to be in the last 20 years as a result of climate variability especially during the time of drought and famine.

Conclusion

This study sought to establish the effects of climate variability on the Borana pastoral women in Isiolo County and the coping strategies they apply. On the basis of the above findings, the following conclusions can be drawn.

First, a majority of the Borana women were knowledgeable about the impacts of climate variability which they narrated as prolonged droughts, shortage of rainfall, changes in rainfall patterns and seasons, and severe rain-storms leading to floods.

Second, climate variability has negatively affected theBorana pastoral women in a great way. Recurrent droughts and floods have led to the death of livestock leading to poverty and displacement. As a result of these some the Borana pastoralists have been pushed out of pastoralist activities since they have lost all their livestock. Among pastoral households is the decreasing herd size due to deaths of livestock during severe droughts. Livestock is not simply a source of protein but it also represents a source of income, savings, social status and security. Severe droughts have contributed to a shortage of livestock forage and water leading to low milk production and the deaths of livestock. This has in turn, contributed to food insecurity in the community, as reflected in their reliance on relief foods. There was also evidence of human diseases related to climate variability which affected the development of the pastoral women. The study findings also indicated that climate variability has led to increased workload for the Borana women in takingon extra duties such as caring for the sick and performing the roles for their migrant husbands.

Finally, the findings of this study have indicated that the Borana women have come up with strategies to cope with negative effects of climate variability. These include engaging in casual labour, small scale farming, businesses, salaried employment and search of edible wild plants for food.

Recommendations

The study revealed that the coping strategies against climate change are not sustainable since women lack adequate skills and funds for their sustainability. This being the case there is need for the policy makers and other actors to assist the Borana women to come up with adaptive strategies which are affordable and appropriate for arid and semi-arid lands.

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Chapter I5

Adaptation to Climate Change and Variability in Agro-Pastoral Production Systems: The Eco-Village Concept

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Abstract

The present environmental challenges of soil degradation and climate change demand for a paradigm shift in regard to settlement issues, especially in the arid and semi arid regions in the developing countries. This paradigm shift would include changes in several areas including property ownership rights and land tenure from individual fragmented to communal consolidated ownership, social interaction, economic activities and a shift to more ecologically sound approach to appropriating natural resources. This can be done by employing the eco-village concept whereby the local indigenous knowledge, together with innovative technology are combined to develop the land in a manner which will be ecologically, economically, culturally and socially sustainable. This will lead to the present generation being able to meet its needs and the needs of future generations to meet theirs. It will also effectively mitigate and help in adapting to climate change, more so in the arid and semi-arid areas which have low adaptive opportunities and options.

Key words: Climate change adaptation, drylands, eco-village, settlements

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Introduction

In Kenya, arid and semi-arid lands (ASALs) cover 80% of the country's landmass, support 30% of the human population (Mganga et al. 2010; Ngugi and Nyariki 2003), 60% of the livestock population and the largest proportion of wildlife. In 2009, the Kenyan Government noted that the ASAL had the lowest development indicators and highest poverty levels. Major contributors to the poverty levels were identified as environmental degradation, insecurity, climatic shocks, and diseases amongst others (GoK 2009).

In the twenty first century, a number of national and international institutions, governments and Non-governmental Organizations (NGOs), supported by scientific research have come to a consensus that climate change is playing and will continue to play a major role either directly or as a catalyst to human well-being, more than any other factor. The World Bank states that climate change is a fundamental threat to sustainable development with a warming planet threatening to put prosperity out of reach for the majority of millions and rolling back decades of development (World Bank 2013). The United Nations' Intergovernmental Panel for Climate Change (IPCC) of the United Nations Framework Convention on Climate Change (UNFCCC) defines climate change as any shift of climate over time, as a result of natural variability or human influence (IPCC 2007). The human influence on climate change over the last century, is primarily due to fossil fuel burning for industrialization, change in land use patterns, especially deforestation and agriculture and urbanization.

An increase of Green House Gases (GHG) concentration in the atmosphere, especially carbon dioxide, is the major driver of climate change IPCC (2007). The overall effect has been a significant increased rate in the change of climatic conditions all over the world. This is especially so in Africa, as in other developing countries, which have little contribution to the GHG concentration, but are set to be adversely impacted. Various aspects of life including temperature, ecosystem, rainfall, drought, human health, water and agriculture among others will be affected.

According to the United Nations (United Nations 1987), development is sustainable if it meets the needs of the present generation without compromising the ability of future generations to meet their own needs.

Climate change threatens both the current generation's ability to meet its needs and destroys the fabric on which the future generations may meet their needs. This is especially so in the arid and semi arid areas in developing countries.

The International Institute for Sustainable Development (IISD) describes arid and semi-arid areas as zones characterized by low erratic rainfalls of up to 700 mm per year (IISD 2013). In general terms, the areas are used for wild life conservation and pastoralism with rainfed agriculture not very successful.

An increase in extreme weather conditions in terms of frequency and intensity is set to lead to greater losses in terms of economic activities and opportunities including agricultural, businesses, health and housing leading to greater poverty levels. Many economies, which are already suffering from other non-weather stressors have had added stress caused by climate change. The ASALs, which experience low rainfall amounts during normal times, are especially prone to weather pattern variations.

In the developing countries inadequate funds and investment as well as technological constraints have contributed to their inability to effectively mitigate or adequately adapt to the impacts of climate change like floods and droughts.

There is an urgent need therefore, for the developing countries like Kenya to adopt techniques which will be holistic, innovative, and able to provide to the basic needs for the rural populations and at the same time providing for ways to adapt and to build resilience against climate change. These adaptation strategies ought to be easily adoptable, able to take advantage of the available opportunities, be sustainable and be able to meet the needs of the population. The eco-village model suits this paradigm.

The Eco-village Concept

According to the Global EcoVillage Network, an eco-village is defined as 'intentional or traditional community using local participatory processes to holistically integrate ecological, economic, social, and cultural dimensions of sustainability to regenerate social and natural environments' (GEN 2013). This definition takes cognizance of the fact that natural resources are not infinite hence the need to intentionally position a community to utilize resources in a sustainable manner (United Nations 1987). The Global Eco-Village Network (GEN) is a network of sustainable communities and initiatives that bridge different cultures, countries, and continents (GEN 2013). GEN is the umbrella organization for eco-villages, transition town initiatives, intentional communities, and ecologically minded individuals worldwide. GEN's main aim is to support and encourage the evolution of sustainable settlements i.e settlements which have minimum negative impacts on the environment at local level. This is done globally by facilitating the flow and exchange of knowledge about eco-villages and putting up demonstration sites.

The eco-village concept is a multi-faceted approach with a stated goal of minimizing carbon footprint per capita while at the same time finding solutions to the current problems resulting from increased carbon dioxide in the atmosphere (GEN 2013). This concept ultimately aims to establish better society by improving the living standards. It aims to tackle the contemporary environmental challenges in a three dimension manner; bringing cohesion in cultural, social, ecological and economic best practices to bear on a consciously and deliberately created village by a community with similar aims; to create a better world for the present and future generations.

The ideal eco-village

The Global Village Network (GEN 2013) has developed a set of criteria against which an eco-village can be recognized. The characteristics include the following:

a. A community to grow from a shared vision and values, the people choose to design own village and lifestyle, live in harmony with nature, become guardians of nature once again, celebrate cultural identity and diversity, uphold human rights for all and support oneness and solidarity through helping individual to one's unique ways of serving the others

b. The community strives to build capacity through empowering and educating all towards sustainable living. This is done through honouring local traditional wisdom while integrating innovative methods and appropriate technology

c. An eco village will strive to implement the following:

- Best cultural practices like connecting to a higher purpose in life / spiritual practice, growing awareness of impacts of modernization, honouring traditions that are good for the people and discarding the harmful ones, political activism and celebrating life – peoples dance, music art etc.
- Best social practices including strengthening community and embracing diversity, participatory decision making processes, conflict facilitation and peace-building skills, recognising and empowering leadership of those willing to serve the community and building networks and alliances
- Best ecological practices including sustainable water management and clean energy, organic agriculture and permaculture, natural and traditional healing methods for humans and animals, ecological and traditional building methods and conservation and restoration of ecosystems
- Best economic practices like significant collective ownership of land, water and resources, strengthen local economy: barter systems, microcredit, local currencies, diverse income streams and green enterprise, work towards economic justice and building bridges between rich and poor, engage in ethical and transparent fair trade, and develop appropriate legal forms and transparent administration for the organisations
- The ideal village is expected to be modified and adapted to fit best in any given region given that there are different circumstances specific to any given eco-village location. However, it can be broadly observed that if the ideals of the eco-village concept are observed, communities and the people living in the arid and semi arid areas of the country can be to sustainably manage their land, derive a decent income while at the same time adapting and mitigating the impacts of climate change

The Senegalese Case Study

The eco-village concept has been embraced in Senegal, West Africa. The country has gone a step ahead to design and implement model eco-villages. According to the Director, Senegal Eco-Village Agency, the eco village model is designed as a multilayer concept which attempts to use the best of the traditional and modern knowledge (Adama 2012). Each village is expected to have a strategic vision with the local governance structure at its apex to ensure that the village runs in the intended manner. Land consolidation, renewal and improvement of land, land zoning, proper planning, use of renewable energy, search for and establishment of markets, ecological preservation and renewable energy are some of the facets in the village life. This helps in ensuring a sustainable eco-village which can meet the ideals of eco village.

The Senegalese government has moved away from theorizing about eco-villages to the implementation of the concept with remarkable success. This has made the country a reference point which ought to inspire many other countries, especially those in the developing countries (global south) which have been classified as being most vulnerable to climate change to take charge of their destiny and respond to the challenge.

Challenges

As noted in the government report (GoK 2005) the poverty in the ASALs stands at 60%. There is extensive degradation of natural environment due to unsuitable or inappropriate farming practices including deforestation, overgrazing and inappropriate farming practices. Farm sizes have continuously become smaller because of fragmentation, the pastures have continued to reduce in quantity and quality with soil erosion becoming more prevalent (Galaty 1984; Mwangi 2007).

The resultant poverty has led to rapid social disintegration with conflicts over the diminished and increasingly scarce resources becoming more prominent. The fight over scarce resources is increasingly cascading to lower levels from intercommunity to family and clan based violence. These resource-based conflicts and poverty levels will increase as the impacts of climate change continue to be felt globally. As the rainfall patterns change and different climatic zones shift, the ASALs will be more affected, diminishing the already scarce resources. However, as the challenges grow, they also present an opportunity for a united, community wide response that will have a greater impact than an individualized response.

Opportunities

The traditional setting of most people living in the ASALs make them better suited for setting up the eco-villages. There still exists a close bond between the social and cultural activities which are centered on economic activity, especially among the pastoral communities. There is extensive potential which can be utilized for the betterment of the society including traditional knowledge for both human and animal health, traditional crops which are drought resistant and indigenous conflict resolution mechanisms, among others. These opportunities can be harnessed to enable people to co-exist, availing space to improve productivity and to preserve ecosystem integrity while at the same time helping to mitigate and adapt to climate change. This is important given that ASALs population growth continues to pile pressure on the available resources.

Conclusion

The United Nations Conference on Environment and Development report calls for sustainable development which encompasses three aspects of economic, social and environmental integrity. The eco-village concept is in line with sustainable development because it addresses the challenges of degradation especially in the arid and semi-arid areas. Eco-village concept calls for communities to be in-charge of all aspects in terms of the lifestyle, buildings, transport and energy consumption. Nevertheless, Eco-village concept is a resource intensive undertaking that requires the targeted communities to be supported by the government or donors.

