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TOWARDS INTEGRATED APPROACHES FOR THE SUSTAINABLE MANAGEMENT OF NATURAL RESOURCES IN THE DRYLANDS: THE CASE OF EASTERN KAJIADO AND SOUTHERN MAKUENI DISTRICTS, KENYA

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ABSTRACT

MOHAMED Ahmed Maalim (2005). Towards Integrated Approaches for the Sustainable Management of Natural Resources in the Drylands: The Case of eastern Kajiado and southern Makueni Districts, Kenya (Doctorate thesis), Gembloux, Belgium, Faculté Universitaire des Sciences Agronomiques. 374 p., 42 Tab., 61 Fig. and 41 Plates, 7 Appen.

The study was conducted between December 2001 to March 2004 at village level in the semi-arid eastern Kajiado and southern Makueni Districts, in South Central Kenya to assess sustainability of the existing management on natural resource components (with emphasis on plants, soil and water) both from the perspectives of farming and pastoral communities. The study was motivated by the failure of finding solutions to pressing problems such as economic stagnation, poverty and land degradation in the drylands of Kenya even after over four decades of research and development with so many projects/institutions concerned. Consequently, the objectives of the research were to characterize the resource components and understand the impact of the existing management practices on the resources. Based on these experiences, sustainable and integrated conceptual models were then to be put forward on their management.

Triangulation technique consisting of participatory field characterization, archival data, experiences and indigenous technical knowledge (obtained through interviews, meetings, household questionnaire and tasks to local community resource persons) were used to collect data. More information were also obtained by analyzing soil and water samples in scientific laboratories. The data were then critically analyzed and means summarized using Excel and SPSS packages. The facts from each village were conceptualised using ARCVIEW and ARCINFO in order to obtain integrated ecological and farm management units.

Soil resources in all the four study villages were found to be eroded accompanied by low fertility in form of limited organic carbon, total nitrogen, phosphorus, cation exchange capacity and base saturation except in few landscapes and farms with soil conservation structures or where animal manure were added. Similarly crop production was relatively low, pastures were overgrazed, bush encroachments common and high value trees and shrubs over exploited for various uses. The underlying causative factors were identified as population pressure, poverty, unreliable rainfall, over cultivation, bare soil surfaces, high livestock numbers, pests and diseases, destruction by wild animals and limited technical and financial support. Other factors include inappropriate, conflicting and ad hoc policies, lack of markets and poor marketing systems and transport related constraints. Furthermore, water resources were inadequate and grossly polluted and contaminated (bacteriologically, physically and chemically) as a result of siltation, inadequate protection from human and livestock and the use of contaminated containers, and destruction of catchments in the surrounding farms and woodlands as mentioned above.

The way forward was seen as creation/strengthening of market catchments along Nairobi - Mombasa road, merger of research and extension systems into one integrated natural resource sector, empowering of the local community technically and financially, diversification of agricultural production and income generation activities, availability of water for irrigation, livestock and domestic use and the conservation of plants, soil and water resources based on the suitability of the different ecological and farm management units within the villages.

RÉSUMÉ

MOHAMED Ahmed Maalim (2005). Pour des approches intégrées de la gestion durable des ressources naturelles dans les zones arides : le cas des districts Est de Kajiado et Sud de Makueni (Thèse de Doctorat). Gembloux, Belgium, Faculté Universitaire des Sciences Agronomiques. 374 p., 42 Tab., 61 Fig., 41 Plates, 7 Appendices.

L'étude a été conduite au niveau villageois entre décembre 2001 et mars 2004, dans les Districts semi-arides de Kajiado (secteur Est) et de Makueni (secteur Sud), au sud de la région centrale du Kenya, en vue d'évaluer la durabilité des aménagements actuels eu égard aux composantes naturelles (en particulier en ce qui concerne les plantes, l'eau et le sol), tel que perçu par les communautés tant agricoles que pastorales. L'étude fut motivée par l'échec de solutions aux problèmes pressants de stagnation économique, pauvreté et dégradation des terres dans les zones semi-arides du Kenya, malgré plusieurs décennies de projets de recherche/ développement et nombre d'institutions et organismes concernés.
En conséquence, les objectifs de la recherche ont été de caractériser les composantes de la ressource et d'appréhender l'impact des pratiques d'aménagement existantes sur les ressources ; basé sur cette analyse, un modèle conceptuel soutenable et intégré est alors proposé.
Une technique de triangulation a été utilisée en vue de collecter les données, consistant en caractérisation sur le terrain, données d'archives, expérience et connaissances techniques locales (via des interviews, réunions, questionnaire par entité familiale, informations ciblées obtenues de personnes-ressource locales) ; des analyses de sols et d'échantillons d'eau ont également été effectuées dans des laboratoires scientifiques et les données traitées et synthétisées. Les éléments récoltés pour chaque village furent traités via ARCVIEW et ARCINFO en vue de définir des unités agro-écologiques intégrées.
Les sols dans les quatre villages qui ont fait l'objet d'une analyse présentent des problèmes d'érosion et sont de faible fertilité, excepté dans quelques sites et fermes où des aménagements de conservation des sols et des apports d'amendement organique ont été effectués. Similairement la production agricole est relativement faible tandis que les pâturages et les zones à production de bois, qu'il s'agisse de broussailles ou d'arbres à valeur ajoutée, sont surexploités pour divers usages. Les causes sous-jacentes identifiées dans l'étude sont la pression démographique, la pauvreté, l'irrégularité des précipitations, les sols peu couverts, la haute densité de bétail, les infections et maladies, la destruction par les animaux sauvages et le support technique et financier limité. D'autres facteurs incluent des politiques conflictuelles et/ou inappropriées, le manque de systèmes de commercialisation et les contraintes liées au transport des marchandises ; en outre les ressources en eau disponibles sont inadéquates et généralement polluées et contaminées (bactériologiquement, physiquement et chimiquement), résultat d'un mode inapproprié d'utilisation par les usagers et le bétail, de l'emploi de containers impropres, et de la dégradation des bassins naturels d'alimentation en eau.
Les solutions proposées sont de créer ou renforcer les marchés le long de l'axe routier Nairobi-Mombasa, de développer la concertation entre la recherche et les services de vulgarisation de façon intégrée par secteur de ressources naturelles, de favoriser l'emploi local techniquement et financièrement, d'améliorer la disponibilité en eau pour l'irrigation, l'usage domestique et l'élevage, et de promouvoir la conservation des ressources en sols, plantes et eau sur base de l'aptitude des différents écosystèmes et entités agricoles au sein des villages.

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LIST OF ABBREVIATIONS

ADRA	Adventist Development and Relief Agency
AEZ	Agro-Ecological Zones
AFC	Agricultural Finance Cooperation
AI	Index of Aridity
ALDEV	African Land Development Board
AMREF	African Medical and Research Foundation
ARIDSAK	Agroforestry for Integrated Development in the Semi-arid Areas of Kenya
ASALs	Arid and semi-arid Lands
CGIAR	Consultative Group on International Agricultural Research
DHP	Dryland Husbandry Project
DFDP	District Forest Development Plan
ENSO	El-Nino Southern Oscillation Phenomenon
ETC EA	ETC East Africa
ELTs	Ecological Landscape Types
FSA	Farming Systems Analysis
FAO	Food and Agriculture Organization of the United nations
FAOSTAT	FAO Statistical Databases
HFTs	Harmonized Farm Types
GAA	German Agro Action
GDP	Gross Domestic Product
GIS	Geographical Information System
GoK	Government of Kenya
GPS	Global Positioning System
GTZ	German Technical Cooperation
IBPGR	International Board for Plant Genetic Resources
ICIPE	International Centre for Insect Physiology and Ecology
ICRISAT	International Crops Research Institute for Semi-Arid tropics
IEA	Integrated Environmental Assessment
IEFMU	Integrated Ecological and Farm Management Unit
ILLUPA	Integrated Land Use Planning and Analysis
INRMU	Integrated Natural Resource Management in Ukambani
ITCZ	Inter Tropical Convergence Zone
ITK	Indigenous Technical knowledge
KAP	Kitui Agricultural Project
KARI	Kenya Agricultural Research Institute
KCB	Kenya Commercial Bank
KEFRI	Kenya Forestry Research Institute
KFA	Kenya Farmers Association
KIOF	Kenya Institute of Organic Farming
KSS	Kenya Soil Survey
KWS	Kenya Wildlife Services
LE	Land Evaluation
LM	Low Midland Zones
L.U	Livestock Unit
MAP	Makueni Agricultural Project
NAS	National Academy of Sciences
NGOs	Non-Governmental Organizations
NORAD	Royal Norwegian Development Agency
NRCs	Natural Resource Components
NRM	Natural Resource Management
PET	Potential Evapo Transpiration
OECD	Organization for Economic Co-operation and Development
RAES	Rural Afforestation and Extension Scheme
SARDEP	Semi Arid Rural Development Programme
SNV	Netherlands Development Organization
SOFEM	Social Forestry and Extension Model
SSA	Sub-Saharan Africa
UNICED	United nations Conference on Environment and Development
UNEP	United Nations Environment Programme
USAID	United States Agency for International Development
USDA	United States Department of Agriculture
USDI	United States Department of the Interior
UNESCO	United Nations Educational, Scientific and Cultural Organization
WCED	World Commission on Environment and Development
WHO	World Health Organization

CHAPTER 1. GENERAL INTRODUCTION

Drylands are dynamic regions that evolved thousands of years mostly in response to climatic changes (Warren 1984 in: Versraete and Schwartz 1991). By definition, drylands are critical and marginal regions with moisture deficit where the ratio of mean annual precipitation (P) to mean annual potential evapotranspiration (PET), that is the index of aridity (AI), is less than 1 (Meigs 1953, UNEP 1992). UNEP (1997) classified drylands to consist of hyper arid (AI < 0.05)arid (AI 0.05 - 0.2), semi-arid (AI 0.2 - 0.5) and dry sub-humid (AI 0.5 - 0.65) climatic zones. While the arid, semi-arid and dry sub-humid are susceptible to land degradation, hyper arid, the true deserts are not because of their naturally very low biological productivity and therefore restrict plant growth and settlement by human populations (Reynolds 2001, UNEP 1997).

"Susceptible drylands" cover 47.2% of the earth's total land surface or 51.7 million square kilometres (km^2) (Bright Edges of the World 2001, UNEP 1997, Squires 1998, Reynolds 2001) and at least 20 million km^2 of the developing world (Bright Edges of the World 2001, Clarke and Noin 1998, UNEP 1997, Reynolds 2001). The drylands support nearly a billion pastoralists and some farmers or 20% of the world population (Bright Edges of the World 2001, Clarke and Noin 1998, UNEP 1997, Reynolds 2001) who attempt to wrest a livelihood from the fragile environment (FAO 1993b). Out of this population Africa houses 108 million people (UNEP 1992) who are characterized by one of the highest birth rates in the world contributing to rapid land degradation encompassing soils, water, vegetation, other biota, and the ecological, biochemical, and hydrological processes that operate therein (Bright Edges of the World 2001, Grainger 1990, Clarke and Noin 1998, Reynolds 2001).

In Kenya, the country of focus in this study, out of the total area of 582,646 km^2, only 7% have adequate and reliable rainfall, soils and topography suitable for crop production. A further 5% can sustain crops in years of adequate rainfall. But the rest of the over 80% is classified as drylands (Pratt and Gwynne 1977, Luukkanen *et al* 1996, KEFRI 1992, Nyariki and Musimba 1997). The drylands of Kenya support 25% of the population, who are about 7 million people mainly the very poor section of Kenya's population (Southgate and Hulme 1996a) and home to 50% of the country's livestock (Muchena and van der Pouw 1981, KEFRI 1992, GoK 2001a). The region is also gene bank to a rich biodiversity (both fauna and flora) and homes to most of the country's national parks and game reserves that supports about 75% of the wildlife (GoK 1986, Pratt and Gwynne 1977, UNEP 2001) and therefore important to Kenya's tourist industry (one of the country's biggest foreign exchange earner), which is heavily dependent on the pulling power of dryland wildlife (Southgate and Hulme 1996b). Kajiado and Makueni Districts in which this study has been conducted form part of this region (GoK 1996).

Studies on the status of land management and development are important because, natural resources, through agriculture, fisheries, forestry, tourism, and agro-based industries and its supporting industries play multiple roles and are the backbone of the developing economies (Jorjani 1990, Defoer 2000, Mbithi 2000). Besides providing continuous and cheap supply of food and raw material, the agro-food industry has contributed significantly to the well being of our societies including the employment of about 80% of the labour force (Defoer 2000, Mbithi 2000).

In Kenya, a part from employment natural resources contribute 53% of Gross Domestic product (GDP) and 60% of the export earning (GoK 2004). Yet majority of the Kenya population is food, water and wood insecure. Fifty six percent of the Kenyan people live below poverty line and households in the drylands are the most affected (GoK 2004). Furthermore, 51% of the population lack access to adequate food and even the little they get is poor in nutrition (GoK 2004). Currently the Government is spending US$ 40.65 million annually on famine relief; and the figure is much higher when relief support by Non-Governmental Organizations (NGOs) is taken into account (GoK 2004). To successfully tackle the whole question of poverty and food insecurity, sustainable growth and development of agriculture and natural resources must be addressed (GoK 2004, Semgalawe 1998).

Until recently Kenya's drylands has not received much attention towards research and development (Chikamai and Muturi 2000). During the colonial period that commenced in 1895, most districts in the arid and semi-arid areas (ASALs) were classified as "closed districts" where development was accorded low priority or were piecemeal in nature (Chikamai and Muturi 2000, Farah 1997). Furthermore, within each district, grazing and water boundaries for different communities were defined using Special District Law Ordinance of 1934, hence reducing flexibility in resource utilization to meet basic needs and undermined mutual interactions between pastoralists and farmers (Farah 1997).

From the dawn of independence to 1978, the significant priority developments that the Government undertook in the drylands were through the livestock sector (Farah 1997) and soil and water conservation (Thomas 1997). However, in the field of livestock, its orientation followed that of the western beef model although the environment and the socio-economic set up were very different. Similarly, the intended beneficiary communities were not involved in its plan and design. Additionally, the model was biased towards beef, forgetting that ASALs supported all the camels and majority of the goats and sheep in Kenya. Therefore, its sustainability could not be guaranteed (Farah 1997). As for the soil and water conservation, although substantial progress has been made, degradation in the drylands continued unabated due to population pressure and loss of vegetation cover (Thomas 1997). Inappropriate practices combined with continuous cultivation on the same plot of land has additionally led to decline in soil fertility (Stroorvogel and Smaling 1990 in: Nziguheba 2001). On the other hand, though insignificant, few other sectoral developments including the Rural Afforestation and Extension Scheme (RAES) of the Forest Department (in few districts) that was mostly based on the promotion of Forest Department and Chiefs' tree nurseries (Mohamed 1997) and isolated large-scale irrigation schemes, which were mainly donor induced (for example USAID and World Bank) were started in the early 1970s (Farah 1997). The Government's research and development priority during the same period was directed at the high potential areas that comprise less than 20% of Kenya's area, which is primarily over populated (Farah 1997, Mohamed 1999a).

The major step by the Government towards the development of the drylands was based on a 1979 policy paper entitled "The Arid and Semi-arid lands of Kenya – A framework for Implementation, Programme Planning and Evaluation" that provided an enabling environment for various donors in funding projects in the drylands. The framework led to the start of a National ASAL Programme under Ministry of Planning and National Development to specifically address development problems in ASALs. The result were Development Plans that emphasized sound management and exploitation of the dryland

resources so as to improve the livelihoods of the inhabitants (Konuche and Muturi 1992, Farah 1997, Chikamai and Muturi 2000). Policies on the drylands were more clearly defined in the Sessional Paper No.1 of 1986 and the subsequent National Development Plans (Chikamai and Muturi 2000, Farah 1997). In 1989, the Government's commitment to the development of ASALs was further strengthened by the formation of the Ministry of Reclamation and Development of Semi-arid, Arid and Wastelands, whose responsibility was to specify, quantify and remedy environmental and production problems of the ASALs. While this was laudable, timely and prudent, farmers and pastoralists of this region for one reason or another have not benefited in terms of resource management and development (Farah 1997). As a result, Famine and droughts are the order of the day. The degradation of the Kenyan drylands whose resource management is not well understood has been further worsened by conflicts and refugee influx from the neighbouring countries (Mohamed 1999a, GoK 2000).

Recognizing these limitations, the Government of Kenya in collaboration with development partners started many research and development projects in order to develop, implement and disseminate appropriate technologies, approaches and policies for the drylands (Chikamai and Muturi 2000, Farah 1997, ETC 1995, ARIDSAK 2000). Examples of these projects are the Kenya/Netherlands ASAL Programme/Semi-arid Rural Development Programme (SARDEP) in Kajiado, Elgeyo, Marakwet and Laikipia Districts, the Kenya/Belgian Agroforestry for Integrated Development in the Semi-arid Areas of Kenya (ARIDSAK) and the District Forestry Development Programme (DFDP)/Integrated Natural Resource Management in Ukambani (INRMU) projects in southeast Kenya, Non-Governmental or semi-autonomous Organizations based projects, for example German Agro Action (GAA)/GTZ, the Kenya/Danish Makueni Agricultural Project (MAP) and the Kibwezi Irrigation Project (KIP) of the University of Nairobi in Makueni District. Other important projects in the region include the Kenya/Japan Social Forestry and Extension Model (SOFEM) Project in Kitui, Kitui Agricultural Project (KAP), Taita-Taveta Agricultural Project (T-TAP), Adventist Relief and development Agency (ADRA) project in South East Kenya, the Royal Norwegian Development Agency (NORAD) Project in Turkana District and Vi Project in West Pokot.

However, after over four decades of research and development with so many projects/institutions concern about the drylands, we are still no closer to finding solutions to pressing problems such as economic stagnation, poverty and environmental degradation in the drylands (Niamir 1990, Warner 1991, GoK 2000, Barrow 1996, Kinyanjui *et al.* 2000). A part from climatic change (Evers 1994), land degradation in the drylands are as a result of several factors related to land use – inappropriate agricultural technologies and practices, use of the principle of maximization of short term economic benefits; recreation practices; outside influences including the introduction of exotic species, practices and technologies; poverty; recurrent droughts and famines; inappropriate or incomplete research activities; inappropriate policies; and accumulating burden of foreign debts (McClure *et al.* 1998, Darkoh 1993, Rowland 1993, Barrow 1996, Reynolds 2001, Barrow 1991, ETC 1995, Mohamed 1999a, Mohamed *et al.* 1999, ETC 2000, Perrings 1996).

Other origins of land degradation are problems related to market and market security of agroforestry (AF) and agricultural products; use of saline water for irrigation; cultural values; land tenure conflict; lack of effective extension service and institutional shortcomings and individual behaviour (Niamir 1990, Warner 1991, Sharma *et al.* 1995,

Dejene *et al.* 1997, Barrow 1991, ETC 1995, Mohamed 1999a, Mohamed *et al.* 1999, Kolowole and Scoones 1991, Mortimore *et al.* 1995, Rowland 1993). Additionally, failure to incorporate participatory and integrated approaches and indigenous knowledge into the process and lack of considering gender issues are other factors causing the crisis (Niamir 1990, Warner 1991, Sharma *et al.* 1995, Dejene *et al.* 1997, Mohamed 1999a, Mohamed *et al.* 1999, Mortimore *et al.* 1995, Darkoh 1996a). Underestimation of the value (goods and services) of natural ecosystems (Edward 1992) and the complex impact of human activities are also some of the factors contributing to the widespread loss and degradation (Niamir 1990). Furthermore, when most of the research and development models for the drylands were being developed and tested it was done not only without the involvement of the local communities but also a way from their environment and were based on unrealistic studies (Oba 1994, Farah 1997, Leach and Mearns 1996, Zaal 1998 and Defoer 2000) and therefore hampering sustainable resource management (Mukamari and Mavedzenge 2000, Kinyanjui *et al.* 2000, Bailey *et al.* 1996, Odera 2003 pers. communication). To supplement, Evers (1994) and Defoer (2000) argue that conventional approaches to the analysis of desertification fail to take into account the complexity of human resource use and multiple factors impacting on marginal areas.

Another major problem in the Kenyan scenario is the ever increasing population caused by continuous intrinsic annual growth of both human and livestock numbers in the drylands coupled with emigration from the over populated central and western highlands (Bernard 1985, Mohamed 1999a, ARIDSAK 2000). This population increase is reducing land available for nomadic pastoralism, which is the traditional mainstay hence encouraging sedentarization and degradation of the environment (Grainger 1990, Bernard 1985, Mohamed 1999a, Barrow 1996). In Kajiado and Makueni Districts, the annual population growth rates are 4.51% and 3.09% per annum respectively (GoK 2001c, GoK 1996) while in Kenya the average economic growth in 1990s was 2.1% (GoK 2000b) and less than 1% in 2000 (GoK 2003). To reduce poverty and attain sustainable agricultural and economic growth in Kenya an estimated 4% is essential (GoK 2000). The dismal performance of the agricultural sector (which must be the engine for overall economic development) has raised serious concern among African policy makers about whether the land can support the expanding population, and produce to combat poverty and food insecurity (Dejene *et al.* 1997).

Overuse and misuse of an already shrinking natural resource base of the drylands of Kenya is threatening the livelihood of over 80% of Kenya's rural population especially in arid zones (Southgate and Hulme 1996a). Although a considerable part of the cause lies in the difficult climatic weather, limited infrastructural development and fragile soils, part of the problem has stemmed from our understanding and activities as agents of development and the subsequent application of inappropriate interventions and approaches (Barrow 1996, Southgate and Hulme 1996a). These constraints could have led to the current unsustainable agricultural practices (Faeth 1993), causing "vicious cycle" of low farm income, poverty, food and water insecurity and environmental degradation and eventually turning into conflicts of interest between different users (WCED 1987, UN 2000, GoK 2000, Mohamed *et al.* 1999a, Cleaver and Schreiber 1994, ACTIONAID 1993). Other consequences include "White elephant" (not useful/unsustainable) structures, deforestation, salinization, overgrazing and urban sprawl/unplanned settlements.

Socio-economics more so policy is the underlying causative factor to all these problems and consequences because it is the over riding issue that sustains or degrades an environment (Reimolds 1998, Claw 1998, Barrow 1996, Edward 1992, Bailey *et al.*1996, Mohamed *et al.* 2000). In Kenya today, farmers have not adequately adopted improved technologies (Kinyanjui *et al.* 2000) because of fear in taking chances in terms of costs versus benefits, inadequate information flow and limited policy support.

Although the proper management of land resources is a top priority of the Government of Kenya (GoK 2004, Thomas 1997), the policies that guide natural resource management are sector specific, and have narrow objectives and assumes that the state can comprehensively control, rather than influence, resource users (Southgate and Hulme 1996a). The ad hoc sectoral research and extension policies implemented by the Government and development agencies through sector departments confuses the farmer/pastoralists because the approaches they use and advises they give at times contradict and conflict each other, hence could be promoting land degradation. Further, the development process in Kenya is at a stage when land-use interests such as agriculture, tourism, wildlife management, forestry, water conservation and human settlements are often in conflict (UNEP and GoK 2000). The situation may deteriorate even further because, in the recent past, based on economic grounds, the World Bank and the donor community had influenced the Government to retrench civil servants including those involved in the management of natural resources. If this trend continues, it may reach a time when even the sector based advises ceases to be there or may remain to only few sectors and this could have further negative impact. Consequently, as conventional wisdom suggests, if the perception of the nature of the problem is wrong, then the solutions are likely to be wrong (Basnyat 1995, Leach and Mearns 1996). As a result drylands resource use need new and comprehensive approaches and policies governing land management (UNEP 2001). Such approaches and policies should be based on past lessons; self-reliance; interdisciplinarity; gender sensitivity; indigenous knowledge and strategies and active participation by all key stakeholders right from formulation stage (Barrow 1996, Darkoh 1993, Perrings 1996, Dejene *et al.* 1997, Bailey *et al.* 1996, Mohamed *et al.* 2000, Vedeld 1992, Mortimore *et al.*1995, Parr and Papendick 1997, Scoones and Graham 1994, Horowitz *et al.* 1995, Munasinghe 1993, Edwards 1992 and Crosson and Anderson 1993).

It was while implementing natural resource management activities/projects with rural communities both in the humid and the drylands of Kenya for the past 17 years that the difficulty of using sectoral approaches was realized. Yet the typical rural farmer/pastoralist whom we serve manages simultaneously and with ease the natural resource endowments under his/her disposal in an integrated fashion, a factor that motivated this study. Of cause it is out of necessity that the small-scale farmers implement on-farm and off-farm activities concurrently for their subsistence (Idris *et al.*1998). Unfortunately, the narrow training approach of most of the agricultural professionals, limit them to only a few commodities at a time therefore not allowing them to deal with the farm holistically. A way out could be looking at farmer' situations in a functional interdisciplinary approach by a group of specialists in different disciplines (Idris *et al.*1998). However, this approach is very costly to maintain. Therefore rethinking the whole extension, research and development system to have a total natural resource manager right at the locational level would be cheaper way forward in the long run.

To contribute towards this goal, the study was expected to come up with sustainable management technologies and approaches that will bring beneficial change in the conditions and characteristics of the ecosystem and narrow the productivity gap between actual and potential yield in order to satisfy the needs of the growing population and avoid natural resource degradation trap (Dejene *et al.* 1997, Toledo 1999). However, the implementation of an integrated study is not easy because it is hard to integrate sector-based data into a concrete database for conservation. They are incomplete, unreliable or difficult to interpret due to application of different methods and tools under a variety of natural conditions, cultural and national standards (Mohamed *et al.* 2000, Duivenbooden 1995). Further, the data needed for integrated resource management is bulky and being a relatively new discipline there are no clear and appropriate foundation in place to implement it (CGIAR 2002). Consequently, a partially qualitative approach based on triangulation technique - a combination of data from direct field assessment, questionnaire, interviews with farmers and groups and archival data (Defoer 2000, Stocking and Murnagham 2000, Mergeai 2001 pers. communication) have been used to compile GIS database that provides crucial information necessary to support sustainable natural resource management from an integrated perspective. Personal experience and knowledge from relevant projects/institutions formed foundation for the study.

Objectives and outline of the thesis

The study examines the driving force behind inappropriate land management in the arid lands of Kenya and the way forward through a case study in two divisions with natural resource base economy, and in a number of respect typical of the drylands of Kenya both from the perspectives of the pastoral and farming communities. It was undertaken in south central Kenya and specifically in Mashuru and Kibwezi Divisions of Kajiado and Makueni Districts respectively based on the hypothesis "*Natural resources in the drylands of Kenya are not sustainably managed*" and with the following aspects:

a) to characterize the existing natural resource components with special emphasis on plants, soil and water resources within the study areas
b) to assess the impact of the existing management practices and use on the natural resource components
c) to contribute to the development of models for the sustainable management of natural resources using vegetation, soil and water as a flagship

The study is organized into five chapters. Chapter 1 covers the introduction (above) that presents the justification for the study. It focuses on the challenges and problems of the drylands in relation to natural resources in the world and Kenya and with focus to Kajiado and Makueni Districts. It finally hypothesizes and sets the objectives of the study. Chapter 2 covers literature review – on what is known about drylands in the world and in Kenya and the latest studies on dryland natural resource management. Chapter 3 explains the how the study was undertaken based on the objectives. Chapter 4 elucidates results and discussions too by objective and Chapter 5 is on conclusions and recommendations. It summarizes the major findings of the study and highlights on the way forward.

CHAPTER 2. LITERATURE REVIEW ON LAND DEGRADATION AND CONSERVATION IN THE DRYLANDS

2.1 INTRODUCTION

The chapter describes the status of the drylands of the world, Africa and Kenya. It also defines the common terminologies used in the management of the dryland natural resources and reviews case studies undertaken in natural resource management, summaries review of existing methodologies for land management and cconceptual framework for the study.

2.2 BACKGROUND ON THE STATUS DRYLANDS OF THE WORLD, AFRICA AND KENYA

2.2.1 DEFINITION OF DRYLANDS

Aridity is a term, which is easy to understand but difficult to define in precise terms (Beaumont 1989, Mohamed 1999a, Clarke and Noin 1998). As a result, various methodologies have been used to classify the drylands (Muller-Samann and Kotschi 1994, Rowland 1993). The commonly used methods are aridity index, moisture index, precipitation/evaporation ratio index, number of humid months, rainfall and length of growing period (Rowland 1993, FAO 1993c).

However, Meigs (1953) developed the backbone of the present internationally accepted definition of drylands (Beaumont 1989, UNEP 1992, Mohamed 1999a). The annual precipitation of the drylands is quite low and the rainfall consists of high-intensity events, erratic (occur over short periods of time), unreliable (highly variable throughout the year) and there is high overland runoff (Reynold 2001). Most, if not all, of the annual precipitation is lost from the system via evapotranspiration rather than via drainage to ground water or surface runoff as a result of the high evaporative demand of the atmosphere resulting from high air temperatures, low humidity, and abundant solar radiation (Reynold 2001). Aridity is as a result of continentality, topography, anti-cyclonic subsidence and ocean current (FAO 1988).

2.2.2 STATUS OF DRYLAND RESOURCES – GLOBAL AND KENYAN PERSPECTIVES

Mankind has had along association in these regions: the first great civilizations (in Egypt and Mesopotamia) developed at the end of the climatic optimum some 3000 years B.C., at a time when the Sahara appears to have been vegetated as parts of the Sahel are today (Butzer 1966 and Lamb 1977 in: Versraete and Schwartz 1991). With time as the climate changed, the landscapes of these regions became arid (El-Baz 1983 in: Versraete and Schwartz 1991). Consequently, humanity has been able to cope with such an evolution by colonizing new areas that are unaffected. However, in the last century it became apparent that land has become finite and mankind realized that the exploitation of natural resources based on the principle of profit maximization has resulted in rapidly deteriorating environmental conditions.

This degradation now affects many or most ecosystems on this planet (Versraete and Schwartz 1991) but the most affected are the drylands especially the developing countries (Stangel *et al* 1991).

(i) Geographical location and size

Drylands cover 47% of the earth's total land surface, that is 5.2 x 109 ha (Bright Edges of the World 2001, UNEP 1997, Squires 1998, Reynolds 2001). This coverage omits 0.98 billion ha (approximately 7.5% of the global land area) occupied by hyper-arid such as the Atacama, Arabia, and the Sahara Deserts (Reynolds 2001).

The earth's drylands are largely situated within third world countries and occupy at least 20 million km² of the developing world. Precisely, eighty out of the one hundred and ten countries with dry regions are in the developing world (Steen 1998) and these countries, are affected by land degradation, and mainly desertification (UNEP 1997). The greatest concentrations of the drylands are in Asia and Africa, which account for 30% of the total land area of the world and 64% of all drylands (Reynolds 2001). On continental basis too, 75% of Australia and 30% of Europe and South America are also classified as drylands (Reynolds 2001). Eighty seven percent of the population of the drylands live in Africa and Asia (Bright Edges of the World 2001, Reynolds 2001, Clarke and Noin 1998, Cardy 1993, Versraete and Schwartz 1991).

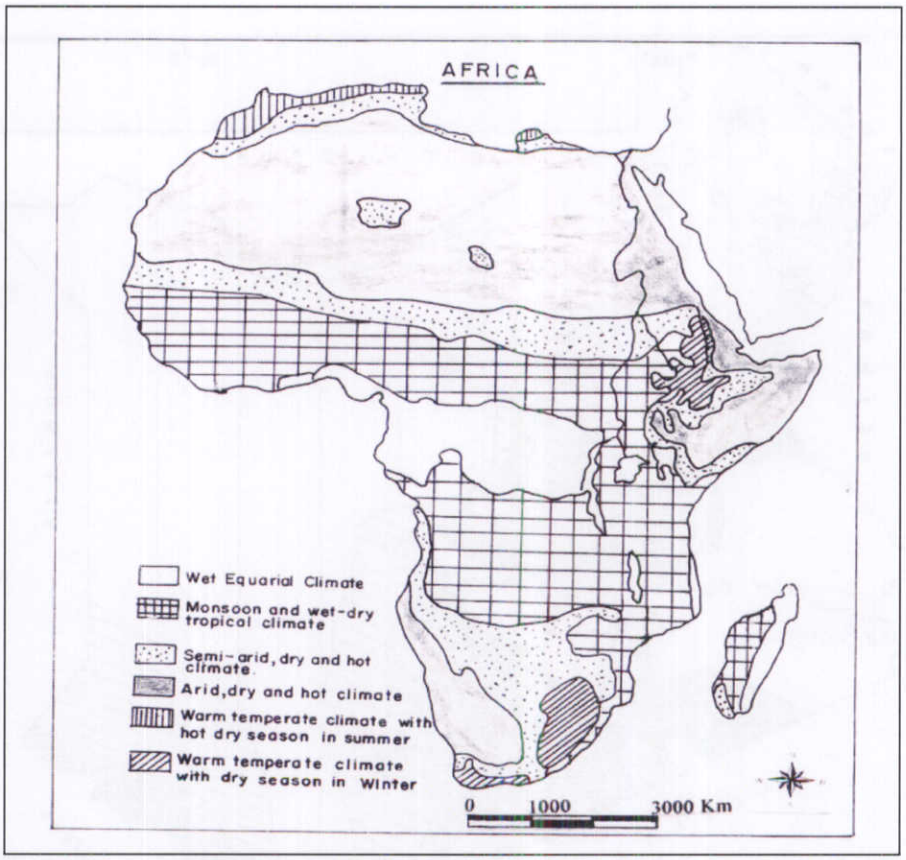
Arid and semi-arid lands (ASALs) of Africa cover 56.96 % of the total land surface (UNEP 1992) while in SSA it covers 65% of the total land area (Oldeman *et al.* 1991 in Dejene *et al.* 199) (Fig.2.2.1) and over 80% of Kenya is classified as drylands (GoK 1986; Pratt and Gwynne 1977; Luukkanen *et al.* 1996) (Fig. 2.2.2).

(ii) Population

Drylands are believed to be the cradle of mankind and has since then experienced a stage of dramatic events in human development and civilization (Bright Edges of the World 2001). The world population in 1993 was 5.3 billion, more than double when compared with the 2.5 billion in 1950 (Claw 1998). Eighty seven percent of the population of the drylands live in Africa and Asia and 72% of this population live in the semi-arid zone (Clarke and Noin 1998).

The general average annual population growth of the drylands of the world from 1960 – 1994 was about 2.3% (Clarke and Noin 1998) while that of Africa especially SSA between 1960 – 1990 was about 3% (Dejene *et al.* 1997, Grainger 1990). This rapid growth of populations in dryland regions (which is one of the highest in the world) has contributed to rapid land degradation (Clarke and Noin 1998, Foster 1987) as the fate of most of the rural people in these regions is ultimately dependent on the use of natural resources (Wandera 1998, Reynolds 2001).

Since the first national population census was carried out in 1948, Kenya's population has continued to grow at a very first pace, rising from 5.4 million in 1948 to 29.6 million in 1999 (Thomas 1997, UN 2001).



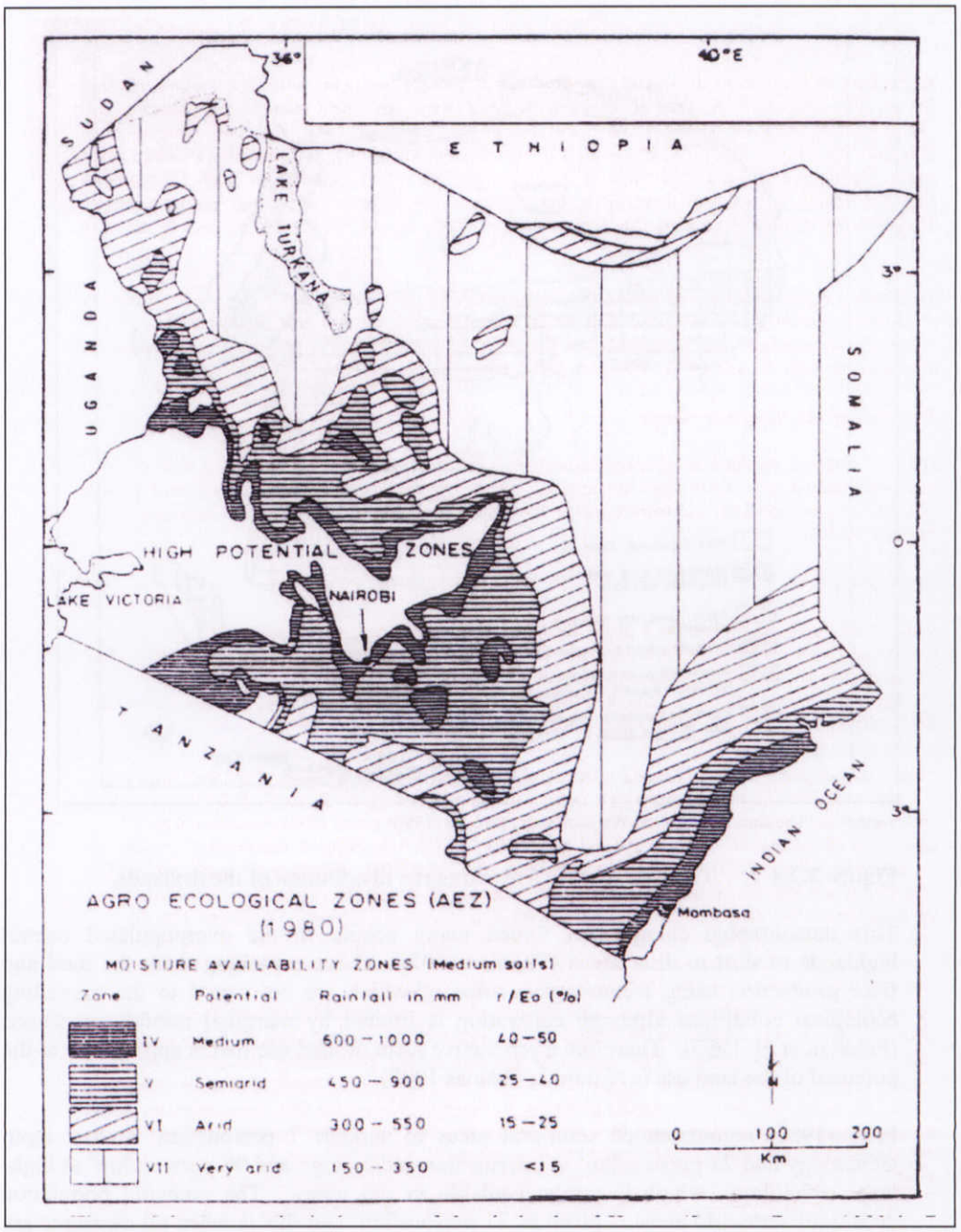
Source The time Atlas of the World 1994 in Barrow (1996).

Figure 2.2.1 The map of Africa showing the distribution of the drylands.

This demographic change has forced many people in the overpopulated central highlands to shift to drier areas (Thomas 1997) and are exploiting them for food and fibre production using technologies, some of which are not suited to the prevailing ecological conditions although cultivation is limited by marginal rainfall conditions (Frenken *et al.* 1993). Therefore a productive form of land use that is appropriate to the potential of the land use is required (Thomas 1997).

FAO (1982) recommended semi-arid areas to support 7 persons/km^2 at low input technology and 21 persons/km^2 at intermediate technology and 98 persons/km^2 at high-level technology, which is rarely available in dry areas. The potential population density of semi-arid areas is given as 21 persons/km^2 and this is when all measures are instituted to prevent the occurrence of natural catastrophes or setbacks against utilization of available resources. The main problems in the area are lack of water, capital and labour to make land productive (Ferguson *et al.* 1985).

In many localized areas of SSA, there is synergy linking declining food production, high population growth and natural resource degradation. This nexus dynamic creates a negative synergy that depletes soil productivity and results in a vicious cycle of poverty and food insecurity (Cleaver and Schreiber 1994).



Source Braun and Mungai (1981).

Figure 2.2.2 Agro-ecological zones of the drylands of Kenya.

(iii) Climate

Dryland's precipitation is generally low and variable throughout the year with maximum annual rainfall averages of 250 mm, 500 mm and 1100 mm for arid, semi-arid and sub-humid respectively which usually falls as torrential rains occurring locally and causing high flush floods (Adams *et al* 1978, NAS 1974, Beaumont 1989). Temperature varies with latitude, longitude, distance from sea and time of the day and the wind velocity (Beaumont 1989). It is also important to note that drought is unquestionably the most important environmental factor influencing the growth of plants in the arid regions of the world (NAS 1974) and hence the soils.

Basic to land husbandry assessment is the concept of agro-ecological/climatic zonation. The zonation is based on the climatic potential of the land and when this information is combined with soil, land form and land use characteristics, the potentialities for, and constraints to crop, wood and livestock production can be clearly seen (FAO 1993c, Thomas 1997, Hornetz *et al.* 1992).

Climatic classification of the Kenya drylands

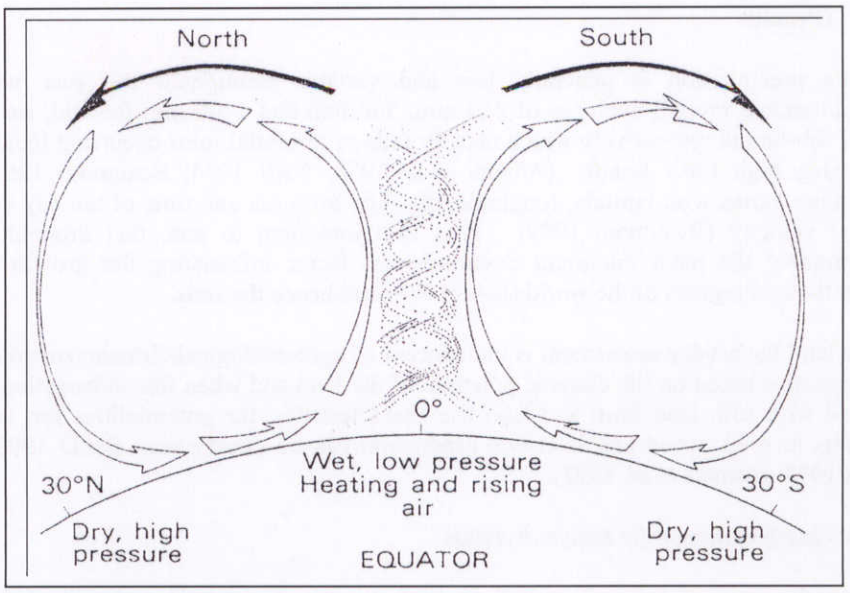
Based on the ratio of average rainfall to average annual potential evaporation and vegetation types, drylands of Kenya have been delineated into four agro-ecological zones (Braun and Mungai 1981) (Fig. 2.2.2). Jaetzhold and Schmidt (1983) further enriched the zones with more details while using a ten days' basis historical profile.

Rainfall and temperature

The climate of the East African region in which Kenya is located is described as one of the earth's most puzzling, anomaly and problematic (Trewartha 1980, Trewartha 1961: in Shisanya 1996). The complications is related to the following diverse natural factors influencing the region (Shisanya 1996, Foster 1987, Southgate and Hulme 1996a, Itabari 1999 and Freken *et al.* 1993, Oindo 2001, Gibson and Pain 1985, UNEP and GoK 2000)

- Inter Tropical Convergence Zone (ITCZ) – Kenya strides along the equator and the impact of ITCZ is great. This unstable seasonal migratory zone too falls between 5° N to 5° S of the equator. With intense heating of the earth's surface at the equator, two dry airs meet at the equator that is, the northerly "Kakuzi" (in December – February) and southerly "Kuzi" (in May – September) trade/dry monsoon wind systems (Fig. 2.2.3).

  These winds and the resulting northward and southward movements of the ITCZ are the major factors controlling climate in the region. The winds are in turn strongly influenced by atmosphere - ocean - teleconnection or El-Nino Southern Oscillation phenomenon (=ENSO) events (Frenken *et al* 1993). Consequently, either El Niño or La Niña can cause floods or droughts. The El Niño events often change to La Niña. For example the 1997 to 1998 El Niño heavy rains were followed by the 1999 to 2000 La Niña droughts.



Source: Gibbson and Pain (1985)

Figure 2.2.3 The general circulation of air in the tropics.

- Topography and aspect – In addition to the towering Mount Kilimanjaro and Mount Kenya, which raises to over 5000 m a.s.l. the region is dissected by the Great Rift Valley with its high mountain ranges and escarpments on either sides. The region in the east of the Rift valley lies about 2000 m above sea level and is dominated by Mount Kenya (5230 m a.s.l) and the Aberdare Range, reaching almost 4000 m. In the west though the country slopes towards L. Victoria, there are mountainous areas that form the western escarpment of the Rift Valley (the Mau Ranges) and Mount Elgon that rises to 4320 m on the border with Uganda. The highlands forming most of the southwest and central parts of the country have an elevation of 1400-2800 m a.s.l. This relief influences the intensity of ITCZ, making it more diffuse and associated with high rainfall. It also exerts great modifications to temperature.
- Latitude – the striding of the region along the equator influences the timing of rainfall minima and maxima.
- Inland waters like Lake Victoria, which provide local source of moisture
- The Indian Ocean water mass that influences the above trade winds.

The above complex factors of the region modify the pattern of the monsoon winds so that there is never a year or season when the whole region receives normal rainfall and does not have any drought (UNEP and GoK 2000).

Throughout the region there are two major rainfall seasons and a minor one that is restricted to Western Kenya and Mount Elgon region of Uganda (Shisanya 1996). The later occurs from October – December and is mainly related to the influence of Lake Victoria water mass. The two major seasons are described as the "long rains" of March – June and the "short rains" of October – December. These seasonal variations are most pronounced in the dry lowlands and north as well as east, but weakest in the humid highlands of the central and Rift Valley areas. There are three major regions of heavy rainfall. A relatively wet Western

Kenya east of Lake Victoria. A second area of high rainfall covers wet belt extending along the Indian Ocean. A third type of region receiving heavy rainfall coincides with the main mountain ranges. Valley barriers extend to stand out as dry areas (Oindo 2001). Moreover, these two seasons have a significant impact on Kenya's drylands climate especially on the performance of the second (=short) rainy season in the study area (Wijngaarden and Engelen 1985). Frenken *et al.* (1993) and Shisanya (1996) noted rainfall to be higher and more reliable in the region when the atmospheric difference in the Southern Pacific Ocean between the island of Tahiti and Darwin, Australia is below 1.054 hectopascal. The condition per short rain season could thus be one of the following:

- ENSO (short rains with longer durations, high amount of rainfall and more reliable than normal) and occurs when the difference in air pressure between Tahiti and Darwin is below 1.054 hectopascal
- Anti-ENSO (short rains with short durations, low amount and highly variable than normal) and occurs when the air pressure difference is above 2.33 hectopascal or
- Normal rainfall conditions.

Temperatures in the region vary with altitude and season (GoK 2001a, GoK 2001b). There is a wide range between the maximum and minimum temperature, from below freezing point on the snow-capped Mount Kenya to over 40°C in the north and northeast parts of the country. Generally, the low-lying northern plains are the hottest areas with maximum temperature commonly exceeding 35°C (Oindo 2001).

Mean annual climatic data is an important tool for planning cropping pattern (best adapted to the predicted rainfall condition) and sustainable food production systems in the drylands, that is, depending on how long a crop variety takes to mature, mean monthly rainfall or its equivalent in form of irrigation water can be used to plan when to sow and harvest (Frenken *et al.* 1993, Budhar *et al.* 1991).

In Kenyan there are seven main agro-ecological/climatic zones based on moisture availability (that is, the ratio of annual rainfall to potential evaporation) and temperature (Table 2.2.1).

Table 2.2.1 Agro-ecological/climatic zones of Kenya

Zone	Kenya's land area (%)	Current/potential land use
I – III Humid/highland	8.4	Cultivation, semi or zero grazing, forest/game reserve
IV Sub-humid/ upper midland (Coffee – sunflower – maize zone)	9.3	Cultivation, grazing, forest/game reserves
V Semi-arid/ lower midland (Cotton - Livestock – millet zone)	15	Subsistence farming, sedentary grazing
VI Arid/lowland (Cattle zone)	21.7	Semi-nomadic and nomadic pastoralism, subsistence farming
VII Very arid/ lowland (Camel zone)	45.6	Nomadic pastoralism, isolated subsistence farming
Total	**100**	

Source Sombroek *et al.* 1982 in Thomas (1997), Braun and Mungai (1981), Hornetz *et al.* (1992) and Mohamed (1999a).

(iv) Geology

The geology of global drylands is very variable not only within continents but even at country and regional level (Adams *et al.* 1978). However, the dominant geology of Kenya's drylands are Sedimentary, Quaternary (for example lacustrine, alluvial deposits), basement complex (Mozambique Belt) and Volcanic rocks (Ojany and Ogendo 1973).

(v) Geomorphology and hydrology

Types of landforms in arid zones vary but a generalized model was mentioned by Beaumont (1989) composed of uplands, alluvial fan, plains and lowlands with salt desert in depressions or in semi-arid areas the desert could be replaced by flood plains (Ojany and Ogendo 1973).

The Kenyan dryland landscape is dichotomously dissected by ephemerals that combine in valley bottoms to form rivers that drain to deserts, flood plains, oceans or lakes (Ojany and Ogendo 1973, Mohamed 1999a).

Although plains dominate the drylands, like any other type of other geographical features of the world, the drylands are composed of mountains, hills and valleys (Adams *et al.* 1978, Beaumont 1989, Ojany and Ogendo 1973). The type of ecosystems found in these areas is determined by the amount of water present (Bright Edges of the World 2001). Hence the most valuable areas for agricultural land use are river valley bottoms, oasis, springs and ameliorated mountains or hills (Scoones 1992b, Scoones 1991, Mohamed 1999a, Clarke and Noin 1998, Barrow 1996).

Valley bottom wetlands of the drylands of Africa are prime resource from agricultural and pastoral systems context (Scoones 1992a, Scoones, Barrow 1996, Oba 1991, Mohamed 1999a, Mukamuri and Mavedzenge 2000, Scoones and Cousins 1994, Southgate and Hulme 1996a). They act as lifeline or bloodline for farmers and pastoralists and in critical periods like drought periods and especially at this period of economic hardship and acute shortage of land (Mohamed 1999a). The wetlands are important resources for cultivators, wildlife and pastoralists, providing a source of arable land or grazing during drought or in the dry season. As well as sustaining rural livelihoods and increasing food security, wetland patches allow the opportunity for diversification of crop production and the provision of a wide range of direct and indirect benefits. Wetlands are central to resource management strategies that make use of catena variations and seasonal and inter-annual changes in resource availability. They are often central to local contests for control and access (Scoones and Cousins 1994). With increasing pressure in African drylands, wetlands are even becoming more valuable components of agro-ecosystems (Mukamuri and Mavedzenge 2000).

Water sources for human and animal consumption, irrigation and industrial use in the drylands has been classified by NAS (1974) as rainwater harvesting, runoff agriculture, irrigation with saline water, reuse of water, wells, groundwater mining, desalting, solar distillation, oasis, springs, rivers, cloud seeding, icebergs, and dew and fog harvesting.

Water resource limitation both in quantity and quality, is intrinsically related to drylands and the water–use strategies and technologies differ according to the prevailing local skills and socio-economic conditions and to the required investment (Spiegler 1962). In Israel, for example, efficient water distribution methods make it possible to irrigate arid soils (UN 2000).

(vi) Soils

More than three quarter of the world's dryland soils are made up of just two sandy Entisols (sandy) and Aridisols with Alfisols, Mollisols and Vertisols being the other more common soil types (Grainger 1990, Archibold 1995).

Dryland soils are susceptible to both water and wind erosions accelerated by anthropogenic factors (Grainger 1990, Muller-Samman and Kotschi 1994, Spaan? b), Mohamed 1999). The texture of the topsoil is mostly silt and fine sand (Sanchez 1976). Soils of uplands are shallow and coarser and those of flood plains that have fine texture, deep profiles, well drained and highly saline if vegetation is removed (Beaumont 1989, Mohamed 1999a, USDI 1984).

Generally, the soils of the drylands have low organic matter content and are brighter coloured (Prichett 1979, Brady 1974, FAO 1988, Mohamed 1999a) and most of them are developed on parent rocks developed during the cretaceous and tertiary periods (Archibold 1995).

Dryland soils contain salts and salts affects plant growth in many ways (USDI 1984). Certain salts, sodium being the best known, when present in high concentrations can affect the physical condition of the soil. Soils with excess sodium tend to puddle, have poor structure, and develop poor infiltration and hydraulic conductivity rates (USDI 1984).

A part from salinity, the potential of wind erosion especially and generally for water erosion increases in warmer areas is high (Spaan ?b). This same degradative processes are accelerated as the moisture regime becomes more arid because, initially, there is a lower inherent organic matter level and less natural vegetation to prevent erosion Not only do soil degradative processes accelerate under hot and arid climatic regimes, the benefit that can be derived from soil conservation practices in these regimes are fewer than those in the cooler and wetter areas. For example, the most important soil conservation practices to alleviate organic matter loss and control soil erosion usually involve crop residues, but the availability of residues decreases sharply within hot and arid areas (Spaan? a).

The soils of the drylands are generally fragile and susceptible to degradation when in-appropriate practices are applied (Spaan? c). Generally organic carbon and nitrogen decrease over the years in farms found in regions with high temperatures; making these soils extremely vulnerable to wind and water erosion and reducing their water holding capacities. This demonstrates that there is increasing difficulty of achieving sustainable systems as annual temperatures increase at somewhat constant precipitation levels. This effect is compounded when precipitation decreases at the same temperature.

Every year it is estimated that runoff and rainfall is responsible for 19 x 10^9 Mg (15 x 10^9 suspended and 4 x 10^9 of bed loads) of material transport to oceans by the world's rivers mainly from ecologically fragile environments (Claw 1998). The relative soil erosion in different continents is highest in Asia and Africa (Table 2.2.2).

Table 2.2.2 Estimated levels of annual soil erosion in the world.

Continent	**Sediment transport to the ocean (x 10^6Mg $year^{-1}$)**	**Suspended sediment yield rate ($Mgha^{-1}year^{-1}$)**	**Estimated erosion (assuming delivery ratio of 10% ($Mgha^{-1}year^{-1}$)**
Africa	530	0.4	4.0
Asia	6,433	2.3	23.0
Europe	230	0.5	5.0
North and Central America	1,462	0.8	8.0
Oceania/pacific Islands	3,062	5.9	59.0
South America	1,788	1.0	10.0
World	**13,505**	**1.0**	**10.0**

Source Claw (1998).

Various resource conservation and management has been tried to minimize land degradation – in the fields of soil and water, vegetation and animals (Claw 1998 and Levin 2001). In general, the more the soil is disturbed and the less the ground cover the greater is the soil hazard. Therefore, erosion from agricultural land is generally more with mechanized than with manual methods of deforestation, more with plough-till than no-till methods of seed preparation, and more with clean-cultivated than mulched soil surface conditions. Low canopy ground cover and mulching using crop residues (especially those of small grain cereals) are effective tools against the erosive forces of rainfall and run-off. Other methods for minimizing the risks of soil erosion are conservation tillage (e.g., no tillage), crop management (e.g., timely sowing, appropriate seed rate, contour planting, judicious and discrete application of fertilizer and soil amendments, integrated pest management, weed control and adoption of crop rotation and improved practices like agroforestry) (Lal 2000).

Soil erosion is a symptom of land misuse and soil mismanagement. Declining soil fertility is a major constraint to crop production in semi-arid areas in the highlands of Eastern Africa (Corbeels *et al.* 2000). Therefore, soil conservation demands appropriate land use and judicious soil and crop management (Claw 1998).

Agricultural expansion programmes have encompassed marginal lands (including drylands) in many parts of the world (Doughty *et al.* 1995). Various land management practices/technologies are being undertaken in different parts of the drylands to use the scarce natural resource, water. As a result, many of the earth's most important food grains are grown in the drylands, including wheat, barley, rice, and millet (Bright Edges of the World 2001) mainly through dryland farming and irrigation.

Kenya's dryland soils are described as problematic due to physical and chemical limitations to agriculture and mainly composed of Acrisols, Cambisols, Chernozems, Ferralsols, Gleysols, Phaeozems, Lithosols, Fluvisols, Luvisols, Nitosols, Arenosols, Regosols, Solonetz, Andisols, Vertisols, Planosols, Xerosols and Solanchak (Muchena and van der Pouw 1981). But Solonetz, Solonchaks and Arenosols are the most common (Gichuru and Wanjogu 1990).

Although a very large amount of money has been poured into research on soil and water management over the last 50 years, soil degradation is becoming increasingly pressing problem in Kenya (Thomas 1997, Kinyanjui *et al.* 2000). If policies are to have a positive impact on the ground, key stakeholders, such as farmers, extension workers, researchers and private sector must be allowed to play an active role in their formulation, which will ultimately determine their success. A policy can only fully supported if stakeholders consider it to be legitimate and relevant to their needs and concerns.

Various site-specific studies and characterization of soils have been conducted through out the world, Africa and in Kenya (Prichett 1979, Brady 1974, FAO 1988, Muller-Samman and Kotschi 1994, Mohamed 1999a). Soil types not only vary with the parent material, topography and climate but also with living organisms existing in the ecosystem and time (Brady 1974, Pomeroy and Service 1992).

Soils supports life and therefore its important to know which soil type is used for what by local communities and scientifically analyze the properties in order to contribute to sustainable land management (Mohamed 1999a, Bonifacio *et al.* 2000). These means that indicators of soil quality requires proper quantification and weighed according to site-specific conditions. This is because; soil quality bridges the strategy of alternative agriculture and the goals of sustainable agriculture. As a result, the concept of soil quality and their relationships provides farmers, researchers, environmentalists, administrators and society as a whole with better understanding of the challenges a head (Parr and Papendick 1997).

Similarly, nutrient cycle within farms are important for sustainability and an experiment in Mangwende, Zimbabwe showed that maize stover, a bio-degradable nitrogen – poor material could effectively absorb ammonia, thereby reducing nitrogen losses from cattle manure and urine (Nzuma and Murwira 2000). They also found out that there is a lot of ammonia lost from aerobically heaped than in anaerobic pits and there was significant yield difference with maize yields (more when manure from pit is applied than from heaps).

While organic farming is a good practice, Stangel *et al.* (1991) recommended combination of local rock phosphate and biological nitrogen fixation, the restoration of degraded soils and the nutrition of small-scale irrigation as the research priority areas for dry areas of the developing countries.

For good land husbandry in the drylands, appropriate policies are required. There are currently two basic policies alternatives for nutrient-cycle management within African agropastoral systems (Scoones *et al.* 1995).

The first involves the more effective management of resources internal to the agro-ecosystem (e.g. mulching, composting and intercropping with leguminous plants), while the second is based on the use of external inputs (e.g. chemical fertilizers). Future research needs to identify the costs and returns of each strategy, and the conditions that are likely to include sufficient pressure on resources to prompt intensification, market conditions, which bring reasonable returns to investment on-farm and assured access to land and other resources.

(vii) Vegetation

Except along rivers and ephemerals and in valley bottoms, as aridity increases, woodlands become discontinuous and eventually reduced to small or clumps of trees, then grassland takes over as the dominant vegetation type and eventually gives way to scrub that is preceded by no vegetation under extreme aridity (Beaumont 1989). The dominant vegetation types along streams, rivers and in depressions are hydrophytes, halophytes, mesophytes and xerophytes (Beaumont 1989, Fanning and Fanning 1989, Mohamed 1999a).

Muller-samman and Kotschi (1994) divided drylands flora into dry savanna, semi-desert and desert while Grainger (1990) categorized the vegetation as desert, thorn woodlands and savannas. Many dryland species endure long periods of harsh conditions unmatched in humid temperate and tropical zones (Bright Edge of the World 2001). Grainger (1990) and Adams *et al.* (1978) while describing the adaption strategies of plants in the drylands noted the most common ones as specialized escapers (ephemerals), drought evaders (uses water economically), drought tolerant (succulents) and drought endurers (become dormant during dry seasons).

The characteristic feature of vegetation in the drylands is low productivity. The restoration of the plant cover of dry areas must be based on both sustainability and high productivity of for human needs. This work must include the restoration of the natural vegetation cover as well as the building and rebuilding of man-made plant cover, in a form better adapted to the hydrological resources, both surface-and ground water. Extensive grazing of low-productive rangelands should be abandoned, in favour of more stationery feeding systems. The change requires simultaneous rural and urban development in the long term (Steen 1998).

Drought is a frequent phenomena in the drylands and at times it causes the collapse of food production systems where people fall back to the use of wild plants and other survival mechanisms (Neefjes *et al.* 1998), therefore on top of in-situ conservation, ex-situ genetic conservation also becomes necessary.

As a result of the expansion of agriculture and urbanization, the areas under forest and woodlands has reduced from pre-agricultural times to the present era as shown in Table 2.2.3 (Claw 1998).

This conversion from forest/woodlands to agricultural use is due to gradual increase in population before modern times and a very rapid increase in population from about 1600 onwards. Deforestation and conversion of land to agricultural use is very high in the tropics and subtropics where the rate of increase in population is also the highest and the problems of soil erosion is most severe (Claw 1998)

Table 2.2.3 Estimates of change in land cover of the world for different vegetation types.

Land cover	Pre-agricultural areas (x 10^9 ha)	Present area (x 10^9 ha)	Change (%)
Total forest	4.68	3.93	-16
Tropical forest	1.28	1.23	-3.9
Other forests	3.40	2.70	-20.6
Woodlands	0.97	0.79	-18.6
Shrublands	1.62	1.48	-8.6
Grasslands	3.40	2.74	-19.4
Tundra	0.74	0.74	0
Desert	1.59	1.56	-1.9
Agricultural land	0.00	1.35	?
Total	**17.68**	**16.52**	

Source Claw (1998).

Planting of more vegetation in the drylands (woodlands, grasslands, and deserts) helps in achieving global carbon storage of up to 15% (equivalent of 0.5 billion tons of carbon per year, that is 0.5 Gt C/yr) of the average annual atmospheric carbon build up in the next century (Keller and Goldstein 1998).

The restoration and rehabilitation of the drylands (that cover 5.2 x 10^9 ha) to their ecological potential will have a significant impact to sink huge amount of carbon (Squires *et al.* 1996, Squires 1998). Therefore scientists should devise ways to raise biomass levels to trap and store C in the long term.

A part from the drier environment the other important ecosystems that causes diversity of landscapes in the drylands are the riparian ecosystems and other wetlands with luxuriant vegetation and animal life that contribute to biodiversity, acts as dry season reserves and forms the bloodline of the drylands and sustains life (Bright Edges of the World 2001, Oba 1991, Shaabani *et al.* 1992, Barrow 1996, Mohamed 1999a).

In Kenya, dryland's vegetation have been described as dry woodlands and bushland, grassland, bushed grassland, wooded grassland and dwarf shrub grassland or scrubland.(Pratt *et al.* 1966, Sombroek *et al.* 1982). Scarcity of fodder and fuelwood are partly responsible for the degradation natural vegetation, which in turn has resulted in ecological problems (Saxena *et al.* 1990). Generally, we have poor knowledge on appropriate species selection, cultural practices and utilization strategies yet they affect the success of any afforestation/reforestation projects (Saxena *et al.* 1990).

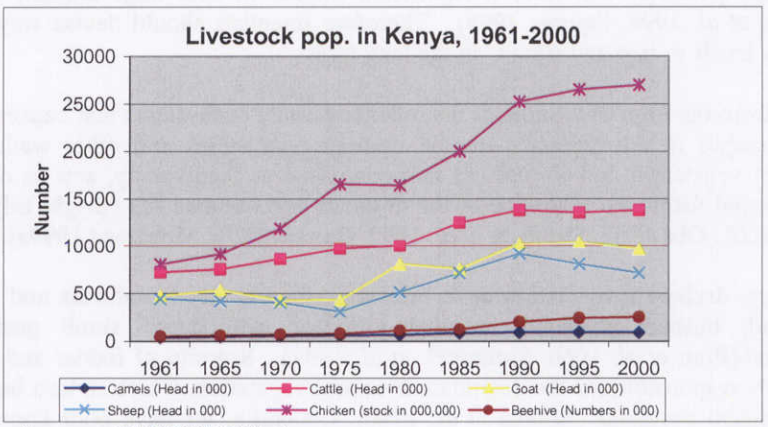
Today natural vegetation has been eliminated or severely reduced, soils are eroding at accelerated rates, and the capacity of land to support human populations, livestock, and wild herbivores has been substantially reduced (Reynolds 2001) One-third of Africa including 70% of the susceptible drylands are undergoing various forms of vegetation and land degradation and increasing livestock population and clearance for agriculture are the most widespread cause of these degradations (Ayoub 1998, Darkoh 1993, Reynolds 2001).

(viii) Animals and range conditions

The drylands house diverse wild insects and other larger animals including many amphibians, reptiles, birds and mammals (Archibold 1995; Pratt *et al.* 1966). The major types of animals are:

- Insects – grasshoppers, crickets, butterflies, beetles, spiders and ants
- Amphibians – frogs and toads
- Reptiles – snakes and lizards
- Birds – ostrich, weaver birds, kites, marabou stork, crows, hornbills and varieties of omnivorous birds
- Mammals – rodents, ungulates (gazelles, buffaloes, kudus, dik dik, water-buck, eland, oryx, hartebeest, wildebeest), zebra, rabbits and hares, squirrels, elephant, rhinoceros, giraffes, lions, cheetah, wild dogs and leopards amongst the many.

A part from the wild animals, drylands are home to many domestic livestock including camels, sheep, cattle and goats (Adams *et al.* 1978). Herd sizes in the dryland of Africa have increased in the present century to such an extent that recent surveys have shown deterioration in pastures and browse and in some cases small stock have had to replace cattle (Foster 1987). Livestock population in Kenya in the last 40 years has been increasing (Fig. 2.2.4).