As the Senegalese model demonstrated, the Kenya government can intervene and better the lives of its citizens through this model. Adoption of holistic approach towards land management, which explores a wide range of solutions to the diverse challenges faced by populations of agro-pastoralists in the arid and semi arid areas; including empowering the people to take charge of their destiny may be the desired goal. This should be a goal of any sustainable land management approach especially in the agro-pastoral areas facing the challenge of climate change.

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Theme IV

Rehabilitation of Degraded Lands through Afforestration, Agroforestry and Natural Regeneration

Chapter I6

Impact of Enclosures on Range Condition and Trend in the Semi-Arid Rangeland of Lake Baringo Basin, Kenya

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Abstract

The effects of enclosures on rehabilitation of degraded semi-arid rangelands were investigated on the Njemps Flats in Lake Baringo Basin, Kenya. The objective was to evaluate the effects of enclosures on range condition and trend, herbaceous layer characteristics, and the overall rangeland quality for livestock production relative to the open grazing area. From a very poor rangeland condition (severely degraded) before intervention, enclosures significantly improved the range condition in all the restored areas. The standing biomass production was significantly ($P<0.05$) higher in the communal than in the private enclosures. The communal enclosures had a mean standing biomass of 4.405 ± 1.216 t ha^{-1} in comparison to 1.852 ± 0.610 kg ha^{-1} in the private enclosures. The open grazing area had no grass cover. All the communal enclosures attained about 75% of their potential range health, or excellent range condition for livestock production and soil protection. Re-vegetation within the enclosures resulted in higher vegetation cover and carrying capacity for livestock. The results suggested that range enclosures is a promising approach for restoring degraded semi-arid rangelands to improve ecosystems productivity and pastoral livelihoods. Particularly, it can be used by pastoral households in transition to sedentary systems where the collapse of the traditional pastoral systems is imminent.

Key words: Enclosures, herbaceous layer, land degradation, range condition and trend, range rehabilitation

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Introduction

Establishment of enclosures, denoting areas closed off from grazing for a specific period of time, is a well-known management tool to restore degraded rangeland ecosystems. In particular, rangeland enclosure is now common place where pastoralism has collapsed or is in the verge of collapsing (Wasonga et al. 2011). Regeneration of the vegetation in the rangelands has positive effects on biodiversity (Asefa et al. 2002; Abebe et al. 2006) and soil fertility (McIntosh et al. 1997; Su et al. 2005; Mekuria et al. 2007); it reduces soil erosion (Descheemaecker et al. 2006) and increases water availability (Hongo et al. 1995). The rehabilitation generally starts from relict vegetation or from the seed bank (Whisenant et al. 1995; Tefera et al. 2007). In severely degraded areas, autogenic recovery is hampered by inadequate supply of seed, absence of suitable micro-sites for germination, and reduced soil functioning (Beukes and Cowling 2003; van den Berg and Kellner 2005; Abebe et al. 2006). In those cases, ecosystem rehabilitation needs to be fostered through tilling, if necessary combined with planting and reseeding (Visser et al. 2004) of indigenous and exotic plant species.

Enclosures demonstrate the direct economic benefit of controlled use of these fenced-off rangelands for rotational or seasonal grazing, as well as for other income generating activities such as steers fattening, grass cutting, grass seed harvesting and bee keeping. According to Beyene (2009) rangeland enclosure by pastoralists is mainly driven by ecological, institutional and socio-economic incentives. A growing body of literature indicates that enclosing and thus privatizing formerly communal rangelands, may result in social conflicts and foster rangeland degradation rather than contribute to rehabilitation and productivity increase (Beyene 2010, Mureithi et al. 2010). Understanding the dynamics of these semi-arid rangelands is therefore a prerequisite for their proper management (Retzer 2006).

In 1982, a community based project was started in the Lake Baringo Basin under the auspices of the Rehabilitation of Arid Environments (RAE) Trust (formally Baringo Fuel and Fodder Project-BFPP). The aim of the Trust was to rehabilitate severely degraded areas around Lake Baringo and on the surrounding hills, which were subject to heavy grazing pressure (Meyerhoff 1991, de Groot et al. 1992). The intention was to work with agro-pastoralist communities to achieve sustainable land management systems in arid and semi-arid areas. Rehabilitation commenced by enclosing areas of various sizes from 6 to 400 ha, preparing seedbed and water harvesting structures, and then planting a variety of indigenous and exotic tree species alongside reseeding with mixtures of indigenous grass species.

The Lake Baringo Basin is currently experiencing a movement towards enclosure of the communally owned rangeland. The main drivers for this shift in the area is the ardent need for restoring degraded rangeland to improve pasture and food security for livestock and pastoralist communities, respectively, especially during the dry seasons and drought periods (Mureithi et al. 2010). In addition, re-vegetation within enclosed areas will reduce soil erosion, reclaim gullies, and significantly limit the amount of topsoil and sediments being deposited into Lake Baringo (RAE 2013). Behnke (1986) noted that if the fencing of rangeland by livestock owners is likely to become more common, then administrators, rangeland scientists and policy makers will need to have some idea of the benefits and costs arising out of the shift from open-range to fenced forms of livestock production. This study aimed at assessing the impact of enclosures on the range condition and trend, herbaceous layer characteristics and rangeland quality for livestock production.

Materials and Methods

Location of study area

The Njemps Flats (1°45'- 0°15' N latitude; 35°45' - 36°30' E longitude) is one of the range units of the Baringo County and covers approximately 30,500 ha. This flat to slightly undulating plain, located west and south of Lake Baringo, has an average altitude of 900 m a.s.l. (Herlocker et al. 1994a) and receives a total annual rainfall of between 300 and 700 mm. The rainfall pattern is bimodal, with peaks in April-May and July-August (Snelder and Bryan 1995). Ekaya et al. (2001) described the rainfall as low, erratic and unreliable. Analysis of a time series of rainfall records by Kipkorir (2002) revealed an increase of the rainfall intensity on the rainy days, separated by longer periods of drought. The temperature shows little variation throughout the year with mean monthly values ranging from 24 to 26°C (Ekaya et al. 2001, Kipkorir 2002). According to the reconnaissance soil survey (GoK 1978) the dominant soils of the Njemps Flats are well drained, silt loam to clay loam, Eutric and Calcaric Fluvisols (FAO 2006a,

b) that are located in an occasionally flooded, ancient lake bed. The natural vegetation is dominated by ephemerals, regenerating after the rains. The main vegetation types consist of *Acacia* woodland (80%), permanent swamp and seasonally flooded grassland (15%) and shrub grassland (5%) (Wasonga et al. 2011). The dominant land use has been grazing and livestock herding by the "Il Chamus" semi-pastoralist community.

Study design and sampling strategy

Six communal and six private enclosures (Table 1) were systematically selected for sampling across the Njemps Flats. The selection criteria were on similarity of terrain, soil, and land use that was aimed at minimizing variability in the abiotic determinants of rangeland vegetation composition and functioning. The age of the enclosures ranged from 3 to 17 years and from 13 to 23 years for the private and communal enclosures, respectively. In the absence of undisturbed reference sites (Ruiz-Jaen and Aide 2005), open rangeland was chosen as a benchmark against which the rehabilitation success was compared.

Range condition and trend

The selected communal and private enclosures and the adjacent open degraded areas were evaluated to ascertain the condition and trend of the range resources for livestock production and soil conservation amongst other ecosystem services according to methods described by (Friedel 1991, Herlocker 1991, Herlocker et al. 1994a and 1994b). The evaluation involved general assessment of the vegetation characteristics including: i) forage value as percentage of palatable vegetation to livestock, ii) grazing intensity whether slight, moderate or severe, iii) disturbance indicators, mainly the abundance of invasive plants, iv) regeneration, the proportion of perennial plant seedlings of forage species, soil and site health, comparison of plant cover (equal, ¾, ½, ¼) with the expected value for the site, v) evidence of erosion, crusting and hard setting.

Table 1 General characterisation of the selected enclosures

ID[a]	Local ID	Management	Area (ha)	Age (yr)	Utilization[b]	Fencing/ User Rights/ Utilization Frequency
Co13	F13	Communal	140.0	13	G – GC – BK	Communal enclosures: -Fenced using solar-power; -Shared but controlled user and access rights; -Utilised occasionally.
Co16	F4A	Communal	102.3	16	G – GC	
Co18	F1B	Communal	16.7	18	G – GC – BK – GS - WC	
Co20	F4	Communal	22.4	20	G – GC	
Co22	F1A	Communal	6.6	22	G – GC – BK – GS - WC	
Co23	F1	Communal	9.3	23	G – GC – BK – GS - WC	
Pr3	LOKOR	Private	13	3	G	Private enclosures: -Fenced using cut-thorn bush or Opuntia live plants; -Private user and access rights; -Utilised frequently.
Pr6	CHEM	Private	2	6	G – GC	
Pr8	CHEROP	Private	0.7	8	G – GC – GS	
Pr11	CHEPKO	Private	1.0	11	G – GC – BK	
Pr15	KOE	Private	2.5	15	G – GC – BK	
Pr17	CHEBU	Private	1.6	17	G – GC	

[a] In the ID, "Co" refers to communal enclosures, "Pr" indicates private enclosures and the number represents the enclosure age

[b] G (Grazing), GC (Grass Cutting), GS (Harvesting Grass Seed), BK (Bee Keeping), and WC (Wood Cutting)

A range condition and trend score within and outside an enclosure was assigned out of a maximum 28 for each criteria, recorded, and averaged. Range condition scoring for the above indicators was assigned as follows: very poor 0-6, poor 7-13, fair 14-19, good 20-24, and very good 25-28. The assigned range condition was taken as a proxy for rangeland health index, ranging from 1 to 5 as shown in Table 2. All the parameters were considered equally important in determining rangeland condition and health. Consequently, the scores and indices were all given an equal weight of 1.

Rangeland in very poor condition is typically characterised by unpalatable shrubs, invaders, bare ground, surface crusting, hard setting and eroded soils. Range in poor condition is characterised by mostly unpalatable shrubs and annuals, low cover with bare patches, low grazing capacity and visible evidence of erosion. Range in fair (intermediate) condition is characterised by presence of many unpalatable seedlings, while that in good condition have more than 50% cover and desirable botanical composition. In assigning the rangeland health index, the enclosure protection (fence maintenance) and overall management was taken into account.

Table 2 Range health index determined from the range condition of sampled enclosures in Njemps Flats

Range condition	Range condition score	Range health index
Very poor (severely degraded)	0 - 6	1
Poor	7 - 13	2
Fair (intermediate)	14 - 19	3
Good	20 - 24	4
Very good	25 - 28	5
Excellent	28	> 5

Range trend scoring was done concurrently: very poor 0-6, poor 7-13, fair 14-19, good 20-24, and very good 25-28. Similar to the range condition, the scores were summed up and averaged. Finally, range trend-rating criteria was assigned as improving for average score above 12 points, or declining for average score below 12 points.

Standing biomass

The standing biomass for herbaceous vegetation was estimated using the point – line transects technique (Brady et al. 1995). Three 50 m long transect lines were placed in a Z-shaped orientation within each enclosure. Sampling for the aboveground standing crop biomass of the herbaceous layer was carried out using a rectangular 0.5 m^2 quadrat frame. Along each of the three transects, five randomly located quadrats were sampled. Individual grasses, forbs and tree/shrub species seedlings represented within the quadrat were counted and recorded. The cover of each species was visually estimated in addition to that of the bare ground, dung, and litter in accordance with the method described by Brady et al. (1995). All standing material rooted within the quadrat was then clipped at 2 cm above ground level and put into paper bags with corresponding quadrat reference numbers. The material was oven-dried at 70^{o}C at 48 hours and the dry weight determined. Above ground biomass yield was expressed in kg ha^{-1} on dry matter basis using the formula shown in equation 1.

$$\textit{Biomass Production (kg ha}^{-1}\textit{)} = \frac{\textit{Dry weight (kg) x } 10{,}000m^2}{0.5m^2} \qquad \text{(Eqn. 1)}$$

Carrying capacity of enclosures

Carrying capacity refers to the maximum number of livestock units that a given rangeland can carry sustainably when forage availability is at its lowest (Herlocker et al. 1994a). The carrying capacity normally reflects the level of management, and therefore poor management leads to a low carrying capacity. This carrying capacity concept is applicable where the range is under multiple uses (by cattle, goats, sheep, donkeys and camels).

One tropical livestock unit (TLU) is equivalent to one mature cow weighing 250 kg. Thus, 10 sheep, 11 goats, or 0.7 camels are the equivalents of one TLU, based on live weight of the animals (Herlocker et al. 1994a). The maximum stocking density or the land/livestock ratio (TLU ha^{-1}) refers to the availability of fodder from land relative to the feed requirement of livestock, and can also be expressed in the number of days in a year an area can be grazed and still maintain optimum productivity. Carrying capacity was calculated based on the estimated annual biomass production and feed requirements of the livestock. However, these calculations did not consider seasonal variations in production and feed quality.

Results and Discussion

Range condition and trend in the enclosures

Sixty seven percent of the communal enclosures were assessed to be in good condition and only 33% were in very good condition (Table 3). All the communal enclosures had attained about 75% of their potential range health, or excellent range condition for livestock production and soil protection. A range in excellent condition will support the optimum long-term carrying capacity for cattle and other multiple range uses (Herlocker et al. 1994b). The private enclosures sampled were assessed to be in good (17%), fair (67%), and poor (17%) range condition. The mean score for the communal enclosures and for private enclosures rated 24 and 15 respectively, out of a maximum of 28. In contrast, the open grazing areas outside the enclosures were overall rated to be in very poor to poor range condition with a mean score of 6.

The open grazing areas continue to be degraded partly due to overstocking on the one hand and poor management as an open access resource on the other. Most of the open areas in Njemps Flats are devoid of herbaceous vegetation cover following years of unsustainable land management practices such as overgrazing which leaves the soil exposed to moisture loss and erosion by wind and water. Other indicators of poor range condition and declining trend outside the enclosures included the overgrazed herbaceous layer and over-browsed shrubs, sheet, rill and gully erosion, soil sealing and crusting, hard setting, and invasive species. Similar observations on open grazing areas have been reported for Tigray region in northern Ethiopia (Mekuria et al. 2007), and in China (Park et al. 2013). Patches having various characteristics were observed within the enclosures e.g. patches having single grass species (glades), patches with only unpalatable forbs, others devoid of vegetation cover or having few ephemeral species and hard surface crust. Enclosures with a higher species diversity of palatable perennial grasses, forbs and shrubs were assessed to be in a better condition to sustain grazing by mixed livestock.

In this study, grazing was considered the key enclosure resource utilisation, bearing in mind the livelihood of the local pastoralists. If the range condition was assessed for rangeland ecosystem quality, glades would result in a higher score due to their contribution to ecosystem heterogeneity. The patches having single grass species (mainly *Cynodon dactylon* (L.) Pers. or *C. plectostachyus* (K. Schum.) Pilg.) were thought to be abandoned cattle kraals *(bomas)*. Abandoned *bomas* form islands of fertile soil, but the visible proxy for this is patchiness in vegetation following colonisation by unique plant community as the manure layer becomes mixed with mineral soil (Stelfox 1986; Young et al. 1995). Perennial grasses like *Cynodon dactylon* and *C.*

plectostachyus establish easily on abandoned boma sites due to nitrogen concentration from urine and dung (Stelfox 1986). Once colonised, such sites become hotspots of grazing intensity that persist for decades after *boma* abandonment (Augustine 2003; Young et al. 1995).

Table 3 Range condition and trend analysis of sampled enclosures in Njemps Flats

				Range condition		Range trend	
Enclosure ID		Grazing management	Year planted	Range score (max. 28)	Total condition assessment	Range trend (max. 28)	Trend Assessment
Pr3	Inside	controlled	2002	10	poor	13	Improving
	Outside	open		4	very poor	6	Declining
Pr6	Inside	controlled	1999	15	fair	15	Improving
	Outside	open		4	very poor	5	Declining
Pr8	Inside	controlled	1997	17	fair	17	Improving
	Outside	open		9	poor	10	Declining
Pr11	Inside	controlled	1994	20	good	18	Improving
	Outside	open		8	poor	13	Improving
Pr15	Inside	controlled	1990	16	fair	16	Improving
	Outside	open		10	poor	12	Improving
Pr17	Inside	controlled	1988	14	fair	15	Improving
	Outside	open		5	very poor	9	Declining
Co13	Inside	controlled	1992	23	good	20	Improving
	Outside	open		2	very poor	5	Declining
Co16	Inside	controlled	1989	23	good	18	Improving
	Outside	open		6	poor	8	Declining
Co18	Inside	controlled	1987	26	very good	24	Improving
	Outside	open		6	poor	8	Declining
Co20	Inside	controlled	1985	22	good	17	Improving
Co23	Inside	controlled	1982	26	very good	25	Improving
	Outside	open		7	poor	8	Declining

Range condition scoring: very poor 0-6, poor 7-13, fair 14-19, good 20-24, very good 25-28
Range trend scoring: very poor 0-6, poor 7-13, fair 14-19, good 20-24, very good 25-28
Range trend-rating criteria: improving, above 12 points; declining, below 12 points

The range trend was assessed as improving within the enclosures, and declining in the open grazing areas except in enclosures Pr11 and Pr15. The improving range trend outside the Pr11 and Pr15 private enclosures could be partly due to changes in ownership and management. The communal and private enclosures had an average range trend score of 21 and 16, respectively. In contrast, the open grazing areas outside the enclosures had a mean score of 8. A high range trend score did not necessarily indicate good or excellent range condition, because range in excellent condition should have scored the maximum, but several enclosures that were enclosed and planted over 15 years ago are still recovering (Figure 1).

Meyerhoff (1991) while assessing the changing socio-economic factors and perceptions of the Lake Baringo basin community reported that though the land in Baringo lowlands was owned and managed communally, the society respected the fact that a household had lived in one place for a long time, thus they viewed it as private land. Therefore, if a household closed off their land, other herd owners would not graze the immediate adjacent open areas except in times of droughts. In this way, conflicts amongst the herd owners are avoided.

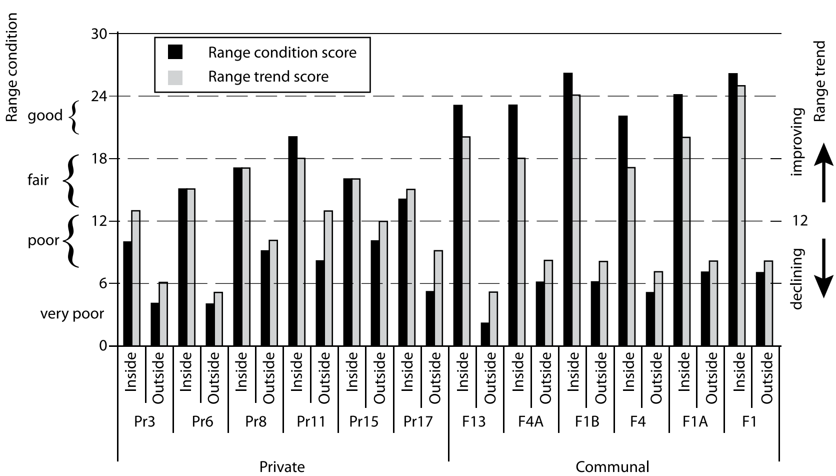

Figure 1 Range condition and trend analysis of sampled enclosures in Njemps Flats. The enclosures are ordered with increasing age for corresponding management regime

Almost all private enclosures were located at the proximity of the owners' homesteads. This allowed watching against illegal grazing by other peoples' herds or wild animals, since the fencing is done using cut thorn bushes of *Acacia* and *Prosopis* spp and/or planted thorn cactus (*Opuntia* spp.). In contrast, the communal enclosures are perimeter fenced using solar-powered electric fence in addition to watchmen employed to guard the resource against illegal grass cutting or grazing during the day.

The level of management in the communal enclosures is significantly higher than in the private enclosures. This is attributed to the fact that the community assisted by the RAE Trust was able to pool capital resources, while the capacity of an individual pastoral household was limited (Mureithi 2012). Direct benefits derived from the enclosures includes grazing resources, sale of cut grass for fodder or thatching, grass seed, poles and fuel wood, and bee keeping amongst others. These benefits tapped from communal and private enclosures are partly fuelling the enclosure movement in the arid and semi-arid rangelands of Lake Baringo basin (RAE 2013). The result is a rangeland that is dotted by a mosaic of numerous forms of enclosures.

Standing biomass

The available standing biomass varied strongly with the management type but had a weak relationship with the enclosure time (Table 4). The communal enclosures had a mean standing biomass of 4.405 ± 1.216 t ha^{-1} in comparison to 1.852 ± 0.610 t ha^{-1} in the private enclosures. This significant difference between the communal and the private enclosures could partly be explained by the initial enclosure preparation, seedbed preparation, seeding rate), level of enclosure protection and different management approaches such as frequency of grazing/grass cutting. Some range improvement measures were implemented especially in communal enclosures such as construction of ditches for rainwater harvesting and re-reseeding with more suitable grass species thus influencing the level of forage production (Verdoodt et al. 2009; 2010). The standing hay inside the enclosure is normally reserved for dry-season grazing, and some stands within the enclosure may be reserved for either harvesting grass seed for further reseeding or for sale or for thatching. Some enclosures were not well protected from uncontrolled grazing while bush and brush heavily encroached upon others.

Table 4 The mean standing crop biomass (t ha^{-1} dry weight and grazing capacity of sampled enclosures in Lake Baringo Basin

Enclosure management	Enclosure	Year of enclosure	Aerial cover[a] (%)	Basal cover[b] (%)	Biomass production in dry wt kg ha^{-1}	TLU[c] ha^{-1}
Baseline	Open area	-	0	0	0.000	0.0
Private	Pr3	2002	45	15	1.000	0.3
	Pr6	1999	55	20	1.830	0.5
	Pr8	1997	60	25	1.680	0.5
	Pr11	1994	70	20	2.500	0.7
	Pr15	1990	60	20	2.600	0.8
	Pr17	1988	55	15	1.500	0.4
Communal	Co13	1992	70	25	3.430	1.0
	Co16	1989	70	25	4.830	1.4
	Co18	1987	70	30	5.250	1.5
	Co20	1985	68	20	2.600	0.8
	Co22	1983	80	20	4.400	1.3
	Co22	1982	82	32	5.920	1.7

[a]canopy cover, before clipping; [b]ground cover, after clipping (simulates grazing); basal cover of 20-30% is the optimum recovery of grass cover in enclosures after grazing. Aerial, or canopy cover, is usually 2 to 3 times the estimates of the basal, or groundcover [c]tropical livestock units (TLU) per hectare based on TLU requirements of 3450 kg of dry matter per year.