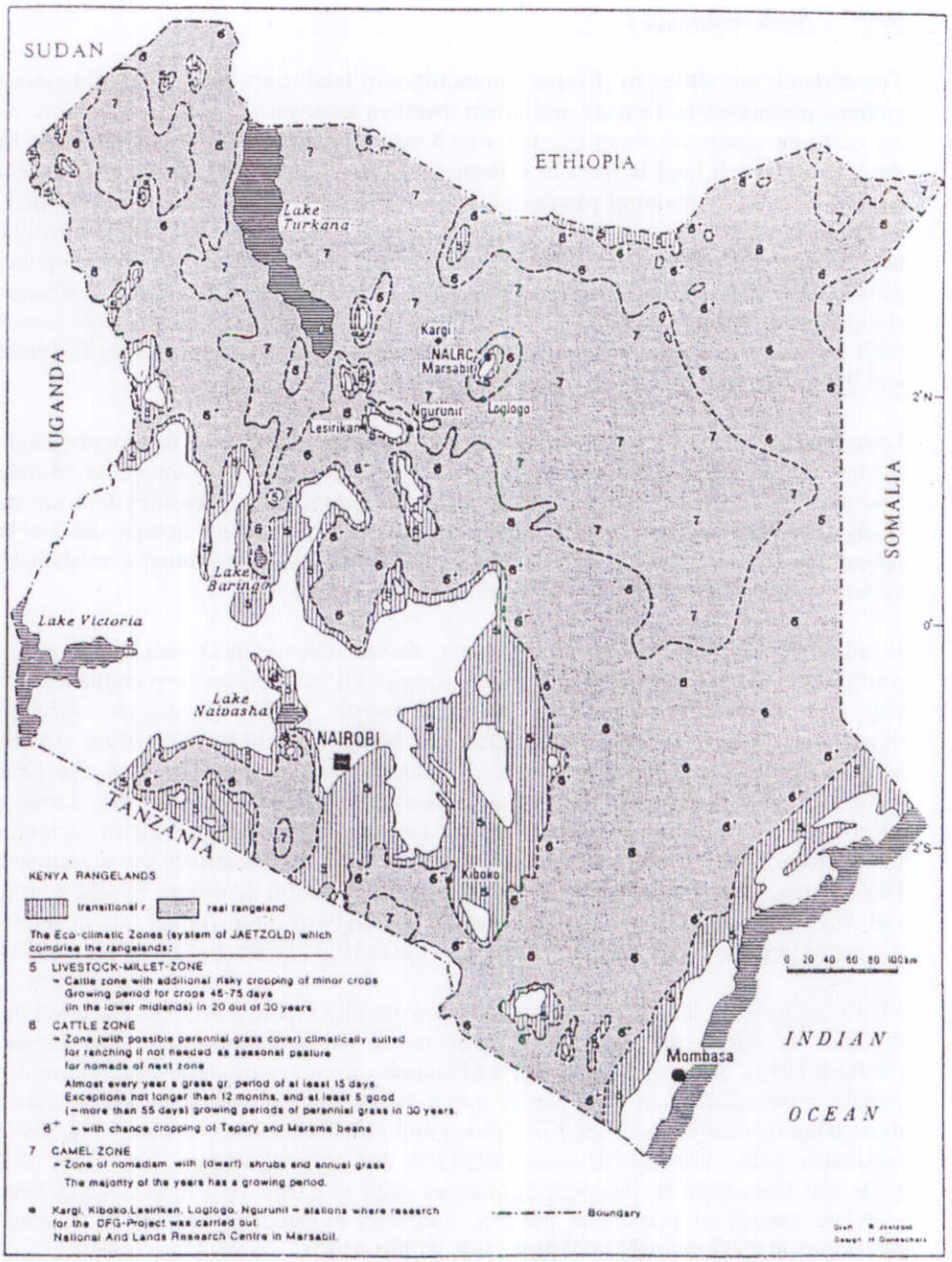


Source FAOSTAT (2001a).

Figure 2.2.4 Livestock population in Kenya between 1961-2000.

Pastoralism, ranching and national/game parks are the major types of land use that incorporate animal components (Archibold 1995; Pratt *et al.* 1966, Southgate and Hulme 1996b). 50% of the livestock population are found mainly in eco-climatic zones V to VII where the growing of crops are hampered by the rainfall (Fig. 2.2.5).

Although grazing is beneficial to natural vegetation on which livestock depends, currently it is being destroyed (mainly through overgrazing, cultivation) or severely reduced causing soil erosion at an accelerated rate, and the capacity of land to support human populations, livestock, and wild herbivores has been substantially reduced (Reynolds 2001).



Source Hornetz *et al.* (1992).

Figure 2.2.5 Kenya rangelands indicating livestock zones.

(ix) Socio-economics

The drylands are settled by diverse communities of land users consisting of hunters and gathers, pastoralistsis, farmers and urban dwellers amongst the many. Therefore there are multiple causes of desertification which operate at many levels, for example from the way in which land is used in a farmer's field, through the impact of land tenure regulations and agricultural pricing policy at national level, to global factors, such as world trade conditions and global warming (Evers 1994). Desertification is also linked to the larger social processes (such as the monitizations of local economy, population growth, urbanization, and sedentarization) that create push and pull factors influencing resource use. Actually, the increased pollution that damages ecosystems is associated with increased urbanization and the concentration of urban populations (Falkenmark and Rockstrom 1993).

Land husbandry cannot be promoted without an understanding of the socio-economic factors that hasten or retard the adoption of technologies/practices the conserve natural resources (Thomas 1997). This is because the conservation measures that are most likely to be adopted are those: leading to increased production and income, demand less labour input, and one that ensures security of tenure whether through a modern legal system or traditional system (Thomas 1997, Tiffen *et al.* 1994).

In addition, even in high-populated areas, market development that makes farming profitable is the determinant factor for environmental recovery and government policies that aid information flows and raise farm-gate prices encourages agricultural development and intensification (Tiffen and Mortimore 1994). Population growth in some areas may provide incentive and means to render intensive land use change towards the development of new sustainable systems (Scoones *et al.* 1995, Tiffen and Mortimore 1994). However, as a result of low population, the process of agricultural intensification may initially be weak, associated with low incentives for investment in land improvement due to lack of demand and poor transport facilities. Similarly, it may fall when population density is high due to the falling of the marginal rate of return to increased inputs of labour and capital in relation to land (Tiffen and Mortimore 1994).

Man's exploitative land use, which serves as a premium mobile for desertification in the drylands of Africa, is a short-term response to socio-econmic and other pressures (Darkoh 1996). The fight against desertification can only succeed if the welfare of the people in the affected dry area can be put at the centre of the development agenda and those adaptive strategies of their livelihood and production systems that confer drought resistance and/or lessen their susceptibility to drought and famine. In an era of free trade and liberalization, developed countries need to ensure that their policies help to alleviate instead of perpetuate poverty, and lead to the achievement of sustainable development and environmental protection within Africa.

Similarly, the failure of many programmes has been the result of a lack of direct and indirect participation of local people who are supposed to be beneficiaries (Mortimore *et al.*1995). The most successful development projects, it is noted, are those that incorporate local people in decision making at every stage of the development process. It should be noted that the brunt hardships of the marginal drylands is increasingly borne by women, children and the elderly. In rural areas an increasing number of women are drawn into the agricultural labour force as men migrate to urban areas and therefore women's role is crucial to the success of pastoral enterprises. Further, women

are neither removed from nor immune to the wider changes, which are taking place and therefore the myth expounded by a great amount of literature that pastoral women are powerless, is a misnomer (Horowitz *et al.* 1995).

A significant drawback in combating desertification and drought is the failure of in African Governments to devolve power to the people who are affected, and to link environmental degradation to economic policy (Darkoh 1998). Consequently many programmes lack local support or are undermined by conflicting trade and agricultural policies pursued by governments. It is contented that for sustainable development to work, policies should put the welfare of the people in the drylands at the centre of the development agenda and give them the rights and the power to determine their future. They should empower the people to sustain adaptive strategies towards sustainable livelihoods. Also the threat posed to environment and sustainable development by the protectionism and over consumption in the north and structural adjustment programmes (SAPs), call for the removal of distortions created by the import barrier of developed countries, the curbing of over consumption and a fundamental revision in the structure of SAPs to help alleviate poverty and protect the environment in these African countries is required. It is in the interest of the global community that the environment in Africa is protected.

Small-scale non-agricultural industries in the drylands especially on-farm or in small-scale industry centres run by trained women (and youth) could contribute to the optimal use of natural resources for sustainable development ensuring high income for inhabitants (Guirgis *et al.* 1995). The industries could be livestock based craftsmanship that attracts tourism, water conservation for drought management and the development of quality fibres require crafts reflecting local traditions and artistic designs from the surrounding environment.

What is now emerging as the future sustainable development in Africa is a more coherent vision for the future, one that builds on lessons from the past (based both on pastoral and farming livelihood and the significance of environmental variability), that is firmly rooted in pastoral/farming people's existing strategies and is supported by a growing body of ecological, social and economic research (Scoones and Graham 1994). Governments have the responsibility to create an enabling environment (through improved marketing arrangements, better roads, increased prices of farm products, reduced taxes, creation of security of land tenure and research back-up to support extension) that will facilitate conservation efforts of the fragile drylands (Thomas 1997). In the Kenyan situation, the Government has to pay special attention to agro-ecological zones III, IV and V.

Without government policies that consider both the interests of the farmer and the community as a whole, land degradation problem will intensify greatly as population pressure increases (Spaan ?a)

(x) Land-use

Farming systems of the drylands have been adapted to the harsh natural characteristics. Pastoralists lead a nomadic or semi-nomadic existence while arable farmers have selected quick maturing crops but have been slow to adopt productive enhancing technologies (Foster 1987). Drylands of the world are subdivided into three dominant types of human land-use categories (Table 2.2.4).

Table 2.2.4 Estimated area of dominant land use in the drylands of the world.

Land use	Area (Million ha)	Percentage of the drylands	Percentage suffering from desertification
Irrigated agricultural cropland	146	3	30
Rain fed agricultural cropland	458	9	47
Rangeland	4556	88	73

Source UNEP (1992).

In terms of general land-use classification, arid and semi-aridlands consist of rangelands and rain-fed farmlands, whereas dry sub-humid lands consists of woodlands, farmlands, and pasturelands (Reynolds 2001)

Land use cover/types in Kenya can be broadly divided into seven types (Table 2.2.5).

Table 2.2.5 Coverage of the different types of land use in Kenya.

Type of land use	Hectares
National parks game reserves	419,800
Forests	197,400
Agriculture – cash crops	504,800
Agriculture – irrigated lands	40,000
Subsistence farming, pasture and settlements cover the rest of the land.	

Source FAO (1993c).

The major limitation to dryland farming and pastoralism are unstable crop production due to uncertain rainfall, heterogeneity in soils, declining natural endowment and policies related to drainage improvement, markets, credit, training and infrastructure (Singh 1993).

(xi) Water for agriculture

There is a lot to learn from ancient farmers concerning water management (National academy of Sciences (NAS 1974). They fitted their agricultural ecosystems into nature and used landscape and topography to their best advantage with minimal damages to the environment in form of erosion and siltation. By using runoff they tamed the flood torrents and prevented the damage that uncontrolled floods usually produce. They certainly did not over irrigate, because water resources were limited. In all water conservation cases, man learned from his natural environment and applied what he had observed by imitating nature and sometimes improving on it.

Water practices developed for the temperate climates do not always work as well in arid regions for technical, environmental, economic, and cultural reasons (NAS 1974). There are two approaches to solve water crisis: increasing the supply of usable water and reducing the demand for water.

Supply and demand, as well as delivery, has to be considered as an integral system. Water can be saved in conventional irrigated agriculture, which is the largest user of water in the drylands through water management on-farm. After all, over irrigation causes problems of water logging and salinity, and leaching of fertility. Water supply can be increased through improving of the existing water systems and thus make more water available without a complete new installation e.g., replacing canals with closed conduits will reduce evaporation, or lining canals will reduce seepage losses.

Sources for increasing supply of water for agriculture (NAS 1974):

- rainwater harvesting – Though rainfall is unreliable in the drylands, it contributes to a considerable amounts of water. The water can be redirected from hills (with gentle slopes – 1 to 5%) to farms, ponds or cisterns. Storage must be an integral part of the rainwater-harvesting system. Runoff can be increased through construction of ditches, rock catchment, clearing of rocks and vegetation, and compacting the soil surface. Other methods include the use of chemicals (e.g., sodium salts, silicones, latexes, asphalt, wax, cement, paraffin wax) to fill pores or make soil water repellant, covering soil with water proof covers (though damaged by wind) e.g., plastic sheet (with gravels on top), butyl rubber and metal foil;

- methods of runoff agriculture, which can be in form of

    - runoff farming is conducted using channels directed to farms from hill sides/open grounds or harvested runoff is used for watering farms.
    - water spreading – an irrigation method used to deliberately divert flood waters from their natural courses and spread over adjacent farms/pastures in floodplains. Have worked well in Tchironzerine, Niger where runoff is blocked with stones and Negev, Israel where water is diverted to floodplains using terraces (reinforced by unpalatable bushes).
    - micro-catchment farming – the building of rainwater catchment basin around a plant, directing rainfall from a larger than normal area to irrigate the plant. A hole is dung on the lower slope to store the water for the plant, which either planted within, or on its embankment. Manure may be applied in the hole, which could also be mulched to reduce evaporation. The technology has been used to successfully grow olives in Tunisia and in Kenya to establish trees in the drylands. The size of the catchment varies depending on the crop and the climate. The method is more efficient than large-scale water harvesting schemes because they conveyance losses are minimised. In light rains, they provide runoff water when others will not. It is much cheaper to convert a certain area into microcatchment than to construct a runoff farm because microcatchments do no need channels, conduits, terraces, and terrace walls. Also microcatchments can be built on almost any slope, including almost-level plains, enabling the farmer to use large, flat areas unsuited for runoff farms It is used to grow wheat and fruits trees over a 70,000-ha area in Khost province, Afghanistan; and
    - desert strip (or contour catchment) farming – A modification of microcatchment farming and good for pasture improvement. Employs a series of terraces that shed water onto a neighbouring strip of productive soil. They are often tiered up a hill slope, but on level terrain mounding soil between the strips can make an artificial slope for the catchment.

It can also be left in natural state or cleared of rocks and vegetation, planted with range grasses, or made impervious by sealants. Easier to establish and maintain than microcatchments. In designing water system, the needs of the user in form of time and amount are paramount. For optimal use of the total water resource, ground water (where available) supply should be combined with that of surface water (NAS 1974).

However, water bodies in the drylands are associated with evaporation, seepage, siltation, transpiration, crop land percolation and decreased ground water levels

Irrigation in the arid and semi-arid lands

Irrigation is "a modern science of survival" that aims to develop and maintain a root zone having a balance of moisture, air and salts favourable for plant growth (USDI 1984).

Although irrigation brought a lot of development and has helped man to provide food for the ever increasing population, but where drainage has been overlooked or neglected, man's development and his civilization has failed (USDI 1984). Irrigation is the science of survival of man and drainage provides the survival for irrigation. A prime requirement for successful irrigation agriculture is the development and maintenance of a soil zone in which the moisture-oxygen-salt balance is favourable for plant growth since plants require both oxygen and moisture to live. Adequate drainage promotes the supply of oxygen, moisture, soil temperature, resistance to diseases, root growth, chemical (e.g. lack of saturation of toxic substances like sulphur in the soil), physical (e.g. promotion of soil structure and workability) and biological (for example aerobic bacteria that provides nitrogen to crops) conditions favourable to plant growth.

The false belief, "that the more water applied through irrigation the better the crop," leads to land degradation (USDA 1959).

Good agricultural drainage will (USDA 1959):

- permit earlier planting and better germination; and
- it increases the active root-zone depth and allows plants to develop their natural root pattern;
- increases the downward percolation of water.

Additionally, if irrigation agriculture is to remain successful, soil salinity must be controlled. However, the type, as well as concentration, of salt in the water is important. For example, the relative concentrations of sodium to calcium and magnesium affect a waters' suitability because high sodium ratios affect soil structure and plant nutrition. In general, irrigation water whose total dissolved solids are below 600 milligrams per litre (mg/l) can be used on almost any crop.

In crops salinity reduces photosynthetic rates, levels of chlorophyll, soluble protein and activities of nitrate reductase, glutamate dehydrogenase and several others, while enhancing levels of reducing sugars and free proline in pearl millet leaves (Garg and Gupta 1996). Salinity also depressed N, P and Ca uptake while Na and K contents is increased. Although pearl millet populations are relatively more salt tolerant than hybrids but due high absolute yields hybrids out yielded populations on saline soils.

The suitability of saline water for irrigation is influenced by the climate (low temperatures may increase salt tolerance and high rainfall dilutes the irrigation water), type of soil, the quality of the irrigation water, the irrigation technique, the type and age of the crop and the knowledge of the resource person undertaking the irrigation activity (NAS 1974). Salinity can be controlled through leaching, which has to be based on leaching requirement (LR).

The irrigation schemes encourage settlements and can have the following impact on the surrounding environment (Kater *et al.* 2000a, Mohamed 1999a, Claw 1998, USDI 1984, Southgate and Hulme 1996b, Barrow 1996):

✓ influences water courses and wetlands through clearing and erosion of natural resources;
✓ the people living in the scheme use large amounts of woodland products such as fodder, fuel and construction wood;
✓ from their farm profits farmers purchase large herds of cattle which are kept in the environment surrounding the scheme hence causing degradation of the remaining resources and cause conflict of use;
✓ increases the occurrence of tropical water-borne diseases such as Bilharzia (transmitted by snails) and Malaria (transmitted by mosquitoes);
✓ there may be water logging as a result of poor drainage and irrigation schemes may have a very high maintenance cost as a result;
✓ destruction of wildlife habitats;
✓ increase in soil and biodiversity erosion; and
✓ reduction of access to dry season fodder reserves for wildlife and pastoralists.

It is also a known fact that the integration of livestock and cropping systems reduces pressure surrounding irrigation schemes and improves soil fertility through the incorporation of animal manure into farms (Kater *et al.* 2000b).

2.3 SUSTAINABLE DEVELOPMENT OF NATURAL RESOURCES IN THE DRYLANDS

The need to avoid adverse impacts and to ensure long term benefits led to the concept of sustainability (Doughty *et al.* 1995). The concept become popular after the Bruntland Report "Our common future" of the World Commission on Environment and Development (WCED) of 1987 (Semgalawe 1998). The report defined Sustainable development is defined as a development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs (WCED 1987, Claw 1998, Semgalawe 1998, Lee 2001, Jorjani 1990). Despite various efforts towards sustainable natural resource management in the drylands the tragedy continues unabated (Darkoh 1998). In the developing world in general, and Africa in particular, the major threat to sustainable development is through degradation and over-exploitation of the finite natural resource components (WCED 1987, Øygard 1995, Versraete and Schwartz 1991). Yet the economies of developing countries will continue to depend on these natural resources for long time to come (WCED 1987, Øygard 1995). The WCED pointed to the close inter-linkages between poverty and natural resource degradation. Other casual factors that the report includes are institutional failures, policies and tenure regimes.

It also contains two key concepts, that is, "needs" and the idea of limitations imposed by the of technology and social organization on the environment's ability to meet present and future needs (Lee 2001). Since then sustainability become accepted as an essential feature of development in order to increased the well being and greater equity in fulfilling basic needs for this and future generations (Doughty *et al.* 1995).

With time, each discipline further fine-tuned the definition and accordingly, FAO (1991) and Huxley and Van Houten (1997) developed the following definition for natural resource management "*The management and conservation of natural resources base and the orientation of technological and institutional change in a manner that ensures the attainment and continued satisfaction of human needs for the present and future generations. It conserves land, water, plant and animal genetic resources, in environmentally non-degrading, technically appropriate, economically feasible and socially acceptable manner*". Today, sustainable development is becoming an almost universally accepted policy objective (Amsberg 1993).

Sustainable agricultural systems requires the support of strong policy from governments (Spaan ?a). However, it is important to note that policy makers will only support sustainable development of natural resources when there is concrete database and that sustainability is generally difficult to achieve in hot and dry climate than in cool and wet climate. Sustainable production in these marginal areas can be realized through appropriate land use planning (Spaan ?a) which can only be achieved by considering and integrating socio-economic and bio-physical factors (Basnyat 1995 and Semgalawe 1998).

Efforts towards sustainable development are now being undertaken at all levels and the concept has increasingly entered the consciousness of the average person. For many, it is not just an abstract concept but a matter of survival as input cost increases, natural resources diminish and soil loses fertility is washed away (Becker 1998).

One of the main challenges to sustainable land management in drylands is to identify reliable indicators on desertification status and trend in order to assess the extent of the problem, forecast the evolution and monitor the impact of the various responses. Within the physical parameters, soil and terrain degradation or loss and soil colour is the most reliable and measurable criterion of desertification. Vegetation coverage, density of species, soil fertility, erosion and salinization are among the most commonly used parameters, but their change may also be due to climatic cycles (UN 2000, Stocking and Abel 1981). The focus is currently more directly on socio-economic issues. Although socio-economic indicators such as migration, income levels and conflict may not be uniquely related to desertification, they may serve as early warning signals that desertification processes are beginning and may provide a useful monitoring framework for assessing impact of related actions (UN 2000).

In the developing world in general, and Africa in particular, the major threat to sustainable development is through degradation and over-exploitation of the finite natural resource components (WCED 1987, Øygard 1995, Versraete and Schwartz 1991). Yet the economies of developing countries will continue to depend on these natural resources for long time to come (WCED 1987, Øygard 1995). The WCED pointed to the close inter-linkages between poverty and natural resource degradation. Other casual factors that the report includes are institutional failures, policies and tenure regimes.

Sustainable natural resource management (NRM) can be enhanced by reducing policy discrimination against natural resources (NRs) to enhance prices (creation sound economic policy), improve capital market, taxes and subsidies to induce socially efficient use of NRs over time, give communities control over their resources although some important traditional norms on the management of NRs have broken down, industrial decentralization and generation of employment in non-farm sector, educating and training of rural population, increased availability of health services and improved nutrition, new institutional arrangements (Edward 1992).

The developments of technologies that are not only economically attractive to farmers but also hold natural resource and environmental costs within sustainable limits and increase per capita total productivity are required. Such technologies form the core of a sustainable agricultural system, *defined here as a system that indefinitely meets rising demands for food and fibre at economic, environmental, and other social costs consistent with the rising per capita welfare of people served by the system* (Crosson and Anderson 1993). Steps in developing sustainable technologies: (i) Issues to include in the demand scenario: demand for food, fibre, other non-staple commercial farm products, services (plant and animal habitat) and non-commodity services (ii) devise a research strategy for developing improved NRM practices and commodity-based technologies that together yield the requisite sustainable increases in total productivity including the identification and measure of the costs and benefits of alternative NRM and commodity technologies. While studying the adoption rate by farmers of the introduced NRM technologies, it is important to have an understanding of the policy, institutional, and other factors bearing on farmer's adoption decisions, for example policies related to imports of fertilizers, property rights, land tenure institutions and realities and rights to water resources.

A sustainable natural resource management should include the whole rural-urban landscape complex. Ecosystem is the lowest complete unit in the ecological levels-of-organization hierarchy (it has all components, biological and physical necessary for survival!); it is a logical level around which to organize both theory and practice. The management at the ecosystem level considers what (energy, materials, and organisms) goes in and out of the system as well as what goes on within the designated area (Odum 1998 (Forward) in Reimold 1998).

Eco-region, that is an area (region) of relative homogeneity based on one or more attributes in ecological systems e.g. physiography such as soil and geology, climate, land-use pattern. Eco-regions has which received more attention recently better characterize ecosystem homogeneities, for example eco-regions with similar physiographic regions have similar species (Reimold 1998). Ecosystem management involve the following (Reimold 1998, Hunsker *et al.* 1998):

- information collection – from inventory surveys to characterize NRCs and NRM;
- problem assessment - mapping of existing resources, develop land-use master plan;
- prevention, control, restoration, and management alternatives;
- goal and priority setting;
- implementation – defining roles and responsibilities of interdisciplinary stakeholders.

A healthy dryland environment can be achieved by managing both natural resources (air, water, wildlife, livestock, crops and forests/woodlands) and anthropogenic influences (impact of development and expansion of the human population on these resources) merits the prevention approach. Common benefit of prudent sustainable management of natural resources include safe-guarding of natural resources for future generation (environmental stewardship); maintenance of stakeholder confidence in the political infrastructure responsible for the stewardship of these resources: provision of sustainable sources of NRCs for present and future generations; low land degradation and flood insurance costs; effective management of limited financial resources appropriated for environmental protection (Hunsker *et al.* 1998).

A principle of sustainable agricultural systems is to conserve soil and water resources and minimize risks of accelerated soil erosion (Claw 1998).

However, Searching for an appropriate intervention process for sustainable natural resource development is problematic. Sustainability means different thing for different people, context, area of interest, the system and systems involved, and the way people perceive the system and/or the environment around them. What is sustainable at one time and place may not be sustainable at another (Basnyat 1995). There is limited knowledge on sustainable NRM, particularly for areas where there is degradation of natural resources and where green revolution technologies have failed to take hold. Furthermore, most of the studies have centered only on farmers as the target of research. This is not sufficient because the responsibility of maintaining natural resources for sustainable development of agriculture remains not only with farmers, but also with many other actors who have definite and significant roles in the process. Biophysical, social, economic, and national policies factors have to be considered for sustainable natural resource management (Basnyat 1995)

Perrings (1996) studied sustainable development and poverty alleviation in Sub-Saharan Africa with Botswana as a case study. He analyzed problems of environmental degradation, causes and the policies and institutions linked to the degradations and those related to sustainable development of natural resources. Perrings concludes by noting that the driving forces behind the degradation of environmental resources in Botswana, as in much Sub-Saharan Africa, are social rather than environmental.

The way forward for the sustainable development of the drylands lies with small-scale schemes, based on traditional agricultural practices, which are well adapted to the local conditions (Wood and Ryden 1991). Such schemes offer more hope than large-scale, high technology agricultural schemes. All plans for sustainability have to be based on ecological understanding and the sound management of natural resources. Further, the key to success is the involvement of local rural communities both in preparing and implementing schemes adapted to their needs. The final message is that drylands are ecologically sensitive and can be easily degraded by the actions of a relatively small number of people.

2.4 *MANAGEMENT PRACTICES*

Management practices are referred to as the myriad, small and large, decisions taken on daily basis by farmers/pastoralists in their use of natural resources (Niamir 1990). It goes beyond descriptive knowledge to what the farmer/pastoralist does with his/her store of knowledge - not just what he/she uses the resources for, but also how (Niamir 1990).

Many efforts in environmental management fail because they pay inadequate attention to the various stakeholders involved and their particular interests especially at grass-root level (Grimble *et al.* 1995). Stakeholders are people who have a stake in the exploitation and management of natural resource components and who have rational but different interests.

2.5 *LAND DEGRADATION*

Degradation is referred to as the geological process of wearing down by erosion, especially through stream action while land degradation refers to the degradation of soil, water, climate, and fauna and flora (Hurni 1996). Land degradation is the reduction or loss of the biological and economic productivity and complexity of terrestrial ecosystems, including soils, vegetation, other biota, and ecological, biogeochemical, and hydrological processes that operate therein (Reynolds 2001). There are two types of degradation that is natural and anthropogenic (Hurni 1996). It is easier to solve the later than the first type of degradation.

Land degradation in the drylands is inform of desertification. Desertification has been defined by United Nations Conference and Environment and Development (UNCED) as the loss of biological or economic productivity and biodiversity in the arid and semi-arid croplands, pastures, rangelands, and sub-humid woodlands resulting from various factors including climatic variations and human activities or both (Bright Edges of the World 2001, Reynolds 2001, Cardy 1993, Versraete and Schwartz 1991). UNEP too shares the above definition and further stresses that it is mainly caused by adverse human impact (Maukonen *et al.* 1995). The human activities include non-sustainable factors such as over-cultivation, fuel gathering, overgrazing by domestic animals, deforestation, and poor irrigation practices, and is often triggered or exacerbated by climate variability, mainly drought (Reynolds 2001). Desertification in the drylands manifest itself through over-exploitation, a decline in soil fertility and soil structure, and degradation of irrigated croplands (Maukonen *et al.* 1995).

Land degradation is examined and measured differently by different specialities, users and donors (Warren 2002). In the drylands, there are two perceptions (Leach and Mearns 1996, Warren 2002) on land degradation. Firstly is the "doomsday" or "received wisdom" pessimists old-fashioned thinking scientists who in several studies have indicated an alarming and generalized high rates of soil erosion, soil mining, deforestation and desertification (Øygard 1995, Leach and Mearns 1996, Zaal 1998, Defoer 2000). These perception, which form the context for mainstream policy interventions in Sub-Saharan Africa (Defoer 2000) sometimes unfairly blame and attack the already poverty burdened farmers, their methods, practices and livestock for causing degradation. Their case is based on inadequate sampled data (in space or in time) and most of the indices are calibrated against a small plot of experiments.

Moreover, some of their data rely on models that have severe limitations especially on economic and social context and few are scale dependent (Warren 2002).

Secondly are what Leach and Mearns (1996), Zaal (1998), and Defoer (2000) termed as the modern school of thought with a "new rethinking" towards indigenous technical knowledge and their resilient environment. They believe that drylands degradation are not that alarming and mainly attribute it to climatic variability than human factors. They point to cases where despite (perhaps because of) increasing population, there have been increases in production (Warren 2002). However, the "new rethinkers" evade full assessment with two stratagems (Warren 2002). One is to use increased food production as an index of the absence of degradation although the increase may be due to application of inputs such as fertilizers at unsustainable rates. The other stratagem is to take the land user's definition of degradation as a check on that of scientists though land user's assessment seldom considers wider national or global future. Above all just like the pessimists these modern team base their optimistic arguments on generalized of data. It is known facts that there is variability within farms leave alone villages. Therefore such studies end up hiding realities of land degradation (Warren 2002). After all neither case is conclusive.

Whatever the argument, whatever the cause, although some of the high estimates may be too alarmist, most of the data we have so far show that there is global dryland degradation be it caused by human or climatic change and therefore there is still plenty cause for concern (Øygard 1995). Similarly, studies that make generalizations about the extent of an important resource loss misrepresent resource dynamics and risks feeding into an unrealistic "crisis narrative"(Ramisch 1999). Consequently, the collection of data for this study took a centrist stand and based itself on biophysical and socio-economic perspectives with an open mind in order to blend indigenous technical knowledge and modern science for an improved food security while conserving the environment at the village level.

Although the productivity in the drylands of Africa are low, at the global level, successes of agriculture are being achieved at the expense of an over-exploited environment (and therefore becoming increasingly unsafe for various forms of life) and the surplus agricultural produce obtained are causing depression of commodity prices (Jorjani 1990).

It is now generally accepted that economic development strategies must be compatible with environmental goals (Doughty *et al.* 1995). This requires the incorporation of environmental dimensions into the process of development. The United Nations conference on environment and development (UNICED) in its Agenda 21, underscored the importance of environmental protection and conservation of the natural resource base (Doughty *et al.* 1995). Yet, the mainstream view in natural resource management in Africa drylands has been that local people are responsible for natural resource degradation (Benjamensen 1997). Today, alternative views or new paradigms are emerging that supports decentralization process in natural resource management in several fields. During colonial periods, heavily centralized governments were installed in all the colonies. The postcolonial governments maintained this structure after independence. Since the wind of democratization started, empowerment of local communities is being stressed. Whether such empowerment is real decentralization is yet to be seen.

Benjaminsen (1997) further stresses that the "gestion de terroir" approach, which is being used in Mali as a tool for decentralization in pastoral areas, is causing damage than benefits.

A lot of effort is required to save the drylands from desertification especially in terms of policy development and modifications for prevention, rehabilitation and restoration (McClure *et al.* 1998, Puigdefabregas *et al.* 1998). Similarly, the UN Convention to Combat Desertification recommended that efforts should move from global assessment to national and local assessments, and focus should shift from physical parameters and directed more to people issues (Ayoub 1998).

International response to the problem of desertification has been too narrow in its approach. Desertification control efforts in the Sudano-Sahel have been focused exclusively on land and natural resource management. What is required is a concerted strategy and a shift or enlargement of the focus of international interventions to include rural diversification and alternative income and employment opportunities. Some of the possible activities and ways in which they might contribute to resolving the problem of desertication include activities low extractive levels, processing of primary products, non-consumptive uses of land such as tourism, and the development of artisan and light to medium industrial production or services, and public works (Mendez 1993).

Land degradation is global in its environmental and socio-economic impacts (UNEP 1997). Successive exploitation of marginal lands including the semi-arid regions have seriously degraded some 1.2 billion ha of land since 1945 (Faeth 1993). Degradation in the drylands of Africa in form of soil erosion is estimated to affect 332.3 million hectares; hence contributing to loss of biodiversity, loss of earth's biomass and bio-productivity, and contributes to global climate change (UNEP 1997). It can also leads to economic instability and political unrest in affected areas; it puts pressures on the economy and the stability of societies outside the affected areas; and it prevents the achievement of sustainable development in affected areas (UNEP 1997). As a result, the residents of the drylands face more difficult problems than ever before (NAS 1974) and are at risk from loss of productivity on their livelihoods and this will in turn adversely affect their heritage, beauty and way of life (Bright Edges of the World 2001). Despite various efforts at the international and national levels towards sustainable natural resource management in the drylands the tragedy continues unabated (Darkoh 1998).

Unsustainable agricultural practices is causing "vicious cycle" of low farm income, poverty, food insecurity and environmental degradation and eventually turning into conflicts of interest between different users ((Faeth 1993, UN 2000, GoK 2000, Mohamed *et al.* 1999, Cleaver and Schreiber 1995, Barrow 1996).

Desertification is responsible for the deaths and destitution of millions of people causing mass rural-urban migration in search of food, housing and work creating more pressure on the already over-burdened social amenities and increasing land-use conflicts between various sectors. Additionally, desertification causes the loss of indigenous high value species and knowledge, increased levels of invader species, and increased water and wind erosion. Similarly as new economic policies are adopted, many pastoral and dryland farmers are marginalized and forced to move to urban areas and socio-economic conditions are rapidly changing (UN 2000, GoK 2000, Mohamed *et al.* 1999, Cleaver and Schreiber 1995, Barrow 1996).

In Sub-Saharan Africa alone, an estimated 14 million hectares are affected by physical degradation and 62 million hectares are subject to chemical degradation. The degradation causes loss of the topsoil to erosion resulting in declining production and intensified food insecurity (Reynolds 2001). The regions mostly affected are northern part of the continent, the Sudano-Sahelian and the Kalahari-Namib in the south (Reynolds 2001).

Realizing this looming disaster, the United Nations (UN) organized two major conferences, one in 1977 to combat desertification and another in 1992 on environment and development (Cardy 1993). The first led to the World Commission on Environment and Development (WCED) report of 1987 and later on the conferences contributed to the adoption of Agenda 21 (devoted to combating desertification and drought) in 1992 and subsequently to the establishment of the UN Commission on Sustainable Development (to review progress on Agenda 21 and promote dialogue and elaborate on policy guidelines on sustainable development) (Maukonen 1992, Cardy 1993, UNEP 1997). The Earth Summit at Rio de Janeiro, Brazil in June 1992 established a separate UN Convention on Desertification to counter the threat of dryland desertification. The UN also adopted Resolution 47/188 to establish a Convention to Combat Desertification (CCD) that calls for programmes and strategies with an integrated approach that aims to promote sustainable development at the community level with emphasis on the social dimensions of the problem and the role of local peoples and non-governmental organizations in solving local problems. Many of the Convention's provisions particularly those relating to programmes in Africa, are being implemented and they include activities that aim at (Reynolds 2001): prevention and/or reduction of land degradation, rehabilitation of degraded lands and reclamation of desertified land. In the recent past, the concept of the causes of desertification has changed from blaming colonization to climatic change and finally to traditional land-use systems and imported exogenous land management (Mainguet *et al.* 1998).

Agricultural production in Sub-Saharan Africa increased at about 1.5% per annum between 1965 and 1990, while population growth averaged close to 3% over the same period. This agricultural growth is well below the estimated 4% per year, which is essential for many Sub-Saharan African countries to reduce poverty and attain sustainable growth (Dejene *et al.* 1997). If the current land degradation continues, it will be difficult for farmers to grow enough food for the next century and effects of desertification and drought will be more acute as pressures on land resources increases. The pressure can become manifest in various ways and eventually turn into conflicts of interest between different users (UN 2000). On the other hand, conventional economic analysis obscures the degradation of natural resources that supports agriculture while research and policy have paid insufficient attention to natural resource degradation (Faeth 1993). Furthermore, instead of handling the root causes of famine and serving the normal function of a healthy community, most institutions especially foreign Non Governmental Organizations have become increasingly relief–oriented (Onyango-Olaka *et al.* 1993).

The dismal performance of the agricultural sector (which must be the engine for overall economic development) in sub-Saharan Africa over the past two decades have raised serious concern among African policy makers about whether the land can support the expanding population, and produce to combat poverty and food insecurity (Dejene *et al.* 1997). Hence, at the 1992 Earth Summit in Rio de Janeiro, African leaders appealed for an International Convention to combat desertification (land degradation and drought).

Although there are evidences of successes (for example, organization of various natural resource management) actions like awareness creation, bush fire control, rangeland and water-point management; and provision of development services to local communities – animal health, training and provision of food and other items), in most projects that involve local institutional-building for resource management, there is evidence of governments and project failures that requires to be addressed if institution-building is to move forward (Vedeld 1992).

As global degradation continues to bite, there is a progressive awareness by the public and the decision makers on the many aspects of land abuse (Versraete and Schwartz 1991). Consequently at international level the scientific community has too started to design and implement a coordinated research effort geared at documenting the current state and the problem evolution (Versraete and Schwartz 1991) and in checking land degradation through bilateral, multi-lateral projects and through non-governmental organizations and government institutions of the affected countries (Barrow 1996).

There were and are a lot of efforts by the public sector (various Governmental and NGOs and donor initiatives) to reverse natural resource components (NRCs) degradation (Parr and Papendick 1997). Proper assessment of the nature of interventions/technologies to support sustainable natural resource management is needed. This approach requires new perspectives, innovative thinking, careful planning, and proper organization of both information and people. A vital requisite will be the involvement of scientists, extension agents and farmers working as a team to conduct the necessary research and development, technology transfer, on-farm testing, practical applications and adaptations that will meet these challenges. Special attention should be given to policy development and modifications for prevention, rehabilitation and restoration (McClure *et al.* 1998, Puigdefabregas *et al.* 1998). Furthermore, the UN Convention to Combat Desertification recommended that efforts should move from global assessment to national and local assessments, and focus should shift from physical parameters and directed more to people issues (Ayoub 1998).

On the Kenyan perspective, the livelihoods of over 80% of the Kenyan rural communities in the drylands are based on the exploitation of natural resources, which they manage (Wandera 1998, GoK 2000, Southgate and Hulme 1996a). The water, plants and animals contribute to the nutritional well being of many people especially the poor (Ogden 1991 and Mohamed 1999a). The animals mainly provide food, traction, organic manure, income and prestige while the plants provide edible products, supplement diet in form of quantity and quality; protect the environment, provide fodder/forage, fuelwood and medicine.

To satisfy the growing demands in food production, people in Sub-Saharan Africa (SSA) have counted on the expansion of cropped land while in other parts of the world increase in food supply has resulted from raising yields per unit of cultivated area (Nziguheba 2001). Despite such expansion, dryland nations especially in Africa are often seen only as recipients of aid (Bright Edges of the World 2001, Foster 1987).

Although land degradation is evident, some internationally respected scientists are of the view that the African drylands are in fact resilient, and could recover quickly from drought once the rains or land use pressures return to normal levels (Bie 1992, Leach and Mearns 1996). They suggest that many development efforts disregard this resilience.

Large-scale tree planting projects, animal restocking schemes, development of energy sources alternatives to firewood/charcoal, or the construction of road networks to facilitate delivery of relief supplies, may therefore be founded on erroneous assumptions (Leach and Mearns 1996). They further indicate that population pressure accelerates innovations and investment towards the development of new sustainable systems (Tiffen and Mortimore 1994). Therefore a realistic understanding of the physical and biological and socio-economic status of the African drylands, and the fluctuations experienced, must be a prerequisite for any development interventions in response to droughts and famines (Bie 1992, Leach and Mearns 1996).

2.6 INDIGENOUS TECHNICAL KNOWLEDGE (ITK)

In the past (and even in some instances today), local communities are the primary recipients of blame for the degradation of natural resources of the tropics (Warner 1991, Benjaminsen 1997). They and their practices are perceived by governments and international organizations to be causing wanton destruction of natural resources of the nations. To blame them and making laws to forbidding or minimizing their activities are easy, but stopping their practices is not. However, recent studies in other parts of the world have shown that much of the blame was misdirected. Rather than wantonly destroying natural resources, many farmers are known to conserve (Warner 1991, Mohamed 1999a).

During the third session of the conference of the United Nations parties on desertification and drought control, there was a general call for special priority to be given to an enhanced role for traditional knowledge and indigenous people in the decision making process (UN 2000). This is because customary natural resources management rules and institutions may provide a better starting point and sustainable alternatives (to the current models of resource use) for the development of policies and programmes than the technocratic/bureaucratic model hitherto adopted in African drylands (Swift 1991, Stocking and Abel 1981). Development initiatives to protect resources should provide the framework and incentives to permit customary institutions to function more effectively and to evolve in desirable ways.

Developing countries have a valuable but largely untapped, reservoir of indigenous agricultural and natural resource experience and knowledge (Warren 1993). Development planners and policy makers are beginning to recognize the need to understand existing knowledge systems and decision-making processes as they focus their attention on the role that small-scale agricultural producers can play in achieving national food self-sufficiency. These systems influence current farming practices and responses of the small-scale producers to agricultural and natural resource policy initiatives and technological innovations.

We understand little of how indigenous knowledge (IK) of nature and human social behaviour has been translated into resource use practices that tend to promote sustainable use of biological resources and conservation of biodiversity.

Current ecological theory helps us little in arriving at practical prescriptions for resource use and conservations. Such prescriptions are best derived from long-term observations of a particular system – very much the "forte" of indigenous knowledge (Fikret *et al.* 1995).

Traditional systems of knowledge are not just curiosities; they are important for rediscovering new principles for the more sustainable uses of the natural environment (Fikret *et al.* 1995). Traditional knowledge and management systems, developed by trial and error through millennia, enable many societies to use environment in a way that maintains the integrity of the local ecosystems.

The relevance of indigenous technical knowledge (ITK) for the sustainable management of various ecosystems including the drylands is recognized not only appreciated by a few specialists but also by international agencies. If such knowledge is not documented, it may be lost. ITK contains the recipes for responding to and manage ecological feedbacks. Resource management characterized by ITK allows unpredictable perturbations to enter the system, instead of locking them. On the other hand, management based on Western scientific knowledge often generates simplified ecosystems either directly or through excessive resource extraction or monoculture-based production, or through pollution and degradation that causes ecosystem stress. Subsidies to these production systems, such as energy inputs or technological innovations or use of a series of substitutions (often with the sequential depletion of resources from elsewhere) tend to mask the degradation of the resource base (Fikret *et al.* 1995).

The case of involving local people and their technical knowledge in planning of natural resource conservation is a pragmatic one since they know better their environment than outsiders (Fikret *et al.* 1995). The failure to ensure local cooperation in resource conservation efforts may make local people in different and perhaps even more hostile to the effort because of the natural tendency of people to be suspicious of top-down initiatives. However community based land management approach, which may be a useful tool in achieving decentralization in farming communities, could cause more damage than benefits in pastoral areas (Benjaminsen 1997).

To understand the tropics well, it is not enough to compile an ethno-botanical list of plants, classification of soils or what the communities know about the environment but rather how the Indigenous knowledge is utilized to develop procurement strategies that provide nutritional and wood security and conserve the environment (Warner 1991).

Through centuries, local farmers have developed time-tested strategies to mitigate the impacts of drought and save natural resources (Hamadesh *et al.* 1999). There are now indications that the once sustainable dryland farming systems are undergoing drastic changes. Marginal lands are increasingly used in crop production and becoming less available to livestock grazing. As a result, traditional agropastoral systems are developing into more sedentary systems constrained by shrinking rangelands and limited feed availability. Pastoral land stewardship by indigenous pastoralists is the most effective method of environmental preservation (Mortimore *et al.* 1995).

A prerequisite for the success of any intervention affecting a local community is that the planners recognize the institutions, systems of indigenous knowledge and management structures that already exist (Stiles 1995). There is a store of knowledge, which people have developed over generations and can be used for the sustainable development of the drylands (Darkoh 1995). Such local systems have sophisticated technical, social and organizational components, which enable people to deal with survival and at the same time, make rational resource management decisions.

In the light of this, it is contended that there are prospects for a community-based management of natural resources in the drylands of Africa.

Although there exists lack of incentives and a clearly defined conventional legal rights over forests and forest products in many parts of Africa, based on their traditional indigenous knowledge, some communities in the communal areas are engaged in the management of woodland and forest resources and value the diverse and varied functions of the forests (Katerere *et al.* 1999, Barrow 1996, Mohamed 1999a).

The systems developed by local people, their skills and acquired technologies in handling natural resources provide a good starting point for improved utilization (El-Sammani and Scoones 1991) technologies that optimizes the full potential use of the resources.

An experience in participatory natural resource management to convert farmers (using farmers' research groups) from mere spectators in on-farm research to full participants has been documented by Mavedzenge *et al.* (1999) in Chivi, southern Zimbabwe. It was found that the team spirit encourages farmers' confidence in the implementation and sustainability of the project.

Oxfam Inshtirak Project in Chad tested a specific approach, of organizing agro-pastoralists in pastoralists associations (PAs) (Bruggeman 1993). This approach was a result of Oxfam's recognition that previous development initiatives in drylands with agro-pastoralists had not fully recognized the herdsman's own considerable technical knowledge, their clearly articulated and consistent production objectives, and the need for channels of communication on development issues between the government on the one hand and herders as groups on the other. The project hard three approaches, including:

- achieving a better understanding of the mechanisms that are crucial for the functioning of the agro-pastoral societies of Chad;
- to install an institutional framework that will allow the agro-pastoralists to participate in decision making and the management of their own development; and
- to search and experiment with appropriate animal husbandry techniques that both take account of the enormous experience and knowledge of agro-pastoralists, but also introduce new subjects like animal production, improved grassland production and water conservation/management.

The official recognition of PAs would allow them access to a revolving fund on credit basis. A variety of different activities were undertaken with the revolving fund on credit in cattle, and sugar, marketing butter oil and mats by the women's PAs.

2.7 INTEGRATED MANAGEMENT OF NATURAL RESOURCES

Integrated Natural Resource Management (INRM) is an approach that integrates research on different types of natural resources into stakeholder-driven processes of adaptive management and innovation to improve livelihoods, agro-ecosystems resilience, agricultural productivity and environmental services at community, eco-regional and global scales of intervention and impact".

In brief it is " Building livelihoods and saving lands" CGIAR (2002). INRM is fundamentally about the need to balance individuals' and society's competing interests in multiple uses for any natural resource. For this reason INRM is strongly concerned with the way people use natural resources to support livelihoods, and the institutional and ecological requirements for long-term sustainability. As a research approach, INRM combines a flexible set of integrative frameworks; methods and tools aimed at capturing synergies among specialized research areas, each of which deals with a natural resource on its own.

UNEP Programme on sustainable management and use of natural resources supports the development of practical approaches to assess the status and dynamics of dryland degradation including its biophysical, social and economic dimensions; lead the effort to establish indicators on desertification; and the maintenance of data bases on global dryland degradation (UNEP 1997). This is necessary to improve assessments underway in critical countries of all regions suffering from dryland degradation with special emphasis on Africa; recommend for policy and mitigation options, based on assessment of socio-economic causes of dryland degradation and desertification; and updating datasets on the dynamics of global dryland degradation. The programme also aims to improve global awareness of dryland and desertification issues through the media; promotes action in support of the UN Convention to Combat desertification and the development of national, sub-regional and regional action programmes; and handles Social Dimensions of Land Degradation and Successful Practices to Control Desertification (UNEP 1997).

Development programmes can fail as a result of insufficient knowledge of natural resource base and sustainable development potential, insufficient project ownership at local level (Mahar and Ducrot 1999). There is emerging consensus that sustainable development must maintain ecological, economical and socio-cultural dimensions (Munasinghe 1993, Nakashima 1998).

What is required is a sustainable approach and technologies that are holistic in nature in order to alleviate poverty through land management, appropriate use of natural resources and the comparative advantages of various ecosystems/farming systems (Adolph 1996, Toledo 1999). When undertaking a large project, an environmental impact assessment will be an effective intervention (Norman 1996). Holistic valuation exercises in Southern Africa reveal clearly the high economic value of communal rangelands resources and the significant contribution they make to complex, diverse and dynamic livelihoods. The realistic valuation of communal rangelands thus needs to be seriously investigated and integrated into poverty assessments as well as being adequately taken into account in land reform programmes (Cousins *et al.* 1998). An interdisciplinary approach is required to study common property regimes (Knudsen 1995).

The village approach as a unit of analysis assisting local interventions has been used to by NGOs and government organizations to improve community level management of natural resources in Burkina Faso, Mali and Niger in late 1990 (Painter 1993). However, prior to development interventions, it is important to consider resource potential, problems and needs of a region (Gjessing 1993). This is best executed through field inventory and remote sensing (Reynolds 2001). Integrated management methods with alternative options offer better results than reliance on one technology (Bekunda 1999, Corbeels *et al.* 2000).

Harmonizing formal laws (national legal framework) and customary land right is the way forward for solving land use conflicts in Africa (Delville 1999).

Although ITK is important, it is a known fact that farmers in the drylands want to improve their knowledge and skills in crop production and in soil and water and therefore need for integrated approach (Rao and Reddy 1997). Managing for sustainability requires an understanding of the system in all its complexity (Fikret *et al.* 1995). Therefore the core of any strategy for sustainable land use calls for a participatory process that actively involves insiders (locals) and outsiders (development experts or researchers) in an integrated manner (Case 1990, Zweinfel 1998). However much of the existing literature in participatory extension programme in the drylands especially for social/agroforestry is written from, primarily, a more theoretical and research approach, not so much from the impact of settlements, traditional natural resources management practices or from the experiences of the existing development programmes (Barrow 1991).

There is need for a model that combines conservation and development so as to promote rural development based on natural resource components, the demand of the present and future generations and that of any upcoming urban centres and agro-based industries. The model should encourage conservation awareness and take in to account both economic and ecological factors in evaluating the various alternatives (Munasinghe 1993).

Food aid and technology alone because they cannot control land degradation (FAO 1993a). Instead the communities should be helped in how their fragile environment can be sustainably managed and developed through integrated and multidisciplinary approaches, modalities and strategies that addresses drought and food security, soil and water conservation, livestock and range improvement and wood and agroforestry (FAO 1993a, Jorjani 1990, Janssen and Goldsworthy 1996, Dejene *et al.* 1997, Toledo 1999, Griesbach 1999). Furthermore an appropriate use of natural resources and the comparative advantages of various ecosystems/farming systems (Toledo 1999) are required. The approach requires programmes tailored to local agro-climatic conditions and the local social and economic factors, since they determine the type of agricultural development that is most relevant (UN 2000).

An integrated resource management with interconnected objectives is necessary to balance environmental, economic and social concerns at macroeconomic level, at the social level and directly at the local-development level (Toledo 1999, Bouman and Kulshreshtha 1998).

The establishment of mechanism/model for such management is essential and helps in the mediation of resource conflict and bring rapid development that help overcome problems related to drought and floods (Swift 1991, Zweinfel 1998, Krairapanond and Atkinson 1998, Toledo 1999). In developing countries, a sector can even improve the sustainability of small-scale farms provided that it is fully integrated with other enterprises and household activities so as to allow farm families and communities to manage their natural resources effectively (Lightfoot *et al.* 1994).

The following factors must be considered in addressing integrated management of natural resources (UN 2000, FAO 1996):

- land tenure and land security;
- economic long term viability must be guaranteed for land users and link conservation with production (low input sustainable agricultural technologies integrated and assessed in terms of the whole farm house hold system);
- empowerment and participation by stakeholders;
- complementarity between national policies and local initiatives (subsidiary);
- recognize the land user's ability to innovate (farmer's experience and knowledge);
- the management should make project funding and implementation more responsive and flexible; and
- strengthen networking in all its forms.

In order to enhance participatory and integrated approaches for sustainable development in the drylands, there is need to understand more the existing ecological factors and the traditional knowledge, cultures and practices that molded them over the years. This should be followed by the incorporation of these knowledge and existing realities into developing adaptable technologies with full participation by the stakeholders of a project/programme (Richards 1985 and Niamir 1990). In addition to the above, studies on the impact of population growth on the existing natural resources of the dry lands will help in the develop of appropriate conservation and management practices.

Selecting appropriate intervention approaches and processes is a problem, and is likely to be a successful only if effective and extension research system is based on examination of local needs and knowledge and only when the negative consequences of traditional practices are made visible, and farmers' capacity to analyze problem situations and take actions strengthened (Basnyat 1995). Therefore, a new perspectives of innovative thinking, careful planning, and proper organization of both information and people is vital and should include the involvement of scientists, extension agents and farmers working as a team to conduct the necessary research and development, technology transfer, on-farm testing, practical applications and adaptations that will meet these challenges (Parr and Papendick 1997).

A possible way out of degradation is to integrate desertification research and development across all levels of concern and relying more on grass-root level approach (Reynolds 2001). This means that a new integrated assessment paradigm for rational decision-making is needed to solve this land degradation or desertification problem (Reynolds 2001). Such paradigm must recognize the simultaneous roles of, and complex feedback between, the meteorological, ecological, and human dimensions of the problem. The failure to recognise and include interdependencies of these dimensions has slowed progress in developing the necessary synthetic framework for tackling the enormous problem of dryland degradation.

The paradigm of multidiscplinarity recognize the simultaneous roles of, and complex feedback between, the meteorological, ecological, and human dimensions of the problem. The failure to recognise and include interdependencies of these dimensions has slowed progress in developing the necessary synthetic framework for tackling the enormous problem of dryland degradation. Multidiscplinarity involving the disciplines of ecology, atmospheric science, social sciences, policy, and integrated assessment – must be combined to define new interdisciplinary approaches for addressing this pressing global problem.

Mohamed *et al.* (2000) used integrated approach to model land use and farm types in Iran in order to capture policies issues from farm level. They used ARC INFO to construct the models for sustainable management of natural resources.

Similarly, Bailey *et al.* (1996) proposed the the use of integrated environmental assessment in resource management and suggested the involvement of non expertise "peer review" and full involvement of grassroot farmers and local leaders to be part of policy development in natural resource management. Integrated management at catchment level has been stressed by Reimold (1998). FAO (1993c) while using Kenya as a case study articulated the need to integrate land use with biophysical factors

2.8 CASE STUDIES ON NATURAL RESOURCE MANAGEMENT OF THE DRYLANDS

Elias and Fantaye (2000) conducted a case study on soil fertility management practices in Meket, North Wollo, Ethiopia, on how farmers with varying resources manage soils. They found out that soil fertility management is limited to the application of mineral fertilizers (to the better-off farmers working on deep soils in the highlands) and some measures to control erosion. Hardly anyone still uses mulch, manure or trash lines on their fields, as all the crop residues are needed to feed livestock, while the eradication of most forests from the zone means that manure is used as fuel rather than as fertility input. Therefore systems of integrated nutrient management (combining use of mineral fertilizers, organic manure and soil conservation) were recommended. Due to limited land availability, diversification and off-farm activities is required to reduce pressure on land and in achieving some measure of security of livelihood. They noted that over the past 20 years agricultural extension has tended to focus so exclusively on packages of specific technologies, in the 1980s on soil and water conservation while since 1995 the emphasis has been on the use of mineral fertilizers and improved variety of crops such that it has failed fully to address the problems faced by farmers in Ethiopia.

Case study on pastoral land tenure and agricultural expansion with special reference to the Sudan has been documented, indicating historical account of the land tenure system prior to the inception of British colonial rule and far-reaching ramifications of the laws and policies introduced by the British colonial administration. It also discussed how these laws were adopted by the successive national governments. The case ended by putting blames on these laws that caused a multiple marginalization to the pastoralists of the Sudan (Shazali and Ahmed 1999).

A case study in Machos, Kenya by Tiffen (1998) showed that as land becomes more scarce, people generally seek new technologies and make investments to improve land quality. It is argued that there natural tendency for farmers to invest in new technologies and soil improvement strategies as land becomes scarce and more valuable. Their greatest difficulty occurs not when densities first starts growing from a very low base, nor when densities have reached relatively high levels but erosion is most likely to increase visibly at the intermediate but growing densities. In response farmers will try to find remedies, or to develop new land. Often, they will first tend to do the later. If this option is not available, they invest in land improvement, but their effort can be either supported, or thwarted, by government policies. Tiffen (1998), stresses that it is useless to promote soil conservation either where low population densities mean land is not valued, or where government policies remove the incentive and means to invest. It is also essential that farmers and those who seek to advise them share the same view of what is meant by degradation or improvement of land and water resources, or they will be acting at cross-purposes.

Milton *et al.* (1994) conducted a study of land degradation of rangelands of South Africa. The study showed that grazing-induced desertification is a stepwise phenomena and model (that is, it increases in severity until a threshold is eventually surpassed whereby the ecological state of the land (e.g., loss of soils and vegetation) is irreversible) and that the potential for recovery at any given step is related to the function of the affected component. The first step in degradation concerns change in the structure of plant population. Palatable species are replaced by invaders, which are either toxic or not very palatable. Here the management options are game ranching, meat production, restoration of desirable species, rotational grazing, reduction of stock intensity, or animal type. The second step of degradation involves decrease in biodiversity and both plant and animal productivity providing fewer ecosystems "goods and services". The reversal of degradation at this stage is usually not cost effective particularly for arid areas in which it would involve removal of domestic livestock, curling of other abundant herbivores and manipulating the vegetation (reseeding, herbicide treatments, bush management etc.). The third step involves processes associated with the reduction of perennial plant vegetation cover and an increase in ephemeral and weedy species. This includes accelerated wind and water erosion and various land surface impacts, such as increased albedo and surface temperatures, reduced soil moisture storage, and cloudiness. Rangeland in this conditions are profitable to ranchers and the restoration must focus on physical environment, e.g., reducing erosion, increasing water infiltration, protecting the soil surface from sun and frost, creating micro-sites suitable for the establishment of perennial seedlings. The final step in degradation process is characterized by a complete loss of vegetation cover, accelerated soil erosion, and soil salinization – a true "human made desert". Such rangelands are usually abandoned due to the high costs of – and - low probability of successful-restoration and rehabilitation.

Mwaloyosi (1992) examined at the recent land-use changes and resource degradation in South-west Masaailand, Tanzania, and evaluated the consequent environmental impacts in part of the Masaai Steppe in the Arusha region. The case study is typical of the Masaai eco-complex and Tanzanian drylands in general. The exercise identified significant land-use changes that cause severe degradation of the environment and natural resource base, especially depletion of woody cover, reduction of rangelands, loss of soil productivity, and accelerated soil erosion.

Environmental degradation in this area is attributed to misuse or break down of traditional common property resource management practices caused by two important factors: (1) rapid population growth which produces pressure for over exploitation of fixed natural stocks to meet subsistence needs, and (2) technological changes which make it easier to overexploit natural resources. The implication of these findings is that the mounting human population and livestock pressures on the land resources will inevitably result in further resource degradation and impoverishment of the rural communities.

Agrawal (1992) studied the Raikas Nomadic Pastorlists of Rajastan, India. He noted that nomadic pastoralism is critical to the economy of Rajastan. The study showed that a significant part of the fodder deficit is met through the migration of stock, especially sheep. Whilst the proportion of sheep owners who migrate is low (35%), the population of sheep that migrate is close to 90%. The description of Raikas life is presented, including the direction, duration, frequency and distance of migration. The report also delineates the characteristics of the moving village (herding camps) and households and assesses farmer-nomad relations. The economic of sheep herding is analysed: income from sheep herding (wool sales, animal sales, sheep fold costs) is balanced against expenses (individual household and collective), including feed and grazing, medicine, gwala (professional herders), consumption, transport and joint expenses. The report also identifies with major loci of decision-making, which involves herding camp formation and dissolution, herding camp and household management, migration, market interaction and external relations. It is concluded that the grazing strategies of the Raikas convincingly show the ability of pastoralists to innovate and to adapt their lifestyles and production strategies to change environmental conditions.

Coping strategies with drought in the two Savanna ecosystems of Southern Zimbabwe have been studies (Scoones 1992a) in order to advice Government policy and institutions towards the facilitation of a flexible and opportunistic pattern of management and to illustrate how ecological responses are modified by different management activities. The activities include herding, transhumant movement and supplementary feeding. Local drought coping strategies respond to pattern of spatial and temporal variability that exists at different scales in the savanna environment. The ability of a household to respond to this variability is dependent on a range of socio-economic factors. The impact of drought on cattle herds can thus be understood only with insight into the interaction of ecological and socio-economic factors. The effect of socio-economic factors was investigated in this study (herding labour availability, ken support networks, cattle loaning and sharing relationships, cash income for labour hire or fodder purchase, and tenurial restrictions on herd movement). Information on herding strategy was obtained from a stratified sample of 71 households between 1986 and 1988 with some follow-up during 1991/92. The study highlighted the different ability of herders to effectively cope with drought.
Labour and cash constraints limited the capacity of poorer households to respond to drought stress through movement or supplementary feeding.

The drylands bear fruits is a case study of how the drylands of North East Brazil (Benton 1992) is a success story in how drylands could be rehabilitated using rural nuclei "Fundacao Ruralistica" approach of Padre lira, a Brazilian Priest. Where there were no settlements in 1960 today has 39 schools and nuclei. In the nuclei, water is conserved, roads, schools, medicares and business centres established.

Case studies on wetlands in the drylands have been undertaken in northern semi-arid belt of Kordofan, the Sudan (El-Sammani and Scoones 1991), Fadama in northern Nigeria (Kolowole and Scoones 1991), Khor Baraka of eastern sudan and Eritrea (Fre and Scoones 1991), the Basafond of Burkina Faso (Hotinga *et al.* 1991) and the Dambos of Zambia and Zimbabwe (Kokwe and Scoones 1991; Cousins and Scoones 1991). The studies investigated the current status and use of seasonal water courses and prospects of improving agro-pastoral production systems. The studies concludes that integration of indigenous knowledge into development of these areas plus need for more efforts to conserve especially the availability of extension services are required.

Analysis of the Barbaig pastoral economy in Hanang District, Arusha Region, Tanzania removes the misconceptions associated with pastoralism (such that they are irrational hoarders of livestock with land tenure systems structurally incapable of efficient land use) and shows the Barabaig to be rational producers, willing and astute livestock traders, without animals surplus needs (Lane 1996). The study also shows that Barabaig customary land tenure are effective in controlling land use. Misconceptions about pastoral systems have lead to marginalization of communities and allocating their land resources for other development activities.

At on-station level, sustainable integrated farming system for the drylands (a combination of crops, pasture and livestock) have proved to give more net returns when compared with a conventional cropping system (sorghum + cowpeas for seed/grain) in Tamil Nadu, India (Sivasankaran *et al.* 1995).

A case study on indigenous range management of the Rendille and the Ariaal pastoralists of northern Kenya was presented (Oba 1994). The study gave weight to the social and ecological basis of the pastoralist's indigenous range management and these may be employed to control desertification. Historical changes in land use are offered as a backdrop to the study of resource use strategies and the way in which interventions, through administrative realignment of the borders and accelerated sedentarization have caused desertification. The fundamental differences between the way pastoralists classify rangelands and rank sustainability and the methods of the mainstream scientists are discussed. The two approaches are compared and suggestions made for better understanding of the indigenous knowledge of land use, to conduct desertification control measures in the drylands of Kenya. The use of grazing optimization models, and the importance of wet season and dry season rangelands are considered.

Poor people living in high-risk environments live continuously with uncertainty, which often threatens their livelihoods (Davies 1996). They have therefore developed effective means of predicting and responding to large fluctuations in rainfall, harvest levels and natural resource productions. This methods of prediction and response often outperform conventional early warning systems promoted by donors and governments, and yet are rarely considered in the conception and implementation of food security programmes. The study focused on indigenous system strategy to combat famine in Mali focuses on how people feed themselves rather than how they fail to do so. The study on coping with food insecurity in Malian Sahel concludes by outlining a simplified methodology for monitoring livelihood security, to be used as a basis for developing contingency plans and regional food security planning capacities and policies.

Traditional natural resource management with focus on Turkana pastoralists of Northern Kenya has been studied both during and post colonial periods (Darkoh and Hjort-af-Ornas 1996). The study states that traditional resource management came under severe pressure during colonial period and the post colonial period carried on colonial policies. The study further stresses on the role of grass-root initiatives in resource management and notes problem areas as land tenure, customary laws, and property rights.

A participatory survey designed to characterize and analyse local knowledge about soil fertility and soil fertility management practices have been conducted in the semi-arid Highlands of Tigray, Northern Ethiopia (Corbeels *et al.* 2000). The survey found out that farmers categorized the soils into fertile, moderately fertile and poor and soil fertility was seen as dynamic. The principle indicators used for identifying declining soil fertility were noted as reduced yield, weed infestation, rocky outcrops, and crops wilting early in the growing cycle. Farmers also classified soils using colour, texture and certain physical characteristics. Corbeels *et al.* (2000) also found out that land shortage and fragmentation have forced farmers to abandon soil fertility management practices such as fallow, manure application, terracing and use of crop residues. The authors recommended the use of integrated soil fertility management (executed jointly by researchers and extensionists) including the close integration of livestock and crops, maximizing the use of crop residues, application of more manure and use mineral fertilizers to complement manure.

2.9 A HISTORICAL PERSPECTIVE OF LAND DEGRADATION AND CONSERVATION IN KENYA

Prior to the declaration of Kenya as British Protectorate in 1895, the drylands of Kenya were mainly for pastoralism and hunting with farming activities limited to shifting cultivation and in ameliorated pockets. Tribes and clans under chiefs and elders owned Land. Since population density was very low degradation was minimal. Additionally, there were no political boundaries to restrict the movement of people and their livestock (Huxley 1948, Mohamed 1999a, Southgate and Hulme 1996a).

The completion of the Uganda Railway in 1901 opened a new chapter in land use in Kenya. Large contingency of Colonial farmers came from as far as United Kingdom, Australia and New Zealand and South Africa. The local African communities who occupied the high potential highlands were moved to less potential African reserves to create an exclusives room for the settlers in what the colonialists named the "White Highlands".

The settlers being new to the tropical environment imported their monocropping and mechanization technologies. Consequently, huge tracts of indigenous forests were cleared in favour of plantations of cash crops such as coffee, tea, wheat, sugar and pyrethrum and the Australia and New Zealand ranch models with substantial investment from overseas. Soon disasters of soil erosion, poor crop yields and deaths of the exotic livestock followed aggravated by the impacts of the first and second world wars. At the same time, African communities were restricted to "native reserves" depending heavily on subsistence agriculture using traditional methods. The restriction encouraged a process of environmental degradation within the closed areas (Huxley 1948, Southgate

and Hulme 1996a, Thomas 1997). Moreover, the creation of exclusive game conservation areas that commenced in the same period denied the inhabitants of the drylands access to key resources (Southgate and Hulme 1996a). Similarly, in the pockets of the ameliorated semi-arid areas that were part of the "native reserves" or African lands, the Colonial Government forced local communities to construct soil and water conservation structures and limit livestock numbers. In turn, it made the locals to associate these measures with colonialism and contributed to the revolution that led to independence in 1963 (Southgate and Hulme 1996a, Thomas 1997).

The economy only improved with the market opportunities provided by the growing towns and cities. Near to Nairobi the overgrazed and degraded lands of Machakos received much attention and an exceptional amount of technical support from both soil conservation schemes personnel and from the Katumani Research Station. But until a greatly expanded city, with excellent road and rail connections, provided markets for both produce and labour there was little response from the Akamba community.

Their response to the commercial opportunities then became strong enough to overcome tradition and to establish freehold tenure and the individual ownership and fencing of grazing land. This essential transformation is not yet in evidence beyond the stimulus of urban markets (Pereira 1997).

In the meantime land degradation become rampant with time even after independence due to population pressure, inadequate technologies and inappropriate Government policies (Farah 1997, Huxley 1948, Southgate and Hulme 1996a, Thomas 1997, Barrow 1996, Mohamed 1999a).

2.10 REVIEW OF EXISTING METHODOLOGIES FOR LAND MANAGEMENT

There are various methodologies developed for the collection, use and analysis of land management data but most of them are mono-disciplinary in nature. Table 2.10.1 summarize the characteristics, advantages and disadvantages of the major methodologies.

2.11 *CONCEPTUALIZATION FRAMEWORK FOR THE STUDY*

As indicated in the Table 2.10.1, in the past, land use systems were not adequately described, and many surveys and detailed studies in a particular area were either specific to biophysical and socio-economic processes without a common framework with specified common goals. Consequently, Integrated land use planning and policy analysis (ILLUPA) (Mohamed 1999b, Mohamed *et. al* 2000) with modifications was found ideal for this study. It integrates biophysical and socio-economic parameters. To appropriately and practically address the integrated nature of the study triangulation technique formed tool for data collection. Fig. 2.11.1 summarizes the approach adopted by the study.

The framework is based on integrated model for land use planning and policy analysis (Mohamed *et al.* 2000); Integrated environmental assessment (Bailey *et al.* 1996), Integrated Watershed Management (Reimold 1998), agro-ecological assessment (FAO 1993c), Integrated transect method (Duivenbooden 1995) and Agro-humid principles (Jaetzhold and Schmidt 1982; Hornetz 1990).

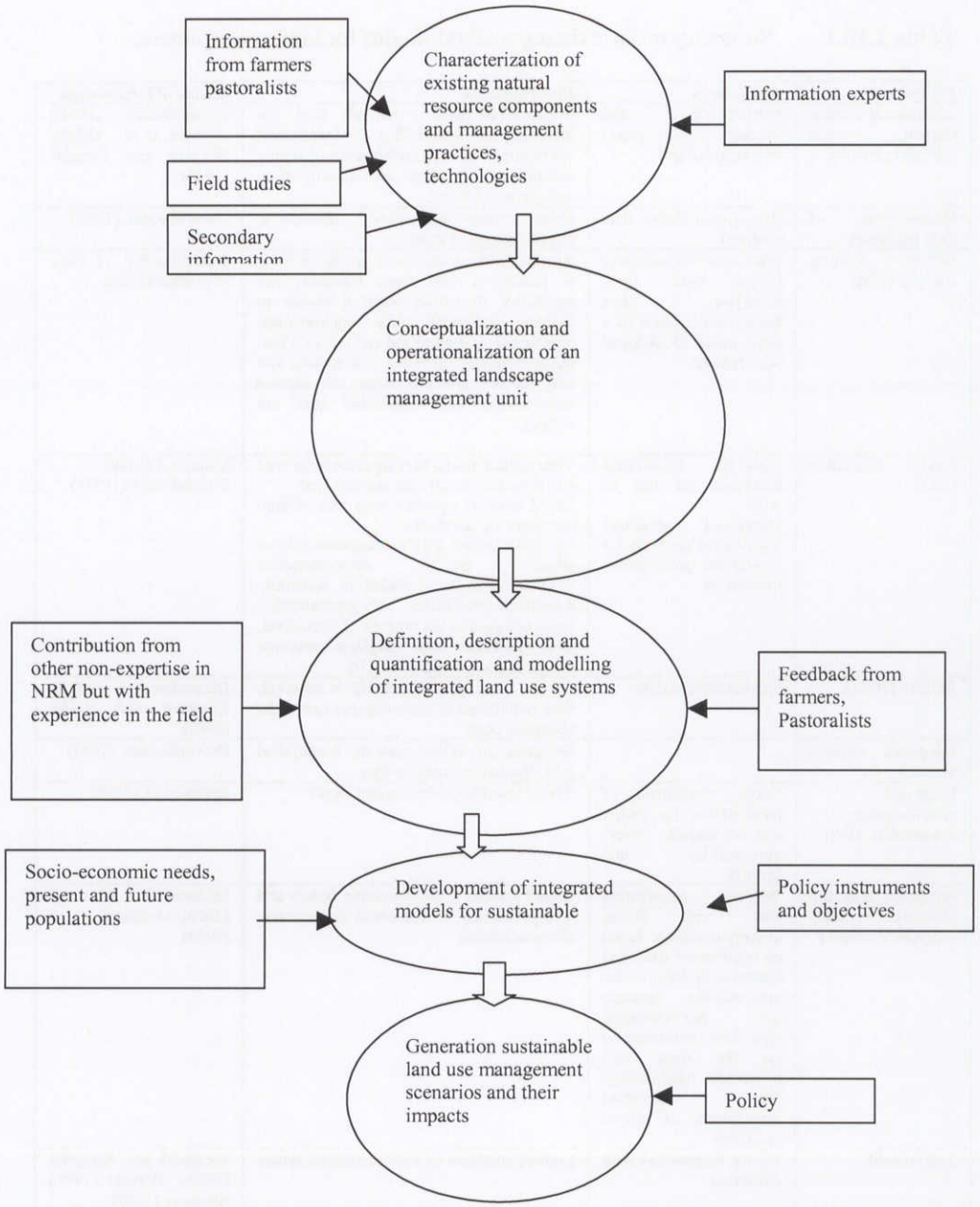
2.12 *CONCLUSIONS*

The drylands of the world, though rich with diverse cultures and biodiversity are facing land degradation caused by climatic and anthropogenic factors. The impact is most felt in Sub-Saharan Africa and in Kenya where drylands cover 65% and over 80% respectively. Though multiple factors contribute to the degradation, inappropriate policies, poverty and ever increasing population are the major factors. However, although all scientists concur on the problem of degradation, there are conflicting views on the extent of degradation and causes by different scholars due to divergence in backgrounds and methodologies used. As a result a framework that integrates biophysical and socio-economic studies was adopted to form platform for the study.

Table 2.10.1 Summary of the existing methodologies for land management.

Method	Advantages	Disadvantages	Source of information
Agricultural Census (formal and informal surveys)	Participation and interaction with grass-root stakeholders	Time requirement; not all land use included; no relationship to biophysical environment; not geo-referenced; changing definition of holdings and classification; comparison difficult	Duivenbooden (1995); Norman *et al.* (1995), Norman and Douglas (1994)
Measurement of field indicators	Actual quantitative data obtained	Often mono-disciplinary; qualitative; emphasis on land cover	Duivenbooden (1995)
Farming Systems analysis (FSA)	Integrates well and gives insight into agro-ecological and biophysical aspects of a farm; opens up dialogue with farmers	Representativity unknown; geo-referencing is lacking a part from transects; too qualitative in nature when it comes to ultimate judgment; time requirements; information is generalized and more on bio-physical factors, restricted to farm level and only farmer oriented; does not address sustainability and sustainable land use system;	Duivenbooden (1995), Mohamed (1999)
Land evaluation (LE)	Considers biophysical potentials for use of land; Developed substantial quantitative methods for it; and has geographical orientation	Time requirements; varying criteria for land unit division; not all land use included; Based only on potential land use; seldom addresses sustainability; Considers people only management skill or labour; purely socio-economic characteristics are excluded in suitability assessment procedures – only generalized; Does not go into the context of farm level, their problems and neglects resource conflicts; no guidelines for EIA	Mohamed (1999) Duivenbooden (1995)
Remote sensing	Geo-referenced data	For land use ground truthing is required; time requirements; scale changes cannot be observed; costs	Duivenbooden (1995), Lillesand and Keifer (1987)
Integrated transect method		Designed for valley systems; biophysical only; limited quantitative data	Duivenbooden (1995)
Integrated environmental assessments (IEA)	Strong component of participation by expert and non-expert "peer" communities and farmers	Biased towards environmental issues	Bailey *et al.* (1996)
Integrated land use planning and policy analysis (ILUPPA)	Reduces aggregation bias; with strong conceptualisation; based on quantitative data; and operationalization for sustainability concept; data geo-referenced right from farm level. So far the most well developed methodology for integrated management of natural resources	Biased towards socio-economic factors and crop production; no household consumption characterization	Mohamed *et al* (2000), Mohamed (1999)
Agro-humid	Strong biophysical data collection	Limited emphasis on socio-economic issues	Jaetzhold and Schimidt (1982), Hornetz (1991) Shisanya (1996)
Land evaluation and farming systems analysis	Has the upper hand over the separate application of FSA and LE	Difficulty of geo-referencing data collected by FSA to incorporate into LE data; lacks guidelines or procedures for linking and combining analysis at macro-level (e.g. regional) with those at micro-level (e.g. farm); there is no operationalization made for the sustainability concept	Mohamed (1999)

Source Mohamed (2001).



Source Mohamed (2001).

Figure 2.11.1 A summary of the major steps towards integrated framework for sustainable resource conservation.

CHAPTER 3. MATERIALS AND METHODS

3.1 INTRODUCTION

This chapter describes the study area and how the study was undertaken. Kenya lies in East Africa with Kajaido and Makueni Districts occupying the south central portion of the country. The region receives bimodal rainfall of 400 – 800 mm per annum and subsistence dryland farming, agropastoralism and wildlife conservation form the major land uses. By 2002, the two districts were estimated to have 1.3 million mostly rural populations.

3. 2 STUDY AREA

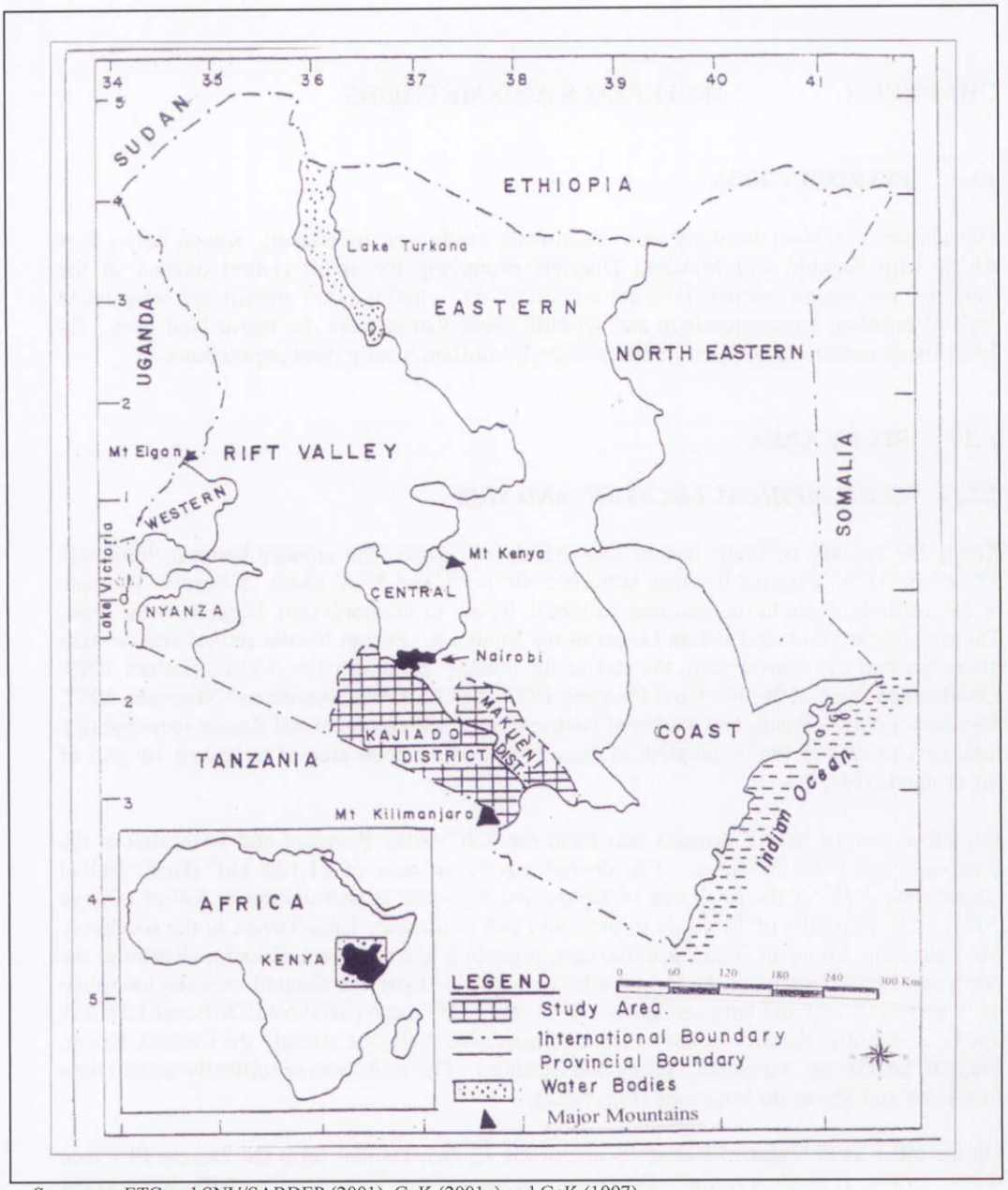
3.2.1 GEOGRAPHICAL LOCATION AND SIZE

Kenya the country of focus lies in East Africa and across the equator between longitude 33°50'and 41°45'east and between latitude 5°40' north and 4°04' south. It borders Ethiopia in the north, Somalia to the east and northeast, Sudan to the northwest, Uganda to the west, Tanzania to the south and Indian Ocean to the southeast. Except for the central and western highlands and the coastal strip, the rest of the country fall under the ASALs (Itabari 1999, Luukkannen *et al.* 1996, Pratt and Gwynne 1977, KEFRI 1992, Nyariki and Musimba 1997, Shisanya 1996). Kajiado and Makueni Districts lie in the south central Kenya (occupying a total area of 28,545 km^2 equivalent to almost 92% of the total area of Belgium) are part of the drylands (Fig. 3.2.1).

Kajiado is one of the 18 districts that form the Rift Valley Province and is located at the Southern tip of the Province. The district covers an area of 21,105 km^2 (GoK 2001c) constituting 3.4% of the total area of Kenya and the ninth largest district in Kenya (Oyaya 2000). The Republic of Tanzania to the south and southwest, Taita-Taveta to the southeast, Machakos and Makueni Districts to the east, Nairobi to the northeast, Kiambu District to the north and Narok District to the west border it. Kajiado District is situated between longitude $36^0$5' and $37^0$5' east and between latitude $1^0$10' and $3^0$10' south (SNV/SARDEP and ETC EA 2001). Currently, the district has seven administrative divisions, namely the Central, Isinya, Magadi, Loitokitok, Namanga, Ngong and Mashuru. The study was specifically under taken in Nkama and Merueshi Locations (Fig. 3.2.2).

On the other hand Makueni District is one of the 12 districts that form the Eastern Province (GoK, 1997). It borders Kajiado District to the west, Taita Taveta to the south, Kitui to the east and Machakos District to the north. The District covers an area of 7,440 km^2 constituting about 1.3% Kenya's area and is situated between latitude $1^0$35' and 2°35' south and longitude $37^0$10' and $37^0$32' east (GoK, 1997). Makueni has 16 divisions namely Wote, Kathonzweni, Kalawa, Kisau, Kaiti, Mbooni, Tulimani, Kasikeu, Kilome, Kilungu, Mulala, Matiliku, Nguu, Makindu, Mtito-Andei and Kibwezi. The research was focused to Ulilinzi and Thange Sub-locations (Fig. 3.2.3).

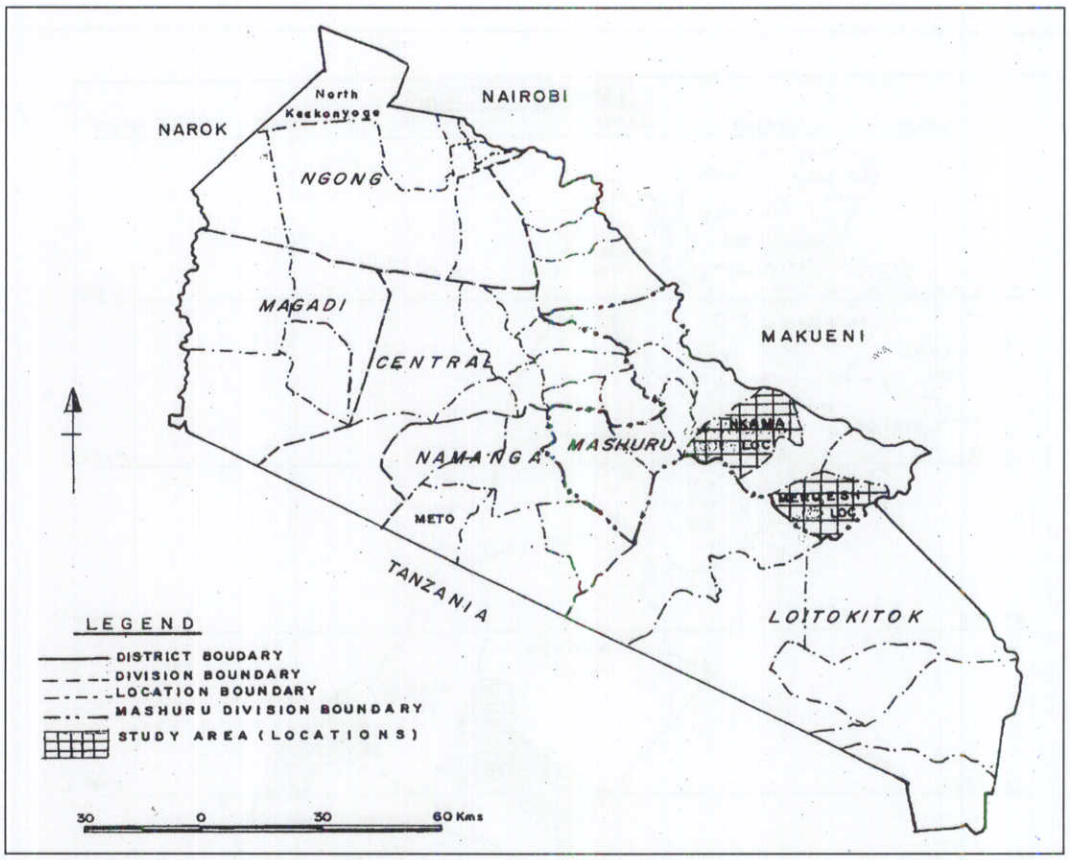
Mashuru and Kibwezi Divisions in Kajiado and Makueni Districts respectively are the focus in this study. The first division occupies eastern part of Kajiado District and covers an area of 2,250 km^2 (10.7% of the district) (GoK 2001c).



Source ETC and SNV/SARDEP (2001), GoK (2001c) and GoK (1997).

Figure 3.2.1 Map of the study area.

Mashuru is divided into ten locations, namely Ilmungush, Osilelei, Maparasha, Imarororo, Arroi, Mashuru, Nkama, Poka, Kinyawa and Merueshi. Mashuru divisional headquarters is situated about 150 km south east of Nairobi. About 40 km south to south east of Mashuru is situated Kibwezi Division. This division that lies at the southern part of the Makueni District comprises of Kikumbulyu, Masongaleni, Utithi and Kinyambu Locations. The division covers an area of 1,251 km square (16.8% of the district) (Emerton 1999). The divisional headquarters is situated about 200 Km southeast of Nairobi.

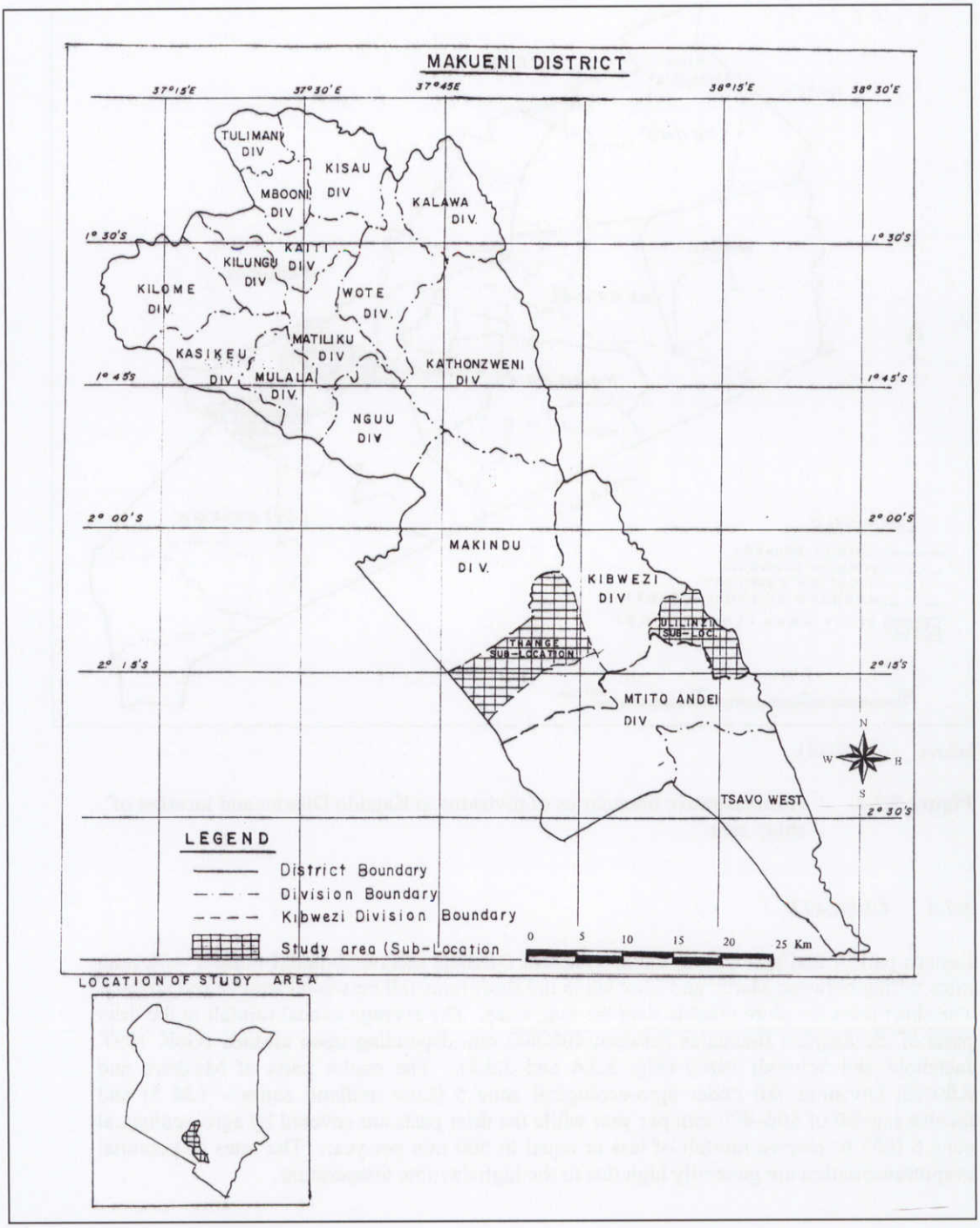


Source GoK (2001).

Figure 3.2.2 Administrative boundaries of divisions in Kajaido District and location of study area.

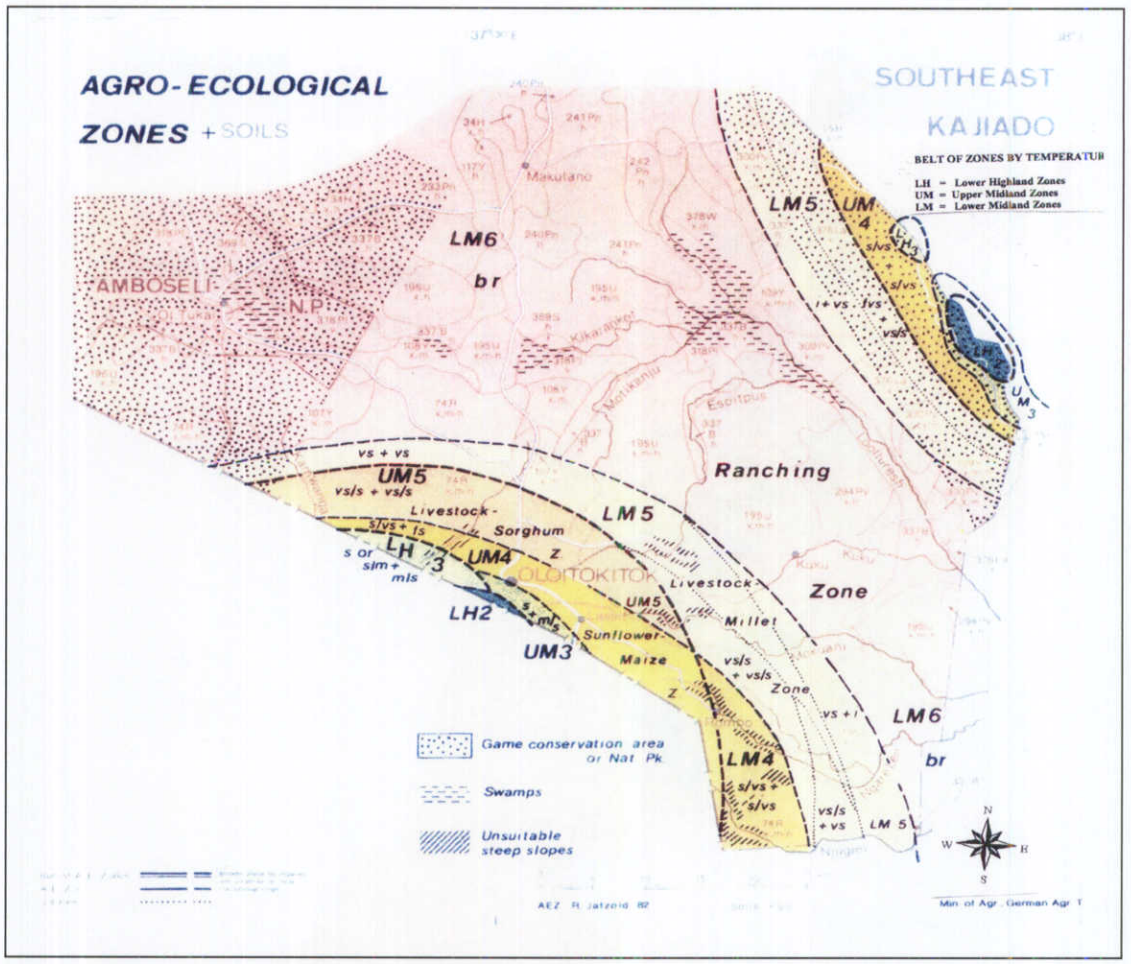
3.2.2 CLIMATE

Eastern part of Kajiado and Southern Makueni Districts receive bimodal rainfall with long rains falling between March and May while the short rains fall between October and january. The short rains are more reliable than the long rains. The average annual rainfall in the drier parts of the districts fluctuates between 400-800 mm depending upon altitude (GoK 1997, Jaetzhold and Schmidt 1983) (Fig. 3.2.4 and 3.2.5). The cooler parts of Mashuru and Kibwezi Divisions fall under agro-ecological zone 5 (Low midland zones – LM 5) and receive rainfall of 500–800 mm per year while the drier parts are covered by agro-ecological zone 6 (LM 6) receive rainfall of less or equal to 500 mm per year. The rates of potential evapotranspiration are generally high due to the high daytime temperature.



Source Forest Department (2004).

Figure 3.2.3 Administrative boundaries of divisions in Makueni District and location of study area



Source Jaetzhold and Schmidt (1983).

Figure 3.2.4 Agro-ecological zones of southeastern Kajiado, Kenya.

Temperatures in the region vary with altitude and season (GoK 2001a, GoK 2001c). Lower altitude areas have higher temperature and vice versa.However, the highest mean temperature (31 – 32°C) prevails during February - March, while the lowest (15-16°C) occur July-August. The region experiences intense heat during the dry periods of May and October (DHP 1997).

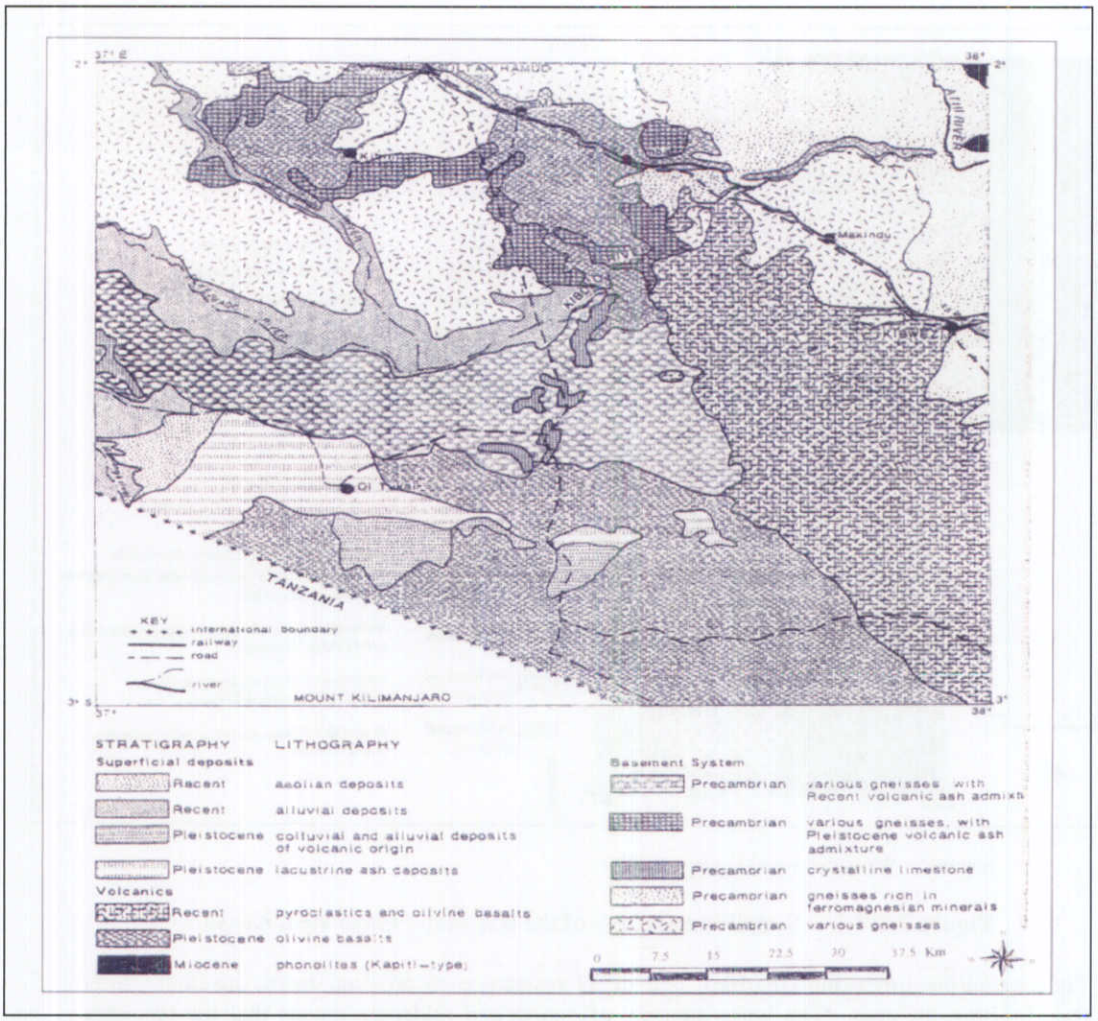
3.2.3 GEOLOGY, PHYSIOGRAPHY, LANDFORM AND SOILS

Touber (1983) and Wijngaarden and Engelen (1985) conducted detailed geo-pedology of the region and produced simplified maps of the study area (Figures 3.2.6 and 3.2.7).



Source Jaetzhold and Schmidt (1983).

Figure 3.2.5 Agro-ecological zones of Makueni District, Kenya. Makueni District constitutes the lower half of the figure.



Source Touber (1983).

Figure 3.2.6 Simplified geology of the Amboseli - Kibwezi area, Kenya.

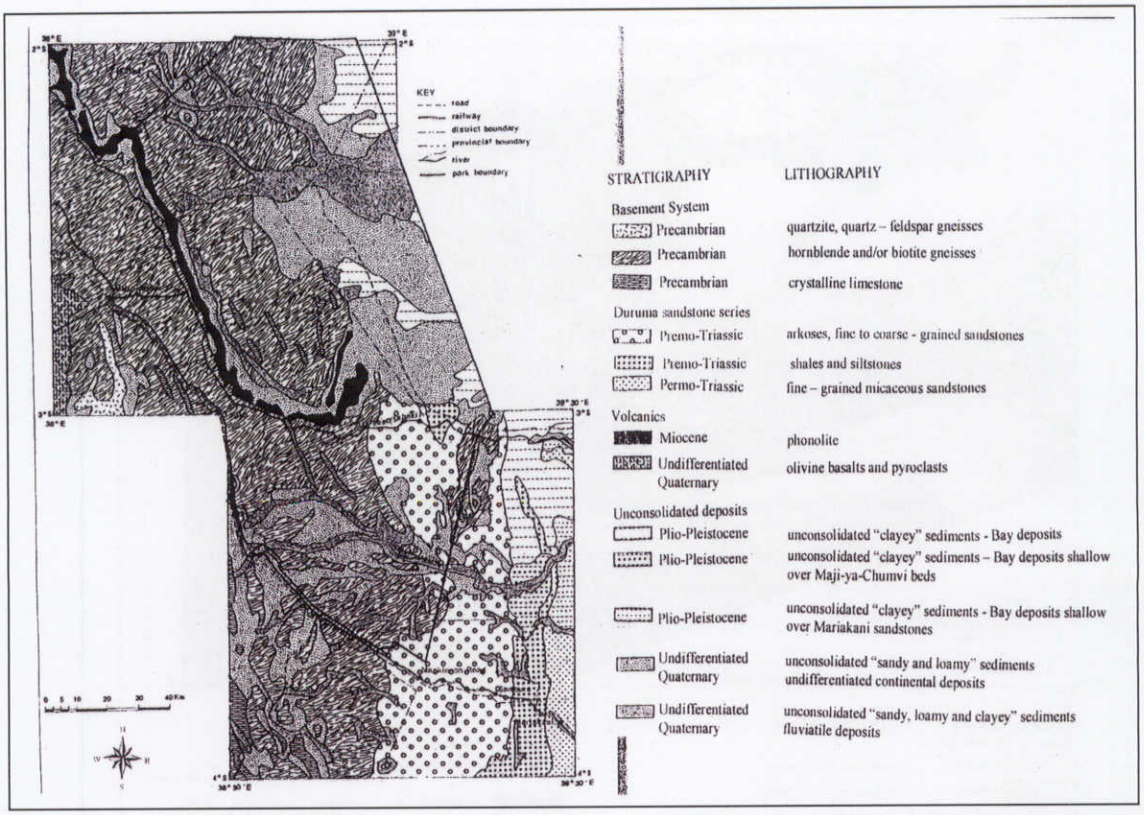
3.2.3.1 Geology

The following parent materials are found in the study area:

- ***Basement System***

These Precambrian rocks belong to the Mozambique belt within the Basement System and they dominate all other rocks in the area. Except for small area with crystalline limestone they consist entirely of gneisses, which are either poor or rich in ferromagnesian minerals.

The chemical properties of the poor rocks are mainly composed of quartz-feldspar and granitoid gneisses while the rich are composed of mainly biotite-hornblende, biotite and hornblende-garnet gneisses together with amphibolites.



Source Wijngaarden and Engelen (1985).

Figure 3.2.7 Simplified geology of the Kibwezi - Tsavo area, Kenya.

The crystalline limestone (marble), due to its resistance to erosion, forms inselburg hills found within the area. The large quantity of quartz and feldspars means that the resultant soils have rather high content of coarse sands. During the Pleistocene and recent times, volcanic activities enriched some of the complexes with volcanic materials. In Kibini area of Mashuru, the East African Portland Cement is mining marbles in large quantities for use in making cement.

- ***Volcanics***

The Pleistocene and recent times volcanic rocks cover mainly the Chyulu Ranges, Simba-Merueshi, and the Yatta plateau (which lies to the north east of the study area). It took place directly, through deposition, or indirectly, through redeposition as colluvial volcanic materials.

The pliestocene volcanic occur in Simba, Merueshi, Emali and Erankau-Olepolos-Arroi areas while the recent volcanic are represented by string of ash and cinder cones that form the Chyulu Range and its surrounding lava flows. The first consists of various plains made of olivine basalts at times in form of boulders, breccias, agglomerates and ashes.

- ***Superficial sediments***

The recent and colluvial sediments that are found along rivers and valley bottoms consist mainly of clay and sandy clay loam sediments derived from both the Basement System rocks and volcanics. Aeolian and lacustrine deposits are also common to the west of the study area in the Amboseli Basin.

3.2.3.2 Physiography and landform

The relief and landform of the study area is strongly influenced by the geology and can be broadly divided into Basement System, volcanic and depositional landscapes (Touber 1983 and Wijngaarden and Engelen 1985) (Fig. 3.2.8 and 3.2.9)

- ***Basement system***

Basement landforms comprise inselburg hills and foot slopes, high and low uplands and erosional plains. The hills with altitudes of up to about 1800 m above sea level (a.s.l) constitute the oldest landform in the study area probably of the Cretaceous and sub-Miocene period. Colluvial materials eroded from the steep hill slopes form concave foot slopes surrounding the hills. Down the foot slopes, gently to very gently undulating upland areas that form vast of the study area are found with an altitude of about 600 - 1000 m a.s.l. They are most likely formed during the late Tertiary period. Intercepting these landforms are the volcanic and sedimentary deposits.

- ***Volcanic landform***

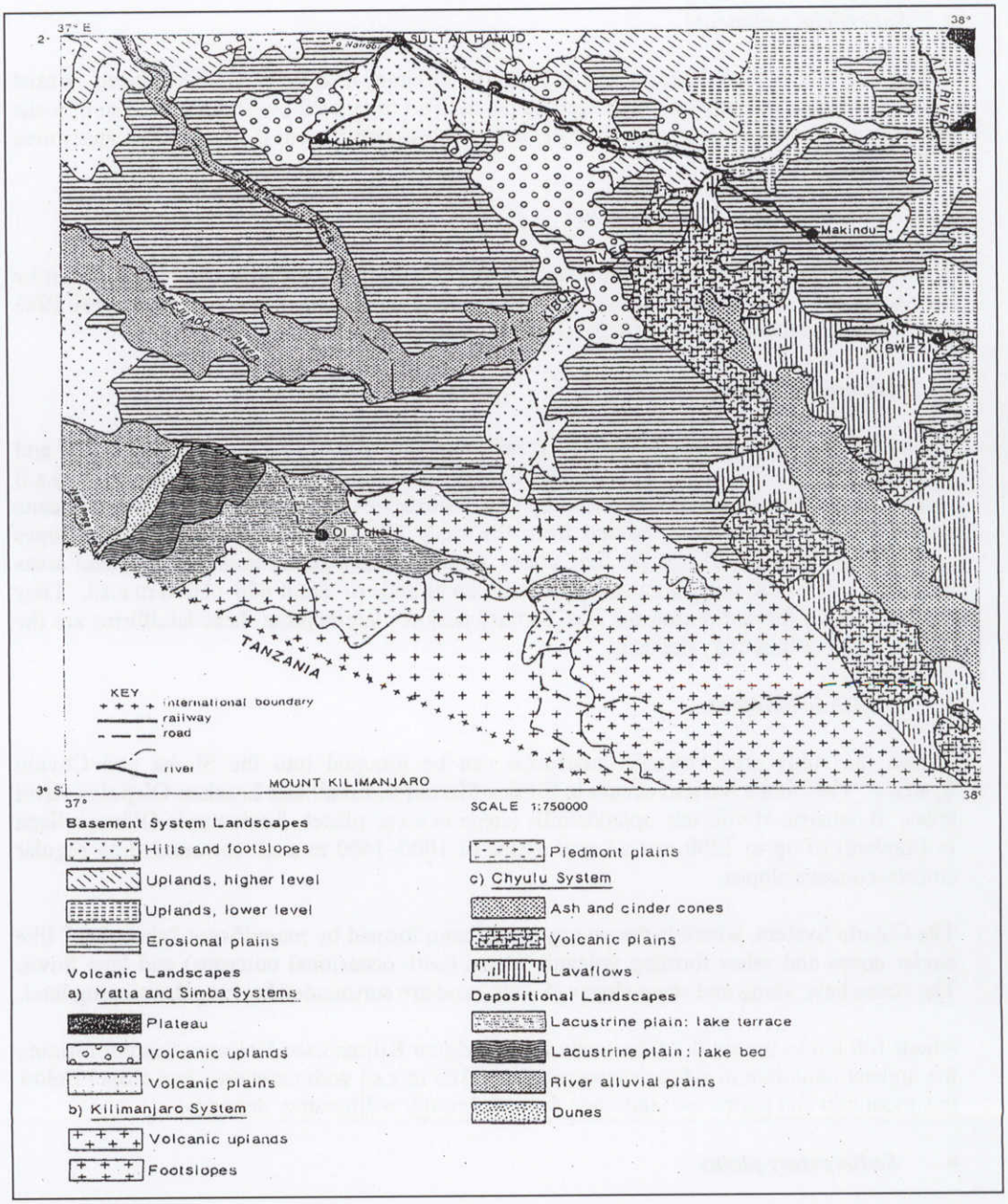
Within the study area volcanic landforms can be grouped into the Simba and Chyulu Systems. The Simba System occurs in Simba, Merueshi, Emali and Erankau-Olepolos-Arroi areas. It consists of volcanic uplands/hills (steep in some places, for example Oldonyo Sepa in Erankau) of up to 2200 m a.s.l. and plains of 1000–1400 m a.s.l. surrounded by regular convex-concave slopes.

The Chyulu System, which is the youngest has been formed by magnificent "chocolate" like cinder cones and ashes forming volcanic plains (with occasional outcrops) and lava flows. The cones have along and steep slopes (5-16%) and are surrounded by irregular sloping land.

About 100 km to the south of the study area is Mount Kilimanjaro Volcanic System forming the highest mountain in Africa rising to about 5800 m a.s.l with extensive foot slope. Below this mountain and plains are landscape formed through sedimentary deposits.

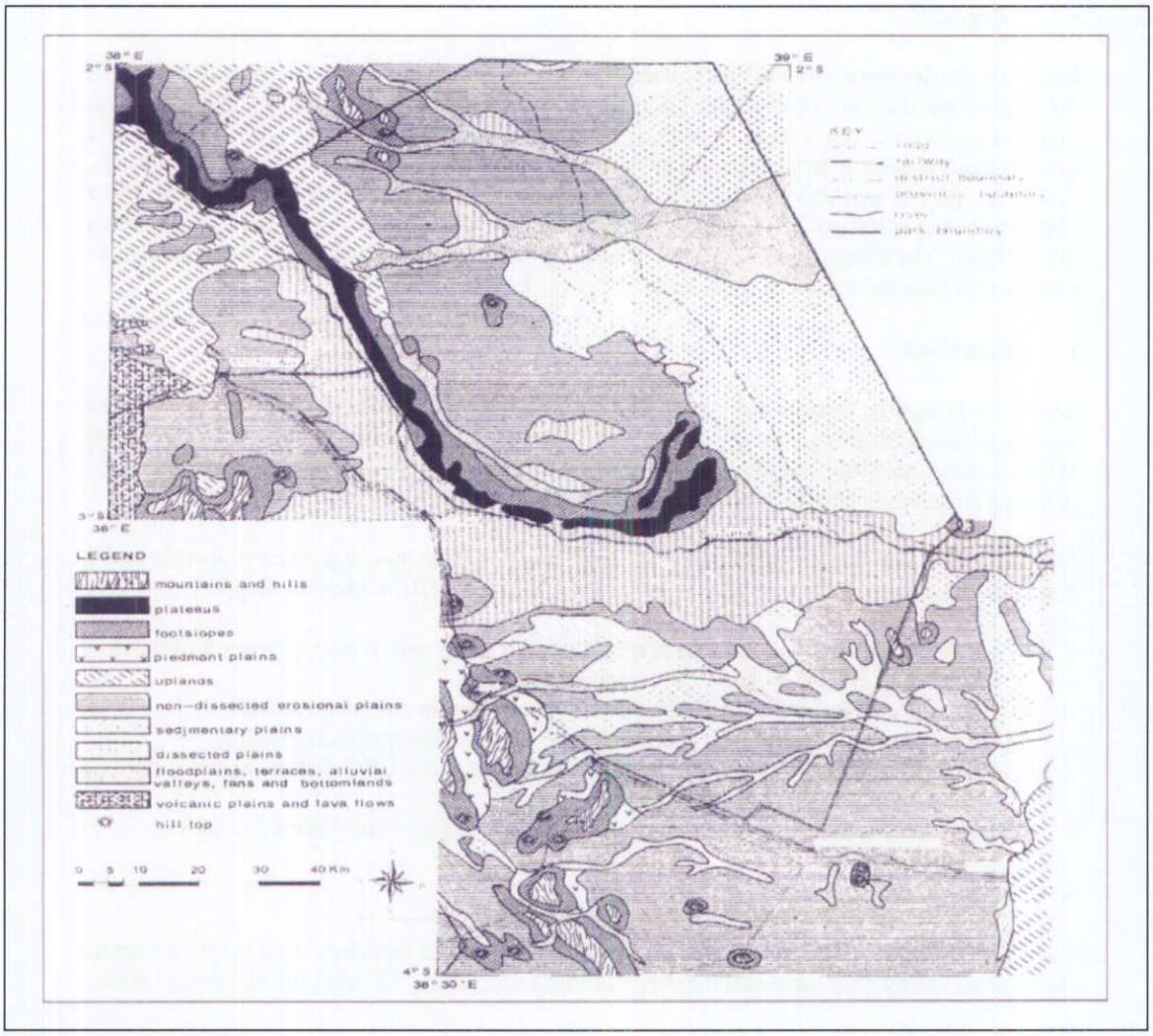
- ***Sedimentary plains***

Dichotomously intersecting and dissecting the uplands and the plains are numerous dry river colluvial and alluvial depositional flood plains and bottomlands. Lacustrine plains of Lake Amboseli are found to the south - south west of the study area.



Source Touber (1983).

Figure 3.2.8 Physiography of Amboseli - Kibwezi area, Kenya.



Source Wijngaarden and Engelen (1985)

Figure 3.2.9 Physiography of Kibwezi - Tsavo area.

3.2.3.3 Soils

The soils of the study area have been described at scales of 1: 1,000,000 (Sombroek *et al.* 1982) and 1:250,000 (Touber 1983 and Wijngaarden and Engelen 1985). They are strongly influenced by the geology, physiography and landform (Fig. 3.2.10). The following are the major soils starting sequentially from hills down the plains and finally in depressions.

- ***Regosols***

Regosols are developed on unconsolidated materials, exclusive of recent alluvial deposits. In the study area they are only found on steep slopes of hills and mountains. They have no diagnostic horizon other than a weakly developed ochric A-horizon that merges into unconsolidated parent material. In general the soils have an AC sequence of horizons. *Calcaric, dystric* and *eutric Regosols* occur within the region but *dystric Regosols* most common in the study area. The *calcaric* are calcareous at least between 20 and 50 cm from the surface. The *dystric Regosols* have a base saturation of less than 50% while the *Eutric* ones have a base saturation of more than 50% over the same depth.

- ***Cambisols***

These are relatively weakly weathered and leached soils with an ABC sequence of horizons in which the B-horizon is *cambic* one. The *cambic* B-horizon is an altered horizon that shows a developed soil structure and colour (reflected in stronger chromas or redder hues) different from the underlying horizon.

Usually cambisols have a high CEC-clay and abundant weathered primary minerals and a subangular blocky structure. Three types of *CAMBISOLS* occur within the region:

- *eutric cambisols*: soils without special features and with a base saturation of more than 50%; high CEC-clay increasing with depth;
- *calcic cambisols*: soils with accumulation of calcium carbonate almost throughout and saline and sodic in deeper sub-soil (*saline-sodic phase*);
- *chromic cambisols*: soils with reddish B-horizon. The CEC-clay increases with depth to about 100 me/100g;
- *chromic Cambisols, lithic and stony phase* is frequent within the study area.

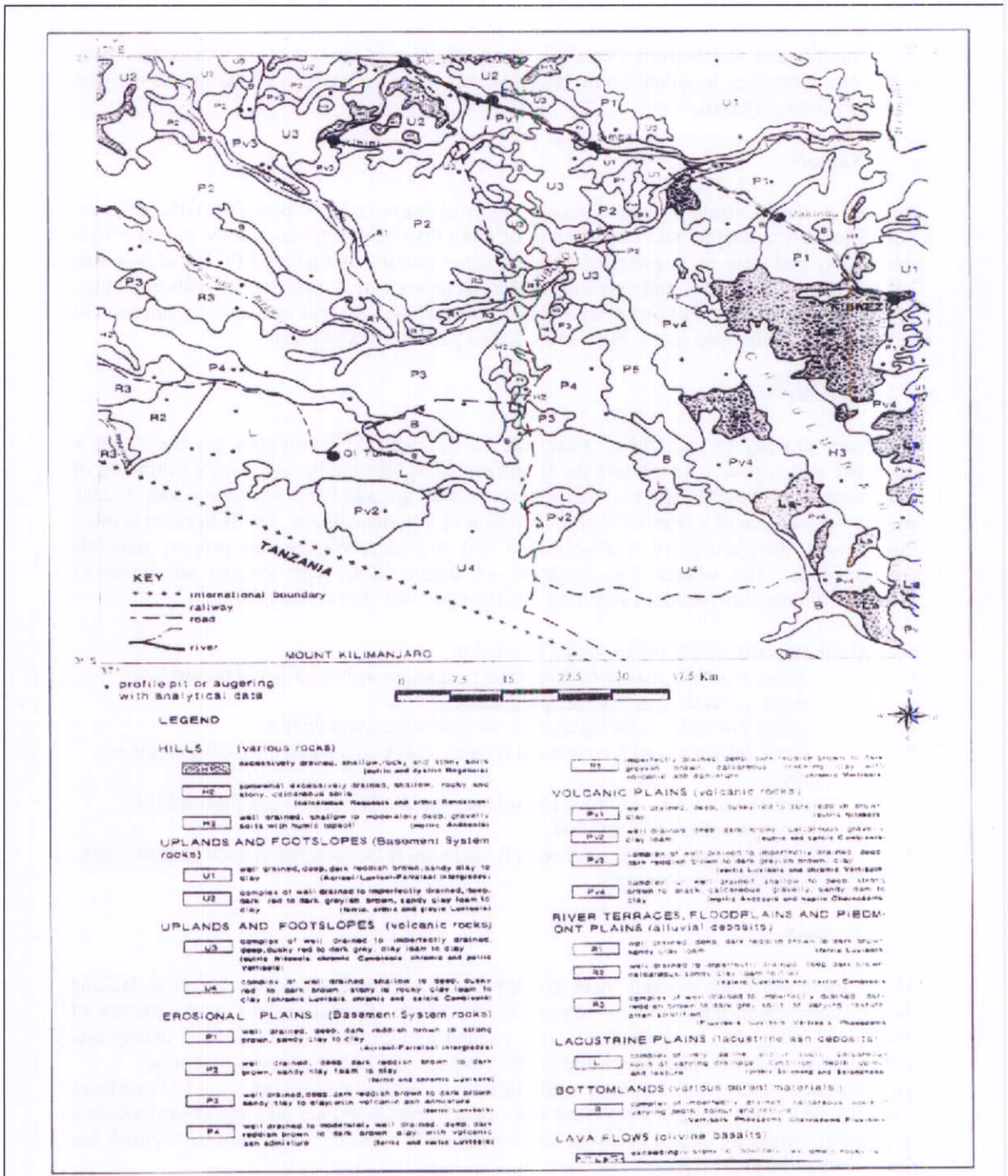
- ***Volcanic lava flow (Rock outcrops)***

Lava flows are excessively and extremely stony, rocky and bouldery with infills of humic and gravely sandy clay loam soil materials familiar around the Chyulu hills and Simba areas.

- ***Ferralsols***

These are strongly weathered and leached soils found within the basement system. They have relatively good physical properties but a poor chemical fertility. They have an ABC sequence of horizons with an ochric (low humic) A-horizon over an oxic B-horizon. The B-horizon is at least 30 cm thick, friable or very friable and with a stable sub-angular blocky to porous massive structure. The soil has a CEC-clay of less than 16 me/100g, low content of weatherable primary minerals. The clay mineral is predominantly 1:1 (kaolinitic group). The *FERRALSOLS* are well drained but according to FAO-UNESCO classification variations in B-horizon colour makes it possible to distinguish it into three subunits within the study area:

- *rhodic Ferralsols* - with a red to dusky red oxic B-horizon
- *Acri*-xanthic Ferralsols* – with a yellowish brown B-horizon
- *Acri*- orthic Ferralsols* – with dark reddish brown B-horizon



Source Touber (1983).

Figure 3.2.10 Generalized soils of the Amboseli - Kibwezi area, Kenya.

Acri*-xanthic and Acri*-orthic Ferralsols occur together in one mapping unit in the study area. The difference in colour could be associated more to drainage conditions in the past than the parent materials.

- ***Nitosols***

Nitosols are fairly strongly weathered soils with distinct boundaries between ABC horizons. The B-horizon is argillic with clay content of more than 40%, angular blocky structure with many shiny ped faces in deeper part, high aggregate stability and with CEC-clay of less than 24 me/100g. Close to the study area in (Mashuru) only *eutric Nitisols* occur with more than 50% base saturation in B-horizon and high biological activity that cause the occurrence of low amount of shiny ped faces. The colour is dusky red to dark reddish.

- ***Luvisols***

These are strongly to moderately weathered soils with ABC horizons but the A has a relatively low organic matter while the B-horizon is argillic and usually a base saturation of more than 50%. Additionally the later horizon has an angular blocky structure and its clay content increases over a relativelly short distance of less than 30 cm. The B-horizon is often little porous, with associated relatively high bulk densities. Weatherable primary minerals are common. The silicate clay minerals are mainly illite with varying admixture of montimorillonite clay minerals, resulting in CEC-clay well above 16 me/100g.

Several subunits can be identified within the region:

- *gleyic Luvisols* – show hydrophobic properties within 50 cm of the surface;
- *vertic Luvisols* – with vertic properties;
- *calcic Luvisols* – with calcic horizon within a certain depth;
- *ferric Luvisols* – with coarse red mottles in B-horizon and CEC-clay is rather low;
- *chromic Luvisols* – with well developed argillic B-horizon and dark reddish brown to redder colours; and
- *orthic Luvisols* – with a rather well devloped B-horizon but the colour is not dark reddish brown or redder.

- ***Vertisols***

These are imperfectly drained, dark coloured, fine textured, cracking clay soils lacking distinct horizons in their profile – (A-AC-C sequence). Because of the predominance of montmorillonitic clay minerals these soils expand and contract strongly upon drying and wetting. As a result of these clay minerals they expose great plasticity and stickiness.
The repeated cycles of swelling and shrinking leads to polished grooved surfaces (slickensides) in the subsoil. They have low organic matter and are alkaline or near alkaline in reaction. Majority of the *Vertisols* have saline sodic subsoil. Two types of *Vertisols* are found within the study region:

- *pellic Vertisols* – have moist chromas of less than 1.5 dominant in the soil matrix throughout the upper 30cm. The black colour prevails throughout the upper 30 cm; and
- *chromic Vertisols* – with dark brown to black colour.

3.2.4 HYDROLOGY

A part from rivers, springs, boreholes, water pans and earth dams other sources of water in the districts are ponds and water holes, shallow wells, pipe lines and roof catchments (SNV/SARDP and ETC EA 2001, ACTIONAID 1993, ARIDSAK Project pers. Comm. 2002, GoK 2001c, AMREF 2002, Southgate and Hulme 1996b, Itabari 1999, District Water Engineer Makueni and Kajaido Districts pers. Comm. 2002). The scarcity of the water leads to loss of productive time as communities spend many hours trekking for water instead of concentrating on income generating activities. The death of livestock and failure of crops makes the poor to open up water catchments to eke out a living through cultivation. The resulting deforestation has led to denudation of land.

Due to the semi-arid nature vegetation cover is limited in most of the year. Additionally, the absence of windbreaks on-farms in the two districts does not only facilitate the loss of the much needed soil moisture but also ripping off roofs (GoK 2001c). Similarly such winds erode the fertile top soils of the farms.

3.2.5 PLANTS AND ANIMALS

Flora is mainly *Acacia-Commiphora* bushland and grasslands dotted with riverine and highland forests on ameliorated hill tops and mountains. Some parts are occupied by *Combretum* species. The other major species are *Adansonia digitata* and *Acacia* spp. Perennial grasses such as *Cenchrus ciliaris, Enterepogon macrostachyus, Chloris roxburghiana and Eragrostis superba* are common (Pratt and Gwynne 1977, Touber 1983, Wijgaarden and Engelen 1985).

A part from threat of farming and settlements, charcoal burning has taken a foothold in the region. As its demand increases in big cities such as Nairobi, tree cutting becomes rampant causing degradation of water catchments, riverside vegetation, hilly areas and the result has been soil erosion, loss of biodiversity, wildlife habitats and adverse climatic phenomena like recurring droughts.

Kajiado District especially Mashuru Division is rich in wildlife that normally grazes with livestock in community pastures. They include Buffalos, Elephant, Zebras, Gazelle, Wildebeest and ostrich (ASAL Programme 1990).

In Kibwezi, wildlife is mainly restricted to Chyulu Hills that forms part of the Chyulu National Park and Kibwezi Forest Reserve. They include Baboons and elephants.

By 2003, Kibwezi Division had an estimated 79000, 64000, 34000 and 475 heads of cattle, goats, sheep and donkeys respectively and 256 000 poultry (Divisional Livestock Production Office 2004). Almost all the animals were local breeds. Similarly, by 2000 Mashuru Division had an estimated 67000, 31000 and 122000 heads of Cattle, goats and sheep respectively. This number was 2 to 3 times less than the animal population for the division as at 1999 due a severe drought that occurred in 2000 (Kajiado District Development Office 2002). Other types of livestock are rabbits, poultry, pigs and camels. Livestock management strategies are mainly traditional using natural grazing lands and local feed resources such as free grazing and tethering (GoK 1997).

3.2.6 DEMOGRAPHY

Kenya has a population of 29 million (GoK 2001a) with a population growth of 2.5% (average 1992-1998) and a population density of 51 persons per km^2 (Mbithi 2000).

The drylands of Kenya including Kajiado and Makueni Districts support 25% of the Kenyan population, as well as 50% of its livestock (Muchena and Pouw 1981, KEFRI 1992). Most of the population in the drylands is made up of pastoralists (14.5% of the total population) who own most of the livestock (Farah 1997). The natural resource components (water, soil, plant and animals) in this harsh environment are the fundamental means of existence for over 80% of the rural poor communities (Wandera 1998, GoK 2000).

In the recent past, population pressure has increased in the drylands especially in areas of relative productive land such as the humid margins of rangelands and around the sparse wetland environments (Southgate and Hulme 1996a). This is as a result of a high (3.3%) annual growth (GoK 1994) and influx of people migrating from the densely populated high potential areas (Itabari 1999) such as Machakos and Kitui. Before 1961 most of the areas in Kibwezi were unoccupied and uncultivated. Thereafter there was a wave of settlements from Machakos and Kitui Districts soaring population density to the present day land deterioration prevalent in the area (Teka 1997). Over 70% of the inhabitants were migrants (Teka 1997).

In the 1999 population census, Mashuru had a population of 35,666 with a population density of 12 persons per km^2. In the same year Kibwezi Division had a population of 80,236 with a density of 85 persons per km^2. (GoK 2001a).

3.2.7 LAND TENURE AND LAND USE

3.2.7.1 Land tenure

Today, except for few scattered sections owned by the Central Government and Local authorities, individual farmers own most of the land in Kibwezi.

In Mashuru, most of the land is owned communally/group ranches although they are currently being subdivided into individual ownership. In some parts, the communal ownership is causing "tragedy of the commons" and therefore may not be ideal for the wise use of natural resources. However, it seems to be good for keeping large herds of livestock. Despite the land being owned by communities/groups (GoK 1997), individuals own the livestock. The pastoral Masaai Community are facing resource use conflicts from various sectors, that is, wildlife, agriculture, pastoralism, tourism and urbanization (Igoe and Brockington 1999, Woien and Lama 1999).

3.2.7.2 Land use

In Kibwezi, crop production through subsistence dryland farming is the most common type of land use. This type of land use takes place against a background of inadequate soil moisture and crop failures (Itabari 1999). The major crops grown are maize, beans, pigeon pea, cowpeas, green grams, sorghum, millet, cassava and cotton. The growing of vegetables

(mainly tomatoes, chilli pepper, kales, onions and okra) are emerging along permanent rivers like Athi River and its tributaries.
Woodlands with trees providing multiple products is another types of land use (Emerton 1999). Wildlife and forest protection also covers part of the sub-region (GoK 1997).

The major type of land use in Mashuru is pastoralism and dryland farming with maize and beans are the major types of land use. Wildlife also freely graze with livestock in pastures while irrigation of vegetables and fruits along River Esenlengei is common in Ngorika area. Kobine (marble) limestone is also mined within the division for cement production (GoK 1997).

3.2.8 MARKETS

Markets in Kibwezi and Mashuru operate on "daily rotational basis" (market days). However, the prices of goods (especially agricultural products) fluctuate with seasons. Livestock products are cheap in dry seasons while the same is true for crop products just after rainy seasons (harvest). Marketing of the farm produce (crop and livestock) has been "hijacked" by middlemen who exploit the poor farmer by capitalizing on farmers' lack of information and ability to organize themselves into functional marketing institutions. Other factors include inadequate agronomic skills and practices, limited labour supply at critical peak periods of planting and weeding, unavailability/inaccessibility of farm inputs, especially seed and farm inputs.

Socio-cultural factors (towards subsistence farming in Kibwezi and livestock rearing in Mashuru) and unchecked population growth has given rise to many mouths to feed which has been matched by increased household production results in cyclic food deficit (Kisyula 1997, Wekesa 2000 pers. com).

3.3 THE SELECTION OF SPECIFIC SITES

3.3.1 THE STUDY SUB-REGIONS (DIVISIONS)

Kibwezi (Makueni District) and Mashuru (Kajiado District) Divisions (Figures 3.2.2 and 3.2.3) were selected as case studies for the following reasons:

a) they represent more severely degraded areas of the drylands of Kenya with widespread poverty and frequent food shortages;
b) the divisions are relatively accessible to conduct fieldwork with limited financial resources and time constraints. The Nairobi – Mombasa Highway passes through the two divisions;
c) the proxy of the divisions to the highly populated areas of central Kenya is encouraging emigration to Kibwezi and Mashuru, hence may cause unsustainable impact on the natural resource components within the area;
d) the communities in the two divisions can act as representatives of all the Kenyan communities living in the drylands. This is so because, the Kamba who settle in Kibwezi Division are mainly mixed farmers while the Masaai who settle in Mashuru Division are mainly agro-pastoralists and therefore appropriate model(s) for integrated management of natural resources can easily be formulated for the two areas at a minimal cost; and

e) there are on-going activities addressing the issue of natural resource management, land degradation, agriculture and agroforestry in these areas, which could provide some data/information for the study to build upon.

3.3.2 THE SELECTION OF THE SPECIFIC STUDY AREA SITES

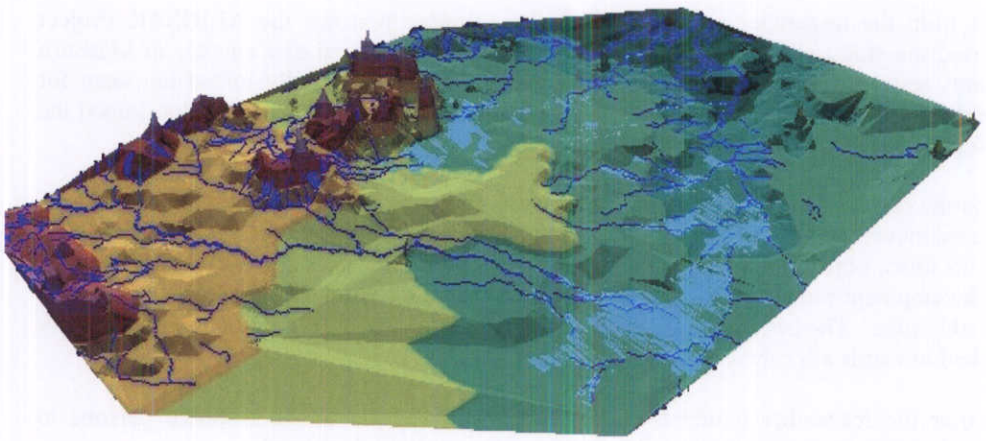
Climate (mainly rainfall) was the basis for the selection of the locations and the sub-locations; the driest and the wettest locations were selected. The driest parts of the divisions are in agro-ecological/climatic zone six while the wettest are in agro-ecological/climatic zone five (Pratt and Gwynne 1977, Braun and Mungai 1980, Jatzhold and Schmidt 1983, Hornetz *et al.*1992). This means that the two agro-climatic zones are adjacent to one another hence can easily be compared in terms of natural resource components (NRCs) and their management. A part from the available climatic data the classification was further supplemented with experiences from field officers working in the area and from vegetation types of the area.

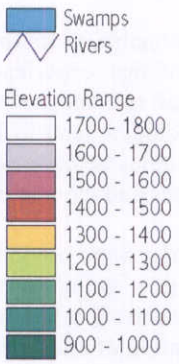
Consequently, in Kibwezi – Thange and Ulilinzi sub-locations of Utithi and Masongaleni locations respectively were selected. Almost the whole of Thange sub-location is in agro-ecological/eco-climatic zone (AEZ) V with annual rainfall of 450 – 900 mm per year while the whole of Ulilinzi sub-location is in AEZ VI with annual rainfall of about 300 – 550 mm per year. As for Mashuru, Sultan Hamud and Imbuko sub-locations of Nkama and Merueshi locations respectively were selected. Large part of the Sultan Hamud sub-location is in agro-ecological zone (AEZ) V while the whole of Imbuko sub-location is in AEZ VI. The occurrence of *Acacia – Commiphora* bush land too indicates AEZ VI while AEZ V is associated with the presence of *Combretum* woodlands.

The study concentrated specifically at the village level. A village, which is the smallest unit of administration in the study area and whose boundary is clearly defined, is too the smallest unit of this study. As a consequence, on-farm studies were only used to understand what is happening in a village. Per sub-location, a village, which is a representative of the typical rural set up and with diverse landscape types to represent the selected location and sub-locaton, was selected. Similarly, in each division, one of the villages had either the highest or the lowest number of natural resource management interventions/natural resource related projects. Accordingly, the chiefs (Government administrators responsible for the locations and sub-locations) were requested to list all the villages within the respective sub-locations and the various development projects that operated/still operating and the activities they undertake/undertook in each village.

From the list, Muusini and Bondeni Villages were selected in Ulilinzi and Thange sub-locations of Kibwezi and Isara and Erankau in Imbuko and Sultan Hamud sub-locations of Mashuru respectively. These villages were representative of other villages within their respective agro-ecological zones and in terms of landscape types and interventions. Bondeni and Erankau represent villages in AEZ V and those with the least interventions while Muusini and Isara represent those in AEZ VI and with the most interventions.

Muusini landscape consists of plains with 690 – 730 m a.s.l. Bondeni is composed of plains and valleys with altitudinal range of 980 – 1020 m a.s.l. Erankau Village is predominantly hilly area (1230 - 1700 m a.s.l) while Isara is made up of few hills and lowlands but the vast of it is made up of plains (1110 – 1240 m a.s.l). (Fig. 3.3.1)





NB: The swamps mentioned occur only in rainy periods

Source Mohamed (2001).

Figure 3.3.1 Digital terrain model for eastern Kajiado, Kenya.

3.3.3 *IDENTIFICATION OF THE RESEARCH TEAM AND SENSITIZATION OF LOCAL COMMUNITY ON THE STUDY*

Once the villages had been selected the chiefs were requested to identify two-community resource persons per village. They were informed that the local resource persons be very knowledgeable on the management and use of the villages' resources including having excellent public relation (PR) with all members of the village. As a result eight community resource persons were identified.

A part from the researcher and the community resource persons, the ARIDSAK Project supported the study with two research assistants, one in Kibwezi and another in Mashuru Divisions respectively. Additionally, the Kenya Supervisor frequently joined the team for guidance and execution. At times interested members of the various villages too joined the exercise not forgetting the chiefs of the study areas.

Prior to the commencement of field studies, the chiefs, community resource persons and the village members were briefed individually and in various meetings on the importance of the study, its aims, objectives and duration of the study. It was made clear to them that this is not a development project with funds but rather an academic study that requires sacrifices of their noble time. The briefings and meetings harnessed a team spirit that could not be easily described in words after three years.