The variation of available biomass within different enclosures was high, possibly due to variations in condition of the range before the enclosures were established (pre-enclosure conditions). For instance, the extent of top soil erosion influences the soil fertility of a site, which in turn affects the rate of re-colonisation by desirable plants, and especially perennial grass species such as *Cenchrus ciliaris* L., *Eragrostis superba* Peyr. and *Cynodon dactylon.* On the other hand, severe degradation of a site akin to Lamalok (outside enclosure Co13 (Figure 2), could have depleted the soil seed bank. In such a case, re-vegetation is largely dependent on reseeding and tree planting, rather than from natural regeneration.

The oldest enclosures did not necessarily have the highest available standing biomass as would be expected (Table 4). The results support a hypothesis that enclosure time is an important factor in arid and semi-arid rangeland rehabilitation by enclosure approach. However, from a certain 'threshold time' in the range recovery, management and utilisation takes over as the key factors determining ecosystem recovery. This is further supported by the observation that enclosures under the same form of management tended to have equal baseline range condition and forage production after a certain period. It implies that with good management, private enclosures can also be in very good range condition. The threshold time among the sampled enclosures in this study was fixed at 6 years, based on the second most recent private enclosure Pr6, and assessed to be in fair range condition (Figure 1 and 2). This enclosure had a mean standing biomass of 1.830 t ha^{-1}.

This threshold enclosure time should however, not be viewed as fixed, as it is likely to shift up or down as the factors influencing the success of enclosure establishment change. The levelling off of the correlation between the management indicator and enclosure time around 20 years (Figure 2) indicates that restoration of good range condition within the enclosures can take ±20 years depending on the factors influencing the success of rehabilitation.

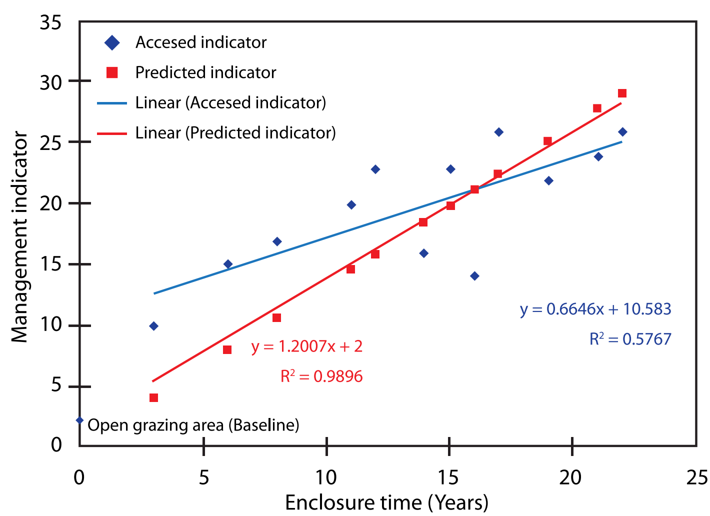

Figure 2 A linear regression of range condition (predicted management indicator) relative to the assessed indicator against enclosures time in years

It follows that enclosure management can tremendously increase the rangeland condition of the enclosure when management is good and stable with time. For instance, the performance of Pr11 and Pr15 showed that private management has potential to be as good as that of the communal enclosures. On the other hand, the management can also lead to a low range condition of an enclosure if it is poor (Figure 2). The difference between the management aspects of the communal and private enclosures in Lake Baringo Basin lies mainly in knowledge gap as local people are used to managing resources without fences.

Carrying capacity of enclosures

The carrying capacity was calculated based on the estimated annual biomass production per hectare and feed requirements of the livestock. However, these calculations did not consider seasonal variations in production and feed quality. The calculated carrying capacity of different managed areas for various livestock species (camels were not considered) is shown in Table 5.

Assessment of the potential carrying capacity was based on the standing biomass data of Pr11 private, and Co18 communal representative enclosures as shown in Table 4. The actual forage intake of 1 TLU of 250 kg live weight is estimated at 2.5% of the live weight per day (Le Houerou 1989). This works out to be 6.25 kg dry matter per day per TLU. Assuming that the actual intake of dry matter is 1.5 times the minimum required intake, the forage demand by 1 TLU per day is therefore estimated at 9.4 kg. The total forage demand per TLU per year is therefore about 3450 kg. In the Pr11 private enclosure, the estimated carrying capacity based on the herbaceous standing crop biomass (2.500 t ha^{-1}) is approximately 1.3 ha per TLU. The carrying capacity of the communal enclosure Co18 in Salabani sub-location is also approximated at 0.6 ha TLU^{-1}.

Goats spend 90% of their time browsing while cattle spend between 4 and 35% of their time grazing (Pratt and Gwynne 1977). Since goats are browsers and cattle are active grazers, there is very little dietary overlap between the two species. The two species are therefore complementary in utilizing range forage (Le Houerou 1989). It is estimated that 1 TLU of goats will require 2.5 ha, while cattle will require 4.0 ha per TLU under the prevailing conditions of the Njemps Flats range unit (Herlocker et al. 1994a). The effect of the enclosures on improving carrying capacity is therefore significant as shown in Table 5.

The grazing capacity for cattle improved by a factor of 2.9 under Pr11and 6.1 in the Co18 (Table 4). Enclosures with higher biomass production will support higher grazing capacity, implying that less hectarage is required for 1 TLU in the enclosures, than that recommended in the open grazing rangeland. This translates into more economic gain to the enclosure owners, whose main source of livelihood is livestock keeping. Improved carrying capacity following establishment of enclosures was also reported by Makokha et al. (1999) in the neighbouring West Pokot County. Numerous other income generation activities have been identified from the enclosures in Baringo (Mureithi 2012) such as grass seed harvesting, thatch grass cutting, hay, bee keeping, wood products like building poles and fencing posts, among others. Restoration of degraded rangelands is an essential part of sustainable land management in agro-pastoral systems. A great task facing the RAE project today is to carry out stepwise community mobilisation and education to enable the resource users to embrace changes in sustainable natural resource management. Hopefully, this will enable them to adapt to the unfolding reality of managing the once open communal rangelands within a fence.

Table 5 The effect of enclosure under private and communal management on carrying capacity for various livestock species

Type of livestock	Live weight (kg)	Number of stock equivalent based on	Unenclosed rangeland open communal grazing	Enclosed rangeland	
				Private[b] enclosure	Communal[c] enclosure
		250 kg lwt[a]	(ha TLU^{-1})	(ha TLU^{-1})	(ha TLU^{-1})
Cattle	250	1.0	4.0	1.3	0.6
Sheep	25	10.0	5.4	3.4	0.7
Goats	22	11.0	2.5	1.8	0.7
Camels	360	0.7	2.7	2.7	2.7

[a]Calculations based on Herlocker et al., 1994.

[b]Pr11 enclosure standing biomass production 2.500 t ha^{-1}

[c]Co18 enclosure standing biomass production 5.250 t ha^{-1}

Conclusion and Recommendations

Rangeland enclosures significantly improved the rangeland condition and trend of the enclosed areas and land productivity for livestock production. Herbaceous cover significantly increased in both communal and private enclosures older than 6 years, consequently reducing the areas with no ground cover. The communal enclosures had relatively higher perennial grass cover, vascular plant seedlings, and litter than the private enclosures. The communal enclosures also had significantly higher mean standing biomass than the private enclosures, which tremendously improved the carrying capacity. Differences in enclosure management regime was a remarkable source of variation for most of the parameters investigated and enclosure time was seen as the primary factor affecting the productivity of an enclosure only to a certain period of time after which enclosure management became more important. This study recommends resting of restored rangeland for a minimum period of 3 years which is an essential sustainable land management practice in agro-pastoral systems. Rangeland enclosure represents changing trends in the ownership and management of pastoral grazing lands in the pastoral areas in transition from extensive to sedentary system.

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Chapter 17

Management of Prosopis to Enhance Natural Regeneration in Northern Kenya

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Abstract

Invasive Prosopis species has invaded pastureland and riparian ecosystems which are the core land production system in rangelands. Although the impacts of Prosopis invasion have been documented, scientific information on management is scanty. Therefore, this study was conducted to evaluate Prosopis management interventions in the recovery of indigenous vegetation in Turkana County where pastoralism is the major source of livelihood. Two demonstration plots of 1 ha were established in 2008 along Tarach and Turkwel riverine ecosystems at Morung'ole and Nadapal sites respectively. The treatments within demo plots were re-spacing Prosopis thickets to 4 x 4 m, 6 x 6 m, 8 x 8 m, and 10 x 10 m. Stump treatment trials through debarking and prescribed burning was also undertaken. Sample plots were laid within demonstration plots to assess population structure both before and after management interventions. Periodical assessments were carried out for 4 years by monitoring emergence of herbaceous and woody species. Stand management effects was determined by collection and comparison of similar data in the unmanaged plots. The study revealed significant differences in species diversity from natural regeneration between managed and unmanaged plots (P<0.001). In all the treatments, regeneration of herbaceous species was higher than indigenous tree seedlings in both sites. However, Morung'ole had higher species density and diversity recruited than Nadapal. The 6 x 6 m spacing and prescribed burning treatments of stumps recorded higher percentages of herbaceous cover, composition and seedlings density. The study recommends up-scaling of best-bet management interventions in all Prosopis invaded areas.

Key words: Prosopis, invasive species, natural regeneration, drylands, Turkana

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Introduction

Prosopis species are native to South and Central America but have been widely introduced around the world over the past 150 years.Although the genus consists of 44 species, only *P. juliflora, P. pallida* and *P. chilensis* have been widely introduced in the tropics (Pasiecznik et al. 2006). In Kenya, *P. juliflora* and *P. chillensis* species (referred to as Prosopis) were introduced between the 1970s and 1980s in drylands regions with the intention of ensuring self-sufficiency in wood products, improving environment and safeguarding the existing natural vegetation from overexploitation by the rising human populations (Choge et al. 2002). The introduction of Prosopis was justified becauseit is ahardwood that matures quite fast, and is tolerant to harsh environmental conditions, such as drought and saline soils. Although they have provided benefits to the dry lands ecosystems and livelihoods worldwide including Kenya, Prosopis species have escaped control in many locations where they have been introduced. This has made Prosopis to start invading valuable fertile riverine ecosystems, wetlands, farmlands and rangelands (Ngunjiri and Choge 2004). In an environment where natural enemies do not occur, invasive species often grow faster, mature earlier, and produce many seeds than native species (Richardson and Petr 2006). They can therefore out-compete indigenous vegetation and replace them with dense infestations. An example of this scenario is evidence of studies by Stave et al. (2003) and Muturi et al. 2010) which showed a decline of dominant riparian tree species along Turkwel riverine ecosystem such as *Acacia tortilis, Acacia elatior* and *Hyphaene compressa* between 1998 and 2008 primarily due to Prosopis invasion.

Pastoralism is the major source of livelihood for the majority of the local community in marginal areas of Kenya. Natural vegetation forms important browse and pasture component for sustenance of livestock production. Turkana county's main economic activity is livestock production, recurrent droughts often lead to widespread losses of livestock, however, starvation and death of people. It is against this background following the famine of 1979/80, that the government through Turkana Rehabilitation Project with support from Norwegian Relief agency for Development (NORAD) initiated irrigation projects, water harvesting and afforestation projects strategies to rehabilitate the environment, produce fodder for livestock and other wood products to improve livelihood and alleviate poverty (Ngunjiri and Choge

2004). Prosopis was the tree of choice owing to its resilience and adaptation to desert conditions, is a source of fodder and occasionally for human food during famine. During introduction stages, Prosopis became very popular and most people planted it including around their homesteads. This way, Prosopis found its way to various habitats across the county where it quickly spread to new frontiers with passage of time(Choge et al. 2002). Prosopis has now invaded nearly all riverine basins, shores of Lake Turkana, major grazing areas, watering points and other wetlands. Furthermore, invasion of Prosopis has been accelerated by over-exploitation of woodlands resources surrounding Kakuma refugee camp to meet high demand of cooking energy to refugees. Previous studies (Kariukiet al. 2007; Muturi et al. 2010) have shown that Prosopis is an aggressive competitor that occupies forest gaps left after harvesting woodland products along riverine forests.