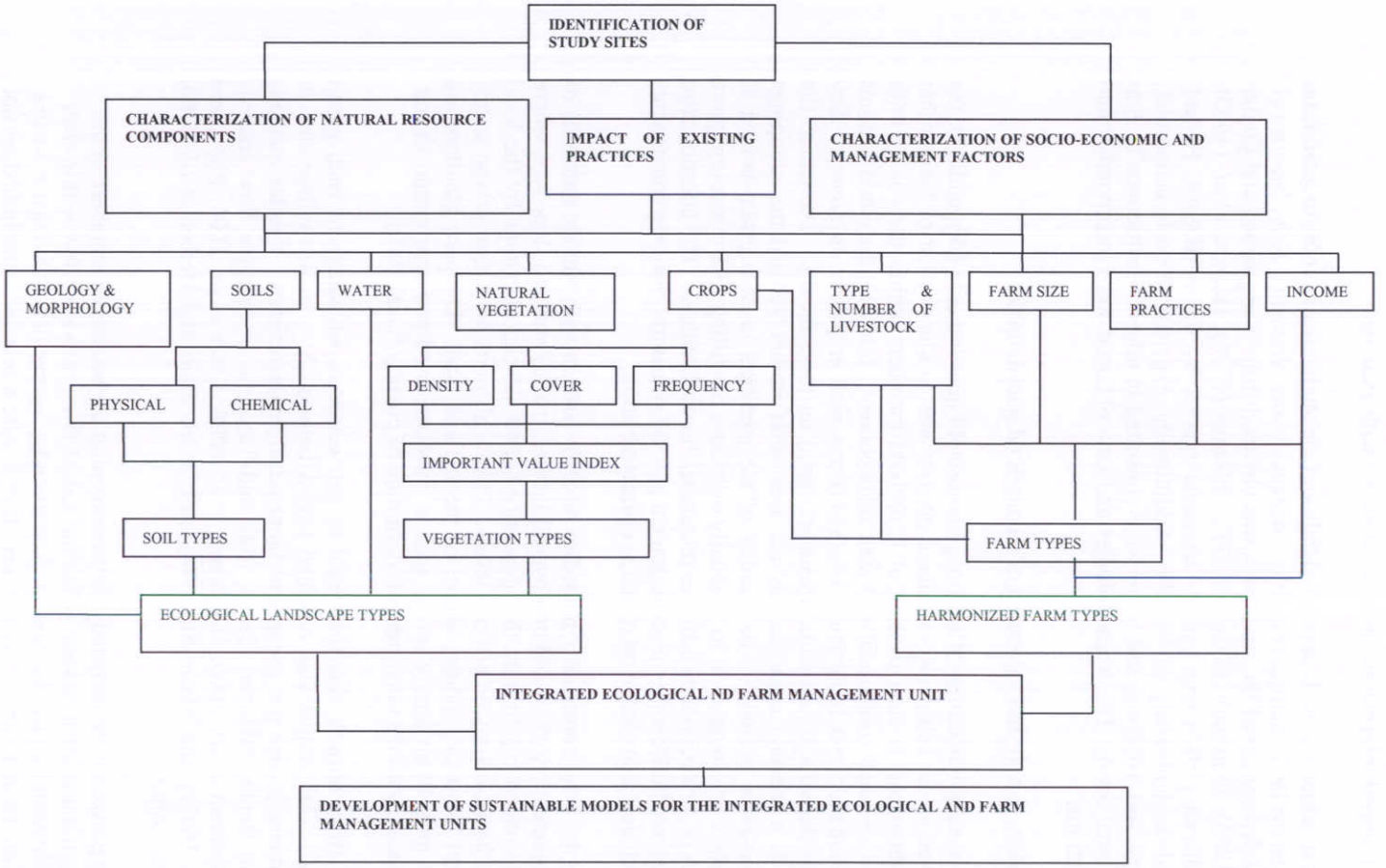
Thereafter the researcher (student) made verbal agreement with the resource persons to commit their time and patience in order to help in the study as "teachers".

After identifying the study sites, research team and sensitizing the local communities, field studies were executed based on the objectives.

3.4 METHODOLOGIES FOR DATA COLLECTION

Archival data on the status of the resources, questionnaire, participatory characterization, discussions with individual and groups at various meetings, experiences, provision of tasks to community resource persons, laboratory analysis of soil and water components, formed the core techniques for data collection. The methodologies lead to the characterization of resources while simultaneously undertaking impact studies before analyzing the data for the identification of landscape types, harmonized farm types and the integrated units (Fig.3.4.1).

Amongst the techniques for data collection, three of them were used in achieving most of the objectives and will therefore expounded upon before going to the methodologies by objectives. They include collection of secondary (archival) information and consultations with expertise and the development, testing and validation of a household questionnaire, and discussions with communities and tasks to the resource persons.



Source A modification of Mohamed 2001, Mohamed *et al.* (2000).

Figure 3.4.1 Conceptual methodological framework for data collection and analysis.

- Collection of archival information and consultations with expertise

Archival data was obtained on the Kenyan drylands and the study area in order to learn from past experiences (Dietz 1987, Semgalawe 1998, Mazzucato and Niemeijer 2000, Norman *et. al* 1995). General description of the study area was obtained from Wijngaarden and Englen (1985), Touber (1983), Pratt and Gwynne (1977), Shisanya (1996), Hornetz *et al.* (1992), Jaetzhold and Schimdt (1983) and various technical reports by the ARIDSAK Project, ACTION AID and the University of Nairobi. Additionally, expertise in socio-economics, agriculture, forestry, soil, livestock and water were consulted in relevant institutions both at international and local levels. The methodologies and data obtained were incorporated into the appropriate sections.

- The development, testing and validation of a household questionnaire

In preparation for the administration of a 35 page household questionnaire (Appendix I), the first field task given to the community resource persons was to identify list of factors that were considered important in classification of household members within the village with attention to natural resource component and their management. Since all the classifications zeroed to socio-economic and biophysical characteristics with emphasis on poverty, they were told to group the village household members based on these factors. Thereafter, the village members in a meeting organized by the area chief further verified the groupings prepared by the resource persons. The number of the members in each group helped in getting the percentage coverage so as to rationally distribute the filling of a minimum quota of 8 household questionnaires planned by the researcher for each village. The questionnaire was meant to understand differences in management and use of natural resource components and indigenous technical knowledge on resource characterization.

The groupings by the local community helped to identify farmers with similar standards of living, farm management practices and biophysical factors (mainly soil and slope type where appropriate). It is interesting to note that generally household classifications by the local communities were based mainly on poverty levels. The locals perceive a poor person as one with no or minimal livestock, spouse, source of income and land. The poor therefore are those who cannot meet basic family needs, such as adequate food and appropriate shelter. This definition concurs with the Governments definition of poverty (GoK 2001b).

The list obtained from farmers was then used to get weighted percentage of each group within the village. The sample size obtained varied between 8 – 10 per village due to differences in percentage size per group and biophysical characteristics. Similar methods have been used in Benin, Ethiopia, Kenya, Mali and Tanzania in resource flow analysis (Eyasu 2000, Budelman *et al.* 2000, Dembemé *et al.* 2000, Kater *et al.* 2000, Piters and Ndakidemi 2000, Defoer and Place 2000, Wennink *et al.* 2000 and Defoer *et al.* 2000, Mergeai 2001 Pers. Com.).

Since the resource persons were knowledgeable concerning the household members of the villages, they helped in the identification of the individual farmers to interview within each group and under different biophysical factors. Additionally, reserve lists of at least 3-4 extra households based on the same above criteria were kept in case a selected household does not cooperate in the interview. It is useful to have reserve list (Wiyoo 1999).

However, a part from one agro-pastoralist who migrated with his livestock to far place, no uncooperative farmer or agro-pastoralist has been encountered. Upon grouping of the households within each village, the questionnaire was pre-tested and validated. Thereafter the questionnaire was administered and verified between March 2002 to March 2003 with sample population in each village (Plate 3.4.1). Before the interview, appointments were made with the head of the households and in case he/she does not keep appointment(s) any elderly member of his family replaced him/her. Then farmers/pastoralists selected were briefed on the aim, objectives and duration of the fieldwork and expected outputs of the study. Local languages of Swahili, Kamba and Masaai were be used to elaborate. At the end of each day of interview, the researcher and the research assistants crosschecked the questionnaires for errors and completeness.



Photo by A. Mohamed in 2002.

Plate 3.4.1 Questionnaire administration involved the full commitment and patience of the farmer, the community resource person and the Researcher/Research Assistant.

A total of 36 questionnaires were administered per the different poverty groups (Table 3.4.1).

Table 3.4.1 Number of household questionnaires administered in four study villages of Kibwezi and Mashuru Divisions, Kenya.

Village	Poverty groups			Total questionnaires administered
	I (Well off)	II (Medium)	III (Poor)	
Muusini	2	2	5	9
Bondeni	2	2	4	8
Isara	2	3	4	9
Erankau	3	3	4	10
Total	**8**	**10**	**18**	**36**

- *Discussions with communities and tasks to the resource persons*

Regular meetings were organized with the community and individual farmers/agropastoralists in order to discuss issues on characterization and understand the impacts of the existing management practices on the natural resource components and for clarification. Additionally, the community resource persons were given tasks at different times in order to fine tune and harmonize the characterization and impact studies.

The following methodologies were used to execute the set objectives.

3.4.1 CHARACTERIZATION OF THE NATURAL RESOURCE COMPONENTS

The characterization of the resource components were undertaken between December 2001 to March 2004. Information were obtained mainly from the household questionnaire, tasks to resource persons and participatory field characterization. Due to limitation of time and resources plus the bulky nature of the work only 36 questionnaires were administered and soil and water samples were restricted to 1-6 per agro-ecological landscape types and to major water sources.

3.4.1.1 Socio-economics aspects

Data on socio-economic aspects were mainly obtained from the household questionnaire, discussions with communities (Plate 3.4.2) and tasks to the resource persons. Other sources were archival data and experiences.

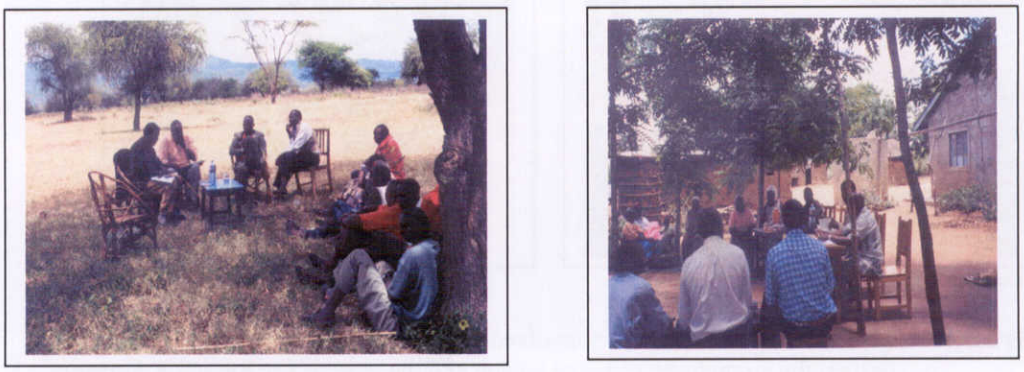


Photo by A. Mohamed in 2004.

Plate 3.4.2 Discussions and meetings with village elders provided valuable information on natural resource management and use.

Once the farmers have been classified, the population structure, levels and accessibility to education, availability of on-farm labour, roles of the different household members, sources of income, entitlements and the estimated food and nutrition use within each village were studied.

3.4.1.2 Vegetation, soil, animal and water resources

The single most important source of information was participatory characterization and assessment (Plate 3.4.3). Based on the past experiences and expertise consultations, participatory resource characterization and assessment was selected as an appropriate tool to understand the status of natural resource components. The methodology has inputs from modern sciences and indigenous technical knowledge (ITK). ITK is important because the people living in a particular environment may best understand of the situation (Idris *et al.* 1998). A research team composed of the researcher; two community resource persons per village and a research assistant jointly executed the characterization in each village. A compass, Global Positioning System (GPS), topographic and registered index maps (farm maps) of the study areas were the major field tools used.

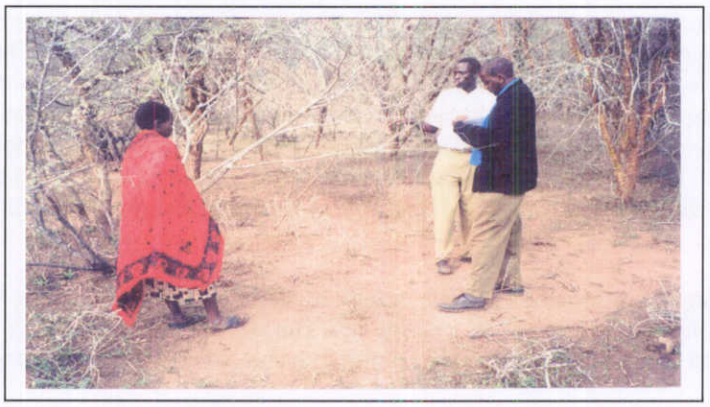


Photo by A. Mohamed in 2003.

Plate 3.4.3 The participatory characterization combined ITK from farmers/agropastoralists, community resource persons and modern science from the researcher.

Since there were no existing village maps, the team delineated each village's boundaries from the existing farm maps. The area chief then verified the new maps. Once village boundaries were delineated, soil types per farm were marked out with the support of the resource persons. Additionally, where the spread and occurrence of natural vegetation was not uniform, the community resource persons helped in delineating the major clusters in the village. Similarly, where the spread of natural vegetation was the major coverage, the resource persons delineated positions of the croplands. The fieldwork commenced with a reconnaissance survey criss-crossing the village and confirming what was delineated on the village map by the resource persons. The field reconnaissance with extra input from aerial photographs and existing maps identified landscape types (a unit made up of areas with similar slopes, rocks, soils and vegetation) within the villages.

(i) Vegetation, soil and animal resource studies

- ***Vegetation and soils under natural woodlands, and animals***

Studies on change in vegetation and degradation of soil resources are necessary because they are valuable indicators of the extent and severity of land degradation and pressures at a particular site (GoK *et al.* 1997). Grazing pressures and the selective human harvesting of woody plants for construction or fuel leads to a change in the ratio of desirable to undesirable species.

In sampling the vegetation and soils, either cluster studies or systematic sampling methodology with quadrats along transects were used, which ever was found appropriate (Kershaw and Looney 1985, Mohamed 1999a).

The study was undertaken in the rainy season of October – January 2002 and 2003. In Bondeni and Muusini Villages, the spread of natural vegetation was segmented into clusters.

As a result, within the major clusters one or two quadrat(s) were undertaken depending the cluster sizes. In Eranakau and Isara Villages, the vegetation and soils covered extensive areas. Thus systematic sampling with quadrats along transects were used. The number of quadrats varied with uniformity of vegetation types. The higher the variation of vegetation within a landscape, the more the quadrats. Sampling was restricted to areas, which had natural vegetation. Settled, cultivated and disturbed areas along transect or to the clusters were recorded. The size of the quadrat varied with the life form of the vegetation under study; 10x10m for trees and shrubs and 1x1m plots for herbs and grasses (Kent and Cocker 1992).

Species composition and structure (physiognomy) by Pratt and Gwynne (1977), Wijngaarden and Engelen (1985), Touber (1983), Thurow and Herlocker (1993), Pomeroy and Service (1992) were used to classify the vegetation. Further details are in Tables 3.4.2 and Fig. 3.4.2.

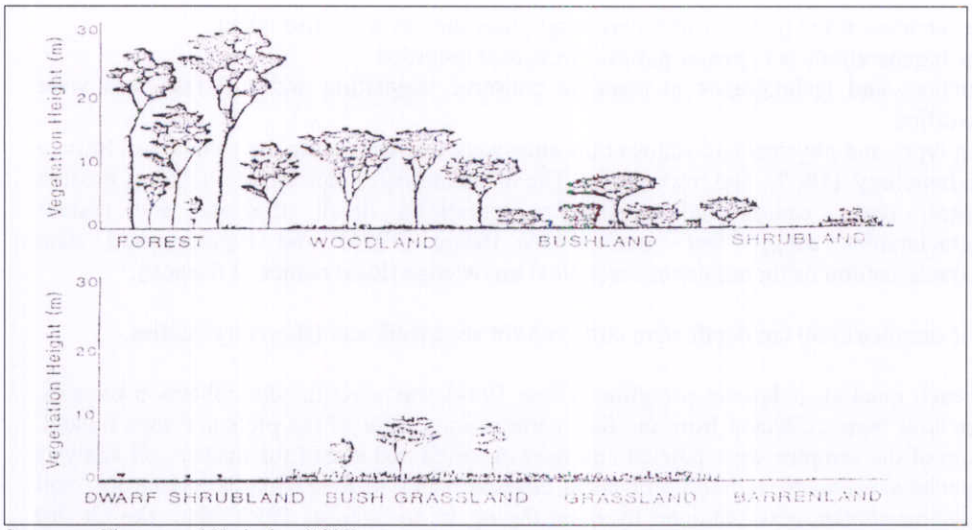
Table 3.4.2 A simplified classification of vegetation of the drylands of East Africa based on the amount and height of woody vegetation.

Type of vegetation	Description
Forest	Dominated by single stemmed trees 7-40 m or taller with interlocking crowns, multi-storeyed
Woodland	Tree to 20 m with canopy cover > 20% understorey mainly herbaceous, grasses and/or dwarf shrubs
Bushland	Multi-stemmed woody plants < 10 m that form entangled thickets but with cover of 20-80%. Herbaceous understorey is sparse. With scattered and conspicuous trees
Shrubland	Woody plants to 6 m without a significant presence of trees. Canopy >20%. Sparse herbaceous layer
Dwarf shrubland	Woody plants to <0.7 m form >2% of total cover
Shrub grassland	Dominated by grasses and dotted with shrubs that form <20% cover
Bush grassland	Grassland with scattered thickets of trees and shrubs, which have a canopy cover of 2-20%. The height of vegetation is < 6 m
Grassland	Tall or short grasses or sedges dominate the community. Woody canopy <20%.
Barren land	Vegetation quite sparse, Cover < 2% and frequently occurs in strips

Source Wijngaarden and Engelen (1985), Thurow and Herlocker (1993), Pomeroy and Service (1992).

The position of each quadrat was taken using Global Position system (GPS). Where found necessary, the vegetation and soils were photographed. The following parameters were then studied.

- Vegetation types and species composition – vegetation type was obtained using the above Table 3.4.2 and based on the appearance of the vegetation. The species found within the plots were identified using the researchers' knowledge, indigenous knowledge (local names) and by referring to Kenya trees and shrubs (Dale and Greenway 1961), Kenya trees, shrubs and lianas (Beentje 1994), Collin Guide to the Wild Flowers of East Africa (Blundell 1987), An illustrated manual of Kenya grasses (Ibrahim and Kabuye 1987) and East African weeds and their control (Ivens 1989). Composition studies involved the identification of the species by vernacular and scientific names. While conducting the surveys, the positions of any change in soil and vegetation characteristics were also taken using GPS.



Source Thurow and Herlocker (1993).

Figure 3.4.2 Schematic representation of the physiognomic vegetation types in Kenya.

- Cover in each vegetation type - for each tree and shrub; the crown was measured using ordinary 30 m tape. For shrubs, they were divided into two, big (with estimated crown diameter of 2.5 m) and small (with estimated crown diameter of 0.25 m). The covers were then entered in respective cover classes. The classes had a range of 5 m.

- Species density of all the trees and shrubs occurring in the plots were counted and their diameters measured using diameter tape (Plate 3.4.4). The diameters were then classified with a range of 10 cm. Density and covers were characterized using the method of Braun-Blanquet (1951). Wijngaarden and van Engelen (1985) and Touber (1983) had also used this method. For the herbs and grasses, cover per species was taken but not densities.



Photo taken by A. Mohamed in 2002.

Plate 3.4.4 Measuring the diameter of a Baobab tree in Muusini Village, Kibwezi Division, Makueni District, Kenya.

- Frequencies of the trees, shrubs, herbs and grass species were also taken.
- The regenerations per species per plot were also recorded
- Practices and technologies in place to conserve vegetation and soil resources were identified
- Soil types and physical soil status at the sites were assessed using the Kenya Soil Survey methodology (1987) and recorded. The characteristics described included erosion (status, types, causes and existing conservation), depth, drainage and texture characteristics using "feel" method by Brady (1974) and supplemented with characterization using indigenous technical knowledge (local names of the soil).

- Soil samples to 30 cm depth were collected for seed bank and laboratory studies.

  In each quadrat, judgment sampling (Cline 1944) was used for the collection of soils. The soils were collected from the four corners and center of the plots and then bulked. Parts of the samples were labeled and later air-dried and stored for further soil analysis especially chemical and some physical characteristics in KEFRI soils laboratory. Soil moisture content was obtained by oven drying in an oven at 105°C then the air dry moisture content (%) obtained according to Rayment and Higginson (1992). Soil pH and electro conductivity was measured using pH meter and Conductivity meter. Soil particle size (texture) analysis was determined using hydrometer method and textural classes obtained using soil texture triangle (Okalebo *et al.* 1993). Carbon and nitrogen were analyzed using Carbon/nitrogen analyzer (the SUMIGRAPH NC-90A) of Sumika Chemical Analysis Services Ltd. Soil colour was determined using Munsell Colour Chart. Solution for exchangeable bases in the soil (potassium, sodium, calcium and magnesium) were extracted using Ammonium acetate (1 M NH_4OAc) solution at pH of 7 (Okalebo *et al.* 1993, Bock 2003 pers. communication). Atomic Absorption spectrophotometer (AAS) was used to analyze macro and micronutrients. The percentage soil organic matter was estimated by multiplying a factor of 1.72 to the organic carbon obtained (Brady and Weil 1996).
  Available soil phosphorus was determined using Olsen Method (Okalebo *et al.* 1993). Booker Tropical manual (Landon 1991) was used as a guide in analyzing soil data
- Causes of the degradation (change in vegetation structure especially cover and composition) were noted

- Seed bank studies - parts of the soil samples collected (from a depth of 30 cm) were studied for seed bank to understand the natural regeneration potential to recover with adequate rainfall. The 30 cm was found appropriate because most seeds occur in the top 5 – 10 cm (Claw 1998). The samples are watered twice a day at Kibwezi ARIDSAK Nursery for six months with effect from November 2002 and monthly records on the species germinating and their life forms are being undertaken (Plate 3.4.5).

A part from the collected samples from the different quadrats per village, control trays (with only sand) has been placed alongside the experiment to detect contamination seeds as per Lyaruu (1998). Seed bank studies are important because the drylands of Africa are known to have impressive resilience following periodic heavy rainfall. The episodic rainfall events trigger rare pulses of seedling establishment increasing range production yet research to understand the nature of soil seed banks of degraded areas is lacking. Information from these types of studies will provide a basis for rehabilitation (Oba 1994).

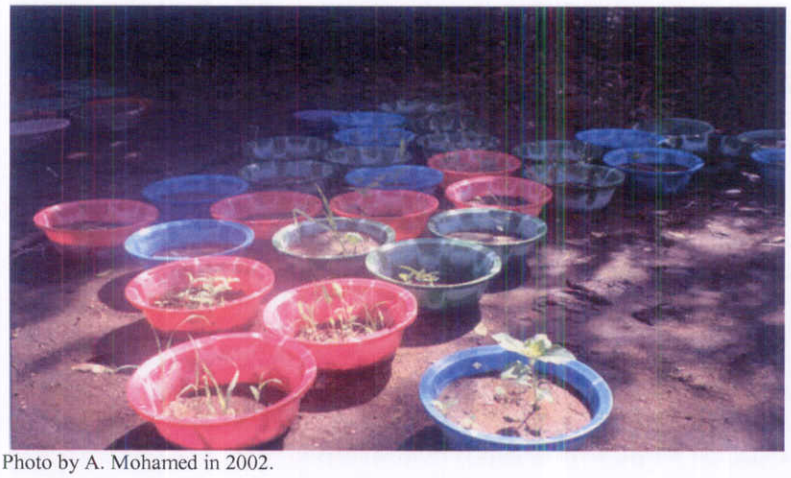


Photo by A. Mohamed in 2002.

Plate 3.4.5 Seed bank testing experiment at ARIDSAK's Kibwezi tree nursery.

Later on in the office, the crown diameters were converted into area in order to get the percentage crown cover per species per plot and site. The plot data was then converted into cover per hectare for standardization purpose. Similar steps were also taken for stems cut, regeneration, diameter and frequency. Because cover, density and frequency determine the dominance of a species, relative values for three core variables were calculated in order to establish the ecological dominance (important value index – IVI) of the species (Misra 1968).

Density = a count of the number of individuals of a species within the quadrat,

Cover = the area of the ground (in percentage) within a quadrat which is occupied by the above ground parts of each species when viewed from above

Frequency = the chance of finding a given species within a sample

$$\text{Relative Density (RD)} = \frac{\text{Density of a given species}}{\text{Total density of all species}} \times 100$$

$$\text{Relative Frequency (RF)} = \frac{\text{Frequency of a given species}}{\text{Total frequency of all species}} \times 100$$

$$\text{Relative Cover (RC)} = \frac{\text{Cover of a given species}}{\text{Total cover of all species}} \times 100$$

Important value index (IVI) = RD + RF + RC.

- Vegetation types were named using the IVI of dominant species.

Data on the type and number of animal resources were obtained from technical reports, interviews with relevant authorities, tasks to resource persons and questionnaire. Where possible the impacts of the animals were photographed.

- ***Vegetation and soils of the croplands***

For all the farmers/agro-pastoralists interviewed, the research team visited their farms and studied the trees/shrubs deliberately left or planted on croplands for cover, density, frequency and regeneration. The procedure for the study followed that of the vegetation in woodlands and pastures. The agroforestry practices and technologies were described according to Nair (1989) and Huxley (1979). Although farmers indicated the crops they grow, the types of crops, their cropping pattern and management factors were verified on-farm and where possible their photographs taken. The severity of all categories of soil erosion and the existing conservation practices were noted. Similarly, soil samples were collected as explained under vegetation and soil of the woodlands and pastures for laboratory analysis. The estimated yields, crop cover and constraints at farm level were obtained through questionnaire administration and field verification. Crop yields under research trials were obtained from the ARIDSAK Project. The estimated crop yields in the region; Africa and the World were obtained from archives.

(ii) Water

Participatory method, which is currently implemented by the Department of Water, was used (District Water Officer Kajiado 2002, pers. Comm.), as it is practical and inexpensive. With the help of topographical maps, aerial photographs data and community resource persons the following were studied:

- sources of water – the distribution of various sources of water (surface and ground) were identified and their status (Static, diminishing) noted in each village. Positions of all the sources were taken using GPS and put on the village maps;
- existing practices/technologies to conserve the sources (if any were be noted); and
- rainfall data from major stations in the study area was obtained from the Meteorological Department and KEFRI Kibwezi Station.

More information on water resources was obtained from farmers through administration of the household questionnaire, discussions with communities, and tasks to the resource persons, experiences and archival data.

The means of the above data were summarized, described and analyzed using Microsoft Excel and SPSS scientific packages. Similarly, all the boundaries of all the villages and the different resource components have been digitized using GIS ARCINFO and ARCVIEW.

3.4.2 IMPACTS OF THE EXISTING MANAGEMENT PRACTICES AND USE ON THE NATURAL RESOURCE COMPONENTS

The impacts of the existing management practices and use were mainly derived from the household questionnaire, archives, participatory assessment and discussions with communities.

The existing management practices and use of the various resources were identified and their impacts (both positive and negative) documented. Whenever possible photographs of the impacts of human and animal resources on soil, vegetation and water resources were taken as supportive evidence.

For example during participatory characterization and assessment, in each sample plots taken in the woodlands and pastures the numbers of stems cut per species/level of degradation e.g. grazing pressure were recorded.

Similarly, more local information on the use per species and stem cut was obtained from the accompanying community resource persons and recorded (Plate 3.4.6).



Photo by A. Mohamed in 2002.

Plate 3.4.6 Counting the number of stems cut reveals the status of high values trees and shrubs.

As for the water resources, the research team with the support of Mr. Musau, the Public Health Officer Kibwezi Division, collected water samples. From the source, the samples (Plate 3.4.7) for biological studies were put directly into standard and sterilized bottles (obtained from the Government Chemist Laboratory) and placed in cooler boxes with ice bags. Samples for physical and chemical analysis were put in clean and dry bottles and jerry cans. The labeled samples were taken to the Government Chemist laboratory within 24 hours for analysis. The aim was to assess the impact of human activities on water quality. The sources included rivers, pipeline, ponds, earth dams, a swamp and wells. The major analysis involved counts of coliform and *Escherichia coli* bacteria, colour, turbidity, organic deposits, oduor, pH, electrical conductivity, major metals, anions, alkalinity and hardness. The procedure for laboratory conformed to the guidelines of WHO (2004) and APHA (1992). The bacteria were analyzed through membrane filtration followed by incubation on selective media and colonies counted after 24 h. True colour was measured using colorimeter, Turbidity was measured Nephelometric method, odour was verified by smell (nose), pH and conductivity by the respective meters, metals were measured by AAS, anions by ion chromatography, alkalinity and hardness by titrimetrically using phenolphthalein and methyl orange indicators, and ethylenediaminetetraactic acid (EDTA) respectively.

Furthermore, institutional support to the conservation of soil, water, crops, animal and woodland resources were discussed and documented. The impacts of the supportive institutions were noted.

Additionally, during various feedback meetings with the local communities, the performances of crucial Government Departments/other institutions in natural resource management were assessed using a modified version of the methodology by Andiema *et al.* (2003). In this methodology the communities listed crucial institutions necessary for sustainable resource management and then assessed their current performances.



(a) Unprotected shallow well, Muusini area.



(b) Kiuwani Earth Dam, Muusini area.

Photo by A. Mohamed in 2002.

Plate 3.4.7 Research team sampling water from the major water sources for contamination and pollution analysis.

3.4.3 CONTRIBUTION TO THE DEVELOPMENT OF SUSTAINABLE AND INTEGRATED MODELS FOR THE MANAGEMENT OF NATURAL RESOURCES

Based on the data obtained from objectives one and two, the data from each village were conceptualised using ARCVIEW in order to obtain integrated ecological and farm management units. The land use was viewed both from the ecological landscape types (formed by zones with similar biophysical characteristics) and the existing socio-economic groups based mainly on poverty levels of well off, medium and poor. Both factors were geo-referenced in the study. The following were undertaken to achieve this objective based on the recommendations by Mohamed (1999b), Mohamed *et al.* (2000) and Mohamed (2001):

(i) ecological landscape types (ELTs). The units were obtained by delineating sites with similar biophysical factors, climate, elevation similarity and geo-pedological homogeneity, vegetation types and locational attributes (longitudes and latitudes). However, since each village is in an agro-climatic zone, the climate remained constant in the characterization;

(ii) harmonized farm types (HFTs). The units were derived from farms with similar socio-economic factors (poverty categories with similar farm resources, management practices and outputs); and

(iii) integrated ecological and farm management units (IEFMUs) were obtained by overlaying ecological units (ELUs) and Harmonized farm types units (HFTs).

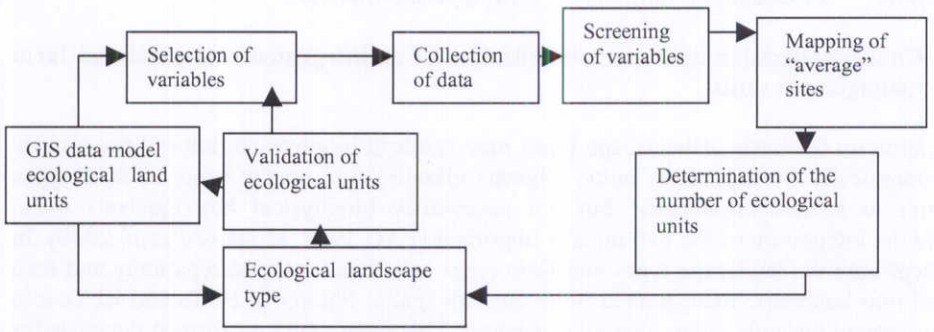
(i) Classification and mapping of ecological landscape types

The process uses the existing environmental characteristics as the basis for development of ecosystems classification methodology to identify ecological landscape types based on biophysical and agro-humid characteristics (Pratt and Gwynne 1977, Jaetzhold and Schmidt 1983, Hornetz 1990, Shisanya 1996, Braun and Mungai 1981, Sombroek *et a.l* 1982, FAO 1989, FAO 1993c, Hunsker *et al.* 1998 and Reimold 1998). The main purpose of the classification was to identify sites with similar characteristics so as to understand their ecological capabilities and identify the possible management and technologies without

affecting the natural resource base. The following factors were the backbone for the classification of the ecological landscape units.

- Climate – based on agro-ecological/climatic zones.
- Geomorphology, hydrology and pedology – the description of the geo-morphological and pedological units was according to Bock and Lacroix (2002) with some modifications. Major factors incorporated here include parent material (geology), elevation, status of water sources, drainage characteristics, erosion status, structure and consistence, colour, texture, pH, salinity, organic matter content, total nitrogen, other macro and micro nutrients and available phosphorus. The field study data was enriched with archival data from Touber (1983) and Wijngaarden and Engelen (1985). The locations of the units (Longitude and latitude coordinates) were georefrenced using geographical positioning system (GPS).
- Natural vegetation type – description of the main natural vegetation types was based on cover, density, frequency and important value index.
- Livestock and wildlife – types and specifically for livestock numbers per socio-economic groups

Delineated sites with similar characteristics within the village were then grouped together in order to get an "average" sites (per unique group of sites) and mapped out using GIS - ARCVIEW. Fig. 3.4.3 summarizes classification and mapping of the ecological landscape types.



Source Mohamed (*et al.* 2000), Mohamed (2001) with modifications.

Figure 3.4.3 Procedure for ecological landscape classification.

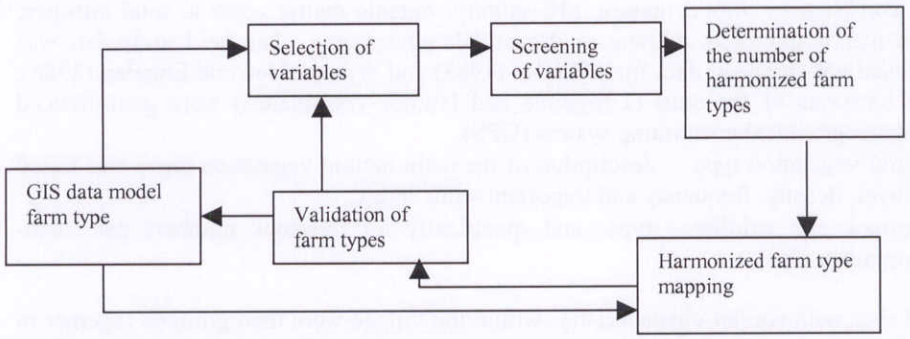
(ii) Classification and mapping of harmonized farm types

The process has been adopted from Mohamed *et al.* (2000) and Mohamed (2001) and uses the farm (the decision-making unit with respect to land use) as the basis for development of harmonized farm types (HFTs) based on farm resources and management.
The main purpose of farm classification is to get average farms with similar management characteristics. The classification of farm types was based on the following factors:

- institutional similarity – farm size, type of land use, type of residential houses, involvement of household members in off-farm activities, the number of animals owned, number of household members, educational level of the household members, social status;

- technological homogeneity – tree planting and application of physical soil and water conservation structures, land preparation methods, cropping pattern, application of inputs, type of residential and food stores; and
- financial similarity – income level.

Farms with similar characteristics were grouped together and mapped out using GIS - ARC VIEW. Fig. 3.4.4 summarizes classification and mapping of harmonized farm types.



Source Mohamed (*et al.* 2000), Mohamed (2001) with modifications.

Figure 3.4.4 Procedure for harmonized farm type classification.

(iii) Conceptualization and operationalization of an integrated ecological and farm management units

Classification on the basis of landscape types may result in biophysical, but not necessarily socio-economically homogeneous units; whereas classification on the basis of farm types may result in socio-economically, but not necessarily biophysical homogeneous units. Therefore the integration of the two units is important (FAO 1989, Mohamed *et al.* 2000). In this concept both the landscape types and farm types have been mapped separately and then integrated into landscape management units through spatial linking of HFTs and ELTs in a GIS environment through a map overlay procedure. This integrated unit formed the basis for the definition of, description and analysis of land use systems and a basis for discussion with local communities and leaders. The inclusion of local leaders offers experts a forum for explaining, to the wider public, the technical issues involved in the models (Bailey *et. al.* 1996). Once the integrated units have been identified, appropriate management and development technologies were put forward for each integrated unit and village (Crosson and Anderson 1993, FAO 1989, Mohamed 1999b, Stocking and Abel 1981, Mohamed 1999a, Fikret *et al.* 1995, Crosson and Anderson 1993). Where necessary models and technologies were borrowed from beyond the national borders (Crosson and Anderson 1993).

3.5 CONCLUSIONS

The methodology adopted was triangulation technique that incorporates data from different sources including archival, experiences, indigenous technical knowledge and field data. The overlays of biophysical and socio-economic factors using GIS have been used to come up with integrated ecological and farm management units in order to come up with appropriate technologies. The major constraints faced in the implementation of the study were bulkiness of the work, finance and time affecting sample sizes for the data collected.

CHAPTER 4. RESULTS AND DISCUSSIONS

4.1 CHARACTERIZATION OF NATURAL RESOURCE COMPONENTS

4.1.1 INTRODUCTION

The natural resource components (water, soil, plant and animals) in this harsh environment are the fundamental means of existence for the rural poor communities (Wandera 1998, GoK 2000, Southgate and Hulme 1996, GoK 2004). Yet their characterization in the Kenyan context have been limited to few general studies to understand the situation. Consequently, in order to contribute simultaneously to poverty alleviation while sustainably conserving natural resources, it is important to have a concrete data base on their existing conditions and on the communities that drive livelihoods from the resources (KEFRI 1999, GoK 2004). Accordingly, this chapter gives the current status of natural resource components in four villages that lie in two different land use systems, that is mixed farming and agropastoralism.

4.1.2 GENERAL INFORMATION

The study was undertaken in Muusini, Bondeni, Isara and Erankau Villages (Fig. 4.1.1 and 4.1.2). Muusini has an area of seven km^2 while that of Bondeni, Isara and Erankau are 3.9, 45.3 and 26.7 km^2 respectively. Muusini and Isara are about 30 km away from the Nairobi-Mompbasa road while Bondeni and Erankau are less than 10 km from the road.

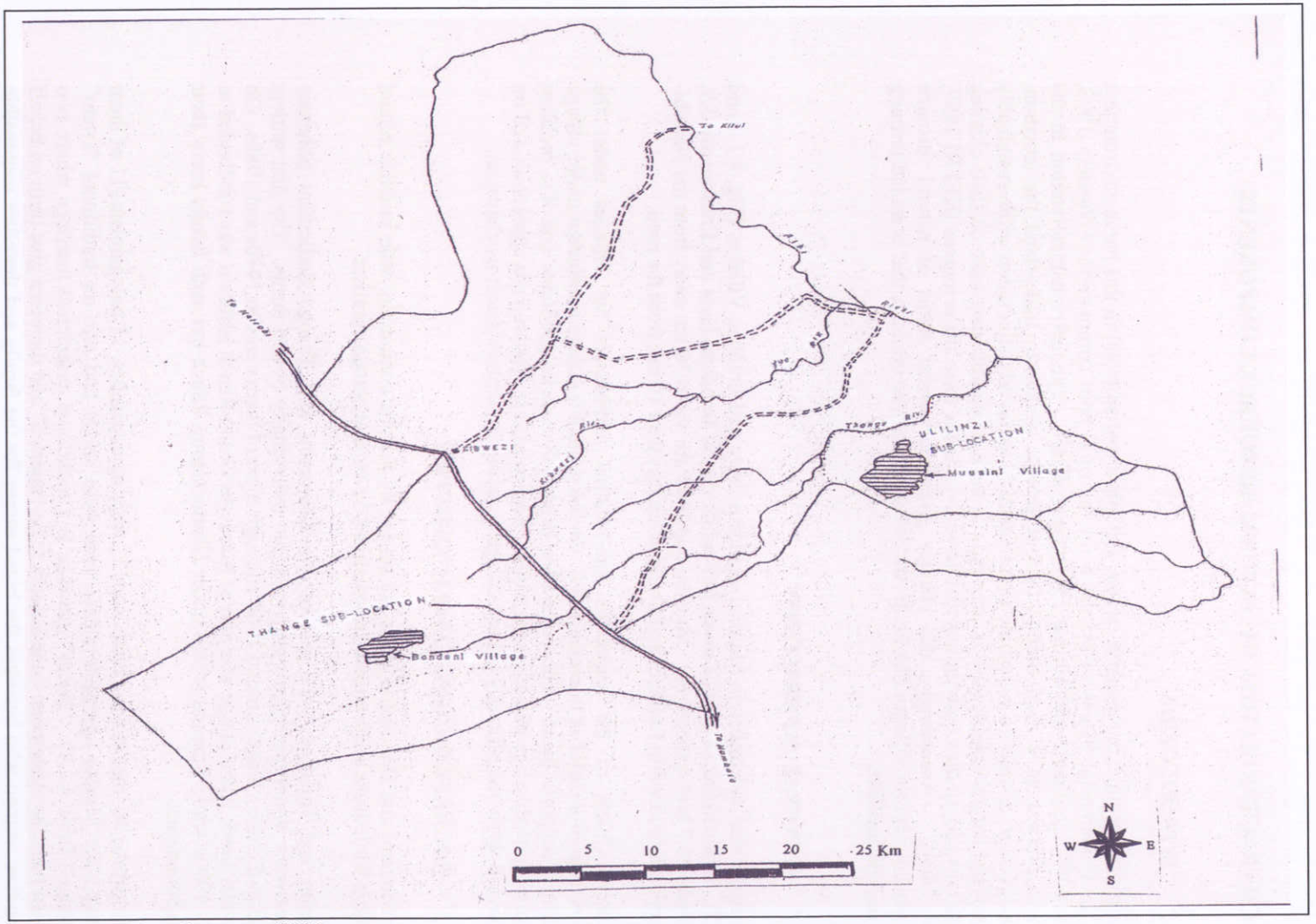
Assistant Chiefs of the respective Sub-location administers the villages under the supervision of a Chief at Location level. On the ground a village committee under village chairman supports them. The committee helps solve social problems and if a problem proves impossible it is passed to the chiefs. The chiefs are Government appointees and on its payroll while the officially unpaid village committee members select its chairman.

4.1.3 SOCIO-ECONOMIC CHARACTERISTICS

The Muusini and Bondeni villages are settled by Kamba community who practice mixed farming while Isara and Erankau are inhabited by Masaai agropastoralists.

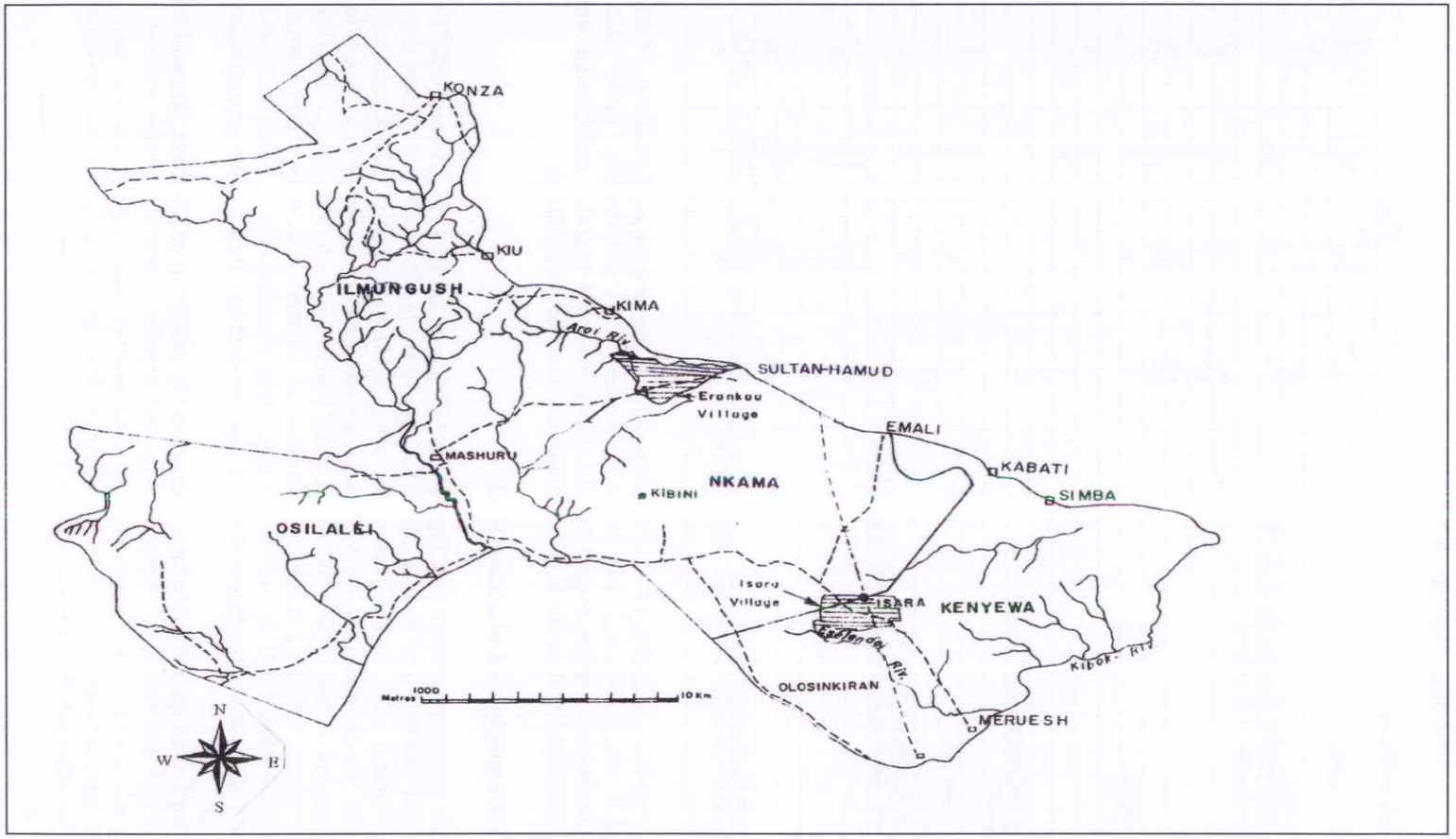
Muusini and Bondeni were part of the Kinyambu and Thange Settlement Schemes respectively, which has been subdivided into individually owned farms. The first settlers came to the two villages around 1965 although most of them came in 1970s and 1980s. On the other hand, Isara village was part of Merueshi Group Ranch before it was subdivided in early 1990s while Erankau is still under Nkama Group Ranch but each family know their farm boundaries.

Amongst the 36 interviewees there were 21 were monogamists, 12 polygamists (11 of them amongst the Masaai agropastoralists), two were single and one on traditional "Iweto" marriage (Table 4.1.1). "Iweto" marriage is a traditional contractual marriage where two women make an agreement – one accepts to be "married" and therefore give birth on behalf of another women who becomes the bread earner for the family and therefore responsible for the up keep and welfare of the family.



Source Forest Department (2004).

Figure 4.1.1 Location of Bondeni and Muusini Villages, Kibwezi Division, Makueni District, Kenya.



Source Forest Department (2004).

Figure 4.1.2 Location of Isara and Erankau Villages, Mashuru, Kenya.

Table 4.1.1 Socio-economic characteristics of four villages in Eastern Kajiado and Southern Makueni, Kenya.

Socio-economic indicators	Village			
	Muusini	Bondeni	Isara	Erankau
Total population (2002)	481	825	483	538
Area (km²)	7	3.9	45.3	26.7
Population density	69	212	11	20
Estimated annual population growth (%) (GoK 2001)	1.94	1.94	4.6	4.6
Poverty level - % under each category				
Well off	14	17	12	12
Medium	26	19	14	20
Poor	60	64	74	68
Total	100	100	100	100
Sample size studied	9	8	9	10
Marital status				
Monogamy	7	6	3	5
Polygamy	1	-	6	5
Single	1	1	-	-
"Iweto" traditional marriage	-	1	-	-
Level of education				
None	-	-	5	9
Primary/Adult education	7	6	3	-
Secondary/college	2	2	1	1
Family size of the sample households	9	8	12	12
Estimated population structure (%) from sample households				
< 5 years	22	22.2	25.1	16
6-14	22	11.1	33.3	25
15-18	11	11.1	8.3	8
> 18	45	55.6	33.3	50
Total	100	100	100	100
Percentage of under 18 years in school	61	55.3	70.5	81.8
Number of sample households with members involved in off-farm activities	6	6	2	5

In terms of modern education 14 were illiterate (all of them were agropastoralists), 15 had primary/adult education and 7 had studied secondary level and beyond (Table 4.1.1). Average household members ranged 8 – 12, being lowest in Muusini and Bondeni and highest in Isara and Erankau due to polygamous nature of the later villages.

(i) Demography and education levels

Within each region, population was high in the villages of agro-ecological zone (AEZ) V (Bondeni and Erankau) and least in the those that lie in the drier AEZ VI (Muusini and Bondeni) (Table 4.1.1). This is because the cooler areas with more rainfall attracts more farming and has reliable pastures/water and therefore more people. When population density is put into consideration, the villages of Kibwezi Division (Muusini and Bondeni) had higher pressure on land resources than those of Mashuru. But if the current annual growth of 4.6% (GoK 2001) in Mashuru continues then the population of Isara and Erankau Villages will in future exceed that of Kibwezi and therefore too impact on the environment.

The high population growth in the later villages can be related to polygamous nature of the community (six and five interviewees in Isara and Erankau respectively were married to two or more wives). The polygamous cultural practice also impacts on the current population structure especially in Isara and Erankau Villages where 50% of the population are estimated to be less than 18 years (Table 4.1.1).

With annual population increase estimated at 1.94% for Kibwezi Divison and 4.6% in Mashuru Division (GoK 2001), if based on neo-malthusian theory of the more the population, the higher the degradation it is likely to contribute to negative impact on natural resources through the clearance of more natural woodlands for settlements, cultivation and intensified use of wood and non-wood products. On the other hand, if we consider the views of the "new thinkers" such as Tiffen *et. al.* (1994) and Leach and Mearns (1996) founded on Boserup's theory of 1965 of the higher the population, the more the development and conservation of natural resource, then the region will prosper. However, although population growth may stimulate conservation usually reverse is common in the fragile drylands due to limitation of inputs and lack of motivation as will be discussed in coming sections. Furthermore, population alone does not cause degradation. Rather degradation is caused by multiple factors including population increase, incentives such as increase in income, distance to major urban markets, land use practices, the condition of natural resource base itself and policies (Zaal and Oostendorp 2002, Swinton *et. al* 2003, Swinton and Quiroz 2003, Pereira 1997).

Fortunately, most (55-82%) of the youths in all the villages were attending modern education (Table 4.1.1), a good foundation for sustainable and integrated natural resource management and poverty alleviation. School children will learn to blend both indigenous (from their parents) knowledge and modern education. The high attendance was at primary level and can be related the current Government policy of free and compulsory primary education. However, as education progresses, the number decreases especially those from the poorer section of the communities. For the "future resource managers" who have not enrolled in school (forming 18-45% of the population), their resource management knowledge will be tilted more towards indigenous knowledge with limited influence from modern sciences.

However, when the roles of children and teenagers on-farm are noted (Table 4.1.2), then it can also be a source of low performance in education specially the girl child. In the mornings and evenings after school, they have to trek long distances to fetch for water and firewood and thereafter cook food and help their parents in washing and cleaning. Over the holidays the children too have to cultivate, dig soil and water conservation structures and rare livestock. The need for children to cheap in their labour on-farm has been necessitated by a deficit in labour force on farm. Potentially the villages have enough labour force to increase agricultural production. But because the would be available labour (in form of able bodied men and women) have migrated to towns for off-farm (job/business), there is labor deficit for on-farm activities. Nineteen out of the 36 interviewees reported to have at least a household member working in white-collar jobs or business (Table 4.1.1). Muusini and Bondeni Village members were the most involved in off-farm (over 60% of the interviewees). As a result the children had more roles than those of pastoral communities. Isara Village members were least involved in off-farm followed by Erankau could be due to limited knowledge in modern education (Table 4.1.1), hence susceptibility to poverty if they loose their livestock resources during disaster periods.

(ii) Poverty levels

Locally, the village members classify themselves into three categories of poverty levels based upon income, employment and ownership of natural resources especially land and livestock (Table 4.1.3). Similarly, the disabled are categorized as poor.

Table 4.1.2 Roles and responsibilities of household members in four study villages of Eastern Kajiado and Southern Makueni, Kenya.

Household member	Roles and responsibilities	
	Muusini and Bondeni, Kibwezi	**Isara and Erankau, Mashuru**
Household head (usually the father)	• General manager on all family resource management and use • All decision making on cropping issues; woodland and pasture management (including timber and poles for modern house, fodder/pasture, honey); water for livestock, crops and trees – at times supported by sons and wife; livestock management and sales (live animals minus poultry); soil and water conservation; sale and purchase of grains, manure, timber, hides and skins; sale or purchase of land – at times supported by sons & wife plus family members • Rare livestock • Fencing • Cultivation • Off-farm jobs and business • Fetch water – by bicycle • Construction of modern houses	• General manager on all family resource management and use • All decision making on cropping issues; woodland and pasture management (including timber& poles for modern house, fodder/pasture, honey); water for livestock, crops and trees – at times supported by sons & wife; livestock management & sales (live animals minus poultry); soil & water conservation; sale & purchase of grains; sale or purchase of land – at times supported by sons & wife plus family members • Rare livestock • Fencing • Cultivation • Off-farm jobs & business
Female members (Mothers, Wives & female teenagers)	• Assistant and acting general manager in the managers absence • Domestic water; firewood; cooking, cleaning and washing; • Sale and purchase of stovers, poultry products, fruits and charcoal • Construction of local houses • Cultivation • Rare livestock • Fetch water • Casual work for income	• Assistant and acting general manager in the managers absence • Domestic water; firewood; cooking, cleaning & washing; warming milk containers • Sale & purchase of stovers, manure, hides & skins, poultry products, milk & milk products, fruits; • Construction of local Maasai houses • Cultivation • Milking • Rare livestock
Male teenagers	• Rare livestock • Fencing • Cultivation • Soil conservation – dig terraces • Cooking • Washing and cleaning • Fetch water	• Rare livestock • Fencing • Cultivation
Children	• Rare livestock • Cultivation • Fetch water, firewood • Washing, cleaning and cooking	• Rare goats, calves, kids & lambs

Table 4.1.3 Criteria for the classification of poverty levels in Eastern Kajiado and Southern Makueni, Kenya.

Poverty indicators	Villages			
	Muusini	**Bondeni**	**Isara**	**Erankau**
Income/day/poverty category (Kshs.)				
Well off	> 280	> 180	> 408	> 350
Medium	70 - 280	80-180	189-408	200 - 350
Poor	< 70	< 80	< 189	< 200
Number of animals/poverty category – cattle				
Well off	> 10	> 4	> 69	> 80
Medium	2 – 9	2-4	20-69	20-80
Poor	< 2	< 2	< 20	< 20
Number of animals/poverty category – goats/sheep				
Well off	> 20	> 15	> 30	> 70
Medium	5 – 20	6-15	10-30	30-70
Poor	< 5	< 6	< 10	< 30
Farm size (acres)**				
Well off	> 7	> 10		
Medium	3 – 6	3-10		
Poor	< 3	< 3		
Involvement household members in off-farm activities/business				
Well off	Employed/in business			
Medium	May be involved		Rarely involved	
Poor	Rarely involved			
Method of land preparation				
Well off	Tractor/oxen	Tractor		
Medium	Oxen	Oxen		
Poor	Mostly by hoe	Mostly by hoe		
Soil & water conservation structure and tree planting				
Well off	Structures in place	Structures in place		
Medium	Structures may be in place	Structures may be in place		
Poor	Rarely in place	Rarely in place		
Type of residential house				
Well off	Permanent	Permanent		
Medium	Semi-permanent	Semi-permanent		
Poor	Temporary	Temporary		

NB 1 Euro = Kshs. 1000 by 2004. ** 1 hectare = 2.471 acres

While Livestock resource was the major classification factor amongst the Masaai pastoralists, the mixed farming community had a wider range of indicators to measure poverty levels for example farm size, methods of land preparation and the existence of soil and water conservation structures. Based on this criteria, over 60% of the all the households in the villages were considered to be poor. This is in agreement with the national poverty level within the country (GoK 2004). The well off formed only 12-17% of the households.

Poverty level has an impact on natural resource use and management. Farmers with limited resources can barely improve their farms and because they have limited alternatives then they resort to over cultivation, which will negatively impact on the environment. This creates "vicious" cycle of poverty and degradation (WCED 1987). While this may be true, poverty alone does not cause environmental degradation as mentioned earlier on.

At the local level, farmers know well that their small farms with minimal output can not support their families and therefore look for other alternatives sources of income. Indirectly, by involving themselves in other sources of income, the pressure on farm is reduced in form of food, water and wood needs while at same time remitting back part of their on-farm earnings towards the conservation of the farm resources, for example the money needed for digging of terraces.

(iii) Sources of income

The different poverty categories of Muusini and Bondeni had lower income than those of Isara and Erankau (Table 4.1.4) due the impact of livestock component. The estimated average annual income per household for the farmers were Kshs. 7200 - 60000 in Muusini and Kshs. 13040 – 89420 in Bondeni while that of the agropastoralists ranged Kshs. 40378 – 83619 and 71411 – 146264 in Isara and Erankau respectively. Income varied with poverty categories. Erankau agropastoralists received the highest annual income while Bondeni farmers had the lowest. Income tend to decrease with increase in population densities and farm sizes. It also increased with the number of livestock owned. However, livestock as a sustainable source of income is affected by the occurrence of frequent droughts and outbreaks of pests and diseases. A farmer/agropastoralist who owns large head of stock and therefore well off may within a year become the poorest due to impact of the above factors. Moreover, when per capita income per day is considered even the well off receives less than a dollar and therefore restricted in their livelihoods.

The major source of income in Muusini and Bondeni villages was off-farm activities while it was second in Isara and Erankau. Members of the families work outside the farm in form of business or as a driver, casuals, maids, store men, matatu (mini buses) conductors, business, mechanics, cobblers, masonry, tailoring and clerical in various parts of the country as far as Nairobi, Mombasa and in other major towns. On the other hand, in Isara and Erankau, livestock resources gave the highest income (Table 4.1.4) again varying with the poverty groups.

The second major source of income in Muusini was livestock while crop products was next to off-farm in Bondeni. The high income from crops in Bondeni can be related to better rainfall and therefore more yields to sale while that of livestock in Muusini can be related to drier environment that does not favour crop performance. Consequently, the farmers in Muusini invested more in livestock, which was favoured too by limited tsetse fly infestation as a result of the drier environment. As poverty levels increased income from poultry products become an important source of livelihood in Muusini, Bondeni and Isara. When farm products/commodities were compared, Muusini livelihoods depended most on maize, cattle and poultry while the people of Bondeni heavily depended on maize, pigeon pea and poultry. Whilst the reliance on maize, cattle and pigeon pea is well known in the region, the role played by poultry and poultry products may give a new direction in the strategies towards alleviation of poverty. Further, it is environmentally friendly and easy to raise by all poverty categories.

On the other hand, the people of Isara and Erankau relied most on cattle, milk and goats for survival. Livestock is their "bank and security on hooves". Contribution from milk and manure was also significant in Erankau Village. The high income from milk by the poor category in Erankau can be related to indigenous social support network in form of borrowing milking cows from the well off and medium members of the village.

Table 4.1.4 Estimated annual income of households in Eastern Kajiado and Southern Makueni, Kenya.

Source of income	Poverty group/Village											
	Well off				*Medium*				*Poor*			
	Muusini	**Bondeni**	**Isara**	**Erankau**	**Muusini**	**Bondeni**	**Isara**	**Erankau**	**Muusini**	**Bondeni**	**Isara**	**Erankau**
Cattle	8500	0	47500	104500	14333	0	36667	66667	0	0	31000	37500
Goats	5700	1400	12750	7350	3450	1650	9133	6833	2420	750	4925	12163
Sheep	0	1050	18000	5650	0	0	9867	4833	0	0	3325	2188
Donkey	0	0	0	1000	0	0	0	2000	0	0	0	750
Poultry	3250	1850	150	1733	2400	1350	850	900	2330	3250	600	975
Eggs	300	300	100	133	425	840	300	1420	502	335	135	165
Milk	3600	0	5119	9691	0	0	0	8715	0	0	0	17545
Hides/skins	13	20	0	407	25	0	223	100	12	5	393	125
Honey	0	200	0	0	0	0	0	0	60	650	0	0
Oxen traction	0	0	0	4000	0	0	0	0	0	0	0	0
Manure	0	0	0	11800	0	0	0	1667	0	0	0	0
S/T livestock	**21363**	**4820**	**83619**	**146264**	**20633**	**3840**	**57040**	**93135**	**5327**	**4990**	**40378**	**71411**
Maize	14040	26400	0	0	4800	5220	0	3333	1186	3850	0	2500
Beans	0	1550	0	0	0	1800	0	1667	0	350	0	0
Pigeon pea	1350	4050	0	0	4275	5940	0	0	658	1125	0	0
Cowpea	1800	0	0	0	1350	0	0	0	636	0	0	0
Green grams	300	0	0	0	2120	0	0	0	676	0	0	0
Dolicos lablab	0	0	0	0	0	0	0	0	400	0	0	0
Sorghum	0	0	0	0	0	0	0	0	198	0	0	0
Ground nuts	0	0	0	0	0	0	0	0	60	0	0	0
S/T crops	**17490**	**32000**	**0**	0	**16285**	**12960**	**0**	**5000**	**3814**	**5325**	**0**	**2500**
Charcoal	0	500	0	0	0	0	0	520	0	0	0	0
Firewood	0	100	0	0	200	0	0	0	0	0	0	0
Fruits	0	1000	0	0	0	0	0	0	0	0	0	0
Seedlings	100	0	0	0	0	0	0	0	0	0	0	0
S/T trees	**100**	**1600**	**0**	0	**200**	**0**	**0**	**520**	**0**	**0**	**0**	**0**
S/T off-farm	**60000**	**51000**	**65000**	**55000**	**24000**	**18600**	**0**	**8000**	**7200**	**2725**	**0**	**9000**
Total	**98953**	**89420**	**148619**	**201264**	**61118**	**35400**	**57040**	**111655**	**16338**	**13040**	**40378**	**85411**
Per capita income	**10995**	**11178**	**12385**	**16772**	**6791**	**4425**	**4753**	**9305**	**1815**	**1630**	**3365**	**7118**

Income from tree products (charcoal, firewood, seedlings and fruits) was minimal and restricted to five interviewees in the well off and medium poverty categories of Muusini, Bondeni and Erankau. Although the number of interviewees were few, the implication of this result is that, poverty may not necessarily cause deforestation and overgrazing.

In all the villages, because of higher income the well off and medium groups had relatively more resources to improve their farming activities because they have more income especially from off-farm activities.

The priority uses of the income earned were for health, purchase of foodstuff, school fees, purchase water, clothes, farms and livestock. Part of it was too ploughed back into the farm (cultivation) while others reported to start small off-farm business or paid labourers. For the Masaai pastoralists, the income contributed too to restocking with livestock and its management (purchase of acaricides/pesticises/salt). In Erankau a part from putting into the above uses, it was clear that income from milk and poultry products belonged to the women who sale their product as a group. Once the cash was in hand they use it to purchase of building materials, goats, clothes, acaricides, salt for domestic and whenever necessary help the head of the household to off set school fees and hospital bills.

(iv) Marketing of farm products

Crop products and domestic animals were sold on farms and in local markets on market days. Livestock were trekked or carried on bicycles to and from the markets. In Isara and Erankau live animals were trekked to and from the markets at a cost by specialized youths called "Imbrokwa(s)". The problems on market days were related to middlemen who wait for farmers some distance from the market centers and coerce them to sale the product at a throw a way price only to resale at a better price in the same centers.

The local centres too house various agro-veterinary commercial shops for farmers who require farm inputs. However, because their products are expensive, farmers fall prey to purchasing cheap but poor quality inputs from the open markets.

Except for a clean kilo of honey (at Kshs. 100 to 120 depending on bargains made) and a litre of milk that remained constant throughout the year at Kshs. 20 in Isara and Erankau and at Kshs. 30 in Muusini Villages, the prices of other livestock products and live livestock were lower in dry periods and high in rainy seasons. For example in Muusini and Bondeni the price of goats/sheep in rainy seasons was Ksh. 1000 but in dry seasons drops to as low as Ksh. 500. On the other hand in Isara and Erankau an average head of cattle and goat/sheep cost Kshs. 20000 – 25000 and 1600 – 2000 respectively in rainy seasons while the same fetch as low as Kshs. 4000 – 8000 and Kshs. 700-1000 in dry seasons. This is because in rainy seasons livestock forage is abundant including food for poultry (in form of insects and green leaves) but it becomes insufficient during dry seasons hence disposing them off at a throw away price becomes an alternative to the farmers. Furthermore, it is the major option for farmers to get income in dry seasons as a coping strategy. The reverse is true for crop products shooting up in dry seasons due to exploitation by middlemen and increased demand (Table 4.1.5). During rainy periods middlemen invade the Muusini and Bondeni villages from all over the country and purchase crop products cheaply and then resale them back at exorbitant prices in dry seasons.

Moreover, most farmers have no capacity to store a lot of food. Additionally, as farmers say "harvest time is a golden opportunity to pay debts in form of school fees, health and get money to travel". They say that they have no alternative to it otherwise later on while in store the products such as maize are vulnerable to fungal, weevils and great grain borer attacks.

Table 4.1.5 Estimated price fluctuations for the major crop commodities used in four study villages in Eastern Kajiado and Southern Makueni Districts, Kenya.

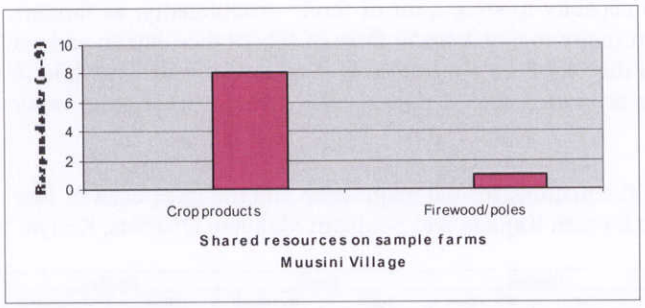
	Muusini		Bondeni		Isara		Erankau	
Product (90 kg)	*After harvest/ rainy season*	*Dry season*	*After harvest/ rainy season*	*Dry season*	*After harvest/ rainy season*	*Dry season*	*After harvest/ rainy season*	*Dry season*
Maize (unprocessed)	360-540	900-1800	360-500	850-1800	625-1025	1225-1725	400-700	1200-2000
Sorghum (Unprocessed)	180-270	720-1500	180-300	300-900	Not known	Not known	900-1125	1125-1800
Beans	2250	3600	750-1260	1250-3600	1500-2700	3000-4500	720-2700	3600-5000
Cowpea	450-900	2250-2700	450-540	900-2700	1300-1800	2700-3600	900-2100	2100-4500
Green grams	900-1800	3600-4500	450-1800	1800-3150	1350-2700	5400	1500-2100	3000-5400
Pigeon pea	900-1710	2250-4500	600-1800	1800-2700	900-1800	1800-3600	900-1800	1800-4500

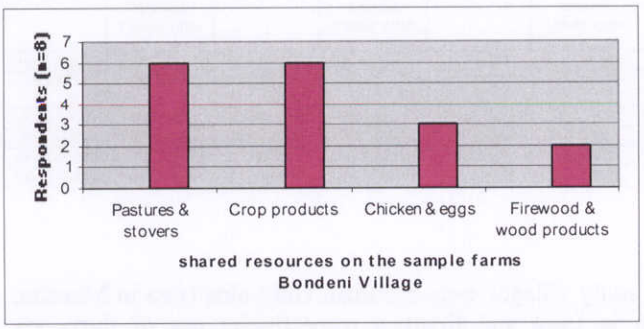
(v) Financial support

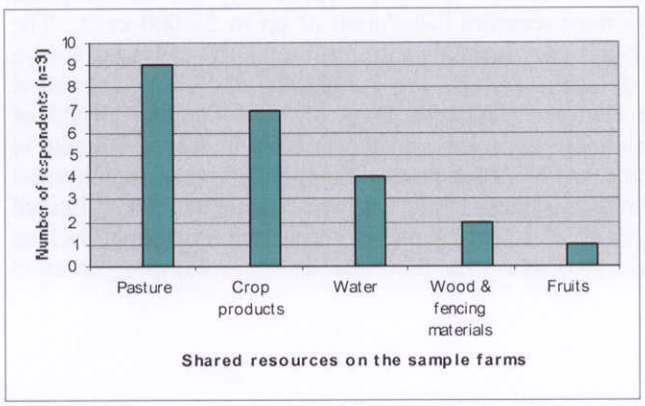
Financial support throughout the study villages were minimal. Only nine (two in Muusini, one in Bondeni and three each in Isara and Erankau respectively) out of thirty six farers/agropastoralists indicated to have received loans/grant of up to 50 000 each. The institutions mentioned include a Non Governmental Organization (NGO) called the Kenya Women Finance Trust, KATE Freight Limited, the ARIDSAK Project, Agricultural Finance Corporation (AFC), the Kenya Commercial Bank and the County Council of Kajiado. The rest of the farmers either said to have no accessibility or fear of not able to pay back due to unreliability of crop and livestock production and marketing, high interest rates and insecure land tenure (Erankau village is under group ranch status). The limited financial support means lack of incentives to long duration conservation practices such as the construction of physical soil and water structures and therefore exposing farm to degradation.

(vi) Entitlements

All farms were individually owned (even Erankau, which was under group ranch status). Therefore farm resources can only be used with authority from the owner. The farmers/agropastoralists interviewed reported the use of farm resources by others specifically citing relatives, neighbours, friends, schools and churches. The major shared resources include crop products (stovers, grains, seeds), wood products (firewood, poles, fencing materials), pastures and water (Fig. 4.1.3). In Erankau milking cows were shared too. Crop products were shared after harvest with no conditions. Pastures were shared in dry seasons on conditions that after it rains the recipient's livestock go back to their farms. Other conditions attached to pasture entitlements were that the recipient should avoid grazing in individually owned indigenous fodder reserves "Olopololi", crop fields and cutting of trees without permission. Sharing of resources means more pressure on land resources.







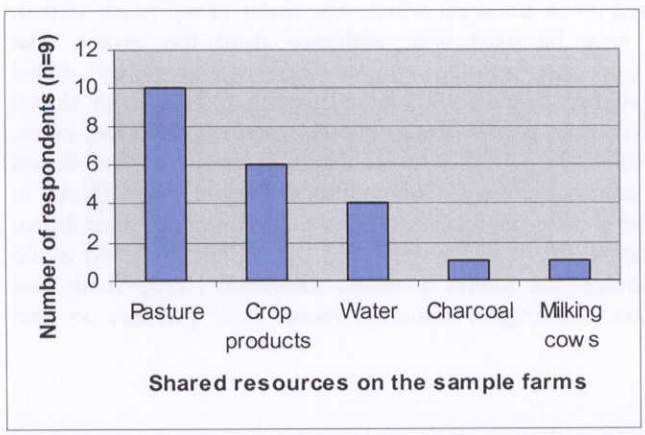


Figure 4.1.3 Shared resources in four villages of Eastern Kajiado and Southern Makueni, Kenya.

(vii) Food and nutrition

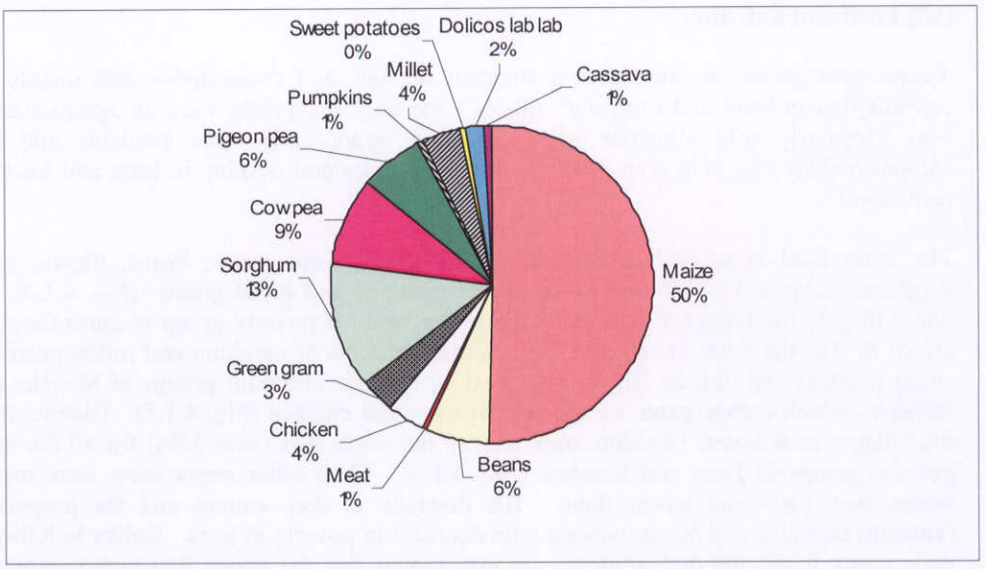
Crops were grown in Muusini and Bondeni for sale and consumption and mainly for consumption in Isara and Erankaui villages - the only exceptions were an agropastoralist who irregularly sold tomatoes when irrigation opportunities was available and two agropastoralists who sold crop products raised from dryland farming in Isara and Erankau respectively.

The main food consumed in Muusini and Bondeni were maize, beans, pigeon peas, sorghum, cowpeas (leaves are also used as vegetable) and green grams (Fig. 4.1.4). In both villages, meat/chicken was restricted to the well off poverty group because they can afford it. On the other hand more food calories in form of sorghum and millet porridge, sweet potatoes and dolicos lablab were used by medium and poor groups of Muusini and Bondeni, which compensates for the lack of meat and chicken (Fig. 4.1.5). Distinct from the villages of Kibwezi Division, milk formed the staple diet (over 50%) for all the three poverty groups in Isara and Erankau (Fig. 4.1.6). Their other major diets were maize, beans, rice, meat and wheat flour. The diversity of diet sources and the proportion (amount) of maize and beans increase with decrease in poverty in Isara. Unlike in Kibwezi meat partly forms the diet of all the poverty groups due the strong livestock component (Fig. 4.1.7). Culturally, dissimilar from Kibwezi millet and sorghum are not appreciated by the agropastoralists. They were instead replaced with rice and wheat flour. Since the Masaai agropastoralists could afford to purchase rice and wheat flour then in the absence of devastating droughts they are wealthier than the Kamba farmers. Moreover, crop growing was a new phenomena and therefore change of diet to grains like that of the Kamba community will take sometime. Just like Kibwezi villages, the amount consumed varied from one household to another even within a poverty group due to differences in the number and age of the household members.

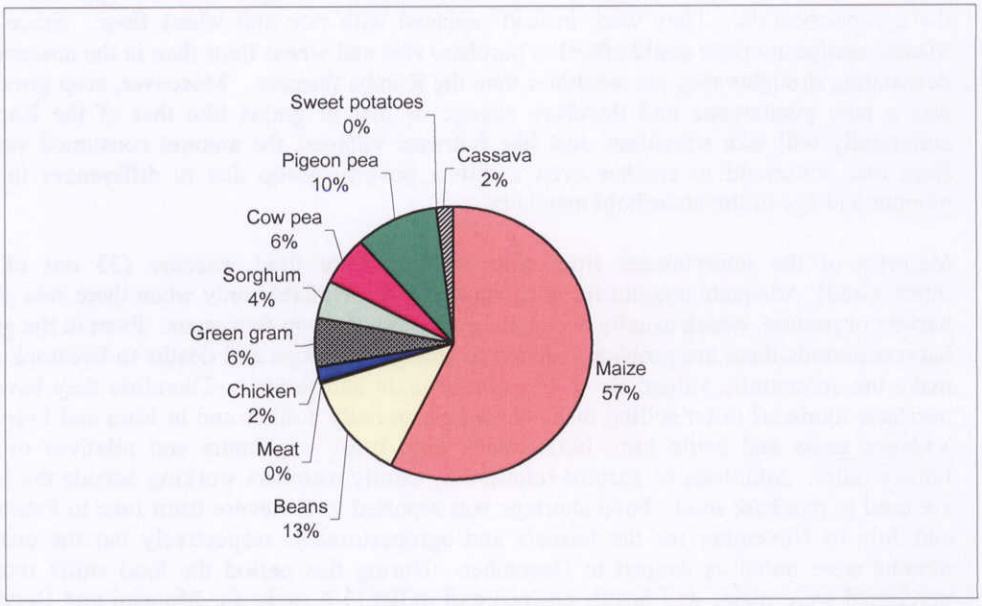
Majority of the interviewees from four villages were food insecure (33 out of 36 interviewed). Adequate amount for consumption were available only when there was good harvest or pasture, which usually occurs once in every three to four years. Even in the good harvest periods there are problems related to storage for crops and deaths to livestock that make the community vulnerable to frequent drought and famine. Therefore they have to purchase foodstuff (after selling their livestock especially poultry and in Isara and Erankau Villages goats and cattle too), borrow/seek help from neighbours and relatives or get famine relief. Additionally, income remitted by family members working outside the farm are used to purchase food. Food shortage was reported to be severe from June to February and July to November for the farmers and agropastoralists respectively but the critical months were noted as August to December. During this period the food stuffs mostly purchased were maize and beans, cowpea and millet (1-4 sacks for Muusini and Bondeni and 1-2 sacks in Isara and Erankau per household per year correspondingly).

(viii) Social networking

Socially, the villages have many informal networking that bring sometimes the whole village members together – they include social ceremonies such "Harambee" of "let us help each other" philosophy to organize fund raisings necessary for development, for example to offset hospital bills, school fees and marriage costs. Others especially in Isara and Erankau are circumcision and "moran" (promotion of the youth to adulthood) related festivals. In the pastoral communities milking animals were also lent to the poor as a survival strategy as mentioned earlier.

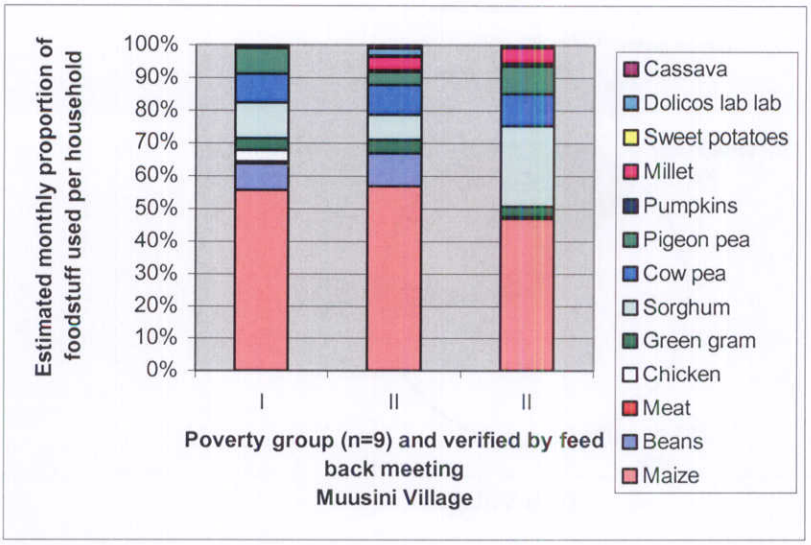


Muusini Village.



Bondeni Village.

Figure 4.1.4 The composition of foodstuff used by an average household in Muusini and Bondeni Villages, Kibwezi, Kenya.



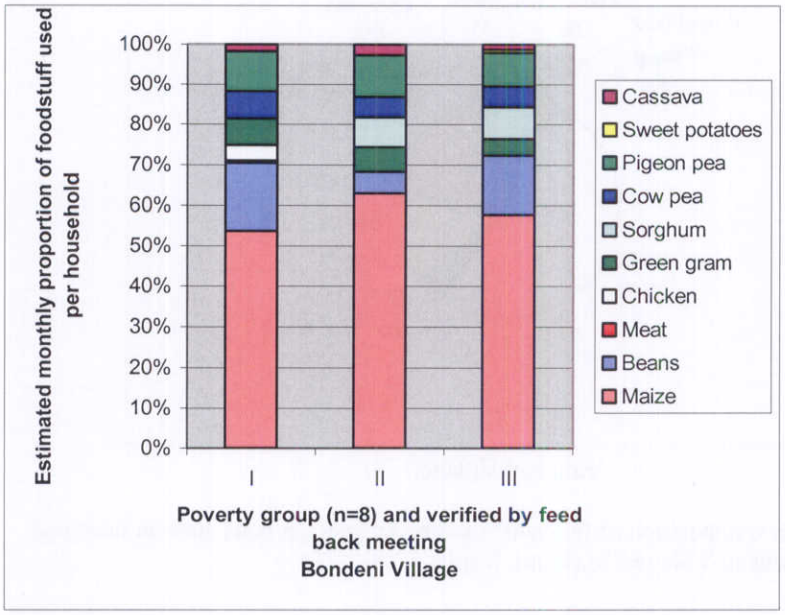
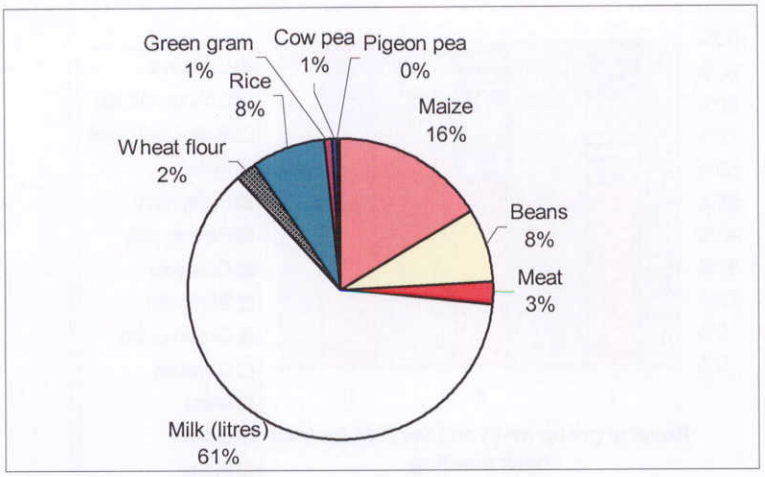
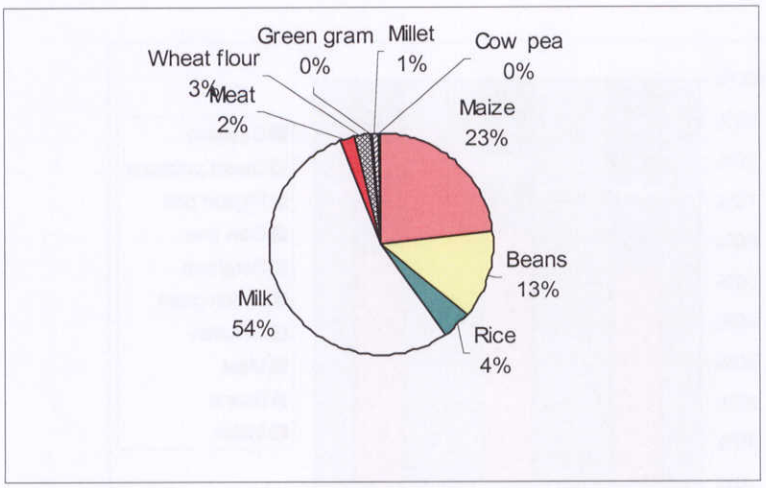


Figure 4.1.5 Average proportion of the amounts of foodstuff used per household in the different poverty groups in Muusini and Bondeni Village, Kibwezi Division Kenya.

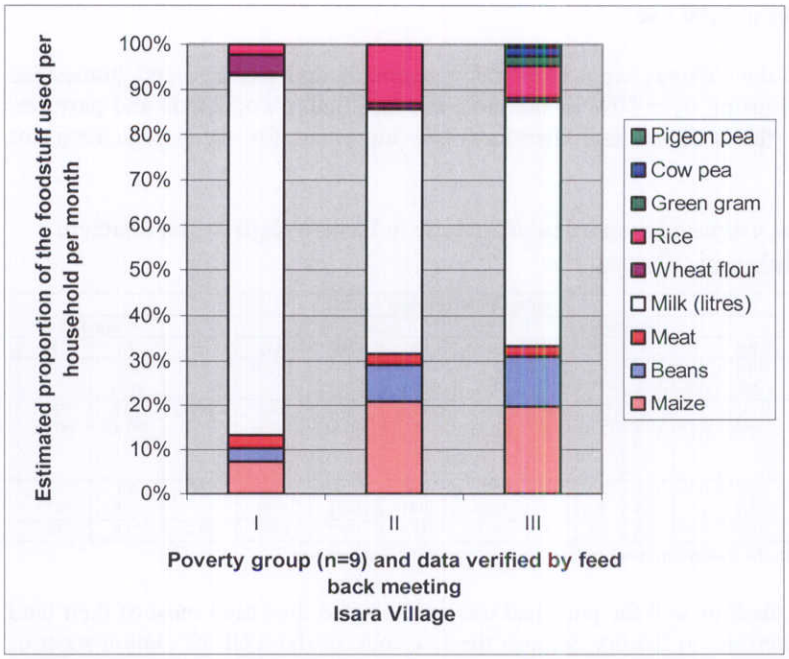


Isara Village.



Erankau Village.

Figure 4.1.6 The composition of foodstuff used by an average household in Isara and Erankau Villages, Mashuru, Kenya.



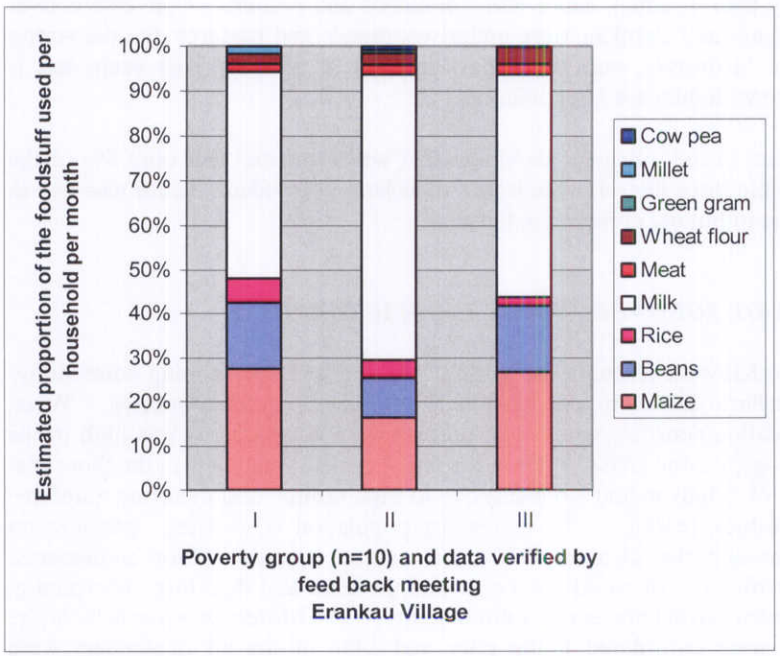


Figure 4.1.7 Average proportion of the amounts of foodstuff used per household in the different poverty groups in Isara and Erankau Village, Mashuru Division, Kenya.

(ix) Major types of land use

Major land uses in the villages were cropland, woodlands and pastures and homestead (Table 4.1.6). In Muusini, over 50% of the land was still under woodlands and pastures, mostly owned by the well off and therefore was important for their large herds of livestock.

Table 4.1.6 The estimated proportion of land use in Eastern Kajiado and Southern Makueni, Kenya.

Proportion of land use per farm	Village/Poverty group (n= 36)															
	Muusini				Bondeni				Isara				Erankau			
	I	II	III	Av.	I	II	III	Av.	I	II	III	Av.	I	II	III	Av.
Cropland (ha)	5.8 (13)	4.8 (58)	1.7 (59)	4.1 (43)	6.7 (76)	1.6 (80)	1.0 (77)	3.1 (78)	1.1 (2.7)	0.8 (0.6)	1.1 (0.8)	1 (1.4)	1.5 (2)	1.4 (1.9)	1.3 (1.6)	1.4 (1.8)
Woodlands and pastures (ha)	38 (86)	3.3 (39)	1.1 (36)	14.1 (54)	1.8 (21)	0.2 (10)	0.2 (15)	0.7 (15)	39.2 (96.8)	140.3 (99.1)	135.2 (98.9)	104.9 (98.2)	72 (97)	70.7 (97.4)	82.1 (97.7)	74.9 (97.4)
Homestead (ha)	0.3 (1)	0.3 (3)	0.2 (5)	0.3 (3)	0.3 (3)	0.2 (10)	0.1 (8)	0.2 (7)	0.2 (0.5)	0.5 (0.3)	0.4 (0.3)	0.4 (0.4)	0.7 (1)	0.5 (0.7)	0.6 (0.7)	0.6 (0.8)
Total (ha)	44.1	8.4	3	18.5	8.8	2.0	1.3	4.0	40.5	141.6	136.7	106.3	74.2	72.6	84	76.9

NB The number in the parenthesis are percentages covered by the land use.

On the contrary the medium and the poor had less animals and thus used most of their land for cultivation. Moreover, in the dry seasons the livestock of the well off exploit most of the pasture resources. The situation was different in Bondeni. In this village, emphasis was more on farming than livestock hence less woodlands and pastures. Conversely, over 95% of the land in Isara and Erankau were under woodlands and pastures due the strong livestock component. However, cultivation has emerged in the past 5-10 years and is expected to accelerate with increase in population.

Lease of land was rare in the villages. In Muusini, it was estimated that only 5% of the farmers practice it while three interviewees leased their land in Bondeni. Lease was rare in Isara and Erankau due to limited cropping in the area.

4.1.4 SUMMARY OF SOCIO-ECONOMIC CHARACTERISTICS

The study villages in Kibwezi Division are settled by Kamba mixed farming communitiy while those of Mashuru Division are inhabited by Masaai agropastoralists. When population and population densities within two regions were compared, it was high in the villages of agro-ecological zone (AEZ) V (Bondeni and Erankau) and least in the those that lie in the drier AEZ VI (Muusini and Bondeni) due to high rainfall and therefore attractive for farming and livestock rearing. The increasing population is exerting pressure on natural resources through the clearance of more natural woodlands for settlements, cultivation and intensified use of wood and non-wood products and therefore undermining sustainable development for the present and future generations. Moreover, over 60% of the villages households were considered to be poor and 54% of the all inhabitants were estimated to be less than 18 years.

Though over 55% of the teenagers attended schools, they too support their parents in farming over the holidays, evenings and weekends. While such activity prepares them as "farmers of the future", it can also be a source of low performance in school especially the girl child. The support of children on farm is necessitated by rural-urban migration of able

bodies men and women to look for job. Consequently, off-farm activities generates the highest annual source of income in the Muusini and Bondeni Villages and substantial income to Isara and Erankau after livestock though most of the income goes to well off and medium poverty groups. Poultry products form a major source of income for the poor. Another important source income especially in Kibwezi are crop products. However, the prices of farm products fluctuate with season. Limited financial support was the major obstacles in making on-farm priority source of income.

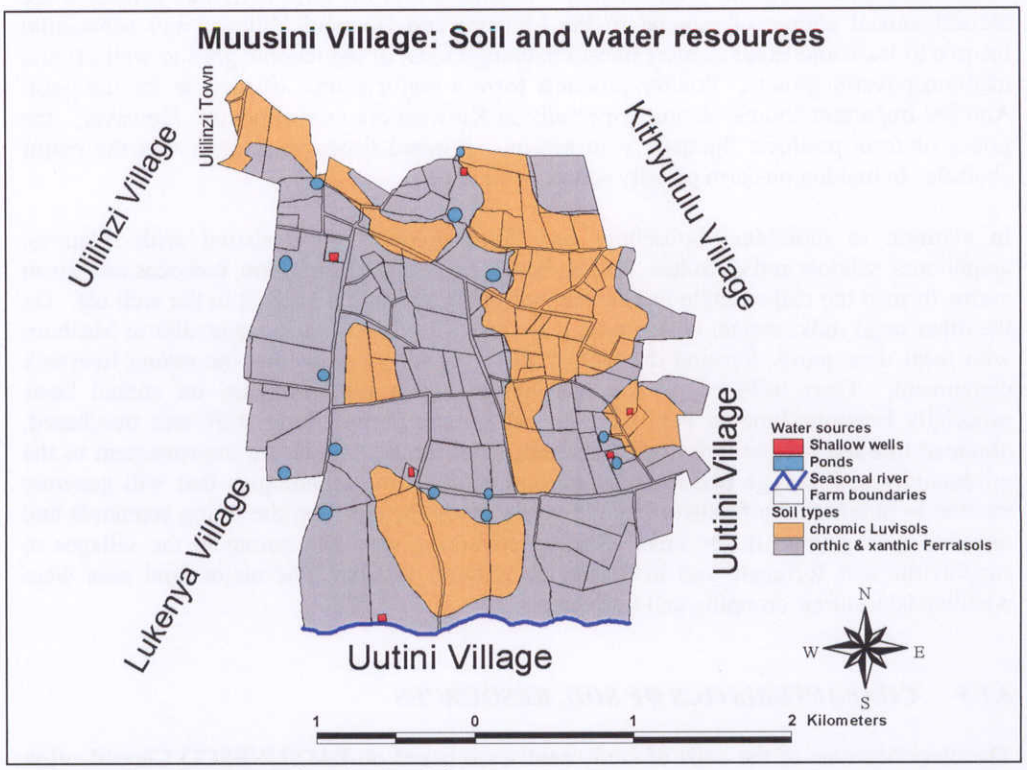
In addition to individual household use, farm products were shared with relatives, neighbours, schools and churches. Maize, beans, pigeon peas, sorghum, cowpeas and green grams formed the major staple in Kibwezi with meat/chicken restricted to the well off. On the other hand milk, maize, beans, rice, meat and wheat flour were major diet in Mashuru with meat meat partly forming the diet of all the poverty groups due the strong livestock component. Over 90% of all the interviewees were food insecure on annual basis especially between June to February. To off set the deficit, food stuff was purchased, obtained through famine relief or by sharing of resources. Therefore improvement to the productivity and storage periods of these commodities or technologies that will generate income to purchase the foodstuff should be the basis for uplifting the living standards and resource management in the area. Social networking was also strong in the villages to support the less fortunate and in preserving cultural values. The major land uses were woodlands/pastures, cropping and settlements.

4.1.5 CHARACTERISTICS OF SOIL RESOURCES

The classifications of the soils of study area were based on FAO/UNESCO Classification (FAO 2001b) and for detailed characterization of the chemical and physical properties of the soil units Bock and Lacroix (2002) and KSS methodologies (1987) was used. The data was then compared with generalized soils of Kibwezi and Mashuru area by Touber (1983) and Wijgarden and Englen (1985) in order to identify and relate to the major soil groups of the area. Because the samples per soil unit were few, detailed variability analysis was not possible and therefore the data averages provided only help understand the tendencies of the soil parameters across the soil types. Muusini Village and Bondeni has less soil units than Isara and Erankau Villages because the later have more diversity of physiographic and parent materials.

In Muusini Village the major soil type consisted of a deep imperfectly to moderately well drained dark yellow brown to yellow Brown (10YR 3/4 – 5/8) dystric loamy sand to sandy loam in associated with a deep well drained dusky red to yellow Red (2.5YR 3/2 – 4/8) loamy sand to sandy loam dystric soil. Both soils are derived from basement rocks - gneisses rich in ferromagnesian minerals. The first soil was in many ways similar to *chromic LUVISOLS, petric phase* and the second had properties comparable to *xanthic* and *orthic FERRALSOLS* (Fig. 4.1.8). Consequently, the names were adopted as working names.

Bondeni Village has three soil units. The southern tip of the village was covered a very dark Gray (5YR 3/1) extremely shallow to very shallow excessively stony and bouldery rocky dystric sandy loam soil of volcanic origin (Fig. 4.1.9) that fitted the characteristics of Volcanic Lava Flow. Much of the central and southern section of the village was covered by a very deep imperfectly drained black to dark Brown (2.5YR 3/1 – 3/3) sandy loam to sandy clay loam dystric soil.

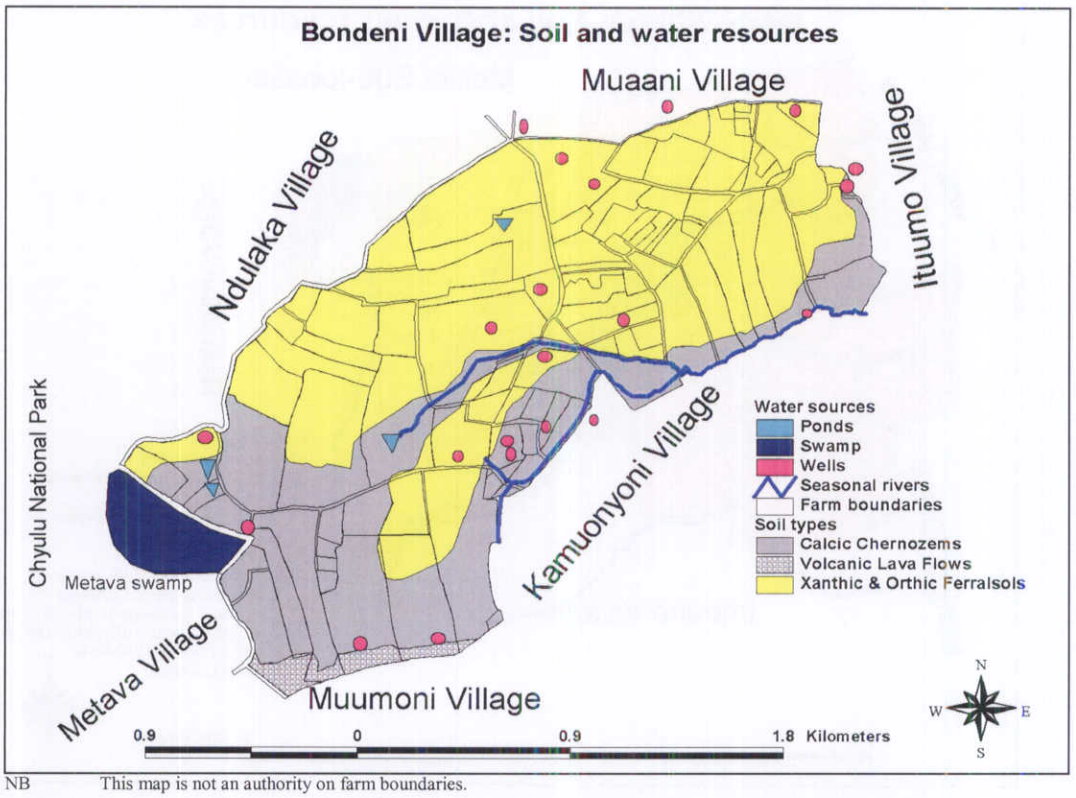


NB This map is not an authority on farm boundaries.

Figure 4.1.8 Soil and water resources of Muusini Village, Kibwezi, Kenya.

The soil had both vertic and chernozems characteristics and was similar to the description of *calcic Chernozems* found in the area, a working name that the soil will referred to in this report. Major part of the northern and central section of Bondeni was covered by a very deep well drained very dark Brown to very dark Gray (10YR 3/2 – 3/1) dystric sandy loam soil that was in many ways similar to ACRI* - *xanthic* and ACRI* - *orthic FERRALSOLS*. The *Chernozems* are alluvial and colluvial deposits from parent materials of volcanic origin mainly olivine basalts in the form of agglomerates and breccias mixed with materials from basement complex rich in ferromagnesian minerals while the Ferralsols are derived from basement rocks of biotite and hornblende gneisses partly rich in ferromagnesian minerals and partly fertilized by volcanic rocks.

Isara Village is composed of seven soil units (Fig. 4.1.10). The northeast corner of the village is Donyo Oiti hill. The hill is covered by a dark reddish Brown (5YR 3/4) very shallow, bouldery and gravely dystric clay loam soil of volcanic origin. that fitted the characteristics of *chromic Cambisols, lithic and stony phase*. On the foothills of the same hill, the soils were moderately deep dark reddish Brown (5YR 3/3) dystric sandy clay with stones. The soils were in many ways similar to *chromic Cambisols, stony phase*. Below the above hill alluvial and colluvial deposits eroded from the hill formed a very deep and very dark Gray (10YR 3/1) sandy clay soils with vertic characteristics similar to *chromic and pellic Vertisols*, here referred to as Volcanic *Vertisols*.

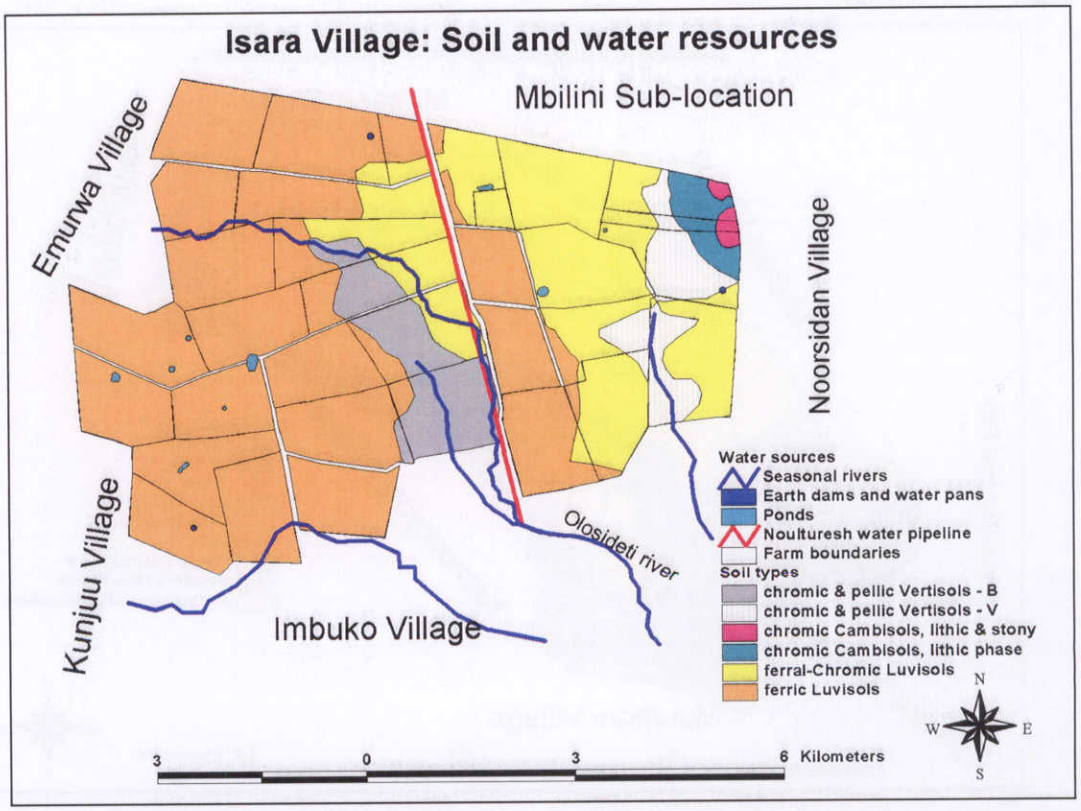


NB This map is not an authority on farm boundaries.

Figure 4.1.9 Soil and water resources of Bondeni Village, Kibwezi, Kenya.

Surrounding the Volcanic *Vertisols* are deep to very deep well drained dark red to yellow Red (2.5YR 3/6 – 5YR 4/6) dystric sandy loam to sandy clay loam soils whose characteristics are comparable to *ferral chromic Luvisols* described in the area by Touber (1983). The major part of the western and southern Isara consists of a well drained deep to deep mysic loamy sand to sandy clay loam whose colour on the eastern portion is brown to dark reddish Brown (2.5YR 3/4 – 3/6) and dark reddish Brown to very dark Gray (5YR 3/3 – 10YR 3/1) on the western part. Its characteristics are similar to *ferric Luvisols*. *ferral chromic* and *ferric Luvisols* originated from basement rocks poor in ferromagnesian minerals. Sandwiched between the *ferral chromic Luvisols* and *ferric Luvisols* is a vertic soil of alluvial and colluvial deposits derived from basement complex poor in ferromagnesian minerals. These soils are imperfectly drained very deep and very dark Gray (10YR 3/1) dystric sandy clay to sandy clay loam fitting the characteristics of *chromic and pellic Vertisols*, here referred to as basement *Vertisols*.

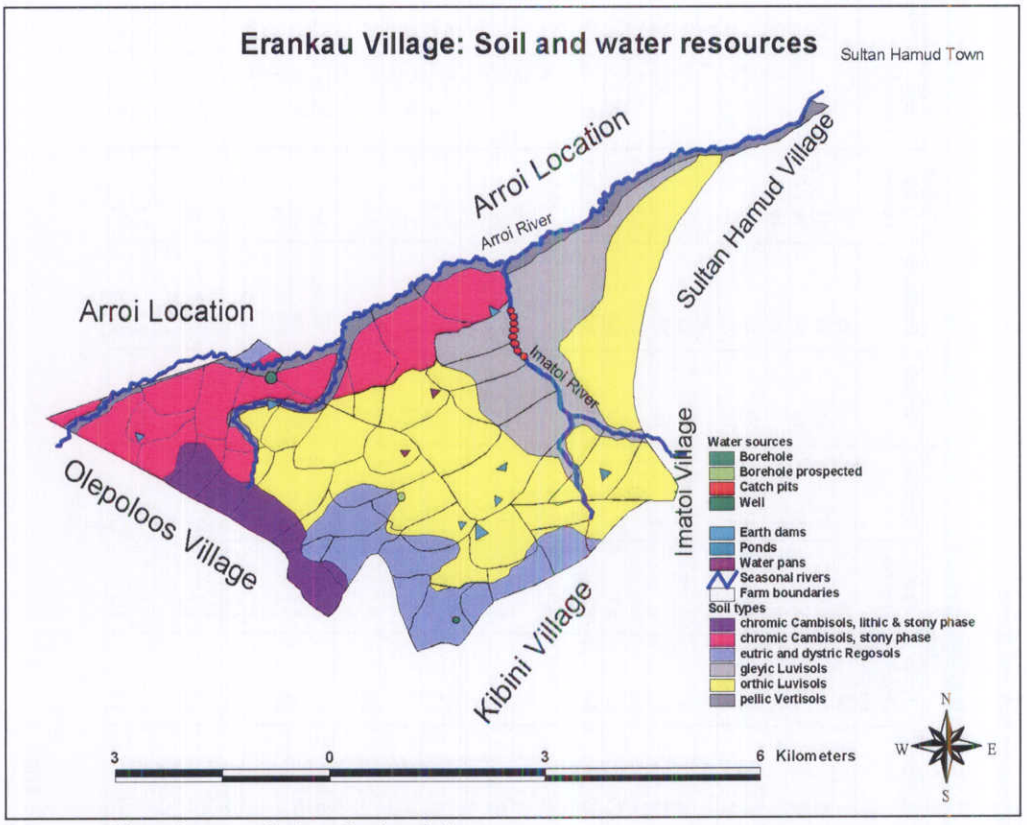
The hilly village of Erankau has six soil units (Fig.4.1.11). The southern end of the village is occupied by the Ngama hills. The soils on these hills are well drained to some what excessively well drained rocky to very rocky and bouldery Brown to very dark gray Brown (5YR 3/4 to 10YR to 10YR 2/2) extremely shallow dystric loamy sand (with few pockets of sandy clay loam/sandy loam), a characteristic very similar to *dystric Regosols* identified by Touber (1983). These soils are derived from basement complex parent materials poor in ferromagnesian minerals.



NB This map is not an authority on farm boundaries.

Figure 4.1.10 Soil and water resources of Isara Village, Mashuru, Kenya.

The south central section of Erankau is Oldonyo Sepa Volcanic hill (formerly known as Lolbeneyioi). The hill is covered by somewhat excessively drained fairly stony to very stony, very shallow to shallow and very dark gray Brown (10YR 3/2) dystric sandy loam/sandy clay soils whose characteristics fit that of *chromic Cambisols, lithic and stony phase*. The eastern corner of the village and part of northern Erankau is formed by a well drained to excessively well drained moderately deep Red to dark Brown (2.5YR 3.6/6 – 7.5YR 3/2) dystric sandy clay loam. The soils description concur with that of Touber (1983) for *chromic Cambisols stony phase* and they are derived from Pliestocene volcanics. Down the Regosols and Cambisols hills the soils are deep, well drained dark reddish Brown to very dark Gray (5YR 3/4 – 3/1 to 10YR 5/8) dystric loamy sand to sandy clay/sandy clay loam. The characteristics are similar to the description of *orthic Luvisols*. On the northeastern section of the village along River Matoi, the soils are formed by colluvial and alluvial deposits derived from various gneisses poor in ferromagnesian minerals. They are very deep, imperfectly to poorly drained dark reddish Brown to Black (10YR 2/1) dystric sandy clay soil with gleyic properties very similar to *gleyic Luvisols*. On the northern boundary of the village along River Arroi, the soils are very deep, imperfectly drained black (5YR 2/1) dystric sandy clay loam with vertic properties very much similar to *pellic Vertisols*.



NB This map is not an authority on farm boundaries.

Figure 4.1.11 Soil and water resources of Erankau Village, Mashuru, Kenya.

All the soil units of the study village had similar soil structure, consistence, electrical conductivity (EC) and pH. The soil strucutres were generally of sub angular blocky to angular blocky, hard when dry and slightly sticky to sticky when wet. The soils were salt free (EC of 0.017 – 0.174 mmhoscm^{-1}) and average pH was neutral to medium ranges (pH water 6.2 – 7.1), a preferred range for most crops. There was also no sodium toxicity problem in all the soils (0 – 1.481) and the average Carbon/Nitrogen ratio was over 10 in almost all the samples implying that mineralization rates were low. As expected soil colour was lighter with soils derived from basement rocks than those from volcanics and sediments (APPPENDIX II). Average values for all the other major soil characteristics have been summarized in Table 4.1.7. The major land uses were cultivation, woodlands and pastures and bricks making for the *Ferralsols* and *Luvisols* of Muusini, Bondeni and Erankau (Plate 4.1.1).

(i) Texture

Ferralsols and *Cambisols* in all the villages had almost same sand, clay and silt contents in both croplands and woodlands. However, *Luvisols* in Muusini had higher clay and silt in the woodlands and pastures than the croplands.

Table 4.1.7 Major soil characteristics in four villages of Eastern Kajiado and Southern Makueni, Kenya.

Soil property	Land use	Villages/soil types													
		Muusiini		Bondeni			Isara				Erankau				
		Luvisols	Ferralsols	Ferralsols	Chernozems	Volcanic Lava	Cambisols	Ferral chromic Luvisols	Ferric Luvisols	Vertisols	Vertisols	Cambisols	Orthic Luvisols	Gleyic Luvisols	Regosols
Sand (%)	Cropland	78	81	77	71	72		68	74			59	76		
	Woodland	66	85	77	68		52	75	80	57	54	58	81	54	80
	Average	72	83	77	70	72	52	72	77	57	54	59	78	54	
Clay (%)	Cropland	17	12	17	19	16		20	20			21	16		
	Woodland	19	10	17	25		32	19	13	35	30	21	11	40	12
	Average	18	11	17	22	16	32	20	17	35	30	21	14	40	12
Silt (%)	Cropland	5	7	6	10	12		12	6			20	8		
	Woodland	16	5	6	7		16	6	7	8	16	21	8	6	8
	Average	10	6	6	9	12	16	9	7	8	16	20	8	6	8
pH (Water)	Cropland	6.2	6.6	6.3	6.6	7.1		6.6	6.4			6.3	6.4		
	Woodland	6.6	6.6	6.6	6.7		6.9	6.7	5.9	7	7.1	6.6	6.2	6.6	6.6
	Average	6.3	6.6	6.5	6.7	7.1	6.9	6.7	6.2	7	7.1	6.5	6.3	6.6	6.6
Soil moisture content (%)	Cropland	3	2	4	6	7		4	5			10	3		
	Woodland	4	2	5	6		11	3	3	11	15	5	2	9	3
	Average							4							
Soil organic matter (SOM)	Cropland	1.5	1.3	3.3	3.2	2.3		2.2	1.7			2.6	2.5		
	Woodland	1.9	1.4	3.3	3.6		5	1.5	1.9	3.1	3.2	4	1.5	2.4	2.3
	Average	1.7	1.4	3.3	3.4	2.3	5	1.9	1.8	3.1	3.2	3.3	2	2.4	2.3
Calcium (me/100g)	Cropland	2	1.3	2.6	5.5	7.7		3.3	2			3.3	3.1		
	Woodland	1	4	1.5	9.7		21.1	3	1.7	27	9.7	6.2	1.7	0.5	2
	Average	1.5	2.7	2	7.6	7.7	21.1	3.2	1.9	27	9.7	4.8	2.4	0.5	2
Potassium (me/100g)	Cropland	1	0.7	0.8	1	1.7		1.7	1.6			1.5	1.1		
	Woodland	1.4	0.7	0.7	0.7		1.4	1.4	0.8	0.8	1.2	1.1	0.8	0.6	0.7
	Average	1.2	0.7	0.7	0.9	1.7	1.4	1.6	0.7	0.8	1.2	1.3	1	0.6	0.7
Magnesium (me/100g)	Cropland	1.2	1	1.4	1.6	1.4		1.8	1.2			1.9	1.8		
	Woodland	1.7	1.4	1.3	1.8			1.9	1.4	2.5	2.1	2.8	1.5	1.3	1.4
	Average	1.4	1.2	1.4	1.7	1.4	2.5	1.9	1.3	2.5	2.1	2.4	1.7	1.3	1.4

Cont. of Table 4.1.7

Soil property	Land use	Muusiini		Bondeni			Isara				Erankau				
		Luvisols	Ferralsols	Ferralsols	Chernozems	Volcanic Lava	Cambisols	Ferral chromic Luvisols	Ferric Luvisols	Vertisols	Vertisols	Cambisols	Orthic Luvisols	Gleyic Luvisols	Regosols
Cation Exchange Capacity (me/100g)	Cropland	25	29	23	46	32		20	36			72	27		
	Woodland	38	18	29	52		71	20	14	59	82	76	28	86	18
	Average	32	24	26	49	32	71	20	25	59	82	74	28	86	18
Base saturation percentage	Cropland	30	21	28	18	35		28	20	54		10	31		
	Woodland	13	42	23	24		36	34	30	54	17	14	28	3	35
	Average	22	32	26	21	35	36	31	25		17	12	30	3	35
Available phosphorus (ppm)	Cropland	8	10	4	3	33		97	52			147	63		
	Woodland	4	6	2	8		28	76	21	6	44	56	26	7	7
	Average	6	8	3	6	33	28	87	37	6	44	102	45	7	7
Total nitrogen (ppm)	Cropland	0.08	0.07	0.12	0.16	0.07		0.09	0.08			0.1	0.11		
	Woodland	0.1	0.24	0.42	0.14		0.22	0.08	0.64	0.11	0.14	0.18	0.06	0.08	0.09
	Average	0.09	0.15	0.27	0.15	0.07	0.22	0.09	0.4	0.11	0.14	0.12	0.09	0.08	0.09
Vegetation cover (%) in rainy season	Cropland	3 (trees/ shrubs)	2 (trees/ shrubs)	7 (trees/ shrubs)	4 (trees/ shrubs)	1 (trees/ shrubs)		< 1 (trees/ shrubs)	< 3 (trees/ shrubs)			< 5 (trees/ shrubs)	< 5 (trees/ shrubs)		
	Woodland	86	89	94	91.5	0	78	78	76	68	77.5	88	89	80	89
	Average	44.5	45.5	51	48	0.5	78	78	74	68	77.5	88	47	80	89
Soil erosion status	Cropland	Severe	Moderate to severe	Moderate	Severe	Severe		Severe	Severe	Severe		Moderate to severe	Slight to severe		
	Woodland	Severe	Slight to high	Moderate	Slight		Severe	Severe	Severe	Severe	Excessive	Moderate to excessive	Slight to severe	Excessive	Severe

Village	Soil type	Land use	No. of samples
Muusini	Luvisols	Croplands	8
		Woodland	4
	Ferralsols	Croplands	4
		Woodlands	5
Bondeni	Ferralsols	Croplands	5
		Woodlands	3
	Chernozems	Croplands	4
		Woodlands	4
	Volcanic lava	Croplands	1

Village	Soil type	Land use	No. of samples
Isara	Cambisols	Woodland	2
	Ferral chromic Luvisols	Cropland	2
		Woodland	2
	Ferric Luvisols	Cropland	6
		Woodland	2
	Vertisols	Woodland	4
Erankau	Vertisols	Woodland	1
	Cambisols	Cropland	2
		Woodland	2
	Orthic Luvisols	Cropland	8
		Woodland	8
	Gleyic Luvisols	Woodland	1
	Regosols	Woodland	6



Photo by A. Mohamed in 2004.

Plate 4.1.1 Ferralsols are important resource for bricks making in Bondeni and Muusini Villages, Kibwezi, Kenya.

In Isara and Erankau Villages, *Luvisols* had higher silt and clay on croplands and more sand in the woodlands and pastures. The difference is due to overgrazing and subsequent soil erosion of the finer clay and silt particles in woodlands and pastures. Protection against livestock in croplands seems to help in the retention of the finer soil particles and therefore improved clay and silt contents.

(ii) Soil organic matter (SOM)

Except for the *Cambisols* that had slightly higher soil organic matter than other soil units, all the four villages had generally low organic matter contents. The higher SOM content in the *Cambisols* was expected due to its volcanic origin. When croplands and woodlands were compared, the later had higher organic matter content in all the soil units of Muusini, *Chernozems* of Bondeni and *Cambisols* of Erankau. However, *Ferralsols* in Bondeni had similar SOM content both in croplands and woodlands while there was more SOM content on croplands of *Luvisols* in Isara and Erankau. The high SOM in the woodlands can be related to drop in organic content after converting the woodlands into croplands. Similar results were obtained by Bewket and Stroosnijder (2002) in Ethiopia. Conversely, the higher organic matter in croplands of the *Luvisols* of Isara and Erankau was due to indirect application of animal manure through gravitational soil fertility management, a unique indigenous practice identified by the study, which will be discussed under impacts.

(ii) Soil moisture content

Soil moisture content was generally low in the *Luvisols*, *Ferralsols* and *Regosols* while it was high in the *Chernozems*, *Vertisols*, *Cambisols* and *gleyic Luvisols* (Table 4.1.7 and Appendix II). The differences can be related to the parent materials. The *Luvisols*, *Ferralsols* and *Regosols* are derived from sandier basement complex and therefore hold less moisture. Conversely, the soils that originate from volcanic and sediments, which contain high clay content retained higher moisture.

Within the *Cambisols* of Erankau, slope factor had an impact on soil moisture content. On the hilly Oldonyo Sepa, woodlands had low moisture than similar land use on the plains (Appendix II).

Similarly, soils of the bottomlands (*Vertisols*, *gleyic Luvisols* and *Chernozems* had more moisture than the plains and the hills – Table 4.1.7 and Appendix II). Moisture also increased with increase in soil organic matter. Land use type did not seem to affect moisture content in Muusini and Bondeni Villages although in Muusini farms that practiced terraces seem to have slightly high moisture – for example Appendix II - Muusini 1 and Muusini 6. Isara and Erankau, cropland had higher moisture content than woodlands and pastures (Table 4.1.7 and Appendix II). The high moisture can be related to the practices of deep tillage and direct and indirect application of animal manure on croplands. On the other hand, woodlands and pastures were overgrazed, clay content eroded and therefore less soil moisture. Consequently, the conversion of pastures into croplands seems to encourage soil moisture retention.

(iii) Total nitrogen

Throughout the study villages' nitrogen level was low (0.06 – 0.42) corresponding to the low SOM. When the two major land uses were compared, most of the soil units had similar nitrogen levels except in *Ferralsols* and *orthic Luvisols*. *Ferralsols* had 2 – 4 times more nitrogen in the woodlands than the croplands due to severity of erosion, over cultivation and limited soil conservation in place. On the contrary, *orthic Luvisols* had almost twice more nitrogen in croplands than the woodlands due to high use of manure based practices.

(iv) Exchangeable cations, cation exchange capacity (CEC) and base saturation percentage (BSP)

CEC refers to the total number of positively charged elements (both basic cations such as calcium, magnesium, potassium and sodium and acidic cations like hydrogen and aluminium) that a soil can hold and is an indication of the soil's potential to hold plant nutrients. On the other hand BSP is the percent of exchangeable sites occupied by the basic cations. Average CEC of the soils ranged 23 – 72 for croplands and 16 – 86 me/100g for woodlands and pastures. *Orthic, chromic*, *ferral chromic* and *ferric Luvisols* and *Ferralsols* had the lowest CEC while *gleyic Luvisols*, *Vertisols* and *Cambisols* had the highest CEC (Table 4.1.7 and Appendix II). The high CEC corresponded with high clay, calcium and magnesium contents and soil organic matter. High CEC is an indication of potentially high soil fertility. However, BSP which is the indicator of nutrients available to plants, was variable in all the soil units increasing with increase in natural vegetation cover and density, intensification of soil water conservation structures and addition of animal manure (Table Table 4.1.7 and Appendix II). BSP was low on farms with minimal or no physical soil conservation structures and where vegetation cover and density was less.

(v) Available phosphorus (P)

In Muusini phosphorus levels were low but slightly higher in croplands than the woodlands and pastures. In Bondeni except for the high phosphorus level in the Volcanic Lava there was no big difference in amount with the other soils irregardless of the land use type. There was big variation of P levels in Isara and Erankau. It was always higher in croplands than the woodlands and pastures. P levels was least on the *Vertisols*, *Regosols* and *gleyic Luvisols* and highest on *ferral chromic*, *ferric* and *orthic Luvisols* and on the *Cambisols*. The high P content on the cultivated fields than the woodlands suggest that a high proportion of P pool is retained and immobilized by microbes in the litter of the woodlands and pastures (Bewket and Stroosnijder 2002).

Another possibility is that of the effect of animal manure in form of dug and manure as a soil conditioner in cultivated fields has been substantial. Similarly, high number of livestock concentration within the woodlands and pastures of Isara and Erankau could have increased their P levels when compared to those of Muusini and Bondeni. When P levels in Muusini and Bondeni are compared, the former had relatively higher P due to the high livestock concentration. Most of these animals freely graze on croplands in dry seasons and therefore could have contributed to relatively higher P levels. The high P in croplands means increase in deforestation has not deterred it's a availability but rather increased it. The lower P in the *Vertisols* of Isara, *Chernozems* in Bondeni and gleyic Luvisols suggests fixation by the clayey soils, which contain abundant calcium, magnesium, iron and manganese cations for the pH neutral soils. Soluble P reacts with clay and the cations compounds in the soil and is converted to less available forms by P fixation.

(vi) Erosion status

Erosion status was severe to excessive (in form of sheet, rills and gully erosions) in all the woodlands and pastures of the Isara and Erankau Villages (Table 4.1.7, Appendix II and Plates 4.1.2) as a result of large number of livestock, hence overgrazed. Moreover, most of the vegetation covers in rainy seasons were annuals and deciduous trees and shrubs and therefore the soil surfaces were exposed to wind erosion in dry seasons and water erosion at the start of the rainy seasons. Further, Isara and Erankau are partly covered by hilly areas that too accelerate erosion once exposed. The woodlands and pastures of Bondeni Village were the least eroded due to the relatively less livestock numbers and higher rainfall compared to the other villages. Moreover, the animals grazed mostly in the nearby national parks and forest reserve. In Muusini, Luvisols both under croplands and woodlands was prone to severe erosion due to inappropriate management and its instable nature. It had soil surface crusting that encourages erosion. Tree cover on croplands in the villages accounted for less than 10% and soil conservation structures were minimal or inadequately and improperly laid, hence susceptibility to erosion was very common (Table 4.1.7). Erosion status was further increased by over cultivation (every rainy season) in most of the farms owned by the poor category farmers especially in Muusini and Bondeni.

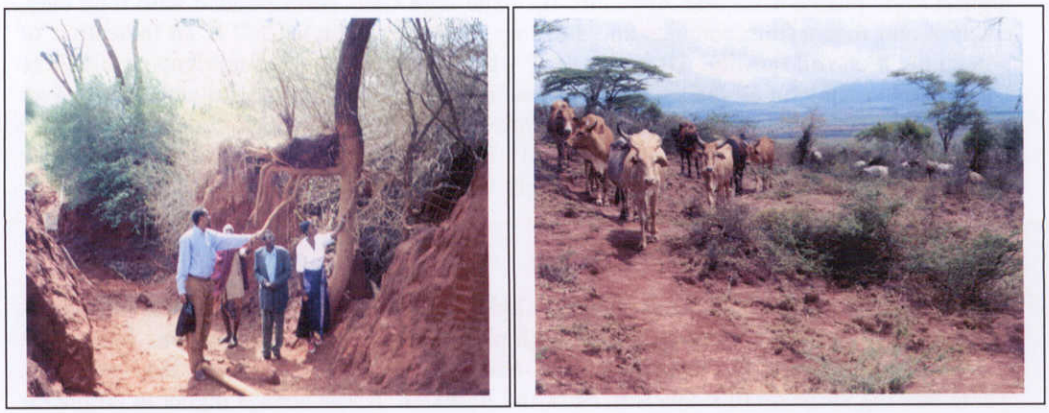


Photo by A. Mohamed in 2002.

Plate 4.1.2 Gully, sheet and rill erosions were common in Eastern Kajiado and Southern Makueni, Kenya but most severe in Mashuru than Kibwezi due to overgrazing.

4.1.6 SUMMARY OF SOIL RESOURCES

After characterizing the soils based on the physical and chemical components, they were related to major soil types so as to get a working name. *Ferralsols* and *Luvisols* covered the Muusini village while *Ferralsols*, *Chernozems* like and Volcanic Lava soils constituted Bondeni. Isara Village has *Cambisols*, *Vertisols* and *Luvisols* soils while *Regosols*, *Cambisols*, *Luvisols* and *Vertisols* are the major soils of Erankau. Except for the *Cambisols*, *Vertisols* and *gleyic Luvisols*, the rest of the soils had sand content of over 60%. In Muusini and Bondeni clay content and SOM was the same or higher in woodlands than croplands and the reverse was true for Isara and Erankau, which can be related to over cultivation and over grazing respectively. The high SOM on croplands in the later villages is related to gravitational soil fertility management. Amount of total nitrogen followed similar trend to SOM. The amount of CEC corresponded with high clay, calcium and magnesium contents and soil organic matter. Phosphorus increased with increase in organic matter and livestock population. Soil moisture content varied with the content of sand and clay, parent material of the soil and slope. As expected, clayey soils, soils derived from volcanics and those found in the lowlands had higher moisture content. Deep tillage and manure also increased soil moisture. Erosion was higher with increase in the number of livestock, over cultivation and on farm with no physical soil conservation structures.

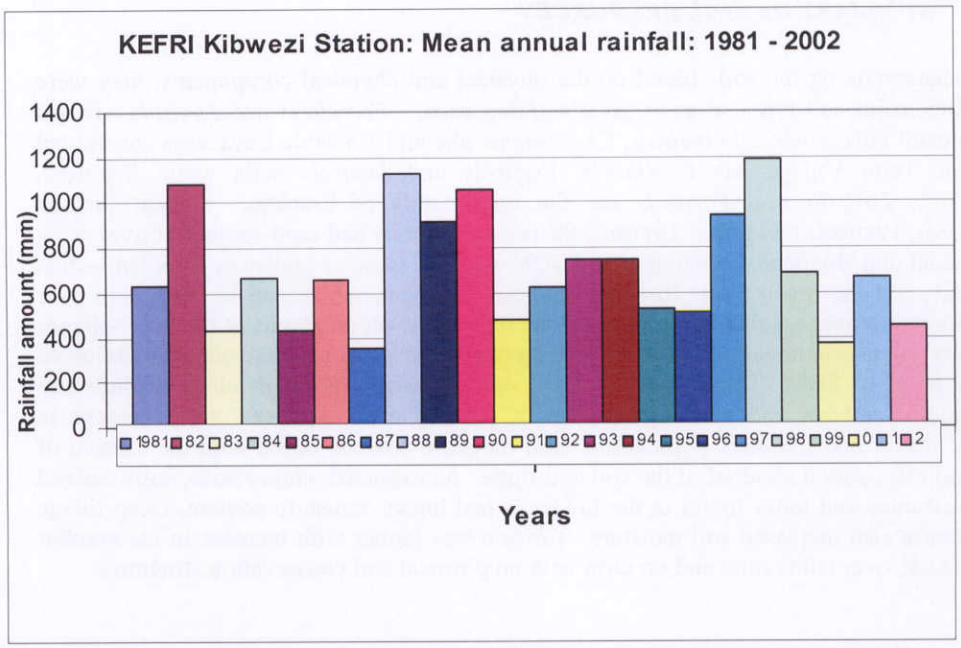
4.1.7 CHARACTERISTICS OF WATER RESOURCES

In the arid and semi-arid lands, rainfall is unreliable and erratic while accessibility to ground water sources also varies with topography, the nature of the underlying parent rock (GoK 2001) and availability of technologies. Moreover, in large parts of Kibwezi and Mashuru, Divisions, there are no permanent rivers (GoK 2001). Local communities in the region face severe water shortages. On daily basis they and their livestock have to trek long distances in search of water. As a result, the conservation and sustainable use of water resource is a top priority for the Kenyan Government (Hon. Martha Karua, Minister for Water Resources Management and Development, Kenya in MWRM&D 2004). To contribute towards water conservation it was necessary to undertake a study so as to understand the current status of the resource and its use at the village level. This section discusses rainfall trends, water sources and their status and current use and demand of water resource in the study villages.

4.1.7.1 Rainfall trends

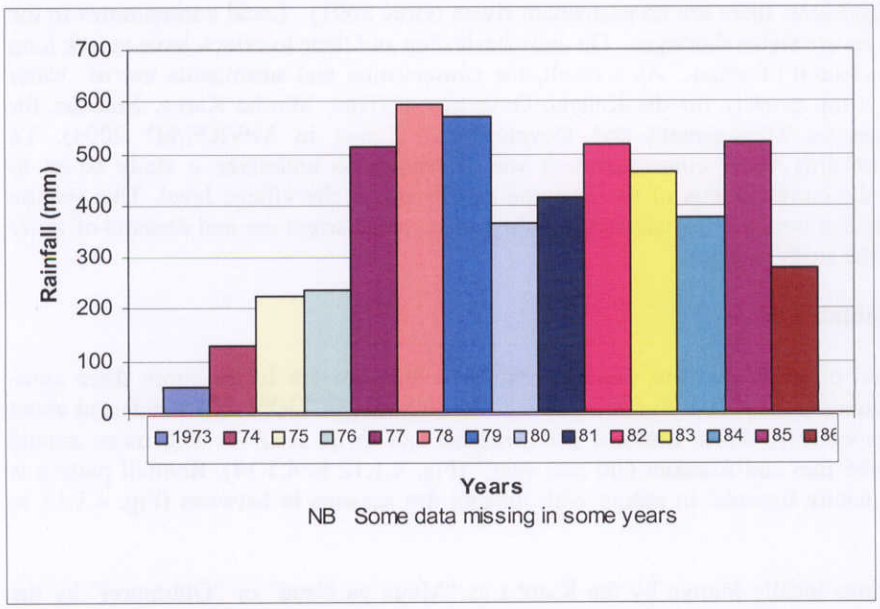
As explained under study area, Muusni and Isara Villages are in the more drier agro-ecological zones (AEZ) VI with annual rainfall of 500mm (ACTION AID 1993) and about 375 mm respectively while Bondeni and Erankau that lie in AEZ V with mean annual rainfall of 695 mm and Erankau 600 mm year^{-1} (Fig. 4.1.12 to 4.1.14). Rainfall pattern is bimodal in nature bimodal in nature with distinct dry seasons in between (Fig. 4.1.15 to 4.1.17).

The short rains locally known by the Kamba as "Mvua ya Nzua" or "Oltumurel" by the Masaai occurs in October to January while the long rains also called "Mvua ya Uowa" in Kibwezi and "Nguku" in Mashuru occurs between March and May.



Data source KEFRI Kibwezi Research Centre, Kenya.

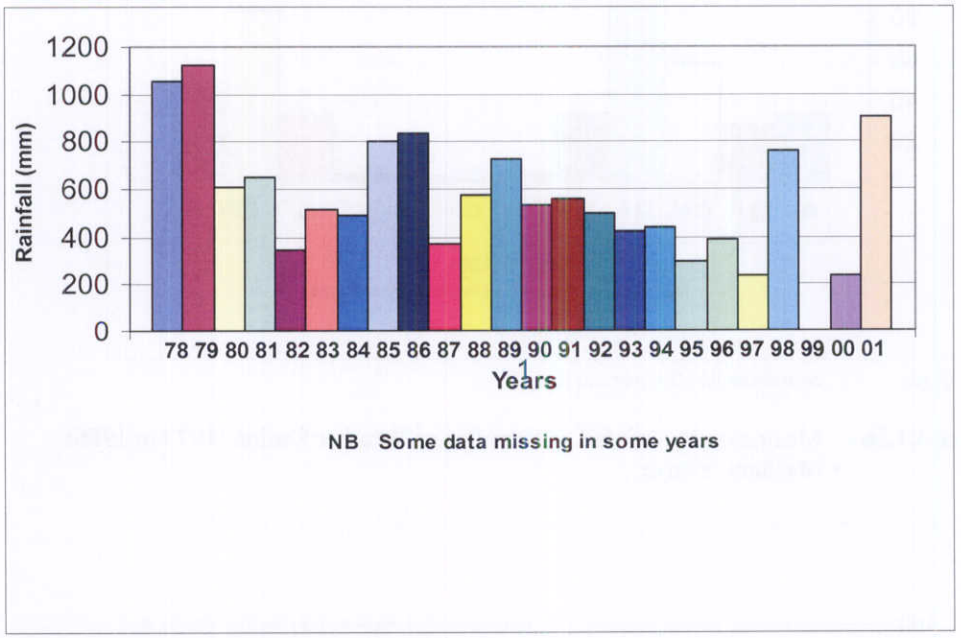
Figure 4.1.12 Mean annual rainfall of KEFRI Kibwezi Weather Station (1981 to 2002), close to Bondeni Village, Kibwezi, Kenya.



Data source Meteorological Department, Kenya.