Since 2002, Kenya Forestry Research Institute (KEFRI) among other stakeholders has been on the forefront in enhancing community awareness on utilization, introducing management and control technologies aimed at limiting further spread of Prosopis while improving the livelihood of the local community. Impacts of Prosopis invasion and experiences on utilization have been widely documented (Mwangi and Swallow 2008; Kigomo et al. 2009; Muturi et al. 2010). However, information on Prosopis management to guide natural resource managers and extension officers is limited. Therefore, the objective of this study was to determine Prosopis population structure along Turkwel and Tarach riverine ecosystems of Turkana County, evaluate effectiveness of Prosopis management methods particularly their potential on recovery of indigenous vegetation in managed areas.

Materials and Methods

Study area

The study sites were Morung'ole and Nadapal located in Turkana County, Northern Kenya (Figure 1). Morung'ole is located on the flood plains of Tarach riverine ecosystem in northern parts of Turkana County (3° 35'N, 34° 50' E) and about 15 km from Kakuma refugee camp. It has an average annual precipitation of 318mm. The vegetation mostly consists of *Acacia elatior, Acacia tortilis* and *Prosopis juliflora*. Since establishment of the refugee camp in early 1990s, this area has been an important firewood harvesting site to meet ever increasing domestic energy demand.

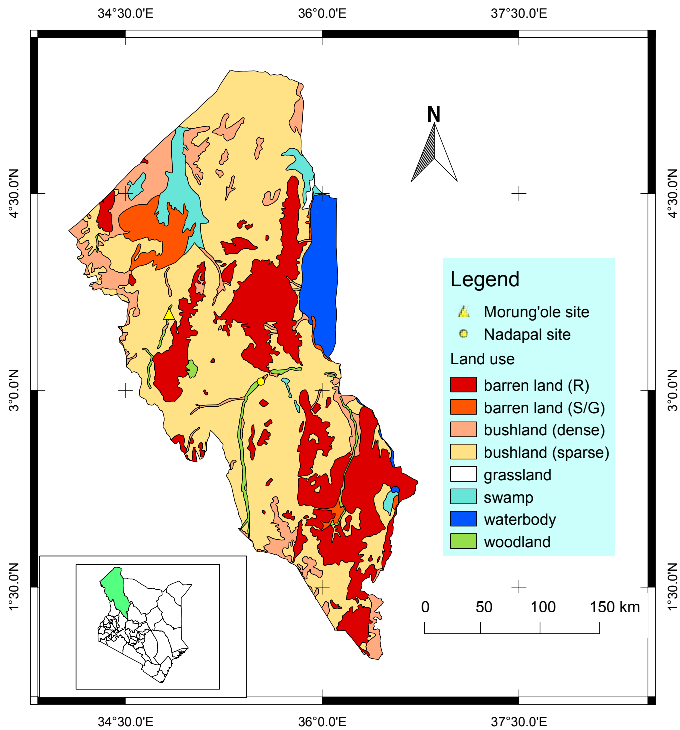

Figure 1 Map showing geographical locations of study areas in Turkana County

Establishment of trial plots and data collection

This study was conducted through participatory establishment of one hectare demonstration plot in April 2008 consisting of six treatments replicated in 2 sites along Tarach and Turkwel riverine forest. The treatments were thinning of Prosopis thickets to approximate spacing of 4 x4 m,6 x 6 m,8 x 8 m and 10 x 10 m according to Patch and Felker (1997) and stump treatment trials through debarking and prescribed burning, control for stump treatment was done within thinning trials. Stems and branches harvested were used to make fences around the perimeter of the plots. Within demonstration plots, intensive plot design (Barnet and Stohlgen 2003) was used to assess population structure before management intervention. This is a nested design consisting of a main plot of 100m^2, one subplot of 10 m^2 at the centre of the main plot and four subplots of 1 m^2 near the plot corners. In the main plot all trees (diameter at breast height (dbh) > 2.5 cm) were identified and diameter at 30 cm above ground (D30), and total height measured. Due to the growth nature of trees in the dryland, D30 have been used in resource assessment (Eshete and Stahl 1998; Padron and Navarro 2004). If the tree was multi-stemmed the numbers of stems were counted and the average stem measured. In the $10m^2$ subplot, all saplings (trees with dbh< 2.5 cm) were identified and counted. Herbaceous species and seedlings data were collected in the 1 m^2 subplots through identification and estimating cover and counting respectively. Fourteen plots were laid systematically in managed demonstration plots and GPS coordinates recorded (seven plots each in Nadapal along Turkwel and Morung'ole along Tarach). Four subplots of $1m^2$ at the corners of each subplot were marked permanently with metal bars to monitor impact of management on natural regeneration of indigenous species. Four intensive sample plots were established within stands neighboring each demonstration plot to act as control for the managed plots. Regeneration was assessed for 4 years by monitoring the emergence of herbaceous and woody species after the rains and monitoring indigenous seedlings survival during the dry season. Regenerating Prosopis seedlings were continuously removed after every assessment (approximately 6 months interval). Stand management effects was determined by collection and comparison of similar data in the unmanaged plots. Species were classified according to Beentje (1994) and Morgan (1981).

Statistical analysis

One way analysis of variance (ANOVA) was used to determine whether stand density, diameter and height distribution differed in the two sites. T-test was used to determine if there was any significance difference in regeneration of natural vegetation in managed and unmanaged areas. The diversity of plant species was determined using Shannon's diversity index (Magurran 1988) described by the equation below:

$$H^1 = -\sum pi\ Inpi;$$

Where $pi=n_i/N$, the proportion of the ith species and ln is the natural logarithm. The index assumes that each representative sample species has an equal chance of being included in each sampling point.

Descriptive statistics was used to compare recruitment of natural vegetation between 2008 and 2012 in Morung'ole and Nadapal. All data entry and statistical analysis was carried out by MS-Excel and SPSS respectively.

Results

Prosopis natural stands structure before management

The stand density of Prosopis before management was 2660 and 3000 stems ha^{-1} in Nadapal and Morung'ole respectively. Other scattered mature tree species encountered in both sites included *Acacia tortilis, Acacia eliatior*, *Zizyphus mauritiana*, *Faidherbia albida* and *Cordia sinensis*. However *Hyphaene compressa* was only observed at Nadapal site. As shown in Table 1, mean diameter at 30 cm above ground (D_{30}) was significantly different($P<0.01$) between the two sites, while mean total height was not significantly different ($P<0.01$).

Effects of Prosopis management on recruitment of natural vegetation

The study revealed species diversity, herbaceous cover, seedlings and samplings density of natural regeneration between managed and unmanaged plots in the two sites were highly significant ($P< 0.001$). However, Morung'ole had higher species density and diversity recruited than Nadapal (Table 2). Results also show that regeneration of herbaceous species was higher than indigenous tree seedlings in both sites (Table 3a and 3b).

Table 1 Population structure of Prosopis stands before management*

Variable	Nadapal	Morung'ole	P
Stems per ha	2,660 ± 134	3,000 ± 165	0.462
D_{30} (cm)	7.40 ± 0.595	5.44 ± 0.222	0.001
Height (m)	6.71 ± 0.266	6.93 ± 0.175	0.466

*Analysis of variance results are shown by corresponding P values. Significant values are denoted by bold. Means and standard errors are shown.

Table 2 A comparison of managed and unmanaged Prosopis stands after 4 years trial*

Site/variables	Managed	Unmanaged	P
Nadapal			
Species diversity (*H'*)	1.07 ± 0.08	0.50 ± 0.04	0.001
Herbaceous cover (%)	9.10 ± 1.23	2.50 ± 0.63	0.000
Seedlings & saplings density (number/ ha)	1,330.0 ± 331	127.0 ± 85	0.000
Morung'ole			
Species diversity (*H'*)	1.57 ± 0.07	0.40 ± 0.09	0.000
Herbaceous cover (%)	21.39 ± 4.10	6.22 ± 1.38	0.001
Seedlings & saplings density (number/ ha)	2,750.0 ± 756	246.0 ± 56	0.000

*Analysis of variance results are shown by P values. Significant values are denoted by bold. Means and corresponding standard errors are shown.

The Prosopis thinning trials indicated that 6 x 6 m treatment recorded higher percentages of natural vegetation recruited in both sites (Figure 2a and 2b). This shows excessive opening in 10 x 10 m would be detrimental to shade tolerant species.Results on the stump treatment trials indicated that prescribed burning was a better method than debarking (Figure 3a and 3b).

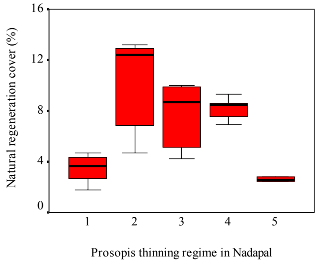

Figure 2a Recruitment of natural vegetation in different Prosopis thinning trials from 2008 to 2012 at Nadapal

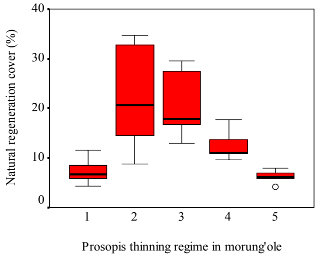

Figure 2b Recruitment of natural vegetation in different Prosopis thinning trials from 2008 to 2012 at Morung'ole

Description of thinning regime;1: 4 x4 m, 2: 6 x 6 m, 3: 8 x 8 m, 4: 10 x 10 m, 5: Control

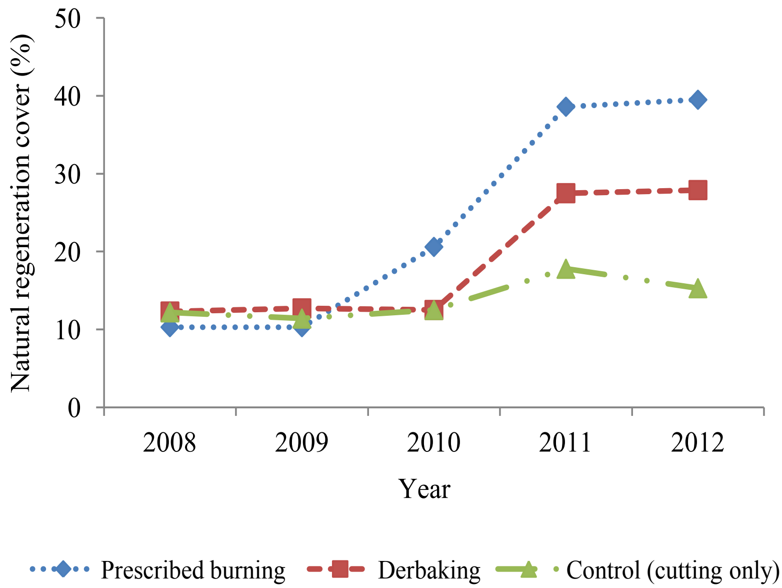

Figure 3a Trend on recruitment of natural vegetation in Prosopis stumps treatment trials from 2008 to 2012 at Morung'ole site along Tarach riverine ecosystem