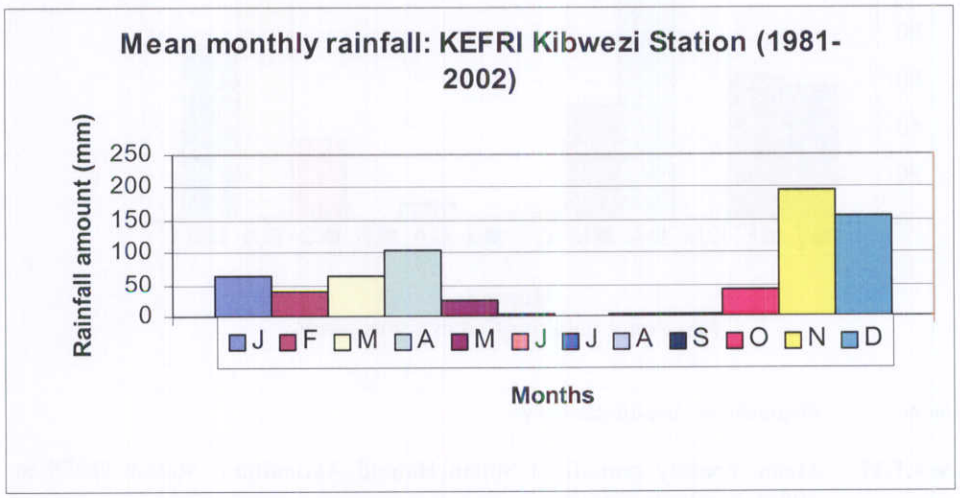
Figure 4.1.13 Mean annual rainfall of Isara Range Weather Station (1973 to 1986), Mashuru, Kenya.

However, the mean figures can be deceptive because of variability in rainfall. Within a decade the region rarely receives more than 250 mm in either season (the short or the long rains) (Jaetzhold and Schmidt 1983). Consequently, both the on-set of the rains and the total amount received are very unreliable and the probability of crop failure is very high.



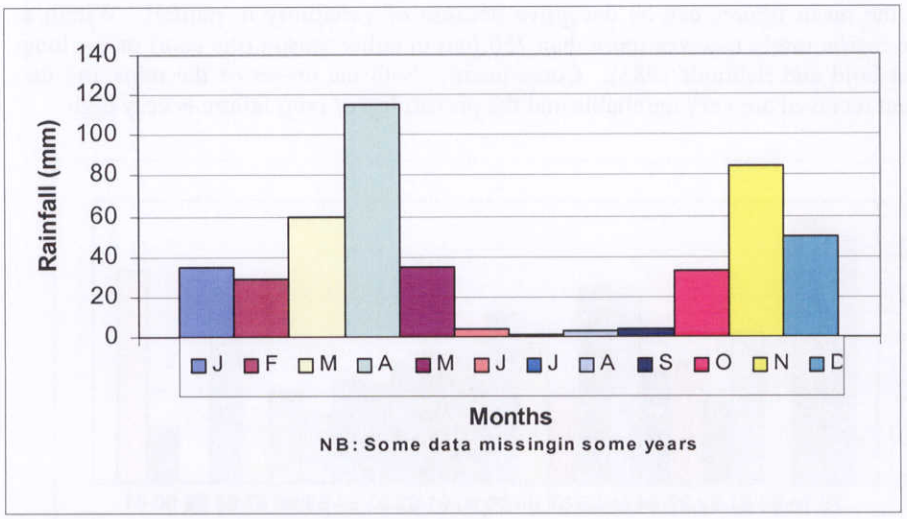
Data source Meteorological Department, Kenya.

Figure 4.1.14 Mean annual rainfall (1978 to 2001) of Sultan Hamud Agricultural Station, close to Erankau Village, Mashuru, Kenya.



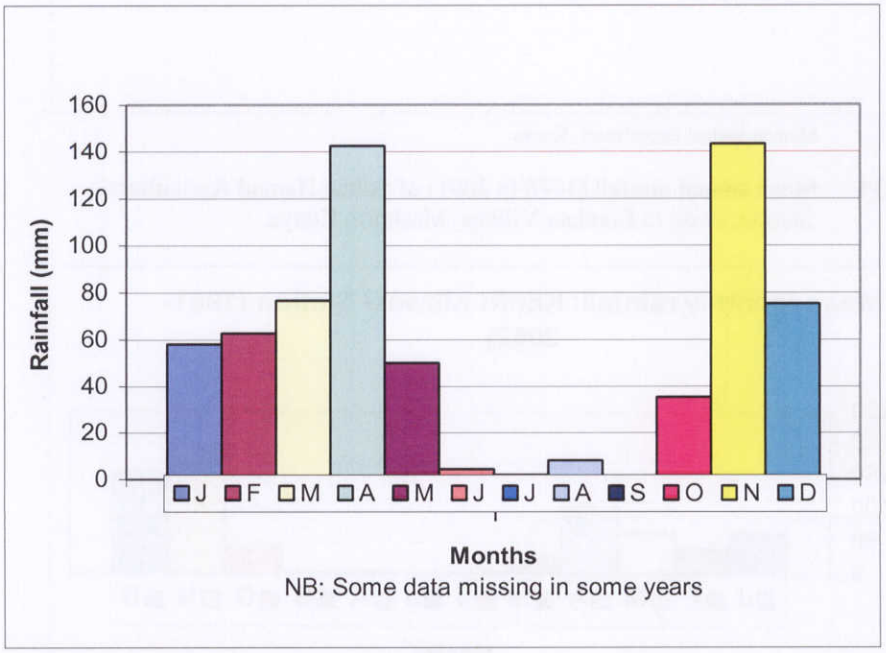
Data source KEFRI Kibwezi Research Centre, Kenya.

Figure 4.1.15 Mean annual rainfall of KEFRI Kibwezi Weather Station (1981to 2002), close to Bondeni Village, Kibwezi, Kenya.



Data source Meteorological Department, Kenya.

Figure 4.1.16 Mean monthly rainfall of Isara Range Weather Station (1973 to 1986), Mashuru, Kenya.



Data source Meteorological Department, Kenya.

Figure 4.1.17 Mean monthly rainfall of Sultan Hamud Agricultural Station (1978 to 2001), Mashuru, Kenya.

The erratic and uneven spread of rainfall causes financial and input losses to farmers who have to replant again (Llano-Alcober *et al.* 1983).

Thirty-five out of the 36 interviewees indicated that the rainfall trends in the last 50 years have been decreasing accompanied by frequent droughts and famine. The farmers noted that the region usually receives one good rain after every three to four years. The droughts in recent times were noted to have occurred in 1953, 1961, 1970, 1974/75, 1979/1980, 1983/1984, 1994, 1995/96 and 1999/2000. However, historical (Tables 4.1.8 and 4.1.9) and climatic data (Fig. 4.1.12 to 4.1.14) reveals no evidence to farmers' perception in Kibwezi though there is relationship in Mashuru.

Table 4.1.8 Historical trends of drought/famine in Makueni/Machakos area (1895 to 1984).

Year	Characteristics of the event	Causes	Government intervention
1895	"Yoa ya ngali" -	Drought, small pox, war, railway construction	None
1897/99	"Muvunga" – sacks: Human deaths of up to 50-75% of population	Drought	None
1907	Famine	Drought	None
1913/14	Famine	Drought	None
1928/29	Yua ya nzalukange" – looking for food every where, cattle death	Denuded grassland, drought, locust, Quelea birds	Appeal for food dismissed by the Governor
1933/36	Food shortages, cattle deaths, intensified erosion	Drought, locust	Maize and pigeon peas distributed; cattle tax suspended
1939	Food shortage	Drought, conscription (Italian/Somali war)	Maize imports; crop export banned
1943/46	Food shortage, death	Drought, locust, small pox, military demands	Maize imports, food relief, intensive soil conservation
1949/50	"Makonge" – sisal sold to buy food	Drought	Famine relief, soil conservation, resettlement
1954/56	Famine	Drought	Conservation, resettlement, dam building
1960/61	Floods - "Ya mafuriko na ndege" floods and planes. Food shortage, cattlle daths	Drought followed by floods	Food aid and air drops
1965	Fodder and food shortage	Drought	Large food import, cattle movements
1971/76	Fodder and food shortages, cattle deaths	Drought	Food aid, drought tolerant crops, stock improvement schemes
1980/1981	Food shortage	Drought, depletion of maize stock by early exports	NGO food for work programmes
1983/84	"Nikw'a ngetwe" – I am dying with cash in my hands), food shortage, cattle deaths	Drought, high prices	Machakos integrated programmes, international aid, yellow maize imports

Source Tiffen *et al.* 1994.

Variability rather than long-term change is the most important characteristic of rainfall behaviour in Kibwezi (Tiffen *et al.* 1994). Recalls by the interviewees also shows that the frequency of natural disasters has increased mainly due to unreliable rainfall, change of climate and deforestation (Fig. 4.1.18 to 4.1.21).

Additionally, all the interviewees noted that each year they face water shortages between the months of May to mid November. This is because of not only unreliable rainfall but also permanent water sources were either located far from the villages or ground water are not easily accessible.

Table 4.1.9 Major natural disasters in Kajiado District (1890 to 2000).

1891/92	Severe drought and major Rinderpest (Olodua) epidemic killing some 90% of Maasai stock
1897	Outbreak of Contingious Bovine Pleuro Pneumonia (CBPP) - Olkipiei in Ngong area
1909	East Coast Fever (Oltikana) – ECF outbreak in the southern Maasai reserve
1911/12	Movement of northern Maasai of the Laikipia area towards the southern Maasai reserve resulting in huge animal losses
1915/16	Lack of rains leading to groups of Maasai wanting to return to the northern reserve
1918	Period of drought and livestock diseases (especially Rinderpest) resulting in heavy losses of stock and consequent raiding of neighbouring groups
1925-27	Loss of stock following severe drought and shortage of grass especially in the Magadi area. Great famine in Maasai land (Olomeyu Loolonito)
1933-35	Great famine (Olomeyu Looloyik) due to drought and locust invasion, some 35% loss of livestock
1938-39	Serious drought
1943-46	Severe drought and hopper infestations. Great famine (Eboot Enkurma Nanyoike). Complete failure in 1944 harvest on Government run Wheat Lands near Kitengela
1948-50	Failure of rains, army worms outbreak and Rinderpest epidemic (especially in Kaputei)
1951	Plenty of rain – flooding (Olari Loonkariak)
1952	Out break of Foot and Mouth (Olorobi) placing the whole of Kajiado District under quarantine regulations
1953	ECF in southeast Kajaido District leading to losses of up to 75% of livestock
1953-56	Period of drought. Famine relief provided
1956	Heavy losses of livestock due to ECF in northwest area of Kajiado
1959	Beginning of several drought and CBPP outbreak
1960/61	Extremely severe drought with stock losses up to some 70%. Famine relief, involving international organizations provided to some 40,000 Kajiado Maasai. It took until 1965 for most drought victims to recover from their disaster (Eboot Enkurma Sikitoi).
1963	Plenty of rain – flooding (Olari le Nteke) – food relief supplied by Helicopters
1968	Outbreak of rabies in an area north of Amboseli
1969	Below average rainfall
1973-76	Severest drought since 1961, 1976 especially was bad year when an estimated 150,000 cattle as well as thousands of wild animals died. Outbreak of rabies and anthrax were reported in 1975. In the whole of southeast Kajiado population received famine relief (maize meal) at the height of the drought. Rainfed agricultural production failed during most seasons in this period, except on the slopes of Mount Kilimanjaro, and because of irrigated agriculture in the plains, farmers were able to produce a reasonable crop.
1979/80	Failing rains
1984	Severe drought and outbreak of ECF resulting in loss of about half of livestock
1985	Devastated pastures due to outbreak of armyworms forcing herders to move to neighbouring districts and Tanzania
1986	Outbreak of CBPP, probably imported from Tanzania
1987	(Local) invasion of wildebeests forcing herdsmen to search for other pastures
1988	Favourable rains but outbreak of armyworms in most of the district and Rinderpest in Ngong area necessitated the closure of livestock markets
1994 – 95	Famine (Olameyu)
1996	The 94 and 95 Olamyeu still felt in Osilalei
1997/98	El-Nino rains brought Blue tongue disease that killed sheep in Mashuru
1998/2000	Prolonged drought (La Nina) leading to loss of about 50% livestock and crop failure

Source Rutten (1992) in SNV/SARDEP and ETC East Africa (2001).

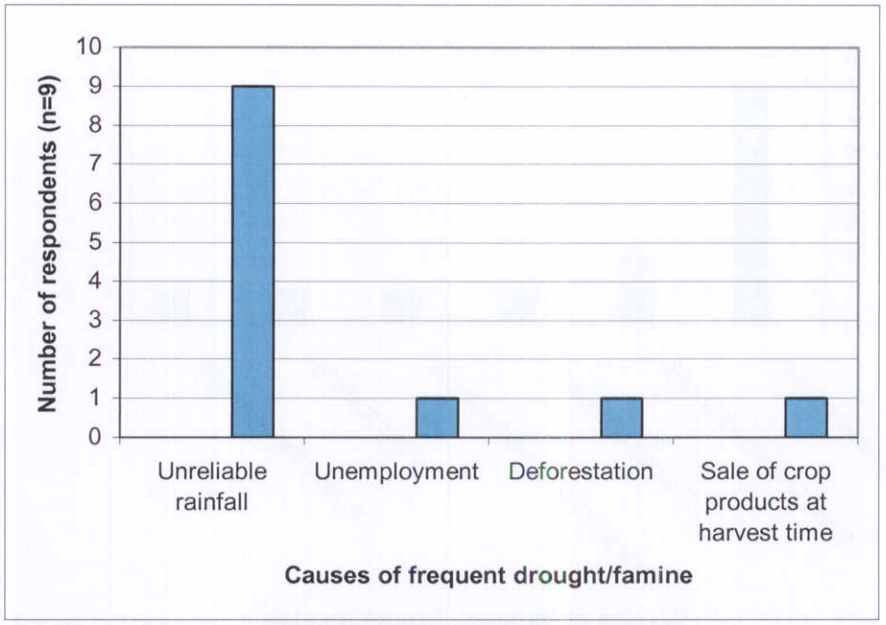


Figure 4.1.18 Indigenous knowledge on causes of frequent droughts/famine in Muusini Village, Kibwezi, Kenya.

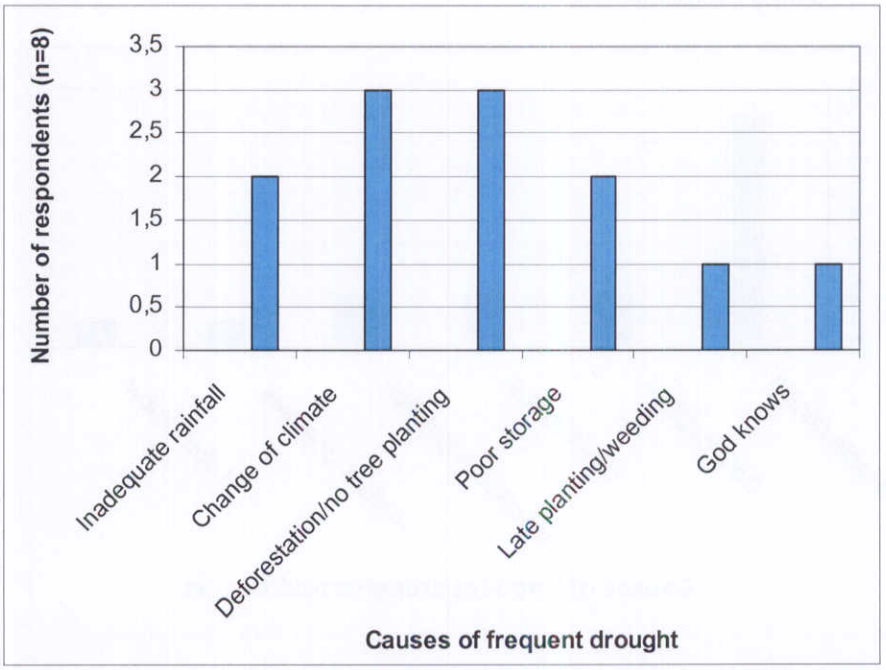


Figure 4.1.19 Indigenous knowledge on causes of frequent droughts/famine in Bondeni Village, Kibwezi, Kenya.

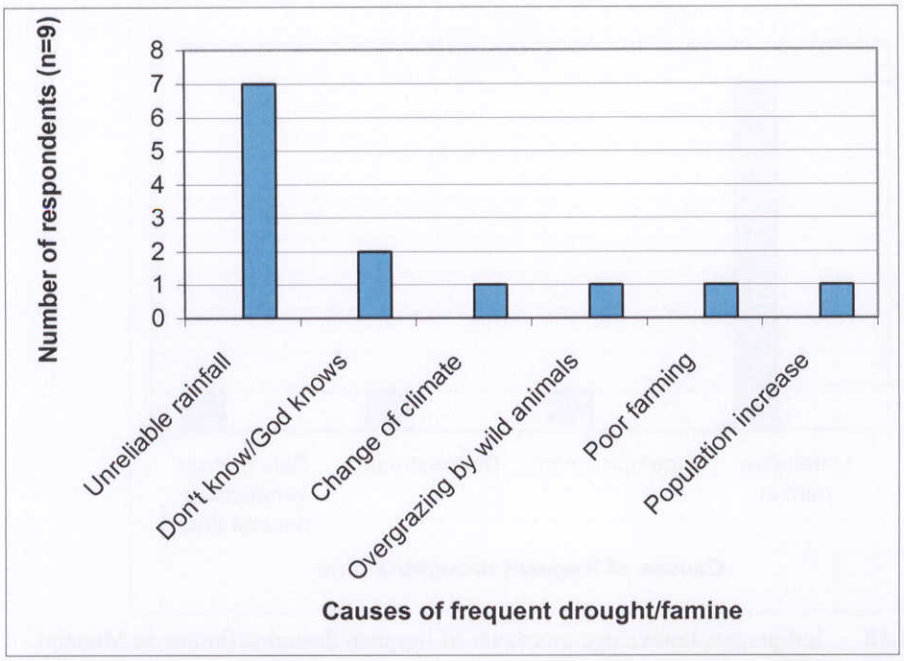


Figure 4.1.20 Indigenous knowledge on causes of frequent droughts/famine in Isara Village, Mashuru, Kenya.

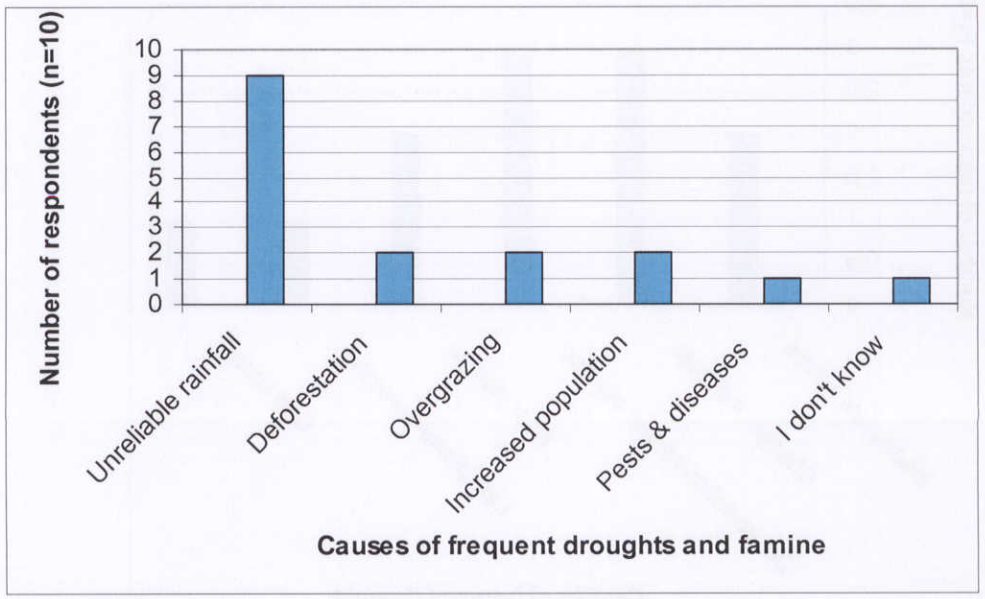


Figure 4.1.21 Indigenous knowledge on the causes of frequent drought and famine in Erankau Village, Mashuru, Kenya.

4.1.7.2 The status of water sources and water quality

The major sources of water were earth dams and water pans, wells, boreholes, rivers, "catch pits" or water holes, ponds, swamps, springs, water pipelines and roof catchments (Table 4.1.10) distributed within the villages (Fig. 4.1.8 to 4.1.11). The most reliable sources for Muusini Village were wells, rivers and earth dam while Bondeni relied heavily on wells and Metava swamp. Isara Village depended largely on Noulturesh water pipeline and earth dams/water pans while Erankau borehole, earth dams and "catch pits" on the dry riverbeds of River Imatoi mainly supported Erankau.

(i) Earth dams and water pans

Earth dam in this report includes all man made water excavations that has been estimated to hold more than 10 m^3 of water when filled to its capacity. If the structure holds less than 10 m^3 then it becomes an earth dam (District Water Officer, Makueni pers. comm. 2002). Several dams and pans have been constructed to divert water from ephemerals (small intermittent streams with water only in rainy seasons) or where ponds were desilted to trap runoff. There are 12 dams/water pans spread throughout the villages and their neighbourhoods. Eleven of the dams/pans were in Isara and Erankau Villages. The high number of dams/pans in the agropastoral areas relate to the need for more water for livestock, far distances of permanent water sources and deep water tables to access ground water. There were no dams/pans in Bondeni due the less number of livestock, the presence of Metava swamp and accessibility to shallow water tables that made it easy to sink wells. The limited number of dams in the mixed farming community area also suggests limited economic power to construct the source when compared with the agropastoralists. However, only half of the sources were useful beyond the rainy seasons due to siltation, high evaporation, inadequate protection and conservation (limited fencing and release of animals into the water), seepage and location on inappropriate parent materials such as the Cambisols, Vertisols and gleyic Luvisols. The cambisols are spongy in nature and allows water through while the Vertisols and gleyic Luvisols expand and shrink due to montmorillonite and illitic clays and therefore form cracks that increase percolation (Wijgaarden and Engelen 1985). Siltation have been aggravated by overgrazing around the dams, which causes strong runoff and consequently flash floods that destroy the dams as it happen during the El-Nino rains of 1997/98.

Although the dams provide the much needed water for domestic and livestock use the quality were grossly polluted and contaminated (Table 4.1.11 and Appendix III). Sample analysis shows that Coliform counts were very high in all the dams/pans while *Escherichia coli* was lowest in Kiuwani dam of Muusini area followed by those in Isara Village and highest in Kimana dam in Erankau. Though the water from the sources were scientifically unfit for human consumption unless further treated, local communities have no alternatives to their use.

(ii) Wells

Thirty shallow wells have been identified in the study villages (Fig. 4.1.8 to 4.1.11 and Table 4.1.10). Over 75% of the wells were found in Bondeni, six in Muusini and one in Erankau. Isara Village had none due deep water table. The high number of wells in Bondeni can be associated to its higher rainfall and proxy to the Chyulu Range Catchment, which falls under a protected national park.

Table 4.1.10 The major water sources in four villages of Eastern Kajiado and Southern Makueni, Kenya as at 2004.

	Muusini			Bondeni			Isara			Erankau			Remarks
Types water sources	**No.**	**Status**	**Reliability/ Yield per day**	**No.**	**Status**	**Reliability/ Yield per day**	**No.**	**Status**	**Reliability/ Yield per day**	**No**	**Status**	**Reliability/ Yield**	
Artificial sources													
Wells	6	Not protected. 1-15 m deep. Dug by hand	2-3 drums	23	6 fully protected, 11 semi protected and 6 were unprotected . Up to 15 m deep. Dug by hand.	1 drum per day to unlimited.	None			1	Unprotected	1 drum per day	Yield decrease and salinity increase with dry season. Domestic, vegetable gardening & livestock use
Earth dams and water pans	1 (outside the village)		Permanent source	None			3	Two are fenced but not one	Used up to 1-3 months after rains	8	2 functioning but only 1 well fenced.	Used 1-6 months after rains	Domestic & livestock use. Fresh water
Ponds	14		Only in rainy Seasons. Variable.	4	Not protected	Only in rainy Seasons. Variable.	8	Not protected	Only in rainy Seasons. Variable.	2	Unprotected	Only in rainy Seasons. Variable	
Roof catchment	Many households (HHs)	Limited amount of water		Many HHs	Limited amount of water		Few homes	Limited amount of water		Few homes	Limited amount of water		
Pipeline	None			1	Protected	Unreliable	1	Protected	Reliable but expensive	None			
Natural sources													
Rivers	2 (outside the village)	Not protected	Permanent source	1 (outside the village)	Not protected	Reliable. For livestock use only due to high salinity	1 seasonal river	Dry river bed. For livestock use in rainy seasons	Only in rainy Seasons.	2 seasonal rivers	Not protected	Only in rainy Seasons	
Springs	None			1 (outside the village)	Lies in protective forest reserve/park	Permanent source	None			10 (outside village)	Not protected	Yields decrease in dry seasons	Multiple uses
Swamps	None			1	Not protected	Reliable in rainy & parts of the dry Seasons.	None			None			
Borehole	None			None			None			1	Protected	Permanent	Multiple uses
Catch pits	None			None			none			8	Protected with dead fence & padlocked	Permanent but low yields	Useful in dry seasons. For multiple uses.

Table 4.1.11 Quality of water sources in four villages of Eastern Kajiado and Southern Makueni, Kenya as at 2004.

Parameter	World Health Organization/ (Ministry of Health – Kenya) Guidelines	Sources of water sampled in the four study villages										
		Dams (n= 4)	Ponds (n= 1)	Rivers (n= 2)	Protected wells (n= 2)	Semi-protected wells (n = 1)	Unprotected wells (n = 3)	Swamps (n= 1)	Springs (n= 1)	Piped water (n= 1)	Catch pits (n=1)	Borehole (n=1)
Coliform bacteria (Count/100 ml of water)	None (0-25)	1800+	61	1800+	31 – 275	1800+	61 – 1800+	1800+	Contaminated	45	250	95
E. coli	None	55 – 1800+	61	250 – 1800+	7 – 20	49	35 - 1800+	1800+	Contaminated	20	39	Nil
Colour (True Colour Units)	15	70 - 2050	1000	35 – 40	<5 – 30	10	20 - 700	15	5	5	25	< 5
Turbidity	Not turbid	Very turbid	Very turbid	Turbid – very turbid	Clear	Clear	Turbid to very turbid. Clear (1)	Turbid	Clear	Clear	Slightly turbid	Clear
Deposit		Brownish organic matter/ silt	Organic matter, silt		Organic matter	Organic matter	Organic matter. Algae (1)	Organic matter	Nil		None	None
Odour	Should be acceptable	Soil	Vegetation	Vegetation and soil	None (1) Vegetation (1) near river	None	Vegetation Urea odour (1)	Vegetation			Vegetation	None
pH	< 8 for effective disinfection with chlorine	6.9 – 7.2	7.6	7.9 – 8.5	7.4 – 7.8	7.4	7.1 – 8.3	8.3	7.6	7.5	7.9	8
EC (mmohs cm^{-1})		97 - 265	130	490 – 3600	2600 – 2900	1700	810-3600	210	542	220	530	940
Chloride $(Cl)^-$	250	2 – 16	16	40 – 1416.7	440 – 520	230	36 - 712	1	2.5	4	4	68
Sulphate $(SO_4)^-$ (ppm)	250	1 – 12.5	40	45 – 300	1.4 – 1.5	10	2.5 - 420	Nil	38	2.5	6	150
Flouride $(F)^-$	1.5	0.45 – 8.3	0.2	0.2 – 0.8	0.02 – 0.04	2.3	0.6 – 3.3	0.4	1.2	0.5	3	2
Sodium (Na)+	200	4.3 –10.1	1.7	12.8 – 552.6	162.6 – 458.6	186.3	59.7 – 702.5	3	55.7	30.8	62.7	109.4
Manganese (Mn)++	0.5	0.04 –0.18	0.03	0.009 – 0.02	0.02 – 0.03	0.03	0.001 – 1.6	0.03	Nil	1.9	0.5	0.02
Iron (Total) (Fe)+++	0.3	1.8 – 8.7	2.1	0.005 – 0.1	0.02 – 0.04	0.02	0.01 – 2.3	0.07	0.3	Nil	Nil	Nil
Remarks		Grossly polluted and contaminated			Polluted and contaminated	Highly polluted and contaminated	Grossly polluted and contaminated		Contaminated	Contaminated and polluted with manganese	Contaminated and polluted with Flouride	Contaminated and polluted with flouride

In Muusini the wells were found mostly within the Ferralsols plains while in Bondeni, the wells are concentrated along the Chernozems lowlands and in the Ferralsols plains. The Volcanic Lava had none due to its spongy nature. The well in Erankau was located along a seasonal watercourse well marked by the occurrence of *Commiphora baluensis* woodland on the Ngama Hills Basement Complex System. Its occurrence can be related to a fracture or a fault line within the complex (ACTIONAID 1993).

Local experts use indigenous knowledge to prospected the wells. Wet juvenile sticks of *Grewia fallax*, *G. bicolor*, *Acalypha racemosa* and *Hibiscus pycnostemon* are used as instruments for prospecting. The stick has to have pith, forked branchlets and at least 50 cm extension after the forks. The prospector holds the forked branches and while trying to complete the circuit with the forks but the ends not meeting, he/she moves round with the extended stick parallel to the ground level at breast height. Where there is under ground water, the extended part bends vertically. After several repetitions, the local expert marks the site and advises the farmer to dig the well. Over 80% of the wells were prospected through this technology at a fee of Kshs. 200 per prospect though negotiable and at times the service was rendered out of good will. The rest of the wells were dug through trial and error and a farmer got water while digging for a pit latrine yet another used sub surface flow that surfaced during the El-Nino rains of 1997/98 as an indicator.

The wells were 1 to 15 m deep and dug by hand. Water replenishment in all the wells decreased with the approach of the dry season. The average yields were one to three drums (200-600 litres) in Muusini and Erankau to unlimited per day for some in Bondeni. Furthermore, most of the water was saline. Salinity levels varied frm one well to another possible due to variation with the salt content of deep ground layers that the water passes through. Muusini and Bondeni Villages are covered by basement complex rich in ferromagnesian minerals while Erankau is covered by the same rock but poor in ferromagnesian minerals. Salinity also varies with the season, becoming more saline in dry periods. The water from the wells was used for domestic, livestock purpose and subsistence vegetable growing in Bondeni (Plate 4.1.3).

Most of the wells were not protected and the use of bucket and rope was popular. Analysis of water sample from the most commonly used wells indicated that the water sources were polluted and contaminated (Table 4.1.11) exceeding the WHO/Ministry of Health maximum guidelines and therefore not fit for human consumption unless further treated.

(iii) Boreholes

Throughout the four villages only two boreholes (one functioning and the other only prospected) were identified in Erankau Village. The few number of boreholes is related to large coverage of the villages by basement complex, which have low to medium ground water potential due to its impervious, compact and crystalline metamorphic nature and the low rainfall experienced (Touber 1983, Wijgaarden and Engelen 1985, ACTIONAID 1993). Ground water occurrence within the basement is restricted to jointed or fractured, broken and faulted zones usually found along valleys or at the base of larger hills yield enough water of good quality with less salinity (ACTIONAID 1993, Wijgardeen and Engelen 1985).



Photo by A. Mohamed in 2004.

Plate 4.1.3 Kales are some of the crops grown around wells in Bondeni Village, Kibwezi, Kenya.

Other parts of the villages are also covered by the spongy Cambisols and Volcanic Lava Flow, which permits free percolation of water and therefore poor in ground water yields (Touber 1983, Wijgaarden and Engelen 1985). Other reasons why there are few boreholes can be related to financial and technological constraints. The functioning Erankau borehole is 182 m deep. The source is owned by community but drilled and maintained by the East African Portland Cement Company as a kind gesture in exchange for mining marble limestone in Sultan Hamud sub-location. The borehole too provides water for domestic and livestock use for the neighbouring villages of Arroi and Olepoloos. The quality of the water is similar to that of pipeline but Coliform count and fluoride levels exceed the maximum limits set by WHO (Table 4.1.11).

(iv) Rivers (surface water)

There were only seasonal rivers and watercourses that criss-crossed the villages (Fig. 4.1.8 to 4.1.11). Permanent rivers such as the Thange, Athi and Kiboko, which are located far from the villages were used for domestic and livestock watering in dry seasons. Nevertheless, in rainy seasons dry riverbeds too provided water. General analysis of water samples from rivers in Kenya shows that contamination and pollution have been on the increase in the past 40 years (Table 4.1.12). Similarly, water samples collected from the Athi and Thange Rivers by the study in 2004 indicate the source to be grossly contaminated and polluted (Table 4.1.11).

Table 4.1.12 The quality of water from different rivers of Kenya (1963 to 2000).

Parameter	Desired level	Actual level				
		1963	1974	1984	1999	2000
Colour	Clourless	Clourless	Clourless	Slightly coloured	Coloured	Highly coloured
Turbidity	Clear	Clear	Clear	Turbid	Turbid	Very turbid
Sediment load	Nil	Nil	Slight	Moderate	Heavy	Heavy
Total dissolved solids	Normal	Normal	Fair	Moderate increase	Moderate increase	Very high increase
Bacteriological contamination	No pathogenic bacteria	Little	Little	Little	Gross	Gross
Biological oxygen demand	Less than 5 mg/l	5-20	10-20	20-40	40-60	60+

Source UNEP and GoK (2000).

When the samples from the two rivers were compared except for *E. coli*, Thange River was the most contaminated and polluted with exceptionally very high salts, salinity, turbidity and total dissolved solids and with soil odour. The high pollution, which was beyond the WHO limits, can be related to its source as underground subsurface flow through basement complex rich in ferromagnesian minerals. As a result, the water from River Thange is not fit for irrigation, livestock and human consumption. Furthermore, the soil odour indicates severity of erosion in Kibwezi area. A part from surface flow, dry riverbeds too provide water in form of "catch pits".

(v) "Catch pits" or water holes

Eight catch pits were identified along the Matoi dry river bed in Erankau (Fig. 4.1.11). The water flows by sub-surface in the sandy riverbed throughout the dry season. The catch pits were initially discovered by trial and error. The depth of the holes increase with the spell of the dry season from 2 to 5 m, therefore at times making it necessary to use rope and bucket to draw water for domestic and livestock use. An average well yields 3 to 5 drums; the productivity decreases with the dry season. Although the community owns the river, individuals who first dug own the holes. During rainy seasons, runoff fills the holes but the owners digs out in dry seasons. Though at a lesser extent than the wells and rivers the water quality was too contaminated and polluted. Both the bacteriological and fluoride levels were beyond WHO recommendations (Table 4.1.11). The digging of shallow holes in sand bed rivers in the drylands is a common practice both by man and animals (Wijgaarden and Engelen 1985). However, sand harvesting, wanton felling of vegetation and charcoal burning threatens this sustainable water source.

(vi) Ponds

There were 28 ponds in the villages half of them in Muusini, 8 in Isara, 4 in Bondeni and 2 in Erankau. Most of the ponds were common on soils of basement complex origin. The origins of ponds are thought to be mainly zoogenetic by origin (Wijgaarden and Engelen 1983). Large animals like elephant and rhino for wallowing use initially small ponds with water. In this process they trample the subsoil and carry away on their skins considerable amounts of soil. When this is repeated year after year, the original pool is enlarged and deepened and the subsoil trampled to such an extent that it becomes fairly impermeable.

However, since the animals have removed from the area to give way to settlements, sediments have slowly filled up the ponds and they have currently silted or are silting lasting only 1-2 months after the rains. The water from the ponds were used for domestic and livestock watering (Plate 4.1.4).



Photo A. Mohamed 2003.

Plate 4.1.4 Although contaminated and polluted in rainy seasons ponds provide much needed water for domestic use.

Analysis of sample from the largest and highly used pond in Muusini indicated that the water to be heavily polluted (Table 4.1.11) and not fit for human consumption unless further treated. Counts of the Coliform and *E. coli* bacteria were 61 each per 100 ml each while the turbidity was very high. Although salinity was very low the colour and iron levels were beyond the recommended rates. Additionally, the water had deposits of silt and organic matter and the smell was that of vegetation. Generally, the physical and chemical properties were similar to those of dams and swamps and therefore ideal for irrigation.

(vii) Swamps

There was only one swamp in the study villages located close to Bondeni village (Fig. 4.1.9) positioned just down the Volcanic Lava on the Chernozems lowlands. It was communally owned and therefore not protected. In good rainy seasons when the swamp fills up it can last months into the rainy seasons. The water was used for domestic and livestock watering. Analysis of water samples indicates the source to be grossly contaminated (Table 4.1.11). However, pollution levels were less than those of rivers and wells but similar to that of springs and therefore good for irrigation.

(viii) Springs

There were no springs in the study villages but were found in nearby villages and reserves. Bondeni and Erankau Village members benefit from the springs that lie 5 to 15 km away. While there was pipeline-connecting Bondeni to Umani Springs in the protected Kibwezi Forest Reserve, Livestock from Erankau trek to communally own unprotected springs on the Ormuntuus hills east of the village. Biologically the source was reported to be contaminated but the physical and chemical pollutions less than most of the other sources of water (Table 4.1.11). Moreover, the Ormuntuus springs contain leeches.

The contaminations and pollutions are caused by lack of protection, use by wild animals and deforestation for cultivation in the case of Ormuntuus springs. Upon treatment the water is ideal for human consumption. It can also be used for irrigation.

(ix) Pipelines

Two pipelines were identified in the villages, one in Bondeni and the other in Isara. In rare instances especially at critical dry periods, communities in Muusini and Erankau too fetch water by bicycles from far away pipelines. The origin of Bondeni pipeline has been mentioned earlier and A Mr. Keath from Canada laid the pipeline from Umani springs to Bondeni village in 1990. Although the source was erratic the village was supplied with the untreated water at the cost of Kshs. two to five per 20 litres. The pipeline that passes through Isara is tapped by gravity from Mount Kilimanjaro for Machakos, Kajiado and Athi River towns. The later also called Noulturesh pipeline is owned by the National Water Conservation and Pipeline Corporation. Within the village its use at a cost is restricted to domestic and livestock use. But when ruptures or pressure breaks outlets, wild animals too visit especially at night. However, unauthorized but isolated small-scale irrigation was common. The corporation's intensive and regular patrols keep on disconnecting the illegal connections and prosecuting the concern persons. The water quality from the source was clear but bacteriologically contaminated with low infestation of coliform and *E. coli* levels (Table 4.1.11). Physically and chemically, the source had the least pollution as a result of protection of the source and use of pipelines. On the contrary, manganese pollutants were above the recommended rate.

(x) Roof water harvesting (roof catchments)

This practice involves the use of roof gutters to channel rainwater falling on roof of houses into tanks, drums and other containers. Farmers with iron sheet roofs implement it especially the well off, medium and a few in poor poverty categories. Some constructed water tanks to channel the water for storage while others place drums and Jerry cans to harvest the resource. However, for most of the poor with temporary housing type (grass thatched) have no access to it. The water collected from clean house roof can be of better microbiological quality than water collected from untreated household wells or open water surfaces (WHO 1997).

4.1.7.3 Water related diseases

All the 36 respondents reported frequent occurrence of typhoid and malaria. Typhoid, which is caused by *Salmonella typhi* bacterium is got through consumption or washing with feacal matter contaminated water. Malaria is a common disease in rainy seasons. It is caused by parasites of *Plasmodium falciparum, P. vivex, P.ovale and P. malariae* and affects the liver and red blood cells. Malaria-infected mosquito spreads the parasites and the insect breeds in stagnant water (for example ponds and dams) and shallow wells. Additionally, interviewees from Muusini and Bondeni indicated amoebiosis and Bilharzia as a major health problem. Amoeba causes Amoebiosis and its infection is similar to that of typhoid. The farmers noted the Thange River to be invested with Bilharzia (Schistosomiasis), a parasitic disease that directly infects humans through skin contact with water inhabited by snails.
Its symptoms are abdominal pain, fibrosis in liver and bladder, blood in the urine and diarrhoea (Esser *et. al.* 2000).

The prevalence of the disease has been confirmed too in the feed back meetings. The data confirms that all the water sources are bacteriologically contaminated. Despite the water related health problems, life has to continue in these rural villages. Each member of the household within the village has a role to play specifically in the management of water resources. In brief, women are responsible for domestic water while the men folk ensure that livestock, crops and trees have received the water. In Kibwezi, children and men help the women in fetching water from far distances by using bicycles.

4.1.7.4 Current use and demand for water resources

As a result of the arid nature of the region, limited technical know how and finance to access, all the villages were faced with acute water shortages for domestic, livestock and irrigation.

(i) Domestic water use

In all the villages, demand was always more than the actual water available (Fig. 4.1.22 to 4.1.25). When the villages' domestic water use trends were compared, an average household from the pastoral community used more water than the mixed farming community (Table 4.1.13). The difference can be related to availability of the resource and the ability to pay for the costs. Noulturesh water pipeline passed through Isara while Erankau Village had a reliable Borehole. Conversely, there were no adequately reliable water sources throughout the year in Muusini and Bondeni. Moreover, the mixed farmers were relatively poorer than the agropastoralists. According to total mean monthly figures per poverty group (Fig. 4.1.22 to 4.1.25), the poor uses more water because they form majority of the population. But at household level (Table 4.1.13), the well off and the medium used more water than the poor because they can afford to buy more water and some of them were elders/leaders and therefore have more guests to take care off.

(ii) Water for livestock

Water for livestock varied with the number of livestock owned and therefore the poverty groups. The villages and poverty groups that had the highest number of livestock too used more water. The actual water use and demand were assumed to be the same because animals travel frequently on daily basis to far water sources and for now have access to water.

(iii) Irrigation for trees and crops

Irrigation activities though necessary were rare in the villages due to unavailability of affordable water.

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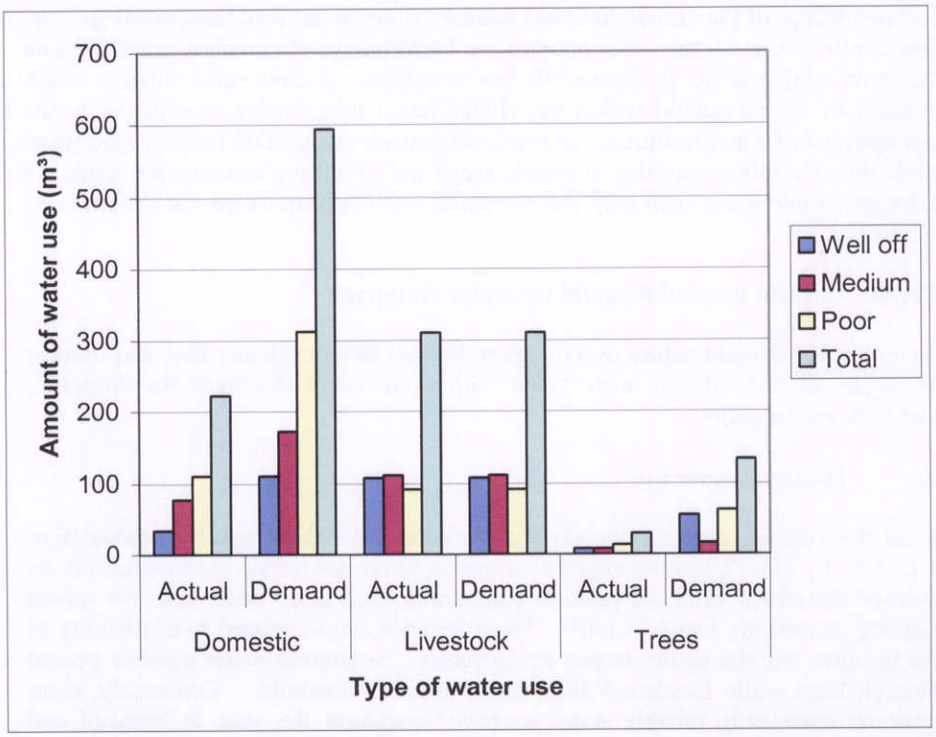


Figure 4.1.22 Estimated monthly water use in Muusini Village, Kibwezi, Kenya.

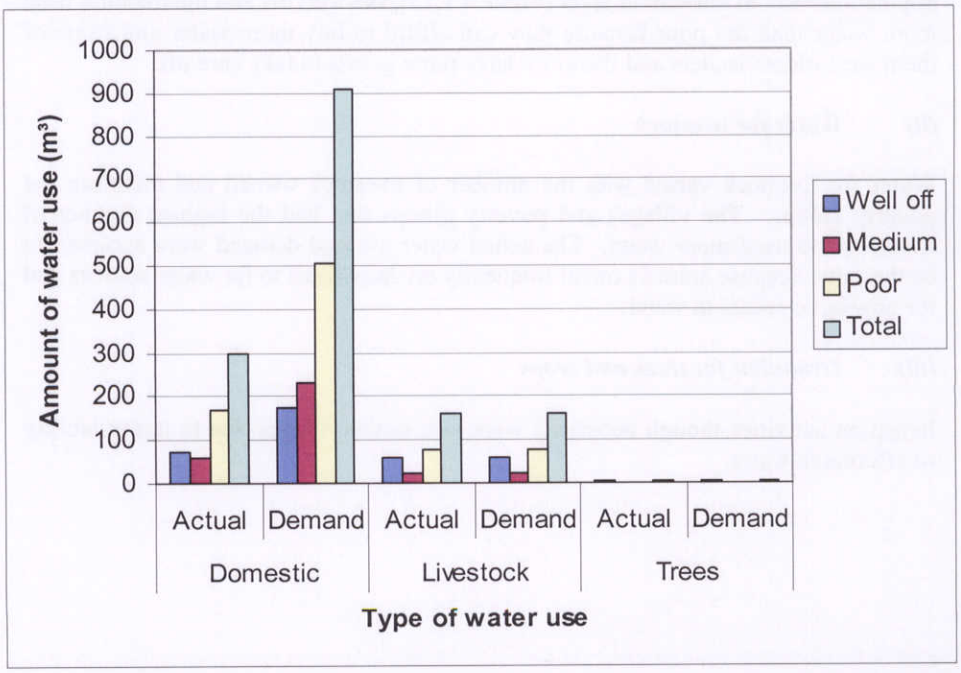


Figure 4.1.23 Estimated monthly water use in Bondeni Village, Kibwezi, Kenya.

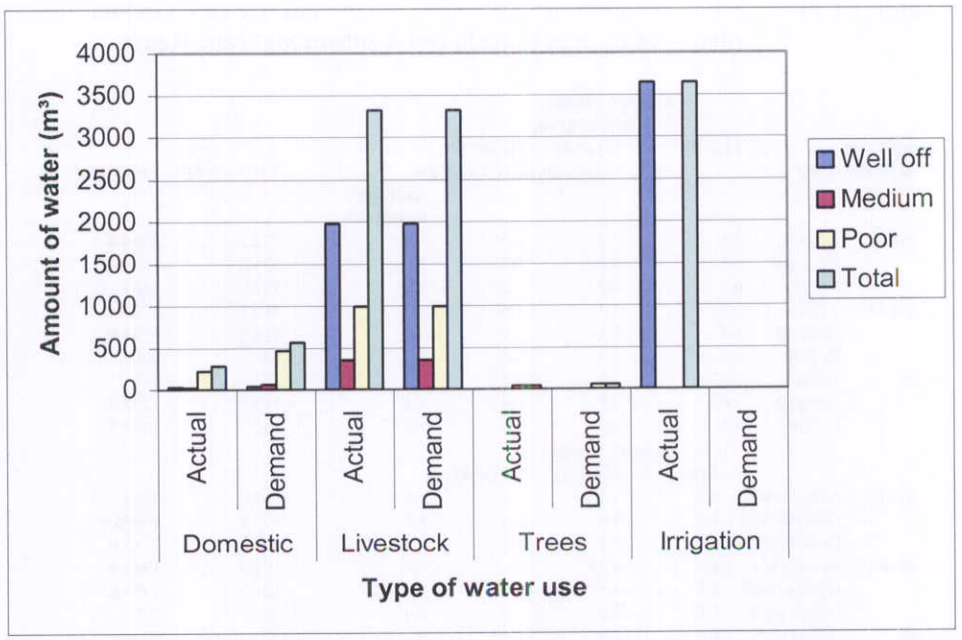


Figure 4.1.24 Estimated monthly water use in Isara Village, Mashuru, Kenya.

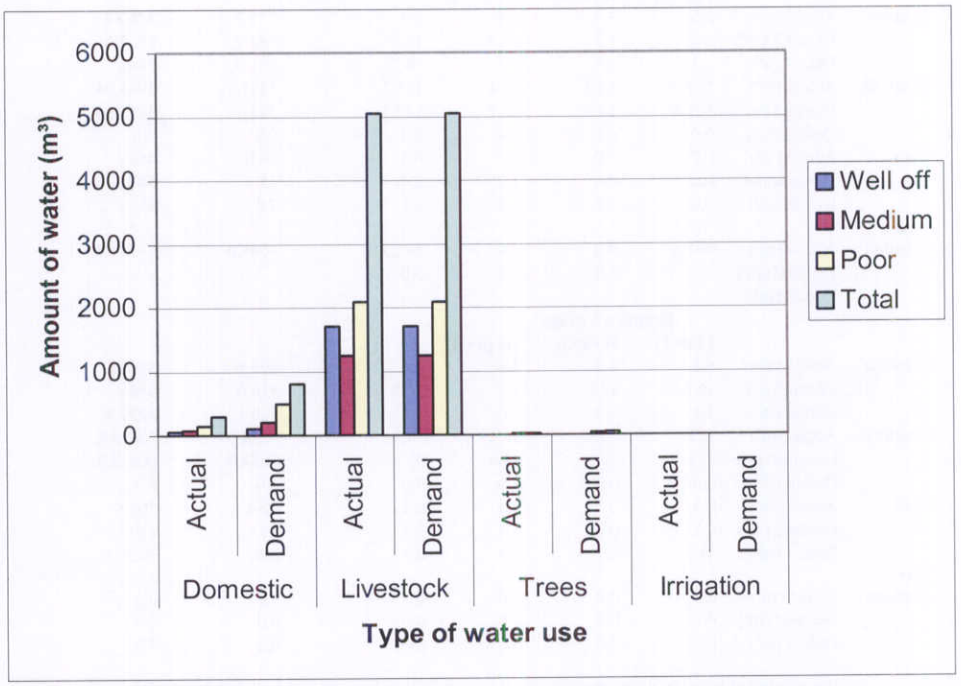


Figure 4.1.25 Estimated monthly water use in Erankau Village, Mashuru, Kenya.

Table 4.1.13 Estimated mean monthly water use per poverty group in four villages of Eastern Kajiado and Southern Makueni, Kenya.

		Muusini Village					
		Poverty group					
Sample size		**I (n= 2)**	**II (n= 2)**	**III (n= 5)**			
Type of water use		**Mean monthly water use**				**Total/ month**	**Total/ year**
					Average/ household		
Domestic	Actual	3.1	3.7	2.3	3.0	222.2	2666.4
	Demand	10	8.2	6.5	10.0	594.2	7130.4
	Deficit	6.9	4.5	4.2	5.2	372	4464
Livestock	Actual	9.8	5.3	1.9	5.7	310.3	3723.6
	Demand	9.8	5.3	1.9	5.7	310.3	3723.6
	Deficit	0.0	0.0	0.0	0.0	0.0	0.0
Trees	Actual	0.7	0.2	0.2	0.4	21.5	258
	Demand	5.0	0.8	0.8	2.2	110.2	1322.4
	Deficit	4.3	0.6	0.6	1.8	88.7	1064.4
		Bondeni Village					
		I (n= 2)	**II (n= 2)**	**III (n=4)**			
Domestic	Actual (m^3)	3.4	2.4	2.1	2.6	297.0	3564
	Demand (m^3)	8.3	9.5	6.3	8.0	906.3	10875.6
	Deficit (m^3)	4.9	7.1	4.2	5.4	609.3	7311.6
Livestock	Actual (m^3)	2.9	0.85	1	1.6	161.3	1935.6
	Demand (m^3)	2.9	0.85	1	1.6	161.3	1935.6
	Deficit (m^3)	0.0	0.0	0.0	0.0	0.0	0.0
Trees	Actual (m^3)	0.2	0.0	0.0	0.1	4.2	50.4
	Demand (m^3)	0.3	0.0	0.0	0.1	6.3	75.6
	Deficit (m^3)	0.1	0.0	0.0	0.1	2.1	25.2
		Isara Village					
		I (n= 2)	**II (n=2)**	**III (n= 5)**			
Domestic	Actual (m^3)	5.5	3.7	5.6	4.9	271.7	3260.4
	Demand (m^3)	6.6	8.5	12.2	19.6	562.7	6752.4
	Deficit (m^3)	1.1	4.8	6.6	14.7	291.0	3492
Livestock	Actual (m^3)	329.4	50.5	26.1	135.3	3321.7	3986.04
	Demand (m^3)	329.4	50.5	26.1	135.3	3321.7	3986.04
	Deficit (m^3)	0.0	0.0	0.0	0.0	0.0	0.0
Trees	Actual (m^3)	0.0	0.0	1	0.3	38.0	456
	Demand (m^3)	0.0	0.0	1.2	0.4	45.6	547.2
	Deficit (m^3)	0.0	0.0	0.2	0.1	7.6	91.2
Crop irrigation	Actual (m^3)	607.6	0.0	0.0	202.5	3645.6	43747.2
	Demand (m^3)		0.0	0.0	0.0		
	Deficit (m^3)						
		Erankau Village					
		I (n= 3)	**II (n=3)**	**III (n= 4)**			
Domestic	Actual (m^3)	6.5	4.9	2.5	4.6	295.8	3549.6
	Demand (m^3)	10.6	12.2	8.5	10.4	815.0	9780
	Deficit (m^3)	4.1	7.3	6.0	5.8	519.1	6229.2
Livestock	Actual (m^3)	171	73.9	35.4	93.4	5054.9	60658.8
	Demand (m^3)	171	73.9	35.4	93.4	5054.9	60658.8
	Deficit (m^3)	0.0	0.0	0.0	0.0	0.0	0.0
Trees	Actual (m^3)	0.3	0.1	0.3	0.2	22.4	268.8
	Demand (m^3)	0.2	0.2	0.4	0.3	29	348
	Deficit (m^3)	-0.1	0.1	0.1	0.1	6.6	79.2
Crop irrigation	Actual (m^3)	0.0	0.0	0.0	0.0	0.0	0.0
	Demand (m^3)	0.0	0.0	0.0	0.0	0.0	0.0
	Deficit (m^3)	0.0	0.0	0.0	0.0	0.0	0.0

NB The number of households per poverty group in each village is given under socio-economics.

4.1.8 SUMMARY OF WATER RESOURCES

Rainfall pattern within the villages were erratic and unreliable. Good rainy years were reported to occur once in 3 to 4 years. Consequently, the villages face frequent droughts and famines. Moreover, most of the water sources were grossly contaminated and polluted. Siltation of surface water sources and unprotected wells was common. As a result, there were acute water shortages for domestic use and animals had to trek long distances to water sources on daily basis. Furthermore, water for irrigation was unavailable.

4.1.9 CHARACTERISTICS OF CROP RESOURCES

Though Kenya is the most industrialized country in East Africa, it is still at agrarian level with 80% of its population largely dependent on agriculture (GoK 2004). Crop production especially in the drylands of the country are hampered by multiple factors including low and unreliable rainfall, low soil fertility, inappropriate technologies/practices, limited application of farm inputs, inadequate access to water for irrigation and pests and diseases. As a result crop productivity is low and the impacts of drought and famine are rampant. In this section, farm sizes and layouts, types of crops grown and their yields are described and finally, the major constraints to crop production of the study villages are elucidated.

4.1.9.1 Farm sizes and lay outs

Farm sizes varied between the villages, with occupation of the communities, population densities, agro-climatic zones and poverty categories (Table 4.1.4). Bondeni had the smallest farm sizes (an average of 4 ha per household) because of the high population density of the mixed farming community and the ameliorated climate. On the other hand, Isara had the largest farm sizes (average of 106.3 ha per household) because of the low density and being occupied by pastoral community plus the relatively more arid environment. In Muusini and Bondeni, larger farm sizes were owned by the well off (4 to 15 times more than the poorer groups). Conversely, in Isara and Erankau the poorer groups owned more or equal to the well off supporting the earlier proposition that livestock is main determinant factor of poverty levels in the villages. Amongst the study villages, Bondeni had the highest proportion of land under cultivation (78%) while Isara and Erankau had only a small portion under croplands (1.4 – 1.8%) (Table 4.1.4). Three farms (two in Muusini and one in Bondeni) had cultivated the whole of their farms. The size of cropland has expanded in the past one to two decades as reported by 25 of the interviewees mainly to increase food production for consumption and sale. Moreover, only 1 to 2 interviewees (in well off poverty group) in each village reported to have land elsewhere.

Due to the scarcity of land the poorer farmers especially in Muusini and Bondeni cultivated their farms through out the year. In the long run intensified cultivation is expected to increase over use of soil under cropland hence soil fertility mining. Although the poorer categories of Muusini Village depended more on crop cultivation, the well off in this village that owned larger farms practised agropastoralism similar to that of Isara and Erankau. They kept major parts (86%) of their farms under woodlands and pastures. Woodlands and pastures also covered over 95% of the farms in Isara and Erankau while homesteads covered the least

portion of the farms in all the villages. The homestead consists of the housing, grain stores, poultry houses and livestock kraals "bomas". The "bomas" were fenced with dead poles and branches and live hedges of *Commiphora* in Isara. All the homesteads in Muusin, Bondeni and Erankau and eight in Isara have planted or left natural trees for windbreak, shade and beauty.

While the existing policies may be good, in the drylands both the on-set of the rains and the total amount received are very unreliable. The probability of crop failure is very high except those crops that complete their growing cycle within one rainy season or those that can with stand the dry spell in between the two rainy seasons.

While crop growing was popular very few farmers in the village practiced fruit growing. The growing of crops in Muusini and Bondeni is a traditional practice with the farming community and it has been adopted by the Masaai agropastoralists of Isara and Erankau in the past decade. The practice is also encouraged by the Government policies, for example, Sessional paper No. 2 of 1994, which supports diversification of food alternatives at farm level in order to achieve a food security base. For the drylands, the Government also encourages farming systems approach, cultivation of drought tolerant crops and intensification of agroforestry activities to retard environmental degradation.

4.1.9.2 Crop diversity

A total of 17 different drought tolerant crops were grown by the interviewees (Table 4.1.14 and Plate 4.1.4a and 4.1.4b). They include maize, cowpea, pigeon pea, green grams, sorghum, pearl millet, cassava, sweet potatoes, beans, cucumbers, gourds, dolicos lablab, groundnuts, finger millet, okra and tomatoes.

Table 4.1.14 Major crops grown by interviewees in four villages of Eastern Kajiado and Southern Makueni, Kenya.

	Type of crop	Villages/No. of farmers who planted (n=36)				
		Muusini	Bondeni	Isara	Erankau	Total
1	Maize	9	8	9	10	36
2	Pigeon pea	9	8	-	1	18
3	Cowpea	9	7	3	2	21
4	Pearl millet	8	-	-	-	8
5	Green grams	9	5	3	6	23
6	Dolicos lablab	3	-	-	-	3
7	Cassava	5	5	-	1	11
8	Beans	2	7	9	10	28
9	Ground nuts	1	-	-	-	1
10	Pumpkins	5	-	-	1	6
11	Gourds	4	-	-	-	4
12	Sweet potatoes	2	1	-	1	4
13	Finger millet	1	-	-	-	1
14	Cucumber	1	-	-	-	1
15	Sorghum	9	6		1	16
16	Okra	1	-	-	-	1
17	Tomatoes	-	-	1	-	1
	Total crops grown	16	8	5	9	



Maize (*Zea mays)*



Green grams (*Vigna radiata*)



Cowpea (*Vigna unguiculata)*



Beans (*Phaseolus vulgaris*)



Sorghum (*sorghum bicolor*)



Pumpkins (*Cucurbita pepo*)



Gourds (*Lagenaria siceraria*)

Photo by A. Mohamed in 2002/2004

Plate 4.1.4a Some of the crops grown in Eastern Kajiado and Southern Makueni, Kenya.



Pearl millet (*Pennisetum americanum)*



Finger millet (*Eleusine coracana)*



Sweet potatoes (*Ipomea batatus)*



Cassava (*Manihot esculenta)*



Pigeon pea (*Cajanus cajan*)

Photo by A. Mohamed in 2002/2004

Plate 4.1.4b Some of the crops grown in Eastern Kajiado and Southern Makueni, Kenya.

Additionally, in Bondeni other village members grew pearl millet, dolicos lablab, groundnuts, pumpkins, gourds, kales, sugarcane, sunflower and finger millet. Other crops grown within specific villages were cotton in Muusini and kales in Erankau.

Muusini Village had the highest crop diversity as a response to relatively more institutional support and for food security purpose while Isara had the least number of crops (though it receives more institutional support than Erankau) possibly due to the combination of agropastoral background, food preference and the drier environment.

In all the villages the diversity of the crops grown increased with poverty (Appendix IV). For example, in Muusini, the poor poverty group grew up to 15 different crops on farm while the medium and the well off had 13 and 9 crops respectively. This is a copping strategy to add variety to the diet and have more alternative sources of food (guarantees food security).

Except for cotton and tomatoes, the other crops were mainly intercropped on the same field. Maize was the dominant crop in all the farms.

4.1.9.3 Crop cover and yields

The average area coverage per crop for Muusini and Bondeni (Fig. 4.1.26 to 4.1.27) and the crop yield per hectare (Table 4.1.15) were estimated from the sample population.

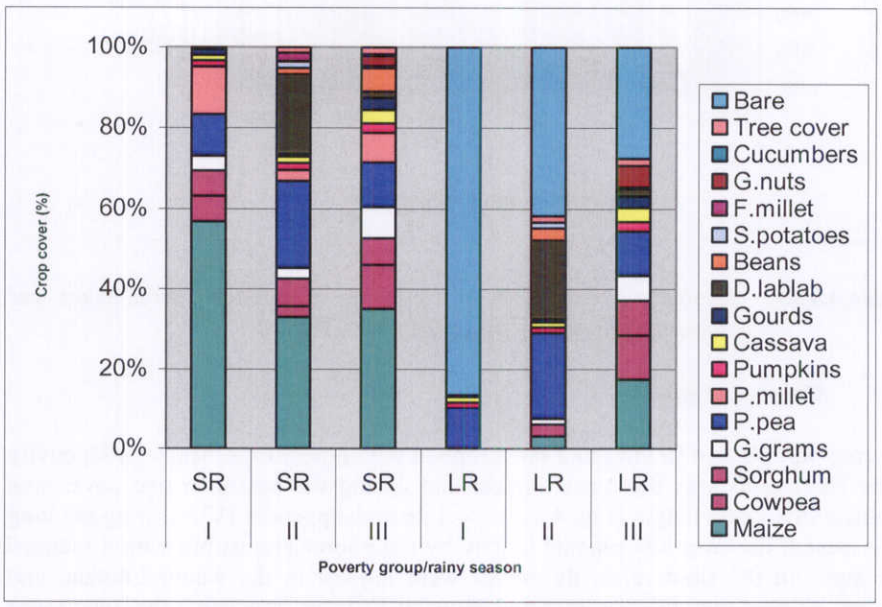


Figure 4.1.26 Estimated proportion of on-farm crop cover percentages per season in Muusini Village, Kibwezi, Kenya.

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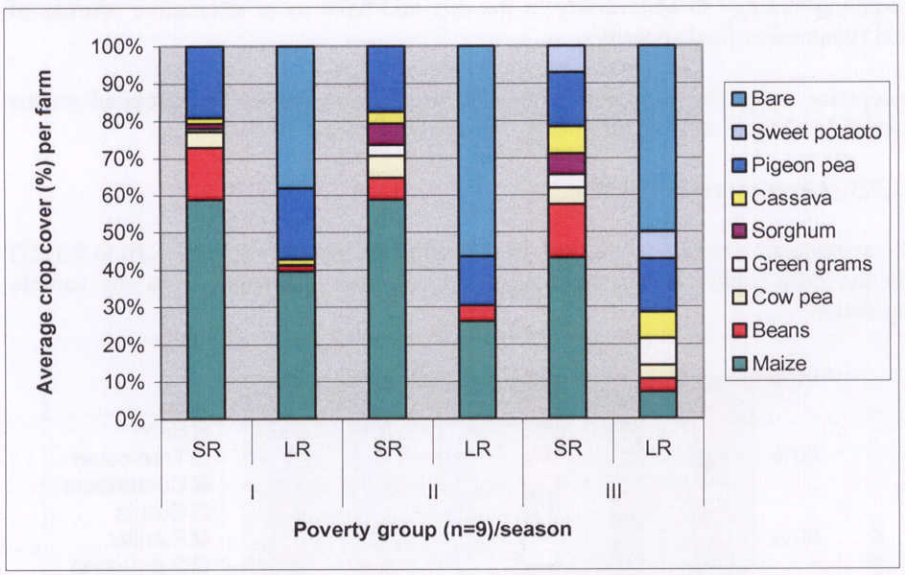


Figure 4.1.27 Estimated proportion of on-farms crop cover percentages per season in Bondeni Village, Kibwezi, Kenya.

(i) *Maize* (*Zea mays*)

The crop was planted in lines and intercropped with other crops. Maize productivity in the short rains was the most reliable and during the season maize cover was dominant in all the villages (Fig. 4.1.25 – 4.1.26 and Appendix IV). During the long rainy season, the crop was planted mostly by the poorer groups but with a reduced coverage. In the short rains, the yields were highest in the wetter Erankau and Bondeni villages than the dry Isara and Muusini Villages, indicating the importance of rainfall and therefore soil moisture. The rainfall pattern too favoured Bondeni and Erankau to achieve higher yields than that of Africa though lower than that of ARIDSAK on-farm research trials and the World unlike Muusini and Isara.

Similarly, the soils that had higher clay content and fertility, for example the Cambisols in Erankau had the highest maize yields (3442 kg ha^{-1}) than those with lower status such as the Ferralsols in Muusini (684 kg ha^{-1}).

Table 4.1.15 Summary of estimated crop production in the short rainy season for four villages of Eastern Kajiado and Southern Makueni, Kenya.