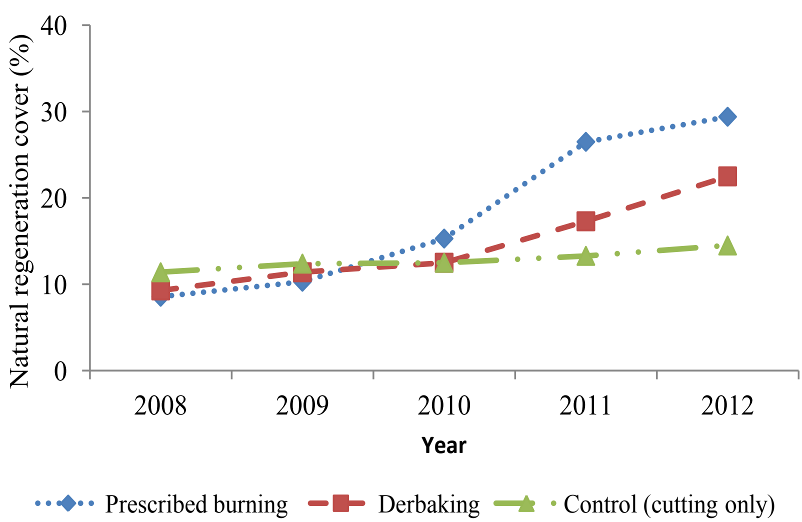

Figure 3b Trend on recruitment of natural vegetation in Prosopis stumps treatment trials from 2008 to 2012 in Nadapal site along Turkwel riverine ecosystem

Table 3a. List of species recruited between 2008 and 2012 showing occurrence and ground cover in Nadapal

Plant Species	Family	Growth form	2008 Mean Cover%	2008 Occurrence (%)	2012 Mean Cover %	2012 Occurrence (%)
Acacia tortilis Hayne	Leguminoceae	Tree	–	–	11.9	33.3
Aerva Lanata (L) Schult	Amaranthaceae	Herb	–	–	5.0	4.2
Amaranthus hybridus L	Amaranthaceae	Herb	5.0	8.3	5.0	20.8
*Aristrida mutabilis*Trin. &Rupr	Poaceae	Grass	–	–	5.0	4.2
Brachiaria deflexa (Schumach)	Poaceae	Grass	–	–	5.0	4.2
Cenchrus cilliaris L.	Poaceae	Grass	11.4	29.2	8.1	54.2
Chenopodium pumilio R.BR	Chenopodiaceae	Herb	5.0	8.3	5.0	4.2
Cordia sinensis Lam	Boraginaceae	Tree	–	–	5.0	4.2
*Cissus rotundifolia*Vahl	Vitaceae	Lianas	5.0	4.2	–	–
*Crotolaria deflersii*Schweinf	Paplionaceae	Herb	5.0	4.2	–	–
Cyperus articulatus L.	Cyperaceae	Grass	–	–	10.0	8.3

Table 3a. List of species recruited between 2008 and 2012 showing occurrence and ground cover in Nadapal *(Continued)*

Digitaria gayana(Kunth) A.Chev	Poaceae	Grass	5.0	4.2	5.0	4.2
Faidherbia albida (Delile) A.Chev.	Leguminosae	Tree			5.0	4.2
*Geigeria acaulis*Oliv.&Hiern	Compositae	Herb	16.0	20.8	25.4	58.3
Glicine wightii (Wight&Arn.) Verdc	Fabaceae	Herb	–	–	10.0	4.2
*Gynodropis gynadra*Briq	Capparaceae	Herb	–	–	5.0	4.2
Hyphaene compressa	Arecaceae	Tree	20.0	20.8	23.1	33.3
*Indigofera errecta*Thunb	Leguminoceae	Herb	–	–	5.0	4.2
Leptadenia hastata (Pers.) Decne	Asclepiadaceae	Herb	–	–	10.5	45.8
Momordica trifolia L.	Cucurbitaceae	Herb	5.0	8.3	10.0	20.8
Ricinus communis L.	Euphorbiaceae	Shrub	10.0	8.3	10.0	8.3
*Ruellia patula*Jacq.	Acanthaceae	Herb	–	–	5.0	8.3
Setaria verticillata (L.) P.Beauv.	Poaceae	Grass	–	–	5.0	4.2
Tephrosia uniflora Pers.	Leguminosae	Herb	–	–	5.0	4.2

Table 3b. List of species recruited between 2008 and 2012 showing occurrence and ground cover in Morung'ole

Plant Species	Family	Growth form	2008		2012	
			Mean Cover%	Occurrence (%)	Mean Cover%	Occurrence (%)
Abutilon hirtum(Lam.) Sweet	Malvaceae	Shrub	4.0	10.4	8.7	12.5
Acacia elatior Brenan	Leguminosae	Tree	–	–	10.0	4.2
Acacia tortilis Hayne	Leguminosae	Tree	2.0	10.4	13.3	12.5
Aerva lanata(L.) Juss	Amaranthaceae	Herb	–	–	10.0	4.2
*Aerva javanica*Juss.	Amaranthaceae	Herb	4.7	6.3	7.6	20.8
*Aloe turkanensi*s Christian	asparagaceae	Shrub	–	–	5.0	25.0
Amaranthu shybridus L	Amaranthaceae	Herb	–	–	50.0	16.7
*Aristida mutabilis*Trin&Rupr	Poaceae	Grass	–	–	10.0	4.2
*Barleria acanthoides*Vahl	Acanthaceae	Herb	–	–	8.0	8.3
*Cadaba rotundifolia*Forssk	Capparaceae	Shrub	10.0	2.1	5.0	4.2
*Chrysopogon plumulosus*Hochst.	Poaceae	Grass	2.0	2.1	–	–
Cocculus pendulus (J.R.Forst. &G.Forst.) Diels	Menispermaceae	Herb	–	–	2.0	4.2
Corchorus olitorius L.	Tiliaceae	Herb	4.3	6.3	28.0	25.0
Cordia sinensis Lam	Boraginaceae	Tree	–	–	5.0	8.3
*Crotolaria fascicularis*Polhill	Leguminosae	Herb	–	–	20.0	4.2
Digitaria gayana (Kunth)	Poaceae	Grass	–	–	5.0	4.2

Table 3b. List of species recruited between 2008 and 2012 showing occurrence and ground cover in Morung'ole *(Continued)*

*Enteropogon*spp	Poaceae	Grass	–	–	7.6	20.8
Euphorbia granulate Forssk	Euphorbiaceae	Herb	–	–	10.3	29.2
Evolvulus alsinoides (l)	Convolvulaceae	Herb	22.2	10.4	90.0	79.2
*Geigeria acaulis*Oliv. &Hiern	Compositae	Herb	–	–	6.5	16.7
Heliotropium longiflorum (A.DC.) Jaub. &Spach	Braginaceae	Herb	–	–	5.0	4.2
*Indigofera erecta*Thunb	Leguminosae	Herb	–	–	5.0	20.8
Indigofera tinctoria L.	Fabaceae	Herb	12.0	10.4	67.0	12.5
Ipomoea hochstetteri House	Convolvulaceae	Herb	1.0	4.2	56.0	27.1
*Justicia coerulea*Blume	Acanthaceae	Herb	–	–	73.8	75.0
*Leptadenia hastat*a (Pers.) Decne	Asclepiadaceae	Herb	–	–	22.0	4.2
Obetia radula (Baker) Leandri	Urticaceae	Herb	–	–	5.0	4.2
Ocimum fruticosa (Ryding) A.J. Paton	Labiatae	Herb	–	–	5.0	4.2
*Ocimum suave*Willd	Lamiaceae	Herb	7.7	6.3	15.2	58.3
*Ornithogalum tenuifolium*Schur ex Nyman	Hyacinthaceae	Herb	2.0	4.2	–	–
Portulaca quadrifida L	Portulacaceae	Herb	–	–	20.0	4.2
*Ruellia patula*Jacq.	Acanthaceae	Herb	5.0	2.1	24.8	20.8
*Sesbania sericea*Welw	Leguminosae	Shrub	–	–	10.0	4.2
*Solanum coagulans*Forsk	Solanaceae	Shrub	4.4	5.3	20.0	16.7
Tribulus cistoides L	Zygophyllaceae	Herb	5.0	2.1	20.0	4.2

Discussion

Prosopis management is a highly prioritized activity in the achievement of environment management sub-sector in Kenya's Vision 2030 as outlined in Second Medium Term Plan 2013 – 2017 (GOK 2013). Although the demonstrations were small in size, the study has documented the extent of Prosopis invasion in a typical drylands riparian ecosystem of Kenya. With the stem per ha exceeding 2500 in both sites. This is far above the recommended spacing in the arid ecosystems for proper growth of drylands species and recruitment of grass and herbs for livestock use and biodiversity conservation (Weber 1986).

The results in this study showed that there was significant difference in recruitment of natural regeneration in managed and unmanaged stands in both sites (Table 2). The negative impact of Prosopis on understory vegetation can be attributed to allelopathy according to Noor et al. (1995) and, Al-Humaid and Warrag (1998). Since Prosopis forms massive thicket and canopy, this could also prevent light in reaching the undergrowth and consequently limiting their growth. Furthermore, studies by Mworia et al. (2011) have shown that indigenous woody species diversity declined significantly as the density of Prosopis increased. This is evident from our studies since the spacing of 4 x 4 m and control recorded low recruitment of indigenous vegetation in both sites (Figure 2a and 2b).

The occurrence of *Cenchrus cilliaris, Geigeria acaulis* and *Hyphaene compressa* was recorded in 2008 at Nadapal, showed remarkable increase in 2013. This can be attributed to reduced density of Prosopis and grazing pressure by roaming livestock since riparian ecosystems are ideal dry season grazing areas (Barrow1996). *Hyphaene compressais* highly utilized by local community in making handicrafts such as baskets and mats. Currently, mature clusters are dominant along Turkwel ecosystem since the local community harvest the young juvenile shoots as their raw materials for utilization in handicraft cottage industry and construction (Amwatta and Omollo2006). Therefore, this demonstration will form a good model for enhancing conservation of *H. compressa* among other important riparian plant species. Table 3a and 3b shows about 60% of the species were recruited successfully in 4 years. However *Chrysopogon plumulosus* and *Ornithogalum tenuifolium* which were recorded in Morung'ole during the first year of the trial were not recorded at the fourth year. This could probably be due to competition or other ecological succession factors which would require further monitoring before conclusive results.

Results of stump treatment indicated that cutting Prosopis stems about 10cm below ground and burning the stump using manure was successful in killing the stump and recruiting high number of natural vegetation (Figure 3a and 3b). However fire should only be concentrated around the stump to avoid damage of soil seed banks of potential indigenous species.

Prosopis management not only involves thinning and stump treatment but also maintenance of fence to prevent livestock from intruding in the managed areas. Studies by Hailu et al.(2004) have shown that 12% to 45% of Prosopis seeds ingested by animals could pass unharmed through their digestive tracts. Since Prosopis is a prolific seeder, regeneration from soil seed bank is normally high especially after reducing the stand density. Periodic manual removal of regenerating Prosopis seedlings should be maintained to reduce competition with the natural vegetation at early stages of management intervention.

Conclusion and Recommendations

Recruitment of natural vegetation is hindered by high density of Prosopis since multi-stems and high canopy cover block light and occupy more space.The optimum spacing of 6 x 6 m and treating cut stumps using prescribed burning recorded high percentages of recruited natural vegetation. Maintenance of managed stands through fencing and removal of regenerating Prosopis seedlings at least two times per year is highly encouraged for success of proposed interventions. Long term monitoring of dynamics of recruited natural vegetation need to be undertaken to elicit restoration interventions. The study recommends involvement of local community and up-scaling of best-bet management interventions in all Prosopis invaded areas.

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Theme IV

Policy and Institutional Frameworks Supportive of SLM

Chapter I8

Enhancing Sustainable Land Management in Kenya Through Policy and Financing

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Abstract

Land degradation is both an effect and driver for climate change. Climate change increases the frequency of flooding and heavy erosive events which increases loss of soil and crucial soil nutrients. As a driver of climate change, deforestation and over grazing lead to increased greenhouse emissions. Climate change increases poverty, disease loads, frequency of flooding, droughts, and food insecurity. Majority of Kenya's population is smallholder rain dependent farmers. The success of rain-fed agriculture depends on actual rainfall (amount and distribution) whose variability is projected to increase as a result of climate change leading to reduction of crop yields by about 50% by the year 2020. Over 40% of Kenyans are classified as resource poor and about 80% of land mass is arid and semi arid land (ASAL) and this may have a significant impact on the quality of life. Furthermore as the impact of climate change is felt, the activities of the poor inhabitants may further exacerbate land degradation through anthropogenic activities related to unsustainable agricultural practices. Therefore, governments should develop policies in relevant sectors that promote Sustainable Land Management (SLM) alongside adaptation and mitigation to climate change. Key among these sectors are: payment for ecosystem services, promoting drought resilient techniques and innovative financing of SLM activities. This paper highlights selected financing mechanisms and policies and their implication for SLM in Kenya.

Key words: Land degradation, sustainable land management, arid and semi- arid lands, climate change

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Introduction

Land degradation increases the vulnerability of rural people to extreme weather events and climate change, because of decreased land productivity (Pender et al. 2009). Worldwide over 250 million people are directly affected by desertification as a result of land degradation while over one billion people in over 100 countries are at risk. These people include many of the world's poorest, most marginalized, and politically vulnerable citizens. Hence combating land degradation and desertification is an urgent priority in global efforts to ensure food security and the livelihoods of millions of people who inhabit the dry-lands of the world (WMO 2005). Climate change and climate variability contributes to land degradation by exposing unprotected soil to extreme conditions and straining the capacity of existing land to maintain resource quality. According to World Meteorological Organization (WMO 2005), land degradation in the arid, semi-arid and dry sub-humid areas results from various factors including climatic variations and anthropogenic drivers. Land degradation also contributes to loss of vegetation cover, soil erosion, salinization, depletion of organic matter and other forms of degradation. These changes can cause land management practices that were sustainable under different climate conditions to become unsustainable, and also induce more rapid conversion of forest or rangeland to unsustainable agricultural uses (Pender et al. 2009).

The global population has continued to increase leading to pressure on and overuse of the farmlands, which global food production depends on, resulting in rapid land degradation. About 24% of the global land area has been affected by land degradation and approximately 1% of this area is lost to land degradation annually. This trend is more profound in Sub-Saharan Africa (SSA) where majority of inhabitants rely directly on natural resources (Figure 1).

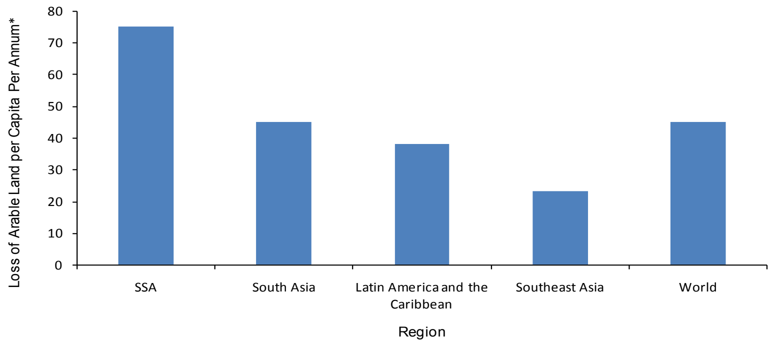

Figure 1 Loss of arable land per capita per annum in Sub-Saharan Africa, South and South East Asia, Latin American and the Caribbean (Source: Nkonya et al. 2011)

Similarly, land degradation in Kenya has been increasing. As at 1997 approximately 23% of Kenya's land was vulnerable to very severe desertification, a figure that rose to 30% in the early 2000s (UNEP 2002). It is estimated that 20% of all cultivated areas, 30% of forests, and 10% of grasslands is subject to degradation (Muchena 2008). Approximately a third of the Kenya's population depends directly on the land that is being degraded. Expansion of cropping into marginal lands and fragile ecosystems was identified as the major cause of this degradation. The drylands around Lake Turkana and marginal cropland in Eastern Province were identified as the areas most affected (Bai et al. 2008).

Materials and Methods

The work presented herein is a result of review of literature from published papers and reports on SLM activities and their impacts on SSA and other similar tropical regions. Emphasis was put on financing mechanisms that enhance SLM and climate change management. Policies relating to natural resource use are also reviewed and discussed.

Results and Discussion

Causes and effects of land degradation

Unsustainable human activities and natural disturbances such as drought and flooding are the leading cause of land degradation in arid and semi arid lands (ASALs). The existing ecological conditions in drylands are harsh and fragile, a condition that is aggravated by climate variability and the influx of people from the high potential areas into these drylands (NAP 2002). Overgrazing and subdivision of land into uneconomical land sizes have exacerbated the situation making the drylands of Kenya more vulnerable to desertification (GoK 2002). The per capita land ownership in Kenya is estimated at 0.32 ha in the high rainfall areas. Further ASALs constitute 80% of Kenya is land surface of which 25% and 5% are susceptible to soil erosion and sodicity respectively.

Land degradation occurs mainly through deforestation, overgrazing and in appropriate cultivation are the main contributors to increased atmospheric green house gas (GHG) emissions that lead to climate change thereby threatening marginal lands further by increasing the risk of desertification (Kilpatrick 2007). The African continent warmed by 0.7°C over the 20th century which translates to 0.05°C warming per decade and is expected to rise by more than 0.5°C per decade (Hulme et al. 2001; IPCC 2001).

Additionally, an increase in precipitation is predicted for Africa, where higher rainfall could be equally destructive because of sporadic and unpredictable heavy inundations as well as beneficial rain. Figure 2 is a summary schematic representation of the key processes (pollution, runoff and sedimentation) involved in land degradation. The general precipitation projections give an increased rainfall of 5 - 20% from December – February and 5 - 10% decreased rainfall from June - August by 2050, and this may cause more frequent and severe droughts and increased desertification in the region (Hulme et al. 2001; Magrath and Simms 2006).

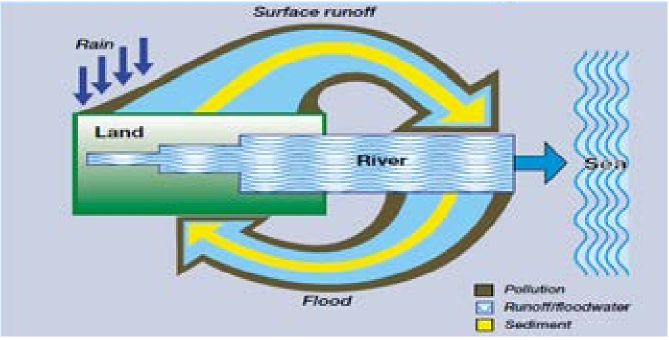

Figure 2 Schematic diagram of rainfall induced processes involved in land degradation (Adapted from WMO 2005)

Climate change

Climate change and climate variability as evidenced by increased drying, irregular rainfall and flooding is a leading contributor to land degradation and this is further aggravated by unsustainable farming practices as people try to cope with adverse effects of land degradation, (Verchot et al. 2008). Thus measures to reduce land degradation should take into account climate change and enhance people's capability to adapt to climate change and to cope with climatic variability (Montoiro 2008). In resource constrained developing countries, it makes sense to link climate change adaptation to desertification mitigation measures rather than designing, implementing and managing the policies separately.

Widespread interventions aimed at reducing impact of climate change have offered financing for implementation of SLM projects. The emerging carbon market which aim at reducing GHG emissions and payments for environmental services provide flow of funds to help promote SLM activities in Africa (Pender et al. 2009). In particular, the Clean Development Mechanism (CDM) interventions allows sale of Certified Emission Reduction (CER) credits in developing countries. Two percent of the proceeds from CERs go to the adaptation fund which finances the costs of adapting to the adverse effects of climate change. SLM projects also benefit from climate financing through sale of CER, the Adaptation Fund and other forms of payment for ecosystem services (PES).

Kenya is already benefitting from some external climate change finance from both global climate funds and bi-lateral agreements and has the potential to scale up this funding by instituting measures to address corruption and good governance of the funds (Norrington-Davies and Thornton 2011).

Although the government has entrenched climate change in its Vision 2030, there is still no national framework for reporting on climate change (Norrington-Davies and Thornton 2011). These authors further state that majority of climate change financing in Kenya is not yet sufficiently earmarked nor is it captured in the government's budget making it difficult to track and monitor. It is unlikely that donors will increase the volume of support channeled through national systems and budgets until improved financial tracking mechanisms for climate change funds are in place.

Thus the government should consider the use of climate change markers within the national budget to enhance tracking of climate finances.

The Ministry of Water, Environment and Natural Resources (MEWNR) is responsible for coordinating climate change at the ministry level and has recently established a Climate Change Secretariat. There is growing awareness of climate change within the Ministry of Finance, Ministry of Water and Natural Resources, Ministry of Health, Ministry of Environment, Ministry of Energy, the Kenya Agriculture Research Institute (KARI), and the Ministry of Agriculture, Livestock and Fisheries. However, domestic knowledge on the amount of global funding available and how it can be accessed still remains limited.

Examples of SLM sectors that can benefit from climate finance

Agriculture and forestry

In agriculture, climate change threatens the suitability and productivity of crops and livestock. In forestry, it jeopardizes wood and non-wood production. Concrete measures in these sectors often aim to combat soil erosion and desertification by promoting agro-forestry, integrated soil fertility management technologies and restricting deforestation (Kilpatrick 2007).

Watershed, biodiversity protection and other environmental services

Improved forest or land management, afforestation and reforestation, forest protection and related activities, are often included in payment agreements between water users and watershed managers. Payments or other forms of compensation are also used to reward the provision of biodiversity protection services. Payment of Environmental Services (PES) is not only likely to contribute to reduction in vulnerability to climate change, but it also has the potential to create effective, efficient and fair incentives for enhancement of the environment as well as provide a channel within which climate-change adaptation funds could be allocated to support local initiatives, within realistic, conditional, voluntary and pro-poor incentive mechanisms (Van-Noordwijk et al. 2011).

Coastal zones

Coastal zones are vulnerable to land loss from sea level rise and increased storm occurrence (Kilpatrick 2007). There is need for measures to address sea level rise, salinization of farmland, and storm occurrence in Kenya especially because the coastal strip is an ASAL that is susceptible to desertification due to land degradation.

Examples of projects that have promoted SLM as well as climate change mitigation and adaptation in Sub-Saharan Africa

Cocoa farming in Ghana

Unsustainable cocoa farming practices in Ghana have been associated with land degradation through soil erosion and deforestation – contributing to both global warming and biodiversity loss. The cocoa industry in Ghana is now threatened by depleted soil fertility, reduced water supplies, and diseases (Vonada et al. 2011). To curb this, carbon finance has been introduced in a bid to shift cocoa farming onto a more productive and profitable enterprise, through a number of activities under Reduced Emissions from Deforestation and Degradation (REDD) and REDD+. Under the REDD+ conservation and sustainable land management are incorporated in cocoa farming, enhancing conservation of biodiversity, increasing amount of carbon sequestered in the farm, and providing an alternative source of income through carbon markets (Vonada et al. 2011). This has led to higher yields and better household incomes, making the households more resilient to changing climate.