Crop type	Village/Yields per ha (kg)												
	Muusini			Bondeni				Isara			Erankau		
	Ferralsols	*Luvisols*	*Av.*	*Ferralsols*	*Chernozems*	Lava Flow	Av.	FCL	FL	Av.	OL	*Cambisols*	Av.
Maize	*684*	*849*	*770*	*1769*	*2055*		1913	1293	1718	1506	2077	3442	2760
Village optimum	*1779*	*2002*	*1890*	*1112*		*2224*	*1853*			*1890*			*1853*
Research trials	*2777*	*2007*	*2392*	*1613*	*3167*		*2390*	*1602*	*5602*	*3602*	*2816*	*1571*	*2194*
Average rainfed for the region			*560*				*560*			*560*			*560*
Africa			*1742*				*1742*			*1742*			*1742*
World			*3627*				*3627*			*3627*			*3627*
Pigeon pea	*287*	*485*	*386*	*1289*	*788*		1039				800		800
Village Optimum	*1446*	890	*1261*	890	445	124	486				*1261*		486
Average rainfed for the region			*572*				*572*						*572*
Africa			*584*				*584*			*584*			*584*
World			*828*				*828*			*828*			*828*
Cow pea	*307*	*576*	*442*	*300*	*160*		230		450	450	900	90	495
Village Optimum	*779*	667	*741*		*99*	*49*	82			*741*			82
Research trials	*2034*	*1574*	*1804*	*1376*	*916*		1146			*1804*			1146
Average rainfed for the region			*462*				*462*						*462*
Africa			*584*				*584*			*584*			*584*
World			*828*				*828*			*828*			*828*
Green grams	216	247	*232*	152	800		476	1550	525	1038	392	1820	1106
Village Optimum	*779*	*667*	*741*	*445*	*222*	0	222			*741*			222
Research trials	*746*	*868*	*807*	*658*	*528*		*593*	450	2886	*1668*	806	1389	1098
Africa			*584*				*584*			*584*			*584*
World			*828*				*828*			*828*			*828*
Beans	Not planted	150	150	1150	1470		1213	1500	792	1146	1166	2109	1638
Village Optimum				222	667	1334	741						741
Research trials				452	1053		753				1202	1867	1535
Average rainfed for the region			*447*				*447*						*447*
Africa			*584*				*584*			*584*			*584*
World			*828*				*828*			*828*			*828*

Cont. of Table 4.1.15

Crop type	Village/Yields per ha (kg)												
	Muusini			Bondeni				Isara			Erankau		
	Ferralsols	*Luvisols*	*Av.*	*Ferralsols*	*Chernozems*	Lava Flow	Av.	FCL	FL	Av.	OL	*Cambisols*	Av.
Pearl millet	*675*	*410*	*447*										
Research trials					*2778*								
Average rainfed for the region			*418*										
Africa			*652*				*652*						
World			*814*				*814*						
Dolicos lablab	*650*	*180*	*415*										
Average for rainfed in the region			*389*										
Africa (On-station research Uganda)			*742*										
Cassava		*242*	*242*	*475*	*450*		463				450		450
Africa			*7440*				*7440*				*7440*		*7440*
World			*9842*				*9842*				*9842*		*9842*
Sorghum	323	591	*457*	567	1067		817				0		0
Village Optimum	*1446*	*1335*	*1391*	*1112*	*1112*	1112	1112						
Research trials	*1070*	*2686*	*1878*	*1222*	*1645*		*1434*						
Average for rainfed in the region			*418*				*418*						
Africa			*825*				*825*						
World			*1305*				*1305*						
Finger millet		450	450										
Average for rainfed in the region			389										
Africa			652										
World			*814*										
Pumpkin	450	450	450								900		900
Sweet potatoes	225	400	313								450		450
Africa			4500										4500
World			14800										14800
Gourds	200	200	200										
Ground nuts	450		450										
Africa			790										
World			1124										
Cucumbers	450		450										

Av. = Average, FCL = ferral chromic Luvisols, FL = ferric Luvisols, OL = orthic Luvisols

NB: Because the agropastoralists of Isara and Erankau had no knowledge on villages' optimum yields, those of Muusini and Bondeni were used to estimate for the average villages yields in the respective agro-ecological zones respectively.

Source Own data (Questionnaire), Rowland (1993), ARIDSAK Project (2004), Belehu (2003), Mbogoh (2000) and Tiffen *et al.* (1994).

Moreover, the villages occupied by the agropastoralists had higher maize yields than those of the mixed farming community, a difference that can be related too to soil fertility and management differences.

Muusini and Bondeni have been continuously cultivated for the past decades unlike the soils of Isara and Erankau that were just being opened up for cultivation. In Erankau and Isara the impact could also be related to the implementation of the more animal manure based fertility management practices.

The yields of maize varied even within the same soil type. In Muusini, it ranged 450 to 1116 and 531 to 1233 kg ha^{-1} on the Ferralsols and Luvisols respectively. In Bondeni yields from the Chernozems were 1543 to 2423 kg ha^{-1} while that of the Ferralsols was 1333 to 2250 kg ha^{-1}. The trend was the same in Isara where productions on the ferral chromic Luvisols and ferric Luvisols ranged 1475 to 2222 and 300 to 2195 kg ha^{-1} respectively. Simlarly, in Erankau the ranges were 1328 to 5556 kg ha^{-1} and 556 to 2667 kg ha^{-1} on the Cambisols and orthic Luvisols respectively. Although minimum range was not very different from that of rain fed farms in the region, the differences in yields within each soil can be related to differences in management of the farms owned by the different poverty categories. In Muusini and Bondeni well off and medium grew maize as a commercial crop and therefore the management was more intensive than the poor. As a result they attained higher yields. There were no tendencies of yields varying with poverty in Isara but Erankau trends were the reverse of Muusini and Bondeni. The medium and poor had higher yields as a result of more intensive management such as weeding to obtain more yields for food security.

Optimal yields of maize was constrained by termites that feed on standing crops, stock borers (*Chilo partellus*) – bores the stalk, head smut (*Sphacelotheca reiliana*), chaffer grubs (*Aphodius ividus*) that feed on the roots of young crops causing them to dry/dislodge, and squirrels that feed on sown seeds. Chaffer grubs (a Lepidoptera larvae) come with animal manure that has not been completely decomposed and cooled. Other causes of low maize yields were caterpillar (different larvae of Lepidoptera), cutworms (*Agrostis* sp) and armyworms (*Laphygma* spp) that defoliate and destroy the crop. Other "pests" include elephants, baboons, monkeys, warthog, wild pigs and porcupines. In the store rats, bruchid weevils (*Callosobruchus chinensis* and *C. maculatus*), great grain borer (*Prostephanus truncatus*) locally known as "Scannia or Usama" feed on the grains. Scannia within few weeks multiplies and turns sacks of grains into powder waste. Fungal infection too impacts on the grains. Most of the farmers/agropastoralists interviewed intercropped maize with other crops such as cowpeas, sorghum, millet, green grams and pigeon peas.

(iii) Pigeon pea (*Cajanus cajan*)

Pigeon pea was the second most heavily planted crop in Muusini and Bondeni (Fig. 4.1.26 and 4.1.27) and its cultivation has reportedly increased within the villages as a drought copping strategy. Amongst the agropastoralists, only one in Erankau grew the crop due to less preference for it, impact of wildlife in the area and limited knowledge on its cultivation.

The crop was planted and intercropped with other crops in relay (lines). The long duration variety, which takes up to eight months to mature was planted in the November – December rains and harvested in August of the following year, although the green peas are eaten from June. The farmers plant this variety because germplasm for the short duration variety that fruits after three months was rarely available. Furthermore it is not tolerant to pests, diseases and drought like the "naturalized" long duration variety. As a consequence under the current farmers' conditions the long duration variety yields more than the short. The tall shrubby naturalized nitrogen fixing variety is also a source of fodder and firewood.

Just like maize, *Cajanus cajan* had high yields in Bondeni (1039 kg ha^{-1}) and Erankau (800 kg ha^{-1}) than Muusini (386 kg ha^{-1}) suggesting the crops preference for higher rainfall. Consequently, the average yields for Bondeni and Erankau were almost the same or above the villages' optimum, the region, Africa and the world. Within Bondeni, Ferralsols had the highest yields (Table 4.1.15) than the Chernozems while Volcanic Lava flow was reported to have the lowest yields (124 kg ha^{-1}) indicating its preference for sandier soils. Though potentially the yields in Muusini could reach as high as 2002 kg ha^{-1} on the Ferralsols in good rainy years, the reported low yields are not uncommon in the region. Mergeai *et al.* (2001) reported yields of 289 - 543 kg ha^{-1} in Kathonzweni within Makueni District.

The productivity too varied with the poverty groups (Appendix IV). In Muusini yields ranged from 135 to 657 kg ha^{-1} $year^{-1}$. Generally, it was lower on the farms owned by the poor poverty group except for a waterlogged farm owned by a well off farmer in Muusini. The difference can be related to differences in soils and management.
The well off groups had better contour-ridged cultivated farms than the poorer group. Therefore the extra moisture conserved influences the yield of the crop. A part from rainfall and soil type and management, the low yields were too caused by early consumption of the green peas and infestation by various aphids, thrips, beetles and caterpillars that feed on the flowers and pods. Elephants stray from parks when the crops are fruiting and they cause a lot of destruction. Other "wild pests" include baboons, monkeys and antelopes. In store brucid weevils are common problems.

The crop was the main determining factor in relay cropping practiced by all the interviewees in Muusini and Bondeni plus one in Erankau.. Since it is biannual, during the long rains of March - April other annual crops such as sorghum, cowpea, millet and green grams are intercropped with pigeon pea.

(iii) Cow pea (*Vigna unguiculata*)

The crop was intercropped and at times sole cropped. Cowpea covered 7 to 8% of the farms in Muusini and Bondeni. The crop was grown not only for its grains but also as vegetable (green leaves). Grain production was highest on orthic Luvisols (900 kg ha^{-1}) in Erankau and lowest on the Volcanic Lava (49 kg ha^{-1}). Luvisols in all the villages had higher yields though potentially the Ferralsols were reported to give more production. This means that for grain production, it is preferable to grow the crop on sandier soils while clayey soils give better production of leaves. Except for Bondeni, the other villages had yield average of 400 to 500 kg ha^{-1}, which was similar to that reported by Mergeai *et al.* (2001) in Kathonzweni (378 to 400 kg ha^{-1}).

In the drier Muusini village, production was higher on farms of farms owned by the well off and medium poverty groups that had higher moisture conservation structures. A part from the crops preference for sandy soils, the lower grain yields in Bondeni can be associated to higher incidence of pests and diseases (termites, aphids, beetles, caterpillars, thrips and cutworms and fusarium wilt, wild animals – baboons, monkey, antelopes). The impacts of aphids were most in Bondeni due to rainfall factor. In store rats and bruchid weevils attack the grains. Except for the case of Erankau, productivity was lower than that of the research trials, Africa and the World.

(iv) Green grams (*Vigna radiata*)

Green grams were either intercropped or planted on their own. The crop covered 5 to 7% of the croplands in Muusini and Bondeni. It was mainly grown by poor poverty category and provided the much needed grains for consumption and sale. Productivity was highest in Erankau and Isara (1106 and 1038 kg ha^{-1} respectively) and lowest in Muusini (232 kg ha^{-1}) corresponding with the high phosphorus levels. In terms of soils, the yields were high with those that had high soil moisture contents such as the Cambisols, ferral chromic Luvisols and Chernozems. Yields were also more on farms where deep tillage were practiced. In Muusini and parts of Bondeni *Vigna radiata* yields were lower than those of village optimum, research trials, Africa and world. Such low yields are not uncommon in the region. KARI (2004) reported average yields of 222 to 445 kg ha^{-1} under traditional rain fed systems while Mergeai *et al.* (2001) reported yields of 511 to 578 kg ha^{-1} under similar conditions. The low productivity was caused by moisture deficiency, low soil phosphorus levels, inappropriate germplasm and pests and diseases similar to those of cowpea.

(v) Beans (*Phaseolus vulgaris*)

Over 70% of the interviewees grew beans. Muusini had the least farmers growing the crop due to the drier environment and limited soil fertility. All the agropastoralists planted *Phaseolus vulgaris* due to dietary preference. Crop yields were highest in Erankau (1638 kg ha^{-1}) and Bondeni (1213 kg ha^{-1}) suggesting preference for higher rainfall. When the production of the drier villages were compared Isara had almost 8 times more harvest than Muusini as a result soil fertility differences as has been explained under maize. Just like green grams, the yields of beans were highest on Cambisols, ferral chromic Luvisols and Chernozems suggesting the importance of soil moisture to the performance of the crop. In Muusini and Bondeni the poorer farmers attained highest yields. However, in Isara and Erankau productivity did not follow poverty trends. Instead interviewees who weeded well and had physical soil conservation structures obtained more harvest. The crop yields were generally above villages' optimal yields, research trials, rain fed farming in region, Africa and the world averages. Despite the good performance productivity was constrained by pests and diseases similar that of cowpea and green grams. In addition, bean fly (*Ophiomyia phaseoli*) and bean bruchid (*Acanthoscelides obtectus*) were also common pests. Tortoise was reported to browse on the crop leaves and pods in Erankau.

(vi) ***Pearl millet*** *(Pennisetum americanum)*

Pearl millet was grown in the short rains by eight interviewees in Muusini because it is drought tolerant. The yields (225 to 675 kg ha^{-1}), were more on the Ferralsols than the Luvisols. Though the production was in the same range as data available for rain fed farming in the region, it was lower than that of Africa and the world averages. Mergeai *et al.* (2001) also reported similar yields of 489 to 667 kg ha^{-1} in Kathonzweni while Syngenta (2004) reported 250 to 750 kg ha^{-1} for rain fed farming in Africa. Relatively higher yields were achieved by medium and the poor than the well off poverty group because the former practiced intercropping while the later planted the millet as sole crop and therefore more susceptible to birds infestation. Other causes of the low yields in the field were stock borer and head smut. Additionally, bruchid weevils and rats attack the grains in store. The crop provides income from sales, flour and nutritious porridge.

(vii) ***Dolicos lablab*** *(Lablab purpureus)*

Dolicos lablab was grown by only three interviewees in Muusini obtaining 180 to 650 kg ha^{-1} the highest being from Ferralsols. The Poor attained higher yields as a result of differences in soils and on individual efforts in weeding. The legume is valued for its nutritious pulses, income generation and as fodder after harvest. The productivity was similar to that reported by Mergeai *et al.* (2001) of 133 to 445 kg ha^{-1} in Kathonzweni. The major constraint to Dolicos lablab was aphid infestation. Other were similar those of the above legumes.

(viii) ***Cassava*** *(Manihot esculenta)*

Cassava was intercropped by five farmers each in Muusini and Bondeni and one agropastoralists in Erankau at small scale of 0.07 to 0.1 ha per farm cutting across the poverty groups primarily as food security crop.
It was grown for root tubers (eaten as raw or after cooking) but not vegetable leaves as is the case in most parts of Central and West Africa. *Manihot esculenta* contributed 1 to 6% of the crop coverage and its productivity per hectare was very low (fresh weight of 242 to 463 kg ha^{-1} $year^{-1}$) when compared with that of Africa and the world as a result of its minimal and scattered planting across the fields. Though the yields were low, Bondeni and Erankau had almost double production than Muusini indicating the crops better performance on relatively higher rainfall zones. Amongst the soil types Ferralsols had highest yields a sign that the crop does better on sandier soils. In Muusini and Bondeni, production was too highest under medium and poor poverty groups due to better protection against wild animal pests and establishment of ridges for the tubers. Baboon, porcupine, warthog, wild pigs, cut worms and cassava mosaic virus, reduced the productivity of cassava. The wild animals eat the tubers while the worms and virus affect the leaves.

(ix) ***Sorghum*** *(Sorghum bicolor)*

Sixteen farmers and an agropastoralist (in Erankau) planted *Sorghum bicolor* with medium and poor poverty groups planting most (Fig. 4.1.26 and 4.1.27). The crop formed 1to 9% of the total crop cover in both the short rains and the long rains in both Muusini and Bondeni. Sorghum was mainly used as porridge and forage after crop harvest.

In terms of yields it ranged from 128 to 1800 kg ha^{-1}, the production being highest with the well off and medium poverty group. This can be related the benefit of mixed cropping that reduced birds infestation. Although the productivity was high but economically, the crop fetched a very low market price (of Kshs. 1.5 to 3 per kg). Consequently, its area coverage was low.

Bondeni Village had higher crop yield and Erankau had the least (0 kg ha^{-1}). The high yields in Bondeni means the crops preference for relatively higher rainfall while its low productivity in Erankau is related to birds' infestation. Though optimally the more sandier Ferralsols were reported to yield more grains (1446 kg ha^{-1}), the data from the interviewees shows the crops preference for the more clayey soils of Chernozems (1067 kg ha^{-1}) and Luvisols (591 kg ha^{-1}) that hold more soil moisture. The average productivity at village level were above regional data but less than the village optimum and that of the world. The relatively low performance was similar to that of pearl millet. Scaring was used to control the birds while ash + pepper and/or neem were applied to sacks of sorghum in store to control weevils.

(x) Finger millet (*Eleusine coracana*)

Although the crop was grown in Muusini and Bondeni Villages only one farmer out of the 36 interviewed grew *Eleusine coracana* due to its difficulty in weeding and the drier environment. However, a farmer has overcome the difficulty through monocropping combined with intensive weeding and ridging and addition of adequate animal manure. The crop covered 0.11 ha constituting 2% of the total cropland. The yield under Luvisols soil was 450 kg ha^{-1}, which was above the average for the region, though it was lower than that of Africa and the world. Mergeai *et al.* (2001) reported slightly higher yields (534 to 578 kg ha^{-1}) in Kathonzweni while Syngenta (2004) estimated the a range of 600 to 800 kg ha^{-1} in rain fed systems in Africa. This means that there is room for improvement of crop production. Finger millet was highly valued for its nutritious porridge and as an income-generating crop.
Apart from pests and diseases, which are the same as those sorghum and pearl millet, weeds and moisture constraints affects the crop productivity.

(xi) Pumpkin (*Cucurbita pepo*)

Pumpkins were grown in Muusini, Bondeni and Erankau Villages. Amongst the interviewees only eight (7 in Muusini and 1 in Erankau) cultivated the crop at a small scale of 0.1 ha intercropped and scattered in the fields. Consequently, the yields (fresh weight) were low ranging 450 in Muusini to 900 kg ha^{-1} $year^{-1}$ in Erankau. Some of the farmers planted the crop close to the homestead for protection purpose. The crop was planted to diversify food nutrition. The major drawbacks to pumpkin productivity were porcupines, warthog, wild pigs and elephants that feed on the fruits. Others were caterpillars and cut worms. Controls of the "pests" were through scare.

(xii) Sweet potatoes (*Ipomea batatus*)

Ipomea batatus was grown by four of the interviewees in Muusini, Bondeni and Erankau. Area coverage ranged 0.02 to 0.1 ha per farm contributing 1 to 6% of the total crop cover.

The crop was grown for food security and exploited for its sweet edible root tubers. The yields were low (fresh weight) of 225 to 450 kg ha^{-1} $year^{-1}$ being highest in Bondeni and Erankau. The yields were very low compared to that of Africa and the World as a result of its minimal and scattered planting across the fields. The productivity difference within the villages can be related to the difference in rainfall and soil types. The common pests of *Ipomea batatus w*ere sweet potato weevils that eat the tubers, caterpillars and cutworms that defoliate the leaves.

(xiii) Gourds (*Lagenaria siceraria*)

Gourd is an indigenous crop, which was grown by the farmers of Muusini and Bondeni for food (juvenile fruits) and sale (mature fruits as containers for drinking porridge and as milk containers). Only four of the interviewees in Muusini planted crop with minimum cover about 0.05 – 0.1 ha per farm, which constitutes 1.9% of the total crop cover on farm. The yield (fresh weight) was 200 kg ha^{-1} $year^{-1}$. Constraints to its production were noted as caterpillars that feed on the flowers, baboons and monkeys that devour on the fruits.

(xiv) Ground nuts (*Arachis hypogaea*)

The crop was grown by few farmers in Muusini and Bondeni Villages but only one interviewee had the crop on his farm with coverage of 4.3% of the total crop cover. The crop was grown on the Luvisols soils and the yield (with case) was reported to be 200 kg ha^{-1} in the long rains and 450 Kg ha^{-1} under adequate moisture in the short rains. The only constraint so far to the crop's productivity was noted as moisture stress. The production was lower than that of Africa and the world because of limited knowledge on its management and the dry environment.

(xv) Cucumber (*Cucumis sativus*)

Cucumis sativus was grown by an interviewee for its edible fruits. It covered 0.02 ha during the short rains making up to 1% of the total on farm crop cover. Its yield (fresh weight) was 800 kg ha^{-1} on the Ferralsols soils.

4.1.9.4 Major Constraints to crop production

Nine major constraints to crop production were identified within the villages (Table 4.1.16). The most widespread constraints were pests and diseases, moisture, storage and wildlife.

Pests and diseases: have been discussed under each crop grown. The most common were stock and pod borers, aphids, thrips, cut and armyworms, caterpillars and Fusarium wilt disease.

Storage: 34 of the interviewees had temporary or semi permanent storage, which are easily infested by rats, bruchid weevils and the great grain borer. Another problem was noted as fungal attack related to the poor storage. As a consequence, most farmers sale their yields immediately after harvest.

Table 4.1.16 The major constraints to crop production in four villages of Eastern Kajiado and southern Makueni, Kenya.

		Villages/number of respondents who reported the constraints				
	Constraints to crop production	**Muusini (n=9)**	**Bondeni (n=8)**	**Isara (n=9)**	**Erankau (n=10)**	**Total**
1	Pests & diseases	9	8	9	10	36
2	Storage	7	8	7	10	32
3	Moisture	8	5	9	10	32
4	Wildlife	8	6	8	10	32
5	Inputs	8	5	8	9	30
6	Market	9	7	4	6	26
7	Weeds & Labour	5	5	8	8	26
8	Inadequate knowledge	0	1	1	0	2
9	Low soil fertility	0	1	0	0	1

Moisture deficiency: The villages are located in a semi-arid area Muusini lies with mean annual rainfall of less than 700 mm per annum. Additionally, most of the soils are sandy with low soil moisture retention.

Wildlife: the constraint has been discussed under each crop but the major animal "pests" were elephants, baboons, monkeys, porcupines, antelopes, warthog, tortoise, wild pigs and variety of birds that inhabit the villages' woodlands and nearby national parks.
Inputs: The farmers indicated constraints in getting the right inputs in form of pesticides, implements and seeds and if available most of them were sold at prices beyond their purchasing power. Farmers noted to have limited access to agricultural extension and therefore have limited in knowledge on appropriate inputs.

Market constraints: The problem were in form of low prices for crop products at harvest times due to exploitation by middlemen, inadequate market intelligence, far reliable markets and poor accessibility to market. Currently, the prices of all agricultural products are liberalized.

Weeds and inadequate labour: The constraint was noted be at its peak during weeding and harvesting. As discussed under the characterization of socio-economics, the situation is aggravated by migration of some of the able-bodied men and women for off-farm activities in towns while children attend schools.

4.1.10 SUMMARY OF CROP RESOURCES

Farm sizes were smallest in Muusini followed by Bondeni where mixed farming community inhabit and largest in the pastoral villages of Isara and Erankau because of differences in population densities. Within each sub-region, the villages that receive higher rainfall had smaller land holdings than the drier villages.

In Muusini and Bondeni, the poorer poverty groups owned 4 to 15 times less land than the well off while in Isara and Erankau, land sizes were almost the same for the poverty groups. The smaller farm sizes for the poor in Kibwezi means more tillage of land for survival, hence lowering the soil fertility and increasing erosion problems. Cropland covered over 40% and 70% of the farms in Muusini and Bondeni respectively and less than 2% in Isara and Erankau. Woodlands and pastures were the major land uses in the later villages.

Twenty-one different crops were grown in the villages with the diversity being more with the villages settled by the mixed farming communities than the agropastoralists due to differences in way of life and food preferences. Amongst the villages, Muusini had the highest crop diversity as a result of more institutional support and to improve food security in the relatively drier environment. Except for tomatoes, kales and cotton all the other crops were mostly intercropped. The popular crops were maize, pigeon pea, cowpea, green grams, beans, pearl millet, cassava and sorghum. The short rains of October – January was the most reliable and the period when all the crops were cultivated.

Although the yields in most instances were lower than that of the expected villages' optimum, research trails, Africa and the World averages, data from the short season indicated that the productivity of the crops were higher in the villages with high rainfall (Erankau and Bondeni) and on soils with higher clay content and therefore moisture. Additionally, maize, green grams, beans and sorghum had higher yields on soils with higher clay content and therefore preference for higher soil moisture. Conversely, grain yields of pigeon pea, cowpea, pearl millet, dolicos lablab and cassava were greater on sandier soils.

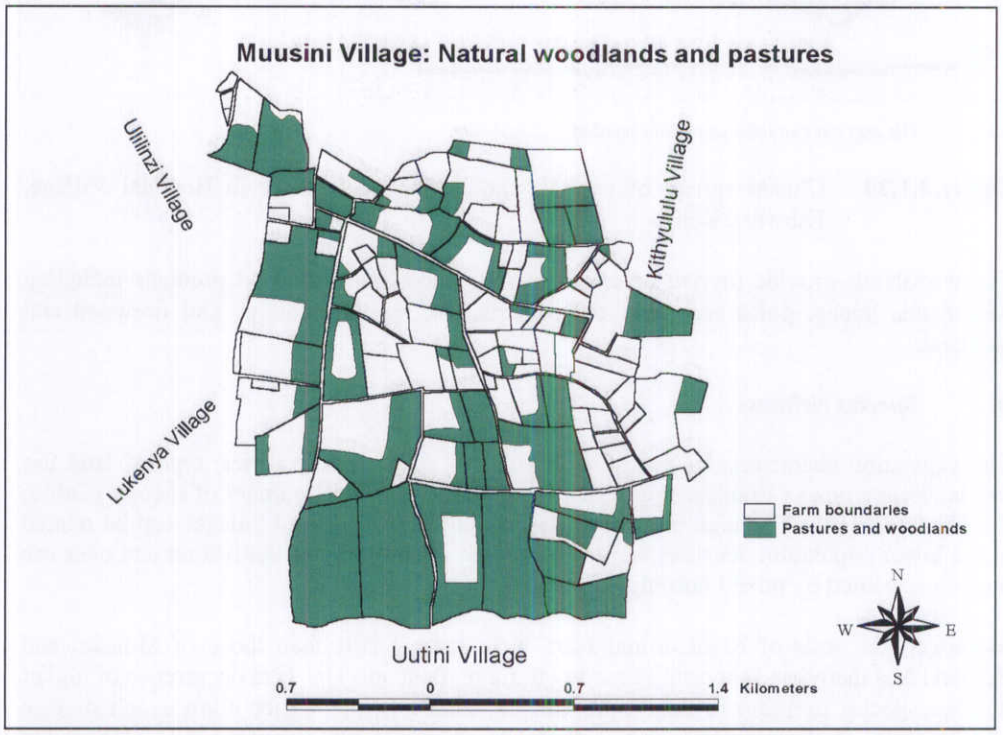
Overall, Erankau had the highest crop yields due to a combination of higher soil fertility and rainfall. In relation to management, grain yields of maize, pigeon pea, cowpea and sorghum were highest on the farms of the well off and medium poverty groups while poor attained higher yields from green grams, pearl millet, lablab and cassava. The well off and medium had relatively better managed farms with soil conservation structures and planted some of the above crops (except sorghum) as sole crops oriented to income generation. The major constraints to crop production were identified as pests and diseases, storage, moisture stress, wildlife and market.

4.1.11 *CHARACTERISTICS OF THE NATURAL WOODLANDS, PASTURES AND ANIMAL RESOURCES*

Vegetation descriptions in the tropics are absent or extremely generalized. Yet valid explanations can only be made once all the necessary facts and information relevant to the situation have been collected (Kent and Cocker 1992). A general view of the vegetation of an area give an expert a first hand impression of the status of an ecosystem while its analysis makes clear the root causes of successes and failures of the existing management practices. The determination of the status of vegetation at the village level is therefore important for environmental conservation and ecosystem management. This section describes the characteristics of vegetation and animal resources found in the study villages.

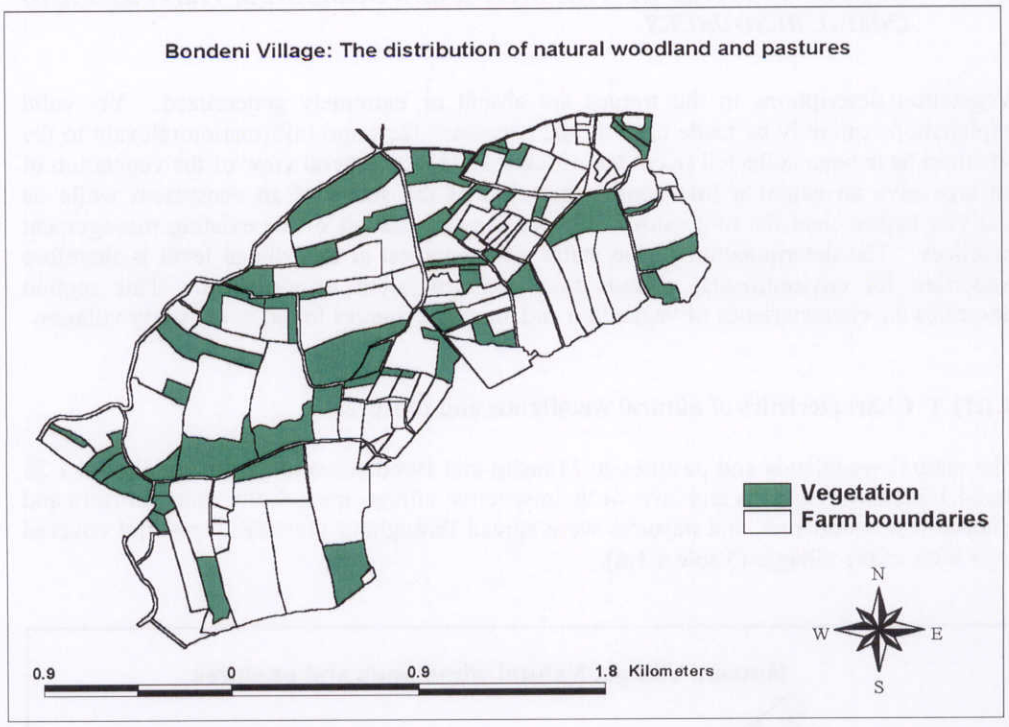
4.1.11.1 Characteristics of natural woodlands and pastures

The natural woodlands and pastures in Muusini and Bondeni were in clusters (Fig. 4.1.28 and 4.1.29) covering 47% and 26% of the respective village areas. Conversely, in Isara and Erankau the woodlands and pastures were spread throughout the landscapes and covered over 90% of the villages (Table 4.1.6).



NB This map is not an authority on farm boundaries.

Figure 4.1.28 Cluster spread of natural woodlands and pastures in Muusini Village, Kibwezi, Kenya.



NB This map is not an authority on farm boundaries.

Figure 4.1.29 Cluster spread of natural woodlands and pastures in Bondeni Village, Kibwezi, Kenya.

The woodlands provide myriad of uses: grazing, wood and non-wood products including wild fruits, honey, poles and posts for construction, herbal medicine and firewood and charcoal.

(i) Species richness

The vegetation characteristics varied with villages, agro-climatic zones, type of land use and landscape types. Erankau followed by Isara had the highest number of species (Tables 4.1.17 and 4.1.18). The high number of species in the agropastoral villages can be related to the lower population densities and therefore less opening up for cultivation and over use than those settled by mixed farming community.

Moreover, the soils of Erankau and Isara were more fertile than those of Muusini and Bondeni and therefore supporting the growth more plant species. The occurrence of higher number species in Erankau than Isara can be related to the wetter climate and diverse physiography in the former village. In terms of landscape, *Regosols* hills of Erankau followed by Brown *ferric Luvisols* of Isara were rich in species because the sampled sites were far from settlements and therefore less deforestation. Similarly, the farms covered by *Ferralsols* and *Chernozems* in Muusini and Bondeni respectively had higher number of species because they were owned by absentee farmers. Consequently, farms were mainly used as pastures and therefore least disturbed.

The *Vertisols* had the least number of species when compared with other landscapes as a result of poor drainage, thus supporting only few adopted species.

(ii) Ecological characteristics

Bondeni and Erankau had the least coverage of trees and shrubs making the pastures ideal for the growth of grasses (Tables 4.1.17 and 4.1.18). Conversely, Muusini had highest coverage of trees and shrubs forming impenetrable bush thickets that suppressed the growth of grasses.

Table 4.1.17 The characteristics of natural woodlands and pastures in Muusini and Bondeni Villages, Kibwezi, Kenya.

Vegetation Characteristics		Muusini			Bondeni		
Life form	**Parameters**	**Ferralsols Plains (n=5)**	**Luvisols Plains (n=5)**	**Average**	**Ferralsols Plains (n = 4)**	**Chernozems Lowlands (n=5)**	**Average**
Trees	No. of species	17	15	16	14	18	16
	Cover (%)	30	34.7	32.4	46.5	11.6	29.1
	IVI	81.4	74.8	78.1	152.3	57.9	105.1
	No. of species with diameter > 10 cm	9	5	7	5	3	4
Shrubs	No. of species	21	23	21	17	21	19
	Cover (%)	37.6	40.1	38.9	3	13	8
	Important value index (IVI)	159.8	179.4	169.6	71.5	141.3	106.4
Climbers	No. of species	2	4	3	1	2	2
	Cover (%)	1	1.7	1.4		r	0.7
	IVI	3.9	8.3	6.1	1.2	2.7	2
Herbs	No. of species	8	3	6	6	7	7
	Cover (%)	12.3	10.4	11.4	23	17.4	20.2
Grasses	No. of species	12	3	8	8	10	9
	Cover (%)	8.9	2.6	5.8	19.3	38.1	28.7
				Total species			Total species
Total No. of species		60	48	60	46	58	57
No. of trees, shrubs, climbers and herbs regenerating		28	23		32	40	
No. of high value species		21	17	19	21	20	21
No. of pasture weeds/indicators of range deterioration		4	7	6	4	5	5
Seed bank status (germination) after six months		Only herbs, grasses and sedge	Only herbs, grasses and Kyllinga	Only herbs, grasses and Kyllinga, sedge	Only herbs and annual grasses	Only herbs, grasses and sedge	Only herbs, grasses and sedge

NB Data was collected in rainy seasons r = Rare (cover < 1%).

Bush encroachment had also reduced grass cover in Brownish ferric Luvisols of Isara to as low as 2.5%. Although wetter climate might have favoured the growth of grasses in Bondeni and Erankau, excessive overgrazing in Isara and Muusini was a major factor. Based on important value index (IVI) hat combines relative density, frequency and cover, *Commiphora – Erythrochlamys spectabilis - Premna resinosa* wooded bush land thicket with *Grewia bicolor* and *Combretum exalatum* common in depressions covered the Luvisols plains in Muusini while Ferralsols plains in the same village was dominated by *Adansonia digitata - Commiphora africana - Combretum exalatum* wooded bushland thicket (Plate 4.1.6).

Table 4.1.18 The characteristics of natural woodlands and pastures in Isara and Erankau Villages, Mashuru, Kenya.

Vegetation Characteristics		Isara							Erankau								
Life form	Parameters	CH (n=3)	VV (n=3)	VB (n=4)	FCL (n=3)	FLR (n=2)	FLB (n=13)	Av.	RH (n=7)	CH (n=3)	CP (n=2)	OLF (n=4)	OLUP (n=3)	OLLP (n=4)	GL (n=1)	V (n=2)	Av.
Trees	No. of species	10	1	9	9	8	18	9	30	8	9	7	10	7	3	3	9
	Cover (%)	36.8		36.8	33.9	41.9	45.7	26.4	30.7	11.8	2.4	36.7	17.5	41.3	25.6	15	26.4
	IVI	111.5		111.5	80.6	109.6	122.1	89.2	87.4	39.8	32.1	85.1	47.9	94	37.4	53.5	89.2
	No. of species with diameter > 10 cm	0		2	1	2	4	2	8	2	3	3	3	5	2	2	2
Shrubs	No. of species	14	5	13	14	7	16	12	29	15	8	17	21	17	8	6	12
	Cover (%)	23.8	53.1	23.8	18.3	14.1	29.9	27.2	26.2	18.1	0.1	15.4	31.2	31.1	9.7	8.2	27.2
	IVI	151.4	202.1	151.4	123.3	130.7	135.3	149	102.2	104.4	12.1	97.5	136.6	115.1	39.4	89.9	149
Climbers	No. of species	2	0	1	1	2	1	1	3	2	0	4	1	1	1	0	1
	Cover (%)	0.1	0		0.1	1.5	0.4	0.4	3.7	2.6		3.7	0.3		3		0.4
	IVI	4.1	0		3.4	14.2	2.2	8.2	14.5	9.3		12.6	4.3	2	41.7		8.2
Herbs	No. of species	7	5	2	3	3	8	5	5	4	4	4	5	4	4	4	5
	Cover (%)	0.5	0.7	0.5	1.1	2.5	1.6	1.2	5.3	7.6		6.3	4.4	9.8	21.7	1.7	1.2
Sedge/ Kyllinga	No. of species	1	1	1	0	0	0	1	0	0	1	0	1	2	1	1	1
	Cover (%)										r		6.2	1.8	5	7.7	
Grasses	No. of species	2	2	4	5	3	5	4	7	4	5	4	6	2	3	3	4
	Cover (%)	11.1	14.5	10.1	24.9	12.5	2.5	12.6	23.8	78.3	63	29.6	27	5	15	45	12.6
Total No. of species		36	14	32	32	23	48	80	74	33	27	36	44	33	20	17	123
No. of trees, shrubs, climbers and herbs regenerating)		12	5	12	12	10	25	13	33	14	13	15	17	17	7	7	13
No. of high value species		9	5	14	16	14	18	13	36	17	13	17	21	14	7	7	13
No. of pasture weeds/indicators of range deterioration		3	1	3	3	2	5	3	7	3	3	4	5	4	2	3	3
Seed bank status		Herbs and annual grasses	Herbs, cyperus, annual grasses		Herbs and annual grasses		Herbs, cyperus, Kyllinga, annual grasses		Herbs and annual grasses	Herbs and annual grasses	Herbs, Kyllinga , annual grasses	Herbs and annual grasses	Herbs, Kyllinga, annual grasses	Herbs, Kyllinga annual grasses	Herbs, cyperus, annual grasses	Herbs, cyperus, annual grasses	

CH=Cambisols hills VV=Volcanic vertisols VB=Basement Vertisols FCL=Ferral chromic Luvisols FLR=Reddish ferric Luvisols FLB=Brownishh ferric Luvisols CP=Cambisols plains OLF=Orthic Luvisols Foothills OLUP=Orthic Luvisols upper plains OLLP=Orthic luvisols lowlands GL=Gleyic Luvisols V=Vertisols

NB IVI= Important value index. Av. = Average. Data was collected in rainy seasons



Photo by A. Mohamed in 2003.

Plate 4.1.6 *Commiphora* spp dominated the natural vegetation of Muusini Village, Kibwezi, Kenya though *Adansonia digitata* (Baobab – background) was also common on the Ferralsols plains.

Both landscapes had dense undergrowth of *Barlaria taitensis* on plains and *Acalypha racemosa*, *Justacia flava* and *Duosperma kilimandscharica* along watercourses. Under these dense thickets, grass species were restricted to shade tolerant *Panicum maximum* and *Enterepogon macrostachyus*.

In Bondeni *Ferralsols* plains were dominated by *Combretum* woodlands (*C. apiculatum, C. zeyheri* and *C. collinum*) (Plate 4.1.7) with *L. triphylla* and *D. melanoxylon* common in some portions. *Chernozems* lowlands was dominated by *Lannea triphylla* - *Combretum* spp. wooded grassland. Although *Truimfetta flavescens* and *Dousperma kilimandscharica* were the common undergrowth. However, where *L. triphylla* dominated the undergrowth was mostly formed by *Anthericum venilosum*. However, the *Chernozems* bordering the Volcanic Lava Flow were dominated by *Acacia drepanolobium* and *Cenchrus* sp. (Plate 4.1.7). All the natural vegetation on the Volcanic Lava had been cleared for cultivation but there were few scattered Baobab, *Commiphora baluensis* and *Balanites wilsoniana* on croplands. The most dominant grasses were *Cenchrus* sp., *Panicum maximum, Enchinocloa colona* and *Heterepogon contortus*. In the Ferralsols plains *Combretum* spp. wooded grassland with *Duosperma kilimandscharica* dominating the under canopy. In few portions, *L. triphylla* was dominating. A unique plant found only on the *Ferralsols* plains of Bondeni was a *Cyphostema* sp. (Ngalatimia - Kamba). Others were *C. zeyheri* and *C. collinum*.

In Isara, Cambisols hills and foothills were dominated by *Chrysopogon aucheri* - *Acacia Senegal – Grewia tembensis* grass bush land *with Pennisetum mezianum* grassland dotted with *A. mosambicensis* and *Acacia mellifera* becoming prominent on the foot hills.



(a) *Combretum* woodlands covered most of the Ferralsols plains



(b) *Acacia drepanolobium* and *Cenchrus* sp. Wooded grassland was found in parts of the Chernozems lowlands

Photo by A. Mohamed in 2003.

Plate 4.1.7 The major natural vegetation types of Bondeni Village, Kibwezi, Kenya.

Deciduous Oloorok kileling - *A. mosambicensis* shrub land characterized the Volcanic Vertisols with *Cyprus bulbosus* occupies most of the bare grounds in rainy seasons while the Basement Vertisols was dominated by sparse *A. tortilis – Serracocomopsis pallida* open woodlands. The Ferral chromic Luvisols, which was reported by the local community to be originally under pure *Digitaria milanjiana* grassland has been invaded by trees and shrubs as a result of overgrazing making the existing vegetation to be of *Acacia tortilis* woodlands with *Pennisetum mezianum – Sporobolus fimbriatus* dominating the grass cover. The presence of *Ipomea kituiensis* and *Commiphora africana*, which are considered to be rangeland weeds are indications of range deterioration (Plate 4.1.8).



Photo by A. Mohamed in 2003.

Plate 4.1.8 *Ipomea kituiensis* is a common rangeland weed on the *ferral chromic Luvisols* plains.

Commiphora africana – Acacia tortilis bush land dominated the Reddish section of the Ferric Luvisols while *Grewia bicolor - Commiphora africana* bush land the common characteristic of the Brownish protion of the Ferric Luvisols. The dominant species along

watercourses was *G. bicolor* dotted with *Acacia tortilis*. *C. africana* and *Boswellia neglecta* were common on level plains a way from the watercourses (Plate 4.1.9).
Unique species identified only in Isara when compared with the other villages were Oloorok kileling, *Klienia squarrosa*, Ngaimurunyai, *Maerua* sp, Ngatia mongi, *Heliotropum* sp., *Vernonia aemulans*, *Solanum* sp., *Ipomea kituiensis*, *Commiphora sambarensis*, *C. holtziana*, *Acacia anistroclada*, *A. Senegal*, *Letepes senegalensis*, *Sesamothamnus rivae*, *Bleripharis lanariolia*, *Sansivaria intermedia* and *Cyperus bulbosus*.



(a) *G. bicolor – A. tortilis* woodlands were common along watercourses

(b) *C. africana and B. neglecta* woodlands dominated far from watercourses

(c) *Sanziveria intermedia* was a unique species in this landscape

Photo by A. Mohamed in 2003.

Plate 4.1.9 The dominant vegetation on the *ferric Luvisols* plains, Isara Village, Mashuru, Kenya.

Two types of vegetation dominated the Regosols hills of Erankau. Along watercourse the vegetation can be described as *Commiphora baluensis – Acacia brevispica* wooded bush land and the parts away from the streams as *Combretum apiculatum* wooded grassland. Along watercourses *Aspilia mossambicensis* formed dense undergrowth while *Digitaria milanjiana* was common on open areas. *Acacia mellifera* formed forests on the orthic Luvisols foothills with undergrowths of *Enterepogon macrostachyus* (a shade tolerant grass), *Solanum incanum* and *Premna resinosa* (at times forming thickets). *Acacia tortilis* and *Balanites aegyptiaca* formed open woodlands on the upper part of the orthic Luvisols plains with undergrowths of *Grewia tembensis, Solanum incanum* and *Cynodon plectostachyus*. Down the slope on the orthic Luvisols lower plains, *Acacia drepanolobium* (Plate 4.1.10 and Appendix V) became the dominant species in certain areas substituted by *A. mellifera*, *B. glabra* or *B. aegyptiaca*. But along streams, *Albizia anthelmentica* and *Cordia ovalis* replaced *A. drepanolobium* with thick undergrowth of shade tolerant *Justacia flava* and *E. macrostachyus*.

The foothills and orthic Luvisols plains were the most severely bush encroached sites within Erankau. On the other hand the Cambisols hills and plains formed bulk of the grasslands.



Plate 4.1.10 *Acacia mellifera* dominated foothills and parts of *upper orthic Luvisols* plains while *Acacia drepanolobium* was common on the lower plains of Erankau Village, Mashuru, Kenya.

Digitaria milanjiana - Sporobolus fimbriatus - Themeda triandra - Chrysopogon aucheri grasslands dotted with *Erythrina abyssinica* and *Sclerocarya birrea* dominated the Cambisols hill while the Cambisols plains are covered by *P. mezianum – D. milanjiana – Chloris roxburghiana* grassland dotted with *S. birrea* and *L. stuhlamanii*. The Vertisols lowlands and the gleyic Luvisols lowlands were dominated by *A. seyal* var. *fistula* (Plate 4.1.11) - *A. paolii* wooded grassland and *Acacia mellifera* woodlands respectively.



Photo by A. Mohamed in 2002.

Plate 4.1.11 *Acacia seyal* var. *Fistula* was the dominant tree species on the *Vertisols* lowlands of Erankau Village, Mashuru, Kenya.

In relation to the other villages there were many species unique to Erankau. Some of them include *Acacia seyal, Sclerocaryia birrea, Xemania Americana, Ochna holstii, Papea capensis, Rhamnus staddo, Teclea spp., Commiphora schemperi, Croton dichogomus, Grewia forbesii, Zizyphus mucronata, xerophyta spikei, Crotolaria goodiformis, Gnidia latifolia, Capparis fascicularis, Carissa edulis, Rubus pinnatus, Hibiscus aponerus, Osyris lanceolata, Euclea divinorum* and *Themeda triandra.*

The spread of invaders such as *Solanum incanum, Occimum* sp. and *Hibiscus pycnostemon, Commiphora africana* in most of the landscapes, *Ipomea kituiensis* in Isara, and *C. oblongifolia* in Bondeni and Erankau, *Gnidia latifolia* on the Regosols and orthic Luvisols foothills, *Indigofera spinosa* on the Regosols and Cambisols plains of Erankau were indications that the range was deteriorating due to overuse.

(iii) Regeneration

The villages that practised free grazing, that is Isara and Erankau had the lowest percentage of trees, shrubs, climbers and herbs regenerating than those of Bondeni and Muusini who practiced controlled grazing (Tables 4.1.17 and 4.1.18). In Bondeni, the percentage of species regenerating in each landscape was above 80% when compared to the others that had less or about 50%. When agro-climatic difference was considered the percentage number of species regenerating were higher under the wetter AEZ V.

(iv) Occurrence of high value species

As expected landscapes that were least disturbed by human activities such as Regosols hills in Erankau, Ferralsols plains in Muusini and Bondeni and the brownish ferric Luvisols plains of Isara had the highest number of high values species (Tables 4.1.17 and 4.1.18).

(v) Seed bank studies

Six months of seed bank studies on soils from all the landscapes had only annuals grasses, herbs, *Kyllinga, Trichodesma zeylanicum, Pupalia* sp., sedge and *Solanum incanum* germination each with 1 - 8 seedlings. The limited germination can be related to seed destruction caused by annual seed browsers such as ants, termites and rodents that are found in plenty within this dry tropical climate and long dormancy of the seeds of some plants that have hard seed coats. It can also be related to human and livestock disturbances such as exploitation for fuelwood and construction, overgrazing and trampling.

4.1.11.2 Characteristics of animal resources

(i) Livestock

By 2003, Erankau followed by Isara had the highest number of livestock while Bondeni had the least due differences in the way of life (Table 4.1.19). The relatively higher number of livestock in Erankau can be related to the wetter climate and better accessibility to pastures than the dry village of Isara. In the Kibwezi, Muusini had more livestock especially goats than Bondeni because of larger farm sizes and the fact that goats are more tolerant to drought and to trypanosomiasis than cattle and sheep and are cheaper to build (Fall 2000). Local livestock such as poultry are also tolerant to diseases.

Table 4.1.19 Livestock population in four villages of Eastern Kajiado and Southern Makueni, Kenya.

Livestock type	Villages/Poverty groups															
	Muusini (n=80)				Bondeni (n=125)				Isara (n=51)				Erankau (n=86)			
	I	II	III	Total	I	II	III	Total	I	II	III	Total	I	II	III	Total
Cattle	59	54	31	144	93	45	12	150	870	205	181	1256	1125	685	286	2096
Goats	208	196	206	610	215	108	123	446	320	130	245	695	620	540	619	1779
Sheep	50	21	2	73	52	14	9	75	188	75	187	450	420	303	249	972
Donkey	0	1	0	1	1	1	0	2	22	25	34	81	59	42	53	154
Poultry (Indigenous variety)	296	324	532	1152	401	232	442	1075	30	84	456	570	150	136	649	935
Beehives (log hives)	22	14	11	47	57	75	60	192	0	0	0	0	0	0	0	0

The cattle reared in Muusini and Bondeni were local Small East African Zebu while Isara and Erankau agropastoralists mainly kept improved breeds of Sahiwal or crosses of East African Zebu and Sahiwal. Similarly, the farmers of Muusini and Bondeni had the local Small East African goat breed and local Fat-tailed brown Masaai sheep while the agropastoralists of Isara and Erankau kept improved breeds mostly the Galla goats and Dupper sheep. Furthermore, in order to control rodents, snakes and predators of livestock (including poultry), each household had at least a dog and a cat. As shown in Table 4.1.3, the well off own most of the livestock that are responsible for overgrazing the pastures of the villages while the impact of the poor is minimal. Similar opinion has been noted in other parts of the world (Duraiappah 1998).

The farmers reported that a goat yields a third to half litres of milk each day in rainy seasons but the productivity reduces in dry season to quarter to one fifth of a litre. On the hand a cow yields an average of one to two litre in wet seasons and then reduce to half to one litre per day. Bee keeping was a common practice only in Muusini and Bondeni but the hives were of the log types.

A comparison between household and animal numbers in Muusini and Bondeni reveal that Muusini farmers have almost twice more cattle and goats due to favourable climate difference as explained before.

The livestock components are kept mainly for draught (ploughing), milk, meat/food and income generation (Table 4.1.20)

Table 4.1.20 Uses of livestock resources in Eastern Kajiado and Southern Makueni, Kenya.

Livestock	Uses
Cattle	Draught, milk, cash, meat, payment of dowry, hides, traction, security (bank on hooves) and manure in all the villages, and blood (drunk), prestige and beauty in Isara and Erankau
Sheep and goats	Milk, cash, meat, skins, security (bank on hooves) in all villages and blood (drunk), prestige and beauty in Isara and Erankau
Donkey	Transport, cash, security (bank on hooves)
Poultry	Cash, meat, eggs (food), security (bank on hooves), prestige and beauty, manure
Honey	Cash and as food

Unlike free grazing practiced by the agropastoralists, the farmers tether their animals in individual pastures or keenly look after to avoid trespassing into croplands or put in sheds where they are semi-zero grazed. Manure from the kraals is put in cropland for nutrient. Additionally, both the farmers and agropastoralists practice natural breeding. Moreover, unlike the farmers who practice uncontrolled breeding, the agropastoralists use napkin to control unnecessary mating of animals and to stop inbreeding especially for goats and sheep (Plate 4.1.12). The bucks will only be allowed to breed by June so that the lactation period coincides with short rains of November and December.



Photo by A. Mohamed in 2002.

Plate 4.1.12 The tying of napkin is a traditional practice of livestock breeding. control in Mashuru, Kenya.

The major constraints to livestock production has been related by all the 36 interviewees as shortages of pasture and water, pests and diseases, wild animals, and market/transport.

- Pasture shortage and inadequate water occur June to mid November. They associated the constraints to unreliable rainfall and increase in the occurrence of drought, increase in the population of human (hence settlements) and livestock and the subsequent reduction in pasture areas, increase of invader plants, inadequate skills in pasture management, invasion of pastures by wild animals, army worms, rats and termites. In Isara and Erankau the agropastoralists link the increase in wild herbivores population to decrease of wild predators and to the traditional conservation culture of the Masaai community of not eating game meat.
- Predation by wild animals especially leopards, Cheetah, eagle, fox, lion, python, Jackal, and Hyena
- Market related factors include low and poor prices, far and unreliable markets and exploitation by middlemen
- Pests and diseases – The common livestock diseases/pests include Trypanosomiasis, worms, contagious pleuro-pneumonia (CPP), East coast fever and Anaplasmosis (Table 4.1.21 and 4.1.22).

Table 4.1.21 Common diseases of livestock in Muusini and Bondeni Village, Kibwezi, Kenya.

Livestock type	Reported pests/diseases (Local names)	Control methods used by farmers
Cattle	Anaplasmosis (Kathatia)	None
	Worms (Minyoo)	None
	Trypanosomiasis (Kisiko)	None
	Contagious pleuro-pneumonia (CPP) (Mavui)	Tramycine, Andamycine, Penicillin, Ash + sweet potatoes + *Lannea* spp or *Senna abbreviata* + Muvuavui or Mwaitha. Muvai (*Entada leptostachya*)
	Malignant catarrh	None
	Foot and mouth disease (Muthingitho)	Andamycine, Penicillin, Fire medicine (burning animals back with hot metal) Pour animal urine on the wound
Sheep	Foot and mouth disease	Tramycine, Andamycine, Penicillin Muvuavui or Mwaitha
	Ordinary pneumonia	
	Nasal bloat (Fly larvae)	
	Skin diseases (Unguu)	
Goat	Contagious pleuro-pneumonia (CPP) (Mavui)	Tramycine, Andamycine, Penicillin, Muvuavui or Mwaitha + Ash Muvai
	Worms	
	Foot and mouth disease	Tramycine, Andamycine, Penicillin Put cold ashes at bomas gate and put it ash in the mouth
	Anaplasmosis (Kathiliko/Kithalia/Nyongo)	
	Contagious pleuro-pneumonia (CPP)	Tramycine, Andamycine, Penicillin, tender castor oil seed + soot + magadi soda
	Fly larvae (Kinyu kya mutue)	
	Skin diseases (Unguu)	
	Hooves diseases	
Poultry	New castle	Soot, Aloe vera, Pepper, goat milk, *Euphorbia tirucalii* , Dendelion, Muvai, + water
	Fleas, lice	Remove by hand, apply paraffin/oil
	Respiratory diseases (Mavui)	

The out breaks of common livestock pests and diseases cited by the agropastoralists of Isara and Erankau were locally related to the abundant wild animals (locally referred to as "Government cattle") especially Wildebeest, which freely browse and graze with domestic animals. As expected there were more diseases cited by the agropastoralists although they depended more on modern medicine unlike the farmers who mostly use local concoctions (Tables 4.1.21 and 4.1.22)

- Low quality livestock (milk and meat production) was noted a constraints to livestock production in Muusini. Additionally all the interviewees indicated the need to improve the breeds of their current stock to animals that will yield more milk and meat

(ii) Characteristics of wildlife resources

The villages are close to Tsavo East National Park (the case of Muusini), Chyulu Natioanl Park (Bondeni and Isara) and Amboseli Game Reserve (Isara and Eranakau). Furthermore, the woodlands of the villages too house wild animals that have become pests to crop products. They include *Hystrix Africaeaustralis* (porcupine), *Papio anubis* (baboons), *Ceracopithecus* spp. (monkeys), *Lepus capensis* (hare), *Rhyncho – tragus* (dik dik), *Aepyceros melampus* (Impala), *Gazella thomsonii* (Thomson's gazelle), *Alcelaphus buleleaphus cokii* (Kongoni) and *Sagittarius serpentarius* (Secretary bird).

Table 4.1.22 Common diseases of livestock in Isara and Erankau Villages, Mashuru, Kenya.

Livestock type	Reported pests/diseases (Local names)	Control methods used by farmers
Cattle	Black quarter (Empurwo)	Tramycine, Andamycine, Penicillin
	Anthrax (Ola kirkir)	Tramycine, Andamycine, Penicillin
	East coast Fever (ECF) (Oltikana)	Tramycine, Andamycine, Penicillin Fire medicine (burning animals back with hot metal) Pour animal urine on the wound
	Contagious pleuro-pneumonia (CPP) (Olkipei)	Tramycine, Andamycine, Penicillin
	Rinder pest (olodua)	None
	Malignant catarrh (Engeng'ati)	None
	Foot and mouth disease (Olkuluk)	Andamycine, Penicillin, Fire medicine (burning animals back with hot metal) Pour animal urine on the wound
Sheep	Black quarter (Empurwo)	Tramycine, Andamycine, Penicillin
	Anthrax (Endemelwa)	Tramycine, Andamycine, Penicillin
	Foot and mouth disease (Olkuluk)	Tramycine, Andamycine, Penicillin Fire medicine (burning animals back with hot metal) Pour animal urine on the wound
	East coast Fever (ECF) (Oltikana)	Tramycine, Andamycine, Penicillin
	Bluetongue – occurs during high rainfall periods	Tramycine, Andamycine, Penicillin
	Contagious pleuro-pneumonia (CPP) (Olkipei)	Tramycine, Andamycine, Penicillin
Goat	Anthrax (Ola kirkir)	Tramycine, Andamycine, Penicillin
	Black quarter (Empurwo)	Tramycine, Andamycine, Penicillin
	Foot and mouth disease (Olkuluk)	Tramycine, Andamycine, Penicillin Fire medicine (burning animals back with hot metal) Pour animal urine on the wound
	East coast Fever (ECF) (Oltikana)	Tramycine, Andamycine, Penicillin
	Contagious pleuro-pneumonia (CPP) (Olkipei)	Tramycine, Andamycine, Penicillin
	Red water (Noda munyatta)	Tramycine, Andamycine, Penicillin
Poultry	New castle like (Sudden death)	Pepper + water orally

Others are Ngorika bustard, *Orycteropus afer* (Antbear), *Oryx beisa beisa* (Oryx), *Taurotragus oryx* (Eland), *Panthera pardus* (Leopard), Cheetah (*Acinonyx jubatus*), *Crocuta crocuta* (Spotted hyena), variety of snakes, Ostrich, Tortoise, Fox and wild pigs and squirrels. Some of the animals common in Isara area are given in Table 4.1.23.

Table 4.1.23 The population of some of the wild animals found in Merueshi Individual Group Ranch, Mashuru, Kenya.

Species	Number in dry season	Number in rainy season
Gazella grantii (Grant's gazelle)	88	400
Equus burchelli (Common zebra)	560	1512
Connochaetes taurinus (Wildebeest)	88	682
Giraffa camelopardalis (Giraffe)		78
Aurotragus oryx (Eland)		178
Tragelaphus imberbis (Lesser Kudu)		1

Source District Warden's Office, Kajiado (2004).

Additionally, during certain parts of the year *Loxondota africana* (elephants) also stray from the above parks and also from the Tsavo West National park destroying not only crops but also kill people. Thirty-five of the interviewees see wild animals as problematic with no benefits to them.

Hence their request is "fence them off in the parks and compensate the damages they cause". The animals migrate to the farms in rainy seasons and then most of them fall back to the parks in dry seasons.

On the other hand farmers close to parks reported to benefit from the park by illegal grazing and obtaining wood products. They also noted the involvement of Kenya Wildlife Services in maintenance of roads around the Bondeni Village.

4.1.12 SUMMARY OF WOODLANDS, PASTURES AND ANIMAL RESOURCES

Woodlands/pastures cover 47%, 26% and over 90% of Muusini, Bondeni, Isara and Erankau respectively and provide multiple uses. The vegetation characteristics varied with population density, agro-climatic zones, type of land use and landscape types. Erankau followed by Isara had the highest number of species. The Vertisols had the least number of species when compared with other landscapes as a result of poor drainage, thus supporting only few adopted species.

The dominant species in Muusini and Isara were *Commiphora* spp. while *Combretum* spp. dominated Bondeni and *Acacia* spp. and grasslands in Erankau. Bush encroachment, increase of invader species and overgrazing were big constraints within the villages. Species regeneration was lowest in agropastoral villages and in the drier agro-ecological zone V due to over grazing and moisture stress respectively. The occurrence of high value species were more at sites far from settlements. Furthermore seed bank studies revealed the germination of only annuals.

Livestock were made up of local breeds in Muusini and Bondeni but of a mixed breed of local and exotic in Isara and Erankau. Goats and cattle were the dominant stock within the villages. Livestock provide much needed protein, income, manure, draught (oxen) and act as security. There were few wild animals in Muusini and Bondeni but abundant in Isara and Erankau. Wild animals were mentioned as big "pest" that destroy crops, overgraze pastures and over use farm resources.

4.1.13 CONCLUSIONS

The study villages are mainly settled by resource poor farmers/agropastoralists who form over 60% of the population. At the current high rate of population increase the trend is likely to increase exerting more pressure on land resources. Further, locals are faced with markets and financially related constraints. To cope with low standard of living there is rural-urban migration to search off–farm jobs. For those who remained behind, they resorted to over cultivation though soil resources are conserved. As a result the productivity per hectare of most crops were less than that of the village optimum, research trials in the region, Africa and the World. Furthermore, harvests stored for food security in the dry seasons were prone to destruction by rats, bruchid weevils, great grain borer and fungal attacks. Moreover, prices of foodstuff were low at harvest times and high in the critically dry periods. On the other hand the large herds of the well off are causing overgrazing. Besides, pasture and water constrains has been exacerbated by sharing of the resources with wild animals who are also vectors of pests and diseases. As a result, the characteristics of resource components in the study villages indicates unsustainably in resource use leading to food insecurity that also encourages the clearing of the natural woodlands for more land to cultivate.

4.2 IMPACT OF EXISTING MANAGEMENT PRACTICES AND USE ON RESOURCE COMPONENTS

4.2.1 INTRODUCTION

The way communities use and manage resources not only determines resource status but also their way of life. Its is only after considering this background that a sustainable management can be put forward. As a result, this chapter describes the existing management practices in the study villages and documents their impacts on the natural resource components. It incorporates what the research team found in the field and indigenous technical knowledge to come up with the positive and negative impacts of the practices.

4.2.2 SOIL RESOURCES

4.2.2.1 Existing management practices on croplands and their impacts on soil resources

Nineteen different management practices were applied on cropland within the study villages in order to enhance soil productivity and maximize crop yields. The most commonly practiced were deep tillage, agroforestry, mixed/multiple cropping, application of animal manure and contour farming (Table 4.2.1). Other popular practices were gravitational soil fertility management with the pastoral communities of Isara and Erankau and terraces and mulching with residues in the mixed farming communities of Muusini and Bondeni. Chemical fertilizer was used only by an agropastoralist in Isara for the production of tomatoes through irrigation. The minimal synthetic fertilizer use is related to the high cost of the fertilizers, which is unaffordable to the by small-scale farmers. Additionally, farmers/agropastoralists have limited knowledge on its use nor are they well enlightened on its benefits. Moreover, due to arid nature of the region, application of fertilizers without adequate water for irrigation may change soil properties and hence may not be appropriate in the long run within the dry tropical environment. Further, the soils of Isara and Erankau Villages are virgin to cropping.

Crop spacing varied from one farm to another and with the crop types grown but generally, crops are planted in lines to facilitate oxen weeding.

(i) Deep tillage

This practice involves deep ploughing using oxen (Plate 4.2.1) or tractor in order to break up hardpan for crops while encouraging infiltration of rain runoff so as to improve crop productivity. 33 out of the 36 farmers/agropastoralists interviewed practiced deep tillage.

Tractor ploughing was restricted to the well off farmers while oxen ploughing were most common in all the poverty categories. Even the poor poverty group members who do not posses oxen exchange it in kind by ploughing for the owner of the oxen. Animal power plays a big role not only in deep ploughing but also weeding. Tillage for the long rains is done before the rains because the soils are still soft after the impact of cultivation and the short rains.

Table 4.2.1 Existing soil management practices in four villages of Eastern Kajiado and Southern Makueni, Kenya.

Soil management practices	Villages/Respondents implementing the practice per poverty groups																
	Muusini				Bondeni				Isara				Erankau				
	I	II	III	Total (n=9)	I	II	III	Total (n=8)	I	II	III	Total (n=9)	I	II	III	Total (n=10)	Grand total (n= 36)
Deep tillage	2	2	3	9	2	2	1	5	2	2	5	9	3	3	4	10	33
Agroforestry	1	2	5	8	2	2	4	8	1	3	2	6	3	2	4	9	31
Non application of fire	2	2	5	9	0	1	4	5	2	2	3	7	2	1	4	7	28
Mixed/multiple cropping	2	2	5	9	2	2	4	8	1	0	0	1	2	3	1	6	24
Animal manure	2	2	4	8	2	2	1	5	0	0	0	0	2	0	0	2	15
Contour farming	2	2	5	9	2	0	2	4	0	0	0	0	0	0	0	0	13
Gravitational soil fertility management	0	0	0	0	0	0	0	0	1	3	3	7	3	2	1	6	13
Terraces	2	2	3	7	1	0	3	4	0	0	0	0	0	1	0	1	12
Trash lines	0	2	3	5	2	1	1	4	0	2	1	3	0	0	0	0	12
Mulching with residues	0	2	3	5	2	2	3	7	0	0	0	0	0	0	0	0	12
Monocropping	1	2	2	5	0	0	0	0	1	1	2	4	2	0	0	2	11
Cut off drain	2	2	1	5	1	1	0	2	0	0	0	0	0	1	2	3	10
Bush trash	0	0	0	0	1	0	0	1	1	1	2	4	2	0	0	2	7
Contour ridges	2	2	2	6	0	0	0	0	0	0	1	1	0	0	0	0	7
Grass strips	0	1	2	3	0	0	0	0	0	0	0	0	1	0	1	2	5
Crop rotation	1	1	0	2	0	0	0	0	0	0	0	2	1	0	0	1	5
Short season fallow	0	0	1	1	0	0	0	0	1	2	0	3	1	0	0	1	5
Cultivation across water courses	0	0	0	0	0	0	0	0		2	2	4	0	0	0	0	4
Water harvesting pits	0	1	1	2	0	0	1	1	0	0	0	0	0	0	0	0	3



Photo by A. Mohamed in 2003.

Plate 4.2.1 Oxen ploughing and weeding improves soil moisture and crop yields. The practice is common in Kibwezi and Mashuru, Kenya.

However, ploughing for the short rains commences mainly after the first showers have softened the hard soils. The popularity of deep tillage is related to increased soil moisture conservation and therefore more yields.

While deep tillage generally improves the soils conditions, it can create hardpan for the deep rooting crops just after the depth the plough has reached. Additionally, if tractor is used harrowing destroys soil clods and so decreases infiltration and increases runoff and erosion. The weight of the tractor also compacts the soil (Rowland 1993, Llano-Alcober *et al.* 1983).

(ii) Agroforestry

Agroforestry is simply defined as the deliberate retention or planting of trees on farm. 31 of the interviewees planted some trees or deliberately left indigenous species on farm. The agroforestry practice is scattered trees on cropland. However, tree cover on farm was very low (less than 2% per farm). The low vegetation cover means wind and water erosions are common. The scattered trees on cropland can contribute minimum to the conservation of soil. Furthermore, when it rains the water which drips from the branches generally has drop diameters two to three times greater than that of the original rainfall (Rowland 1993). Such drops, if they fall from branches more than four metres from the ground are likely to have kinetic energy of 8 – 27 times than that of the original rain drops from which they were formed. Because there is very little vegetation or litter cover beneath the trees, the soil is susceptible to erosion. The rest of the farmlands either remain bare in parts of the year or are mainly covered by annual crops. In the tropical dryland environment, removal of trees means quick degradation of the soil.

Despite the limited cover, agroforestry on croplands have helped conserve 30 indigenous tree species (in the four villages) that would have otherwise been over cut in the woodlands. Examples of these species are *Senna abbreviata, Platycelyphium voense, Melia volkensii, Lonchocarpus eriocalyx, Sterculia africana, Boscia anguisitifolia, Acacia tortilis, Lannea stuhlmanii, Delonix elator*, Mulindete (Kamba), *Dalbergia melanoxylon, Kigelia aethiopum, Terminalia brownii, Adansonia digitata, Strychnus* sp., *Albizia amara, Albizia anthelmentica, Commphiora baluensis, C. holtziana* and *Cordia quercifolia* valued for their high value poles, timber, fodder, fibre, charcoal and medicine. Additionally, the farmers/agropastoralists have planted high value exotic species on croplands. They include *Mangifera indica, Psidium guajava, Carica papaya, Annona muricata, Tamarindus indica, Sysigium cuminii, Azadirachta indica, Eucalyptus cameldulensis, Grevillea robusta, Citrus lemon, C. sinenesis, Musa* sp. (banana) and *Morus alba*.