Individual farmers in Uganda

In Uganda, ECOTRUST in conjunction with World Agroforestry Centre (ICRAF), CARE International, Land and Timber Services International (LTS), and Edinburgh Centre for Carbon Management (ECCM) began to coordinate a project to pay local farmers to sequester carbon. Individual farmers were encouraged to participate in sustainable farming practices and earn from it. This is through planting of trees that are left intact for a period of over ten years. The land can be used for multiple benefits, provided the trees stay intact. Payment for carbon sequestered is paid in installments over the agreed period of time, after which the farmers are free to harvest the trees. These farmers generate additional income through carbon finance to supplement their other incomes while protecting the community's natural resources and rehabilitating degraded land, (Vonada et al. 2011). These authors assert that the project has been a success with the number of farmers joining the program rising to 300 farmers in 3 sub counties by year 2011.

Watershed management in Naivasha, Kenya

In Naivasha, a pilot project on watershed management around Lake Naivasha where the major economic activities include small and large scale agriculture, horticulture, ranching, tourism, fishing and geothermal power production, and pastoralism was developed by World Wide Fund for Nature (WWF-Kenya) and CARE-Kenya together with local partners. Significant environmental threats in the area emanate from population pressure, unsustainable use of natural resources, weak policy implementation, water pollution and climate change. These threats have resulted in degradation of ecosystem services, economic losses, worsening poverty and reduction of biodiversity. The goal was to develop a viable financial mechanism for payments for watershed services that delivers sustainable natural resource management and improved livelihoods. Highly degraded hot-spots upstream were identified and small-scale landowners were provided with incentives so as to engage in land management changes aimed at improving downstream water quality and quantity (Chiramba et al. 2011). Some of the benefits accrued include improvement of water quality, soil and water conservation, improvement in the forest cover due to reduced pressure on forest from grazing. This resulted in increased fodder supply from material used for conservation. Planting of fruit trees and use of higher quality material for potato planting as well as an increase in milk production led to increased household incomes which consequently improved livelihood (Chiramba et al. 2011).

Western Kenya smallholder agriculture carbon finance project

The Western Kenya Smallholder Agriculture Carbon Finance Project aims at restoring soil productivity, farm enterprise, and carbon sequestration. It is run by the VI Swedish Cooperative Centre. The aggregator role is played by Farmers Associations that group together 60,000 farms with an estimated emission reduction of 134,000 t CO2 $ha^{-1}yr^{-1}$, (Bockel et al. 2011). The estimated direct benefit to local communities amounts to over \$350,000 with a first payment of \$80,000 in 2011 (Sharma and Suppan 2011, Bockel et al. 2011). However, the project cautions against setting high expectations on carbon payments and emphasizes that carbon revenues are a small proportion of the benefits with the primary benefits being the increased agricultural productivity.

The Kasigau corridor REDD Project

In 1998, Wildlife Works acquired conservation rights to 75,000 acres of degraded forest land in Coast Province, Taita-Taveta County, Kenya. The land is an important wildlife corridor between Tsavo East and Tsavo West National Parks. The organization established a conservation based development project, with the goal of providing communities with real economic alternatives to slash and burn practices. They gained support from the community in restoring the wildlife to the ecosystem. In 2009, with REDD becoming viable in the voluntary market (VCS), they launched Kenya's first REDD project to expand the protection to the entire 500,000 acres of the Kasigau Corridor to bring conservation related income to over 3000 Kenyan shareholders of the land. The project area is primarily low density forestland, shrub land and grassland savannah (Bockel et al. 2011). The funding for the project is provided by Wildlife Works Carbon LLC.

Challenges for SLM activities in Kenya

Investment risk

CDM projects involve investments, and this entails the assessment of the degree of risk that follows this investment. Investment risks in Kenya, are compounded by large infrastructure deficits, double digit inflation and high levels of poverty with majority of the population (50%) living below the poverty line. In 2011, Kenya's public debt was about 50.9% of the GDP having grown from 46.3% in 2009, in addition, the economy suffered double digit inflation (2005-2006) which became stable at 4.2% in 2010 (Davidson et al. 2011). Further, the foreign inward investment and the pursuance of bilateral partnerships between developed countries and Kenya have been on a declining trend since the 1970's due to political instability, crime/insecurity, institutional factors and concerns over the transparency and approach to governance, reaching an all time low in 2005-2006 (Davidson et al. 2011).

Limited local expertise in CDM

There are only few local professionals with expertise in CDM. This limits the CDM projects to foreign experts a situation which may not capture all the locally available climate change mitigation opportunities.

Limited financial resources

Government and donor investment in climate adaptation program is low. This limits the financial resources available for SLM activities (Chiramba et al. 2011). In addition, the scarcity of resources for SLM activities has caused the government to heavily rely on few multinationals such as the World Bank and the United Nations etc. This has the potential of initiating competition and limiting the diversity of project participants by narrowing the scope of involvement to selected partners. Over 77% of the registered CDM projects in Kenya fall into the category financed by a Direct Foreign Investment (DFI) or a similar funding source with the rest coming from private investors both within Kenya and foreign countries (Davidson et al. 2011).

Unpredictable weather patterns

Climate change has disrupted the seasons resulting in adverse effects within the projects area. Prolonged drought destroys most of the conservation plants while heavy rainfall results in accelerated soil erosion and sedimentation.

Degraded public lands

Non-point source sedimentation from degraded public land may threaten efforts to prove a business case for PES through water quality monitoring since such sedimentation may obscure the hydrological benefits arising from land-management improvements on the targeted hot-spot farms.

Low buy-in from buyers

Like other PES schemes around the world, especially those relating to watershed services, securing commitment from direct beneficiaries of those services is a challenge; especially in a situation where they are already paying a statutory fees such as water fee to the regulating body and therefore payment for PES appears as if it is a “double” payment.

Policy implications for Kenya

- Derivative financial products should be developed to hedge risk and minimize project transaction costs, this is key for managing CDM risks in-light of the various risks experienced in the region.
- Engage more buyers and sellers. Consultative meetings should be organized to discuss with potential buyers their participation in the scheme. The selling point would be the opportunity to improve their business through investment in PES scheme, like through reducing the cost of water treatment. Ecosystem service sellers should be mobilized through community sensitization meetings involving the county administration.
- Institutionalize PES, SLM and climate change management in the policy framework of the country.
- Link PES and SLM to climate finance initiatives like REDD. Schemes like payment for watershed services could be combined with carbon finance scheme to generate multiple benefits.
- Link the farmers to markets. This can be achieved through facilitation of farmers to form producer and marketing groups which will increase their bargaining power, market competitiveness, reduce transaction costs and therefore increase return on investment in SLM projects.
- Partnerships between the private and government institutional organizations should be facilitated to gain the best possible project outcome for Kenya with domestic capacity building being a key stipulation of this arrangement.

Conclusions

This paper establishes that SLM and climate change management complement each other. Consequently, an integrated approach that incorporates SLM and climate change management would deliver more benefits in combating land degradation and increasing climate change resilience and adaptation. There are limited resources in terms of finance and expertise available for SLM projects, however, there exists numerous opportunities for SLM projects to benefit from climate financing.

Currently, there is heavy reliance on large international organizations to fund SLM projects. In Kenya this has done little in creating a friendly investment environment for smaller financing institutions and individuals. The government needs to enact and implement institutional policies that will create enabling environment for internal and external investors in SLM projects.

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Chapter I9

Conclusions and Recommendations

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Conclusions

This book offers a wide ranging overview of efforts to improve the understanding of the land resources available in the ASALS and how they can be utilized sustainably. Some of the issues brought up include land cover and land use change, up scaling of soil and water conservation; adaption to climate change and variability in agro pastoral production system; rehabilitation of degraded land through afforestation, agroforestry and natural regeneration and issues on policy and institutional framework supportive to SLM.

Although the studies discussed in this book are very varied, a number of conclusions have emerged regarding sustainable land use management:

- It is evident that land use change in the arid and semi-arid lands may cause significant change of agro-ecology of an area within a short time as for the case of the Lower Tana River forest complex.
- Dry land cropping systems continue to face great challenges in the face of a changing climate. For sustainable development to take place in the vast agro pastoral areas of Kenya there is need for holistic approach that is easy to adopt or replicate across all the affected areas. Soil and water conservation continue to offer opportunities for the communities to gain relevant resilience against the effects of climate change. Evidence from the water conservation technologies has provided answers for sustainable development in the areas. Up scaling these technologies through the institutional capacity building to counties across the country are solid proof that this approach to dry land cropping has the ability to transform the dry lands of the country and the world at large to be viable food production zones.

- It is also revealed in this volume that neighbouring famers are a major source of information on improved SWC and they also greatly influence adoption of SWC. This shows that farmer to farmer extension is very critical in technology transfer and adoption. To ensure that farmers convey the right message to their fellow farmers, extension agent will have to concentrate on training of trainers who then become the agents of technology transfer.
- It has also come out clearly the majority of community members in the agro pastoral areas are knowledgeable about climate variability. An example of how they understand climate variability is demonstrated by Borana women whose workload has increased due to climate change and variability.
- Modeling of climate scenarios can assist in predicting climate change. In particular monitoring NDVI is very essential in crop assessment since the trend can be analyzed to observe when periods of dryness or drought stress occur during the growing season. These could be caused by reduced moisture content, nutrients, or pests and diseases infestation. Vegetation index is not only useful in past and current growth assessment but also forecasting and early warning.
- It is evident from one of the chapters that rangeland enclosures can significantly improve rangeland conditions and productivity for increased livestock production. Difference in enclosure management regime was a remarkable source of variation for most of the parameters investigated and enclosure time was seen as the primary factor affecting the productivity of an enclosure only to a certain period of time after which enclosure management became more important.
- It is also established in this volume that an integrated approach that incorporates SLM and climate change management would deliver more benefits in combating land degradation and increasing climate change resilience and adaptability. Land degradation in ASALs is a complex issue and the move towards holistic mainstreaming of SLM across all national planning processes will be a step in the right direction. There are limited resources in terms of finance and expertise available for SLM projects, however, there exists numerous opportunities for SLM projects to benefit from climate financing. Currently, there is heavy reliance on large international organizations to fund SLM projects in Kenya and this has done little in creating a

friendly investment environment for smaller financing institutions and individuals, thus the government needs to enact and implement institutional policies that will create an enabling environment for internal and external investors in SLM projects.

Recommendations

This book captures results of several initiatives addressing different interventions towards sustainable land management. Due to the threat of land degradation and reduced land productivity in the arid and semi-arid areas, there is need to demonstrate hope in land reclamation and conservation for improved productivity. The following recommendations are suggested:

- Set up demonstration sites in different counties where best practices on sustainable land management (SLM) activities can be initiated. Such sites will serve as training ground for farmers who would adopt the technologies and implement them in their farms.
- Popularize SLM through holding biennial conferences which can be opened up to the African region and later beyond the continent. This will create a forum for technology transfer and capacity building.
- Develop alternative channels for information dissemination including establishment of a journal of sustainable land management.
- Establish a link with existing relevant journals to fast-track publication of special journal issue from good quality papers that may be presented at the biennial conferences.
- Promote SLM through organized competitions and award system.
- Promote research and innovations through postgraduate research, curriculum development in SLM and seeking competitive grants.