In dry seasons, due to the presence of pigeon peas on farms of Muusini and Bondeni animals are not allowed to graze freely on croplands until after its harvest in July. Vegetation cover is an important factor in soil and water conservation. Perennial and biannual crops/trees protect the soil against water and wind erosions over a longer duration than annual crops.

On the other hand, perennial and biannual crops such as pigeon pea, lablab, pumpkins, sweet potatoes, gourds and cassava cover an average of 27% of the cropland. The biannual crops remain on the farm from November until July. Annual crops that take three months to mature cover the rest of the croplands (Fig. 4.1.26 and 4.1.27). Normally, the only dependable season is the short rains of November/January.

Most of the times the annuals planted in March/April fail due to the low rainfall reliability and therefore the cover percentage indicated may not always be there. Above all after the crops are harvested the soils become bare except for the few scattered trees on farm. Consequently, the impacts of wind erosion encouraged by free grazing livestock on farm takes its toll and at on-set of the rains especially in November when there is high soil erosion and this continues for few weeks before effective crop cover is achieved.

(iii) Non-application of fire in land preparation

In normal circumstances, while preparing farms for cultivation, farmers burn trash. But 28 of the interviewees apply no fire. The trash is instead incorporated into the soil during ploughing and this has positive impact on soil organic matter content. Muusini and Isara had the highest respondents implementing the practice while Bondeni had the lowest. The practice is an indicator of enlightment in good land husbandary as a result of the impact of natural resource management institutions

(iv) Mixed/multiple cropping

Mixed cropping is the growing of two or more crops on the same field and in the same season. All the interviewees in Muusini and Bondeni Villages plus one in Isara and six in Erankau practiced intercropping in order to optimize the use of land and labour resources while diversifying house hold diet and reducing the risk of a crop failure. All the farmers in Muusini and Bondeni practiced relay cropping - involves the combination of perennial with annual crops. Pigeon pea was the determining crop in the combination. Since Pigeon pea is a biannual, during the long rains of March - April annual crops such as sorghum, cowpea, millet and green grams are intercropped with it. While there were variations in the combinations, pigeon peas, cowpea and maize formed the core crops in Muusini and pigeon pea plus maize in Bondeni. Other biannual crops that form part of the mixtures include cassava, dolicos lab lab, beans, cow pea, sorghum, sweet potatoes, pumpkins and gourds. In Muusini, the least species mixture composed of sorghum + cow peas while the highest number of crop mixture consisted of 11 species, that is maize + cowpea + pigeon pea + groundnuts + dolicos lab lab + cassava + sorghum + pearl millet + green grams + pumpkins + gourds. Seven of the farmers used this combination. The least species mixture in Bondeni composed of maize + cow peas/sorghum/cow pea while the highest number of crop mixture consisted of 7 species, that is maize + cowpea + pigeon pea + beans + green grams + cassava + sorghum. The relatively higher species combination in Muusini is related to diversification to increase food security in the harsher environment. Unlike the farmers, the agropastoralists except for an interviewee in Erankau mixed only annual crops and therefore exposing the soil to more wind and water erosion.

Although there is initial delay in crop cover when they are still tender, as the rainy season progress, the different crop layers help cover the soil and therefore reduce erosion. The crops maximally used the soil nutrients at different depths and the many legumes planted will help improve soil nutrients. However, if a lot of the crop residues are removed from the farm in form of forage and direct livestock feeding as was the case in eight farms then it can also lead to soil fertility mining.

(v) Application of animal manure

Animals are part and parcel of the mixed farming and agropastrol systems of the study villages. A part from the provision of animal power, they also contribute to crop production through the provision of farmyard manure (FYM). 15 of the interviewees applied FYM in small and variable quantities. These farmers practice nutrient cycling through provision of crop forage to livestock and then bringing it back as manure into cropland. The application of animal manure increases soil fertility and moisture content. Moreover, while foraging on croplands, animals too release their droppings on farm. Although livestock population was highest in the agropastoral villages, only one and six interviewees of Isara and Erankau Villages respectively acknowledged to directly apply FYM on to the croplands. The minimal use of the practice can be related to the relatively more fertile soils of the these villages and as a result of applying manure indirectly into the croplands using gravitational soil fertility management.

(vi) Gravitational soil fertility management

Gravitational soil fertility management is an interesting and unique practice identified by the study in Isara and Erankau Villages. Thirteen of the interviewees implemented the practice. The farms are located down slope the animal kraal "Boma". Consequently, when it rains runoff washes animal manure down hill into the farm thus improving soil fertility and hence crop production. Additionally, one agropastoralist manually placed animal manure on upper slopes of the cropland so that it is drained into the crop land by runoff (Plate 4.2.2). The practice also saves the problem of chaffer grub, which has been noted to dislodge crops on farm in Muusini and Bondeni Villages. The implementing agropastoralists reported to have higher yields than most others within the villages.



Photo by A. Mohamed in 2004.

Plate 4.2.2 The placement of animal manure upslope cropland is a modification of gravitational soil fertility management in Erankau Village, Mashuru, Kenya.

(vii) Contour farming

Contour farming entails the ploughing, planting and weeding across the slope rather than down the slope in order to reduce the velocity of run off, reduce erosion and encourage percolation. The practice was implemented by 13 farmers interviewed in Muusini and Bondeni only in the form of contour planting and ploughing using oxen. The popularity of the practice in Muusini can be related to the high influence of agricultural institutions.

(viii) Application of crop and weed residues as mulch

The practice was implemented only in Muusini and Bondeni. 12 of the interviewees use crop and weed residues as mulch and incorporate it into the soil in order to improve soil fertility and conserve soil moisture (Plate 4.2.3).



(a) *Astripomea hyoscyamoides* weed is spread and incorporated into the soil to improve soil fertility and moisture



(b) Mulching with crop residues plus early planting improves crop yield

Photo by A. Mohamed in 2003.

Plate 4.2.3 Application of weed and crop residue mulch is popular in Muusini and Bondeni villages, Kibwezi, Kenya.

After the harvesting of pigeon pea in July, most of the residues are used as forage for livestock and pigeon pea stalks are used as firewood and therefore what is ploughed back in October is minimal. Termites also consume part of the residues. Crop and weed residues are not ploughed back into the croplands of Isara and Erankau. Agropastoralists have limited knowledge on diverse soil fertility and moisture conservation practices. Consequently, livestock mainly consumes the residues.

(ix) Trash lines

Trash in form of weeds from the farm and crop stovers were heaped in lines along contour by 12 of the interviewees in order to retard run off and trap soil. After some time grasses grow along the trash lines and eventually they form bench terraces.

Nine farmers in Muusini and Bondeni, three in Isara but none in Erankau, implemented the practice. Erankau has the least influence from agricultural institutions. Termites and livestock also consume part of the residues making the practice to have minimal impact.

(x) Terraces

Terraces are physical barriers constructed along contours by throwing the excavated soils either up slope or down slope to form what is locally known as "Fanya juu" or "Fanya Chini" structures respectively. The aim is to divert and retain runoff in croplands. Eleven farmers and an agropastoralist had terraces on their farms. Terraces were more popular in Kibwezi than in Mashuru Villages. Seven out of the nine interviewees in the drier environment of Muusini had constructed "Fanya juu" terrace in order to maximize the harvesting and retention of moisture.

However, except well off and partly the medium poverty groups (Plate 4.2.4), the terraces were not technically constructed and at times not necessarily following the contours.



Photo by A. Mohamed in 2003.

Plate 4.2.4 A well-protected terrace with *Eragrostis superba* grass owned by a well off farmer in Bondeni Village, Kibwezi, Kenya.

Above all, most of the terraces embankments were bare and not protected. Maintenance of the structures were minimal too.

(xi) Monocropping

Eleven of the interviewees (mainly the well off) grew green grams, maize, sorghum, pearl millet, beans and cucumber as sole crop on parts of their farms order to maximize their yield. Such maximization of yields can adversely affect the soil fertility status unless replenished. The practice was mainly implemented in the villages with highest interventions as a result of influence by natural resource based institutions, which is in Muusini and Isara. The institutions promote sole cropping under crop rotation. However, the farmers/agropastoralists though practice the sole cropping part of the institutions' advice but hardly implement crop rotation component (only five interviewees implement sole cropping with crop rotation).

(xii) Crop rotation

The practice involves the growing of a variety of crops each season but each crop is rotated to another area within the farm in successive seasons. The practice was implemented by five of the interviewees to improve soil fertility after growing a sole crop in an area. Legumes such as green grams and beans are interchanged with cereals such as maize, sorghum and pearl millet or the cereals with multiple cropping. Though limited in practice, crop rotation was more common in villages that received institutional support in agriculture.

(xiii) Cut off drain

Cut off drain are structures dug a cross a slope to intercept runoff that would have otherwise eroded cropland or homestead and carry it safely into an outlet. Ten of the interviewees constructed cut off drains half of them in Muusini, again suggesting the impact of natural resource based institutions. Like the terraces the drains were not technically constructed nor were they well maintained.

(xiv) Bush trash

Bush trash involves the placement of bushes across rills and gullies in order to retard runoff velocity, trap eroded soils and heal the eroded site. Seven of the interviewees implemented the practice with in the woodlands and pastures. Except for a well off farmer in Bondeni, the rest were agropastoralists of Isara and Erankau. Majority of the implementing agropastoralists were from Isara where pasture shortage was found to be acute due to overgrazing and drier environment. The concentration of the practice in Mashuru indicates the importance of pasture in the livelihoods of the agropastoralists.

(xv) Contour ridges

Another cropping practice identified within the villages is contour ridges. The practice, which was implemented by seven farmers (six of them in Muusini and one in Isara) is meant to increase crop yields through soil moisture conservation by constructing furrows and ridges along contours. Oxen plough and hoe are used to create the structure in order to harvest runoff and control soil erosion. The crops are planted in rows and on the ridges in order to benefit from the moisture conserved in the furrows. The implementation of the practice in Muusini can be related to institution influence and the drier environment.

(xvi) Grass strips along contours

Grass strips as a soil conservation structure was not very popular in the villages. Only five farmers/agropastoralists in Muusini and Erankau mainly from the poor poverty group practiced. Strips of *Eragrostis superba* and *Cenchrus ciliaris* grasses were deliberately left along the contours as a barier to runoff and eventually lead to terrace development. The grasses also provide forage for livestock and materials for thatching. After sometimes the farmers too reseed the grasses in order to maintain the strips.

(xvii) Short season fallow

The practice alternates one or two no cropped season(s) equivalent of 6 – 12 months period with cultivation season(s) so as to replenish the site with soil fertility. During the fallow period, the site was left under grass or shrubs cover though livestock was allowed to graze. Five interviewees mainly in Isara practiced short season fallow mainly a result of institutional influence. In Muusini, only one farmer practiced despite encouragement from agriculture based institutions due to limitation of land to implement the practice.

(xviii) Water retaining pits and run off harvesting from homestead area

Pits were constructed by three farmers from Muusini and Bondeni in order to catch rainwater and retain runoff from homestead and other parts of the farm for banana farming. The pits, whose dimensions were about 1m x 1m x 1m, were dug along "Fanya chini terraces". At times long deep furrows a dug with a high ridge in between instead of pits in order to facilitate banana plantations (Plate 4.2.5). Nevertheless, being close to the homesteads the pits can act as breeding grounds for harmful mosquitoes.



Photo by A. Mohamed in 2003.

Plate 4.2.5 Long furrows and pit for harvesting runoff to facilitate banana plantation in Muusini area, Kibwezi, Kenya.

(xix) Cultivation across seasonal watercourses

The practice was limited to four agropastoralists in Isara. The aim was to maximize the use of runoff and nutrients that come with the runoff in the driest village amongst the study villages.

4.2.2.2 The impact of existing management practices and use of the woodland/pastures on soil and water resources

In Muusini and Bondeni the management of the natural woodlands was minimal and limited to dead fencing and surveillance except for a farmer in Muusini who laid few terraces and another in Bondeni who used bush trash to control erosion (Table 4.2.1). Additionally, in Isara and Erankau, the agropastoralists had traditional pasture farms locally called "Olopololi", which were well fenced. Bushes, thickets and unwanted weeds were removed to encourage growth of grasses that covered the sites adequately. Also, four and two agropastoralists in Isara and Erankau respectively used bush trash to conserve soils within their farms. But in the larger part of the woodlands and pastures the resources were overexploited through overgrazing, trampling and over use of the wood resources for poles, timber, fence material and medicine. Unlike in the croplands, there were no physical soil conservation structures in the vast woodlands and pastures. Consequently, the status was severe to excessive in Isara and Erankau especially on the Luvisols plains, Vertisols lowlands and Regosols hills as explained under the characterization of soil resources.

As a result, the grass cover has been reduced through over use and by bush encroachment. Previous studies in the region had noted erosion to be slight (Touber 1983, Wijngaarden and Engelen 1985). More on this topic is explained under the impact of existing management practices and use on woodlands and pastures. In the meantime, all the soils eroded from the village are silting and polluting the existing water sources and encourage the outbreaks of water borne diseases.

4.2.1.3 Indigenous knowledge soil erosion and fertility/ degradation

(i) Soil erosion

The local community in Muusini defined soil erosion as "the washing way of top soil into the ocean and remaining with infertile soil on farm. Erosion is caused by limited vegetation cover and lack of or minimal soil and water conservation structures". In this definition, wind erosion has hardly been captured. In Bondeni soil erosion is defined as "the washing away of soil by water, animals (including humans) and wind and ending up with an area that has gullies and stones". This definition captures the totality of soil erosion from the causes to the consequences and is therefore more versed with erosion concept than the farmers of Muusini. The agropastoralists of Isara define soil erosion as "The carrying away of top soil by water and wind as a result of overgrazing and lack of soil conservation structures causing land to be barren". In Erankau erosion is defined as "washing away of top soil by agents of erosion such as water, wind and animals into rivers and remaining with sand on farms". The two definitions capture the entirety of erosion just like the Bondeni definition and therefore the agropastoralists are too well aware of it.

Sixteen (8 each in Muusini and Bondeni) farmers and 14 (8 in Isara and 6 in Erankau) agropastoralists believe that there is soil erosion in the villages. The six remaining farmers/agropastoralist perceive decrease in erosion. They relate the decrease to constructed terraces and the conversion of formerly communal owned land into individual ownership. While there is a point in the land ownership to have motivated more investment in soil and plant conservation, the terraces mentioned were inappropriately laid and inadequate. Moreover, most of them were bare and eroded with minimal maintenance. Furthermore, tree/grass cover on farm was negligible.

Other causes of erosion were indicated as over cultivation in Muusini and Bondeni especially the poor poverty group members, deforestation, poor farming practices, overgrazing, bush encroachment and limited knowledge on the construction of physical soil conservation structures (Fig. 4.2.1).

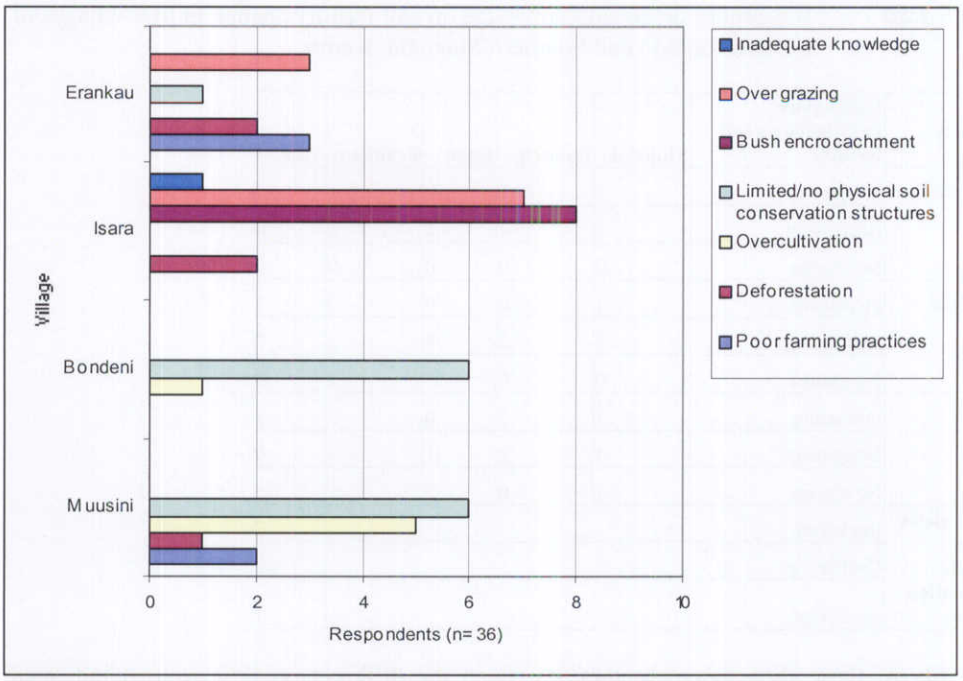


Figure 4.2.1 Indigenous technical knowledge on the causes of soil erosion in Eastern Kajiado and Southern Makueni, Kenya.

In the agropastoral villages, overgrazing and bush encroachment were the major concerns due to the importance of grass for their livestock. Physical soil conservation structures on croplands were the worry of the farmers reflecting to the importance of crops in their livelihoods. All the farmers/agropastoralists acknowledged having signs of soil erosions on their farms. These consequences/indicators of soil erosion were noted to be sandy and hard soil surfaces, rills, gullies, limited vegetation cover and low crop yields.

Generally, the perception of the farmers on soil erosion is in agreement with what was found during the field studies.

(ii) Soil fertility

The farmers of Muusini and Bondeni Village define fertile soil as "reddish/black soil rich in organic matter content leading to high productivity in terms of crop yield and vegetation growth". On the other hand, the agropastoralists of Isara and Erankau define a fertile soil as "dark coloured (red or black) with fine texture, high moisture retention capacity and nutrients leading to high crop yields and vegetation growth". The definitions from the farmers cover colour, nutrients and productivity while the agropastoralists in addition consider texture and moisture retention capacity.

These definitions especially that of the agropastoralists captures the important qualities of a fertile soil and therefore an indication of the awareness of the importance of soil fertility by farmers/agropastoralists. In the villages, 29 interviewees reported soil fertility change on their farms (Table 4.2.2).

Table 4.2.2 Indigenous technical knowledge on soil fertility change in four villages of Eastern Kajiado and Southern Makueni, Kenya

Poverty group	Indigenous knowledge on soil fertility	Muusini	Bondeni	Isara	Erankau	Total
Well off	Increasing	1	1	0	1	3
	Decreasing	1	1	2	2	6
	No change	0	0	0	0	0
Medium	Increasing	1	0	0	0	1
	Decreasing	1	2	2	2	7
	No change	0	0	1	1	2
Poor	Increasing	1	2	0	0	3
	Decreasing	3	2	1	3	9
	No change	1	0	3	1	5
Total views of the sample population (n=36)	Increasing					7
	Decreasing					22
	No change					7

Majority of these farmers/agropastoralists (from the different poverty groups) indicated fertility to be decreasing over time. Soil sample analysis from the farms showed lower fertility in Muusini and Bondeni farms than in Isara and Erankau. The relatively higher fertility in Isara and Erankau is due to the virgin nature of the soils, which has just been opened up to cultivation, use of gravitational soil fertility management, fertilization by volcanic rocks and more animal manure due the high animal numbers.

Additionally, farms owned by the well off and medium poverty groups in Muusini, Bondeni and Erankau had higher fertility than those of the poor (Table 4.2.3). The reverse was true for farms in Isara. The difference can be associated to better conservation practices such as terraces in the former villages and the implementation of gravitational soil fertility management in the later. Instead the farmers apply crop residues and animal manure and constructed different soil conservation structures to improve soil fertility. The fertility of woodlands and pastures in Muusini were higher for farms owned by the poorer poverty groups due to the few animals they owned and therefore less erosion of top soil.

Table 4.2.3 Impact of poverty levels on soil fertility in croplands and some woodlands and pastures in four villages in Eastern Kajiado and Southern Makueni, Kenya.

	Soil types	Land use	Poverty	Soil organic matter	Phosphorus	Cation exchange capacity	Base saturation percentage	Erosion
Muusini	Ferralsols	Cropland (n=4)	I	1.5	10	32	9	Moderate
			II	2.2	16	36	7	Severe
			III	0.7	10	23	34*	Excessive
		Woodland (n=5)	I	0.1	7	18	15	Severe
			II	2	4	20	68	Slight
			III	1.5	9	17	30	Moderate
	Luvisols	Cropland (n=8)	I	1.5	12	10	68	Moderate
			II	1.7	8	29	16	Severe
			III	1.4	6	26	36	Severe
		Woodland (n=4)	I	1.6	3	36	12	Severe
			II	2.6	4	32	18	Moderate
			III	1.7	5	41	11	Severe
Bondeni	Ferralsols	Cropland (n=5)	I	5.2	4	8	57.5	Moderate
			II	3.3	3	20	25	Moderate
			III	2.9	4	32	17	Severe
		Woodland (n=3)	I	3.1	2	56	9	Moderate
			II	3.7	2	24	8.3	Moderate
			III	3	3	8	51.3	Moderate
	Chernozems	Cropland (n=4)	I	3.9	6	53	19.3	Severe
			II	2.3	4	40	13	Severe
			III	3.4	2	46	20	Severe
		Woodland & Pastures (n=4)	I	3.9	3	54	30.9	Slight
			II	3.7	7	52	23.1	Severe
			III	3.4	11	50	20.7	Moderate
Isara	Ferral chromic Luvisols	Cropland (n=2)	I	1.9	67	14	48	Severe
			III	2.4	126	26	28	Severe
	Ferric Luvisols	Cropland (n=6)	II	2	17	38	13	Severe
			III	1.3	43	49	11	Severe
Erankau	Orthic luvisols	Cropland	I	3.2	59	31	36	Moderate
			II	2.3	81	41	31	Moderate
			III	1	54	15	39	Severe
	Cambisols	Cropland	II	2.5	149	74	10	Excessive
			III	2.7	145	70	10	Severe

* The high BSP (59) is as a result of a farmer who applied manure before sampling. Another farm in the same group had BSP of 9.

All the farmers and agropastoralists reported to use only two factors as indicators of soil fertility change, that is, indicator plants and crop yield. The indictor plants for soil fertility decline in Muusini and Bondeni were: *Aristida kenyensis* (Lamuyu), *Acanthospermum hispidum* (Ikongo), *Digitaria ciliaris* (Kikuku), *Tridax procumbens* (Mumela), *Eragrostis* sp (Poverty grass), and Kisong'e (Kamba). Indicators of fertile soils were noted as *Trichodesma zeylanicum* (Mukuutu), *Sphaeranthus ukambensis* (Musonzoia), *Astripomea hyoscyamoides* (Ithea ituku), *Eragrostis superba*, *Cenchrus ciliaris*, *Panicum maximum* (Mbeya), *Cynodon plectostachyus* (Ikoka), *Amaranthus* sp (Mchicha), *Rottoboellia exalata* (Nzeembi), Walange (Kamba), Mukengesya and Kithui (Kamba).

The agropastoralists reported to use *Commiphora africana, Bleripheris* sp, *Premna resinosa, Aristida* spp, *Ipomea kituensis,* sedges, *Occimum* spp., *Acanthospermum hispidum (*Oitai*),* Engesijioi (Masaai), Ngamba (Masaai) as indicators of decline in soil fertility while the presence of *Acacia tortilis, A. drepanolobium, A. mellifera, Commiphora habessinica, C. schimperi, Grewia spp, Acalypha racemosa, Balanites glabra, B. aegyptiaca, Boswellia neglecta, Sericocomopsis pallida, Themeda triandra, Panicum maximum, Digitaria milanjiana* and *Cynodon plectostachyus* indicates fertile soils.

4.2.1.4 Institutional support in soil conservation

Seven interviewees (five in Muusini and two in Isara) acknowledged technical support from the Agroforestry for Integrated Development in the Semi-arid Areas of Kenya (ARIDSAK Project), Departments of Agriculture and Forest. The support involved training on the construction of terraces and cut off drains and provision of minimal inputs, for example tree seedlings. As a result of the impact of the terraces constructed, a farmer in Muusini reported to have achieved 75% more crop yields while those of Isara reported an increase in crop yields by 1.5 to 2 times. During a feed back meeting in Muusini, the impact of the ARIDSAK Project on another farmer (Mr. Joseph Muli) within village and many in the surrounding villages were also highlighted. The project supports the farmers as "model teacher farmer" in many agroforestry activities including the planting of drought tolerant crops and trees and laying down of soil and water conservation structures such as terraces.
No direct support has been reported in Erankau and Bondeni. However, during a feedback meeting in the later village, ACTIONAID was noted to have trained few farmers in soil conservation in the early 1990s. Some farmers also attended trainings by ARIDSAK project in the neighbouring Kithasyu Village.

4.2.2 WATER RESOURCES

Environmental degradation in form of deforestation and overgrazing was eminent in the villages. More land was being opened up for cultivation while overgrazing and supply of fuelwood and wood for shelter continued unabated threats to biodiversity conservation, water supply and livelihoods of the rural poor. In the drylands water resource is the engine of development. Therefore if this resource is not wisely used it can also be the beginning of environmental degradation and poverty. Unsustainable management including limited protection, direct drawing by humans and the direct drinking of livestock at the water sources have subjected the resource to contamination in form of the release of faecal matters, contamination from containers and dirty feet and hands.
Consequently, the quality of water from the open sources were coloured sometimes even turning to greenish.

Moreover, most of the pans have silted or were silting up due to luck of desiltation and erosion from the surrounding bare croplands that had limited physical soil conservation structures. The villages woodlands had limited grass undergrowth. What's more, with an estimated annual population increase of 1.94% in Kibwezi and 4.6% in Mashuru (GoK 2002), the pressure for more water supply is likely to increase.

4.2.2.1 Existing management on water sources

(i) Earth dams and water pans

Only six out of the 12 earth dams and water pans in the study villages were useful beyond the rainy seasons as discussed under characterization of water resources because of inappropriate management. The dams were silting due to limited fencing and release of livestock into the water sources. An exception was Kimana Dam in Erankau that was hand dug in 1940s and whose compound was well fenced, padlocked and with water trough not to allow animals inside (Plate 4.2.6). The inlet of this model dam for conservation was covered by dense vegetation especially grass but was also prone to siltation.



(a) Siltation of a water pan by direct livestock entry.



(b) Kimana Dam's compound (bachground) and Earth trough (insert) in Kimana Dam, Erankau Village, Mashuru, Kenya.

Photos by A. Mohamed in 2003.

Plate 4.2.6 Siltation of water sources was common in the study villages though indigenous knowledge also exist in the conservation of water sources. An example of a relatively well managed dam was Kimana Earth Dam, Erankau, Mashuru, Kenya.

Other tangible management of the dams/pans was restricted to dead fencing while a water pan in Isara was within a farm fenced with barbed wire and *Commiphora* living fence.

Analysis of water sample showed that Coliform counts were very high in the dams/pans. However, *E. coli* counts were lowest in Kiuwani dam of Muusini area followed by those in Isara Village and highest in Kimana dam in Erankau (Table 4.1.11). The high coliform contamination could be related to general sanitation problems and inappropriate cultivation and livestock management within the villages. The differences in *E. coli* in the mixed farming zones and the agropastoral areas can be associated with the high number of livestock in the later villages.

More livestock means more dug that are drained into the dams and acts as a breeding ground for the bacteria. The use of bush toilets may also have contributed to the difference (AMREF 2002).

Furthermore, the high *E.coli* in Kimana dam may have been caused by accumulation of the bacteria over a long period (since its construction) and therefore the younger Kiuwani dam of Muusini (constructed in 1998) and those of Isara (constructed in the last 20 years) would have less *E. coli*. In terms of colour, the dams in Isara area had the highest true colour units (TCU) followed by that of Muusini area while Kimana dam in Erankau had the least. The low TCU of Kimana was related to the dense vegetation as explained earlier. Conversely, the high TCU in Isara and Muusini is related to the severity of erosion caused by over grazing and inappropriate cultivation practices. Moreover, the two villages fall in the drier agro-ecological zone VI and therefore less vegetation cover especially in dry seasons. Similarly turbidity was high for the samples as result of siltation and deposition of organic matter. On the other hand, being surface water source salinity, pH and salts were one of the lowest when compared with other sources as a result of less impact from deep parent rocks that are concentrated with salts. Consequently, the source is ideal for irrigation.

(ii) Wells

Thirteen out of the 30 wells in the study villages were not protected while 11 others were partially protected and therefore susceptible to contamination through the drawing buckets or through siltation as a result of bank erosion. In Muusini and Erankau the wells were not protected at all while six of the wells in Bondeni were fully protected and 11 partially protected. The relatively high number of protected wells in Bondeni is due to the impact of the African Medical and Research Foundation (AMREF) that provided technical and material support. Except for the protected wells that had hand pumps, drawing of water was by bucket and rope. Consequently, laboratory analysis of samples taken from popularly used wells show that the water was unfit for human consumption both bacteriologically and mineral contents for drinking purposes unless treated (Table 4.1.11). The contamination and pollution levels exceeded the WHO/Ministry of Health maximum guidelines. As expected, counts of the Coliform and *E. coli* bacteria, true colour units and turbidity were highest in the unprotected followed by the semi-protected. Moreover, all the wells had deposits of organic matter and in addition, the unprotected had algae contamination. While the protected and semi-protected had almost no vegetation odour (except for a well near a river bank), all the unprotected had odour of vegetation and the Erankau well had urea smell. The sources of the contamination were contaminated containers, erosion and siltation from bank erosion, wind and runoff and direct drawing by humans. Infestation by baboons was also a source of contamination in the case of the Erankau well.

The salinity (EC), chloride, sulphate, fluoride and sodium levels were high in the wells of Muusini and Bondeni than that of Erankau. Similarly, pH was slightly higher for the wells of the former villages. The high mineral contents can be related to the impact of the underground rocks as explained under characterization of water resources. Conversely, iron and manganese levels were higher in the Erankau well similar if not more than that of the earth dams because of the excessive bank erosion and continuous siltation by large population of baboons and direct drawing by humans. The levels of fluoride and salinity were also higher for livestock consumption. When compared with the maximum guideline by FAO (1985) of 16 $mmhoscm^{-1}$ and fluoride of over 2.0 mg/l, the water is not suitable for livestock. Fluoride and salinity levels were 3.3 mg/l and 3600 $mmhoscm^{-1}$ respectively.

High fluoride level causes tooth mottling and bone problems. Since the local community had limited choice and had no knowledge of the water quality, they continue to use it.

The number of wells being dug within the villages especially in Bondeni to access water was on the increase. The wells negative impacts include over use of the scarce water resource, which can reduce the ground water table. There were also degradation around water points – soils were bare, degraded, muddy and/or dusty due to the constant human and livestock concentrations (Plate 4.2.7). Moreover, some of the unprotected wells have already collapsed.



Photo by A. Mohamed in 2003.

Plate 4.2.7 Environmental degradation around Nguku Imwe well, Bondeni Village, Kibwezi, Kenya. The degradation is caused by high concentration of people and livestock.

(iii) Boreholes

Erankau borehole, the functioning borehole in the study villages is owned by community but had been drilled and still maintained by the East African Portland Cement Company as a kind gesture in exchange for mining marble limestone in Sultan Hamud Sub-location. The borehole too provides water for domestic and livestock use for the neighbouring villages of Arroi and Olepoloos. The high fluoride levels exceeding the maximum limits set by WHO (Table 4.1.11) is a result of the influence of parent material. An agropastoralist is also using the leaked water for growing of kales and banana.

The impact of the water source on the soil and vegetation within a radius of about 300 m is enormous. There is almost no vegetation and the soil texture was soft as a result of trampling by livestock.

(iv) Rivers (surface water)

Permanent and seasonal rivers provided much needed water for domestic and livestock use both in dry and rainy seasons. However, just like the dams and water pans, water samples from the major rivers in the study area were contaminated and polluted (Table 4.1.11). Although part of the contamination and pollution could be natural, it was also caused by anthropogenic factors.

The contamination and pollution can be related to poor farming practices, deforestation and destruction of water catchments, settlements, overgrazing, bush encroachment that reduced grass cover and inadequate conservation mechanisms at the village levels to protect the rivers. Additionally, the interviewees in Muusini and Bondeni indicated that the water from this river is invested with Bilharzia (Schistosomiasis), a parasitic disease. Humans are directly infected through skin contact with water inhabited by snails. The breeding of snails along Thange River could have been encouraged by the growth of dense clumps of *Typha* on and along the riverbeds (Plate 4.2.8).



Photo taken by A. Mohamed in 2004.

Plate 4.2.8 Dense clumps of *Typha* sp. along River Thange, Kibwezi, Kenya can be breeding sites for snails, a vector of Bilharzia disease.

Typha normally comes up due to siltation caused by poor methods of farming, limited soil and water conservation structures and deforestation on the upper catchments. Similarly, part of the Athi River water source is Nairobi, Ngong and Athi River towns where there are high pollution levels from industries, fertilizer and herbicide based faming and urban wastes. Most of the affluents from Nairobi and its environs drain into the Athi River (District State of Environment Committee (DSEC) Kajiado 2003).

(v) "Catch pits" or water holes

The "catch pits" identified along the Matoi dry riverbed in Erankau were individually owned although the riverbed belongs to the community. Individuals who first dug own the holes. To lay claim, the owners dead fence them, planted nippier grass and at times padlock them (Plate 4.2.9). The use of each hole is restricted to owners use or with his/her consent. During rainy seasons, runoff fills the holes but the owners re-dig in the dry seasons. The existing contamination and pollution of the water (Table 4.1.11) has accelerated by wanton felling of vegetation, charcoal burning increase in settlements, cultivations on upper slopes, overgrazing and sand harvesting.



Photo by A. Mohamed in 2002.

Plate 4.2.9 Individually owned and protected "catch pit" in Erankau, Mashuru, Kenya. On the right hand side of the foreground is planted nippier grass for security of tenure.

(vi) Ponds

The 28 ponds in the four villages were silting up as a result of poor farming practices, deforestation, reduced vegetation cover on-farm, limited soil conservation structures, lack of protection and overgrazing in the surrounding environment. Additionally, even where there are bush/woodlands the undergrowth had limited grass cover meaning the washing of more soils into the ponds. Similarly, there were no wild animals to wallow the ponds nor were farmers desilting them. Although the ponds were individually owned, they were free for all to use and there were no existing practices in place to manage the source.

Both man and animals shared the source subjecting it to uncontrolled contaminations through direct drawing of water and washing by humans and contamination by the livestock's hooves, faecal matter and fur. Additionally, calls of nature in the surrounding woodlands and bushes may have contributed to the high levels of contamination (Table 4.1.11). The true colour of the water were high (up to 1000 TCU) and the level of iron exceeded WHO limits while turbidity was very high due to deposits of silt and organic matter and the high levels of iron. The high levels of soil erosion in the area were the root cause of the pollutions and siltation.

(vii) Swamps

The only swamp in the study villages (Metava swamp in Bondeni) was communally owned and used without protection and management. The source was bacteriologically polluted with coliform and *E. coli* counts were beyond 1800+ and therefore very unsafe for human consumption (Table 4.1.11). The lack of protection made the source to be susceptible to erosion and contamination caused by use humans (drinking and washing), livestock and wild animals. Siltation levels have also been increased by similar factors to those that impact on earth dams/water pans and rivers. The water was too noted to be turbid as a result of organic deposits.

(viii) Springs

Umani and Ormuntuus springs provide water to the residents of Bondeni and Erankau respectively. The Umani lies deep in the Kibwezi indigenous Forest Reserve and the heights of the Chyulu Hills Catchments that lies above the springs is also protected by the Chyulu National Park. The Forest Department is responsible for the protection of the forest reserve while Kenya Wildlife Services manages the park. Conversely Ormuuntuus springs in Mashuru are owned by the local Masaai community and free for the local to use. While the former is well protected the later is unprotected. Consequently, the relatively better quality of the Umani springs water can be related to the good management of the source (Table 4.1.11). Water from the protected springs had minimal contaminations and pollutions.

However, the forest reserve and the park are currently threatened by illegal harvesting of wood products for carvings, charcoal burning and poles for building. Another cause of the contaminations was direct use by wild animals. Ormuuntuus springs were not protected and therefore threatened by overgrazing, deforestation and cultivation - growing of vegetables.

(ix) Pipelines

The Bondeni – Umani springs pipeline is owned and maintained by the local community. However, it was unreliable source and water not treated. The poor service of this pipeline can be related to inadequate financial capital and technical knowledge of the community to maintain. Conversely, Noulturesh pipeline owned by the National Water Conservation and Pipeline Corporation is well maintained and a reliable source but inaccessible to the local community because of the relatively expensive monthly bills. Moreover, its use is restricted to domestic and livestock use only. However, unauthorized but isolated small-scale irrigation was common. To control unauthorized use the corporation executes intensive and regular patrols. The water quality from the source was clear and its contamination and pollution levels were the lowest when compared with the other sources (Table 4.1.11) as a result of protection of the source and use of pipelines.

The pipelines' impact is both positive and negative. The positive ones include provision of water for domestic, livestock watering and irrigation while the negative impacts include soil erosion caused by large concentration of livestock at watering points (Plate 4.2.10) and social apathy by the locals to the National Water Corporation for denying them access to irrigate agricultural crops.

4.2.2.2 Impact of the existing practices on water conservation on-farm

The Villages were faced with water shortages for agricultural development. The shortages were related to unreliable rainfall, inaccessibility to tap ground water and impossibilities to the use water pipelines for irrigation, increase in human and livestock population and deforestation. Consequently, there was lack of sufficient supply of quality water for domestic, livestock and irrigation. Water being a precious commodity, the farmers/agropastoralists adopted various conservation practices to use it wisely.

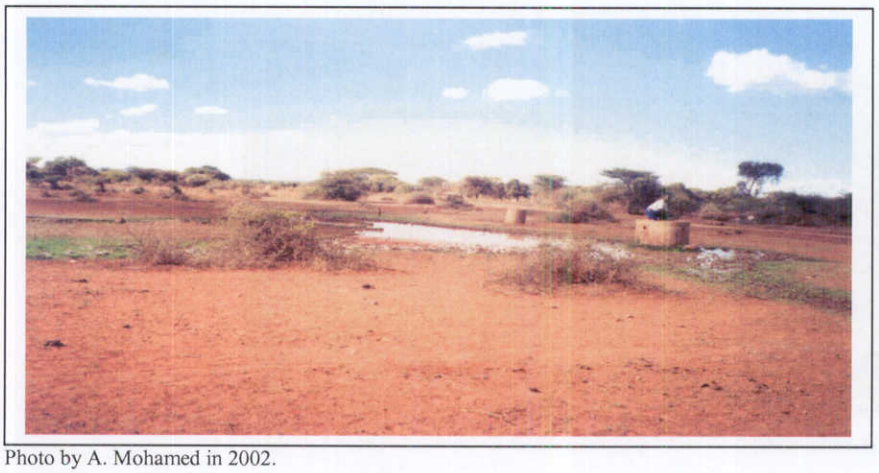


Photo by A. Mohamed in 2002.

Plate 4.2.10 Impact of Noulturesh pipeline on the environment in Isara Village, Mashuru, Kenya. In the background are the pipelines' pressure breathers. In the foreground, the soil surface have been trampled upon by animals that drink from the pipeline.

The most popular in all the villages were deep tillage, planting of drought tolerant crops, use of small containers/drums, trekking livestock to water sources, watering of tree seedlings and roof catchment (Tables 4.2.1 and 4.2.4).

Table 4.2.4 Coping strategies to water shortages and soil moisture stress in four villages of Eastern Kajiado and Southern Makueni, Kenya.

Water and moisture conservation practices	Number of respondents (n= 36)				
	Muusini	*Bondeni*	*Isara*	*Erankau*	*Total*
Drought tolerant crops	9	9	9	10	36
Use of small containers/drums	9	8	9	10	36
Trek animals to far water sources	9	8	9	9	35
Water tree seedlings	7	5	4	6	22
Bicycle transport	9	8	0	0	17
Roof water catchment	6	4	2	8	20
Microcatchment	9	2	2	2	15
Reduce frequency of livestock watering	0	0	8	7	15
Donkey transport	0	0	4	1	5
Construction of water tanks	2	1	1	1	5
Extension of piped water to homestead	0	1	2	0	3
Irrigation	0	0	1	1	2
Animal troughs	0	0	1	1	2
Construction of dam/pans	0	0	0	1	1

Practices unique to Muusini and Bondeni was bicycle transport while donkey transport (Plate 4.2.11), reducing the frequency of livestock watering in dry seasons, use of animal troughs and individually owned dams/pans were only practiced in Isara and Erankau indicating the impact of livestock component on water use and management in the later villages.



Photo by A. Mohamed in 2003.

Plate 4.2.11 Donkey transport is a key coping strategies to water shortages in Erankau Village, Mashuru, Kenya.

The use of bicycle in transporting water in the Kibwezi villages by all members of the household can be related to culture and technological differences between the communities. The Masaai follow strict cultural tradition where domestic water is the responsibility of the women folk who do not traditionally ride bicycles. The high number of interviewees implementing the watering of seedlings is an indication of the communities' interest in tree planting. Construction of water tanks and extension of piped water to homestead were unique to the well off poverty groups due to financial implications.

As indicated in Table 4.1.13 there were acute water shortages in the villages especially for domestic use. The estimated annual domestic water deficit range from 3492 m^3 in Isara to 7312 m^3 in Bondeni. The critical months were mentioned as June to mid November. Despite the high water deficit in Bondeni, ground water level in the village was estimated at only 10 to 30 meters. The water table depth was deeper in the other villages.

4.2.2.3 Institutional support in the conservation and management of water resources

The ARIDSAK Project, German Agro Action (GAA), AMREF, the University of Nairobi, the National Conservation and Pipeline Corporation and the East African Portland Cement Company were mentioned as the institutions that support the local communities in the conservation and management of water resources within the study area. The ARIDSAK project prospected a well for one of the interviewees in Muusini while it was credited for its technical support in soil moisture conservation efforts in Muusini and Isara villages. GAA dug the Kiuwani Dam in a neighbouring village – a dam used too by the Muusini community. AMREF supported five farmers in covering/protecting and placement of hand pumps through cost sharing arrangements in Bondeni while University of Nairobi prospected a well in the same village. Additionally, as mentioned before a Mr. Keath from Canada connected a pipeline from Umani Springs to Bondeni village in 1990 and is still helpful to the village members through a community kiosk and individual pipeline connections. The National Water Conservation and Pipeline Corporation own and maintains Noulturesh water pipeline, which is the most reliable permanent water source in Isara.

However, the representatives of local community who were interviewed noted 100% that they are not getting support in this field. They criticize the Corporation of being less concern with their progress in agricultural development. No irrigation activity was allowed to use the pipeline and if illegally used, the Corporation was swift in disconnection. In Erankau the East African Portland Cement Company supports the most reliable permanent water source that is the Erankau Borehole.

4.2.3 CROP RESOURCES

The existing crop management practices in the study villages are based on low input agriculture and geared towards mainly subsistence farming. The practices are established on hybrid of traditional practices and modern agricultural technologies obtained from various Government and Non-Governmental organizations. The impacts of these practices on crop production are reflected in the diversity of the crops and their productivity.

4.2.3.1 Impacts of the existing practices on crop diversification and production

(i) Crop diversification

Out of the 17 crops grown except for gourds and pumpkins, the rest were either obtained from outside the villages or are hybrids of the two. Most of the farmers/agropastoralists obtain their germplasm from agro-veterinary stockists (Table 4.2.5) and from their own farms.

Table 4.2.5 Sources of crop seeds/germplasm in four villages of Eastern Kajiado and Southern Makueni, Kenya.

Village	Sources of seeds/germplasm			
	Agricultural institutions	Own farm	Open market	Agro-veterinary stockists
Muusini	3	5	1	2
Bondeni	1	8	0	0
Sub-total Kibwezi	***4***	***13***	***1***	***2***
Isara	2	0	0	9
Erankau	1	0	2	10
Sub-total Mashuru	***3***	***0***	***2***	***19***
Total	**7**	**13**	**3**	**23**

The rest obtain their seeds/germplasm from local open markets, agricultural based and related institutions such as ARIDSAK, GAA, and the Catholic Church, Kenya Farmers Association (KFA), Cereal Board and the Department of Agriculture.

Majority of the farmers in Muusini and Bondeni obtain their seeds/germplasm from their own farms while the agriculturalists heavily depend on outside sources because they have minimal traditional expertise on crop production.

All the farmers in Muusini and Bondeni practiced multiple cropping as explained under soil management practices. They also mixed most of the crops on the same piece of land to reduce risks of total crop failure, diversify household diet, optimize the use of land resources and to maximize the limited labour resource while increasing sources of income from the different products. If we consider crop diversity with in each village (including the interviewees) Muusini had the highest (18) followed by Bondeni (14). When we zero to the interviewees, crop mixtures ranged from two to eleven per farm with the lowest being in the well off poverty group and highest diversity on farms owned by the poor. Conversely, the diversity of crops grown by the agropâstoralists was least (Table 4.1.14) with five and nine respectively in Isara and Erankau. The fewer number of crop species grown is related to the limited experience of the community has in crop production. However, when the agropastoral villages were compared Erankau had higher crop diversity. The high species numbers can be associated with the proxy of the village to Makueni District, which is settled by the Kamba farming community. Additionally, the settled part of the village is 10 -15 km from Sultan Hamud town and therefore agropastoralists have reliable access to seed sources. Further, the village receives higher rainfall than in Isara.

(ii) Crop production

Management is a very important factor in crop production. The well off groups has large farms and other resources to improve their productivity unlike the poor. As a result they are more commercial minded and therefore emphasize on the productivity of crops that will generate more income. Consequently, the productivity of maize, cow pea and green grams decrease within increase in poverty (Table 4.1.14) while the crops with limited income generation, for example sorghum is mostly produced by the poor. The only major crop that is almost the same in production under all the different management was pigeon pea.

Moisture and soil fertility deficiencies are also two major drawbacks to crop productivity in this villages. Thus the farmers adopted various practices (contour farming, ridging, deep ploughing, terraces, cut off drains, trash lines, grass strips, water retention pits and runoff harvesting, multiple cropping, short season fallow, crop rotation, application of crop residues and animal manure) already discussed to encourage the retention of runoff and enhance soil fertility on croplands. The replenished soil moisture and improved soil fertility has made the farmers achieve the current crop yields and help contribute towards poverty alleviation.

However, the practices too have other negative impacts on the crop productivity. The trash lines and farmyard manure act as habitat for pests and diseases. Chaffer grubs that cause substantial loss of maize yields comes with animal manure that have not decomposed well. Termites and stock borer hide in the trashes prior to attacking the standing crops. Similarly, the mechanical methods of soil erosion control such as terraces and cutoff drains were mainly not technically well laid nor protected and therefore accelerate soil erosion and reduced crop yields.

Nine farmers/agropastoralists in Bondeni, Isara and Erankau use fire as a management tool in land preparation. The use of fire can contribute to loose of organic matter and causes the soil to be susceptible to erosion. Moreover, in Muusini and Bondeni because of the few number of animals kept, the amount of manure applied is too little to cause tangible productivity change. Additionally, six agropastoralists in Isara and Erankau reported not apply manure (though abundant due to the high livestock population) nor use gravitational soil fertility management.

Above all, chemical fertilizers are not used at all in the villages for the conventional crops. If this trend continues it means lower crop production in the future, hence food insecurity and further environmental degradation through the clearance of more woodlands for cultivation. The low tree cover on croplands, the low BSP in most of the cultivated areas especially in Kibwezi coupled with no or minimal conservation and minimal addition of animal manure are indicators towards this end.

The relatively lower yields were aggravated by destruction of crops by pests and diseases and wild animals especially elephants that stray from the nearby Tsavo, Chyulu and Amboseli Parks. Unless appropriate measures are taken food insecurity in the villages will remain an obstacle to sustainable development.

The impacts of the existing crop management practices on soils and vegetation have been discussed under the respective topics of soils and woodlands and pastures.

4.2.3.2 Institutional support in crop management and conservation

Ten out of the 36 interviewees reported to have got support from agricultural institutions. Half of the the interviewees who acknowledged support were from Muusini and three from Isara. All interviewees in Bondeni and eight in Erankau reported to obtain no support from institutions. The institutions who supported the farmers/agropastoralists were ARIDSAK Project, GAA, Kenya Institute of Organic Farming (KIOF), Department of Agriculture and the Catholic Church. The support was in form of training, technical advice on appropriate planting and provision of improved germplasm for drought tolerant crop varieties and application of appropriate pesticides including the use of a concoction made from neem, pepper and ash to control of the great grain borer and weevils. Although production for some of the crops was reported to have increased one and half to twice the normal crop production, others reported the germplasm provided to be of poor quality or not appropriate. The farmers/agropastoralists provided two important feedbacks:

- the quality and appropriateness of some of improved crop varieties require further socio-economic testing before release. For example green grams variety (N26) – its taste was reported not to be as sweet as the local variety and even its market price was 25% lower in Muusini. The farmers describe the taste as "nylon" and have low preference for it. Another in Erankau said not support the idea of growing high breed maize which is being promoted by the institutions. He says that they are expensive and with limited resources it is not easy to purchase such seeds as often as the researchers recommended. Yet another agropastoralist in Erankau who was supported with sorghum seeds indicated that institutions should provide crop seeds not appreciated by birds. He says out of the 0.1 ha he invested he got zero yields. He even wished to have eaten the seeds he was provided with; and
- the above institutions advised the farmers to practice sole cropping and under crop rotation to increase productivity. However, in addition to the many benefits already discussed under mixed cropping, farmers in Muusini and Bondeni especially in the poor groups noted that the size of their croplands were small and therefore cannot implement the above advice which requires more land space.

The rest of the interviewees reported to obtain no support from institutions. When enquired as to why they said "I do not know, they have not come to teach us, Extensionists and researchers are far from us, we have been forgotten, they think that Masaais do not farm". The statements can be interpreted in to three meaning:

- literally in terms of distance – the villages are remote;
- desperateness for the much needed support;
- the extension/research-farmer linkage does not exist or is wanting.

4.2.4 NATURAL WOODLANDS AND PASTURES

4.2.4.1 Existing management practices for the natural woodlands and pastures

Despite the importance of natural woodlands and pastures the existing management practices in the woodlands/pastures were restricted to surveillance against unauthorized use of the resources, dead fencing and indigenous individual fodder/forage reserves, which was only practiced in Isara and Erankau (Table 4.2.6). The few trees planting near homesteads received more attention than the woodland and pastures.

Table 4.2.6 The existing management practices for trees, woodlands and pastures in four villages of Eastern Kajiado and Southern Makueni, Kenya.

Tree/woodland and pasture management practices	Villages/Number of respondents						
	Muusini (n= 9)	Bondeni (n=8)	Sub-total Kibwezi	Isara (n=9)	Erankau (n=10)	Sub-total Mashuru	Grand total
Surveillance	7	7	14	9	10	19	33
Dead fence	4	4	8	6	8	14	22
Tree planting	9	6	15	4	8	12	27
Pruning & thinning	4	6	10	4	8	12	22
Watering & weeding	7	5	12	4	6	10	22
"Ololopololi" pasture farms	0	0	0	9	10	19	19
Bush management	0	0	0	2	0	2	2
Reseeding	0	0	0	1	0	1	1
Bush trash	0	4	4	4	2	6	10
Microcatchment	1	0	1	0	0	0	1
Terraces	1	0	1	0	0	0	1

In Muusini and Bondeni, emphasis was more on surveillance and management of the planted trees. The major tangible management practice for the woodlands and pastures was dead fencing to control unauthorized grazing. In Isara and Erankau, although surveillance too took precedence, the agropastoralists had a special individually owned indigenous fodder and forage reserve locally known as "olopololi" (Plate 4.2.12).



Photo by A. Mohamed in 2002.

Plate 4.2.12 The fencing of natural pastures "olipololi" for the milking cows, calves, goats and sheep is a traditional pasture/fodder management practice in Mashuru, Kenya.

The "Olopololi" were fenced off for special category of livestock including milking cows, calves, weak animals and goats/sheep. The owner also maintains the pasture farm by removing weeds, pruning trees and shrubs and heals soil erosion through placement of bush trashes across rills and gullies and diversion of runoff into the pastures to boost vegetation growth. Consequently all the trees and shrubs in the "Olopololi" are rarely shared. The sizes of the pasture/fodder farms range from 0.5 – 5 ha but a well off agropastoralist (not an interviewee) have even fenced an "Ololopoli" of up to 2 km² with modern barbed wire combined with living fences of *Commiphora* spp (Plate 4.2.13). The modified "Olopololi" had relatively high grass cover than open areas.



Photo by A. Mohamed in 2002.

Plate 4.2.13 Barbed wire combined with *Commiphora* living fence is a modernized modification to the management of "Olopololi" in Isara Village, Mashuru, Kenya.

Despite the special "olopololi" initiative that covered a small area the rest of the woodlands and pastures had minimal management. The limited management of woodlands and pastures was coupled with unsustainable exploitation of the resource through overgrazing, charcoal burning, harvesting of poles and posts for construction, fencing materials and traditional medicine. Consequently, grass cover was minimal and has been replaced by bushes and thickets especially in Muusini and Isara. Soil erosion in form of sheet, rill and gully was common.

Additionally, in Muusini and Bondeni the area under woodlands and pastures has decreased since the first settlers arrived around 1965. Today woodlands form only 47% and 26% of Muusini and Bondeni Villages respectively (Figures 4.1.28 and 4.1.29). Most of the remaining land was under cropland. This means that the woodlands were cleared at the rate of 1.4% and 1.9% per annum in Muusini and Bondeni Villages respectively for cultivation purpose. If the current scenario of land management continues, in 33 and 14 years time respectively all woodlands will be cleared in the two villages. By the time of the study, woodlands and pastures formed over 90% of the farms in Isara and Erankau. However, when the current estimated population increase of 4.6% for Mashuru Division (GoK 2002) is put into consideration, it is likely to have negative impact on natural resources. Over 60% of the village population is estimated to be less than 18 years and therefore in the near future current farms will have to be further subdivided and settlements are expected to increase. This will further put more pressure on demands for wood, non-wood and agricultural products.

4.2.4.2 Impacts of the existing practices on the natural woodlands and pastures

All the farmers interviewed noted decrease in vegetation cover within Muusini and Bondeni Villages over time due to clearance for cultivation and settlements, exploitation for fuelwood and construction, unreliable rainfall and overgrazing (Fig. 4.2.2). Conversely all the agropastoralists in Isara and four in Eranaku indicated that vegetation cover within the villages have increased over time due to enhanced conservation of trees on-farm, the disappearance of large herbivores such as elephants that use to feed on *C. africana* and the effect of the 1997/98 and 1961 El-Nino rains that encouraged regeneration of trees species.

In Isara, the conservation of trees increased in the past 10 years due change of land ownership from group ranch to free hold (individual ownership). However, in Erankau five of the interviewees reported decrease in vegetation cover due to increase in frequency of drought, charcoal burning, opening up for cultivation, provision of building and fencing materials (Plate 4.2.14) and increase in settlements.

Tree production and conservation

In Muusini over 50% of the agroforestry species planted around homesteads were exotic while the reverse was true for Bondeni. The difference can be related to the strong institutional support in Muusini that provides mainly exotic species. Because Bondeni farmers rarely receive seedlings from institutions, they mostly conserved indigenous species.

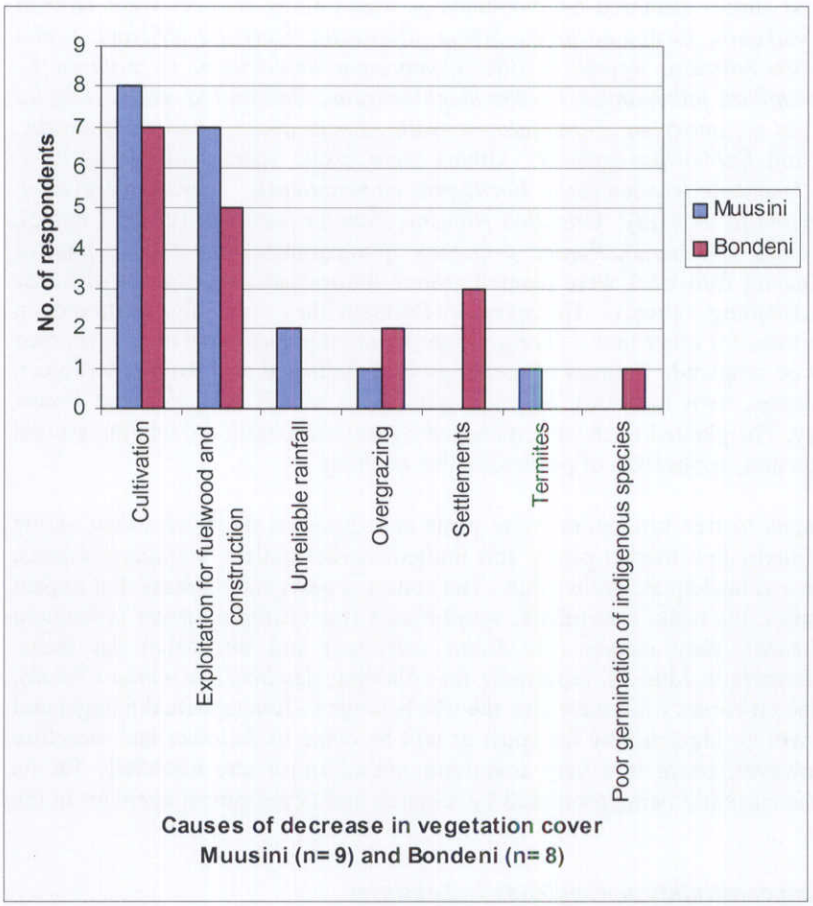


Figure 4.2.2 Causes of deforestation in Muusini and Bondeni Village, Kibwezi, Kenya.



Photos by A. Mohamed in 2002.

Plate 4.2.14 Charcoal burning and fencing material were major cause of woodland depletion in Erankau Village, Mashuru, Kenya.

The major trees and shrubs scattered on croplands or found along terraces were *Lannea stuhlmanii, Melia volkensii, Bosica coriacea, Senna abbreviata, Sterculia africana, Senna siamea, Commiphora rostrata, Acacia tortilis, Combretum apiculatum, C. zeyheri, C. collinum* and *Commiphora habessinica, Croton megalocarpus, Azidirachta indica Kigelia aethopum, Dalbergia melanoxylon, Terminalia brownii Albizia amara, Ficus sycomorus, Syzigium cuminii* and *Euphorbia tirucalli*. Others were exotic species of *Morus alba, Mangifera indica, Leucaena leucocephala, Eucalyptus cameldulensis, Thevetia peruviana, Citrus lemon, Terminalia mentally, Grevillea robusta, Annona muricata* (custard apple), *Musa serpentium* (Desert Banana), *Punica granatum* (pomegranate) and *Carica papaya* (paw paw). In Muusini fruit trees were planted around homestead for purposes of better protection against roaming animals. However, in Bondeni they were also scattered on croplands just like trees for other uses. Trees scattered on croplands have been discussed under agroforestry on cropland. Sources of seedlings were indicated as ARIDSAK Project, Wildlings and cuttings, own nurseries, Women group and school nurseries and Forest Department nursery. The planted trees were managed by watering, pruning, fencing around each plant for protection, application of pesticides and weeding.

The major constraints to tree production were pests and diseases, moisture stress, saline water, roaming animals, low market prices and limited market outlets, storage problems, cultural constraints and inadequate knowledge. The common pests and diseases that impact on trees were termites, die back, caterpillars, wood borers (for example *Apates indistincta* and *Salagana discata*), stem canker (for *Melia volkensii*) and birds that eat fruits. Culturally, some farmers in Muusini reportedly fear planting *Azadirachta indica* (Neem). They belief that since it comes from the coast, the tree belongs to Jinn (spiritual beings) and whoever plants it will be impacted by the spirit or will be come its follower and therefore far from God. However, neem is a very important multipurpose tree especially for its medicinal use and is currently being promoted by research and development agencies in the drylands of Kenya.

Synthesis of existing constraints to woodlands and pastures

The major constraints of the woodlands and pasture were overgrazing, over exploitation of wood and non wood products and impacts of wild animals. The overgrazing and over exploitation accelerated soil erosion.

(i) Overgrazing

When the total livestock population in the study villages (Table 4.1.19) were converted into livestock units (L.U), assuming each zebu head is 0.8 L.U because of its small size and that 8 goats/sheep is equivalent of 1 L.U and 1 donkey and a Sahiwal is equal to 1 L.U, then there were approximately 267 and 187 L.U using 330 and 100 ha in Muusini and Bondeni respectively. According to Pratt and Gwynne (1977), the recommended hectares per L.U for Kenya's agro-climatic zone VI (where Muusini Village lies) and V (where Bondeni Village lies) are 12 ha and 4 ha respectively. This means that currently, 1 L.U is using only 1.2 and 0.5 ha in Muusini and Bondeni respectively. Optimally, the villages' pastures and woodlands can accommodate approximately 83 L.U and 25 L.U in that order. Therefore the villages were accommodating 184 and 162 extra L.U. respectively more than the recommended. Based on the same conversion principle, Isara and Erankau were accommodating 1177 and 1976 extra L.U more than the optimum. When concentration of grazing animals is confined to restricted areas over grazing (Plate 4.2.15) becomes the overriding problem (Pratt and Gwynne 1977).



Photo by A. Mohamed in 2003.

Plate 4.2.15 Overgrazing was rampant in Isara Village, Mashuru, Kenya.

Over grazing combined with no burning have reduced mean grass cover in individual pastures to < 6% in Muusini and woody vegetation has completely suppressed grasses. In Bondeni grass cover was < 30%. In Isara, average grass cover was < 13% (dominated by stemmy *Pennisetum mezianum)* while in Erankau mean grass cover was < 36%. Thus, if overgrazing is not checked it may cause further range deterioration. The consequences of shortage of pasture have been reported by 35 of the interviewees. The interviewees noted pasture shortage to have become part of the villages' phenomenon between June to mid November. In dry seasons grass cover becomes no more yet most of the woodlands and pastures were not bush managed.

Some of the farmers/agropastoralists were aware of the impact of bush encroachment but did not know what to do or do not comprehend direct benefits from pasture improvement unlike the croplands. They also associated the degradation to unreliable rainfall, overgrazing by wild animals and increase in the occurrence of drought, increase in the population of human (hence settlements), increase of invader/unpalatable plants and land tenure problem in Erankau – the land though individually owned was officially under group ranch status. They also reported increase in soil erosion and decrease of palatable species. Due to these impacts almost all the interviewees believe that carrying capacity is important for sustainable pasture management. To overcome this difficulty they use crop residues, lopping of fodder trees, purchase pastures (at Kshs 1500 per acre)/forage/minerals/hay and some have reduced their stock. An important copping mechanisms to pasture shortage during the dry seasons for Bondeni, Isara and Erankau was illegal grazing in pastures of the near by forest reserve and parks as the last alternative. Similarly, during the pasture crisis period, the agropastoralists use migration (to Chyulu Hills, Ngong, Kajiado, Nairobi, Loitokitok, Athi River – Some times covering over 100 km distance), purchase of feeds (forage/pasture/minerals/hay), crop residues as copping strategies. Suggested strategies to pasture shortages were reseeding, paddocking, fencing of pastures, bush management and intensification of the lying down of physical soil and water conservation structures.

The unpalatable species/invaders on the increase include *Solanum incanum, Barlaria taitensis, Hibiscus pycnostemon, Parvonia urens, Acanthospermum hispidum, Aristida kenyensis, Acacia paolii, Commiphora oblongifolia, C. africana, Ipomea kituiensis, Trichodesma zeylanicum, Indigofera spinosa* and *Hoslundia opposita*. Increase of the unpalatable species/invaders was related to site degradation through overgrazing, depletion of preference species, unreliable rainfall that encourages aggressive weeds and dispersal of their seeds by livestock, wild animals, water and wind. The increase of the invaders was also related to their unpalatability. A part from limited grass cover and increase of unpalatable and invader plants, palatable species like *Duosperma kilimandscharica, Balanites aegyptiaca, Melia volkensii, Acacia tortilis, A. brevispica, Combretum exalatum, Grewia bicolor, Acalypha racemosa, Thunbergia holstiii, Platycelyphium voense, Acacia nilotica, Premna resinosa, Senna abbreviata, Talinum portulacifolium, Sericocomopsis pallida,* S. *hildebrantii, Cordia quercifolia,* Oloorok kileling, *Momordica spinosa, Aspilia mosambicensis, Eragrostis superba, Cynodon plectostachyus, Panicum maximum, Commelina sp, Dactylotenium aegypticum, Themeda triandra, Chrysopogon aucheri, Digitaria milanaiana, Sprobolus fimbriatus* and *Cenchrus ciliaris* have been over browsed/overgrazed (Appendix V). Furthermore, species like *Acacia tortilis* and *A. mellifera* have been over exploited for charcoal burning in Muusini and Bondeni. In Isara and Erankau high value species such *A. mellifera* and *A. brevispica* and *Premna resinosa* also formed bush thickets reducing grass growth.

In Isara and Erankau, over grazing has been further aggravated by the high number of wild animals within the pastures. Browsers like giraffe too compete for the highly palatable pods of *Acacia tortilis* at a time when it is critically needed by livestock in dry seasons.

The high value species whose cover had reportedly increased were *Acacia tortilis* and *B. aegyptiaca* in Isara and Erankau. The species had relatively regenerated well within pasture especially around former Kraals (Boma's). This can be related to the spread of the seeds by animals that feed on the pods/fruit and release the seeds through faecal matter or discarded by goats after chewing cud. Similarly being a drought tolerant fodder necessary for livestock, the plants are protected by the agropastoralists. They only lopped but did not uproot.

(ii) ***<u>Over exploitation of wood and non wood products</u>***

Parallel to the unsustainable grazing of the woodlands and pastures, overexploitation of other high value species for dead fences, firewood, charcoal, medicine, timber and poles and withes for construction had occurred. The field study has identified various species that has been cut. Additionally, the local community confirmed the impacted species and added others that were most affected. In Muusini and Bondeni the affected species were *Senna abbreviata, Melia volkensii, Acacia mellifera, A. tortilis, A. nilotica, Acacia Senegal, Terminalia prunoides, T. brownii, Boscia coriacea, B. anguisitifolia* (Plate 4.2.16), *Albizia anthelmentica, Platycelyphium voense, Berchamia discolor, Newtonia hildebrantii, Commiphora holtziana, C. baluensis, Commiphora habessinica, Dalbergia melanoxylon Combretum apiculatum, C. zeyheri, C. collinum, Zanthoxylum chalybeum, Lonchocarpus eriocalyx* and *Lannea triphylla,* (Appendix V). Most of what remains, as the dominant species today are the less valued species. The major causes of species erosion were cited as cultivation, overgrazing and provision of wood and non-wood products.



Photo taken by A. Mohamed in 2004.

Plate 4.2.16 *Boscia anguisitifolia* over exploited for construction in Muusini Village, Kibwezi, Kenya. The species has been cut to below the ground level because of its durable poles.

All the interviewees in Muusini and Bondeni indicated to have shortages of wood and non-wood products on their farms. Based on the questionnaire data, each household in the village was estimated to use 293 and 325.5 kg of firewood per month in Muusini and Bondeni, translating to 3516 and 3906 kg/household per annum respectively. In total, there were 80 and 125 households respectively in the two villages. Based on the current use it is estimated that they use 281,280 kg (281.3 tonnes) and 488250 kg (488.3 tonnes)/year. By the time of the study, the firewood was obtained from a distance of about 1 - 5 km from the homestead in their own farms or at a cost/with consent from neighbours. However, other wood products like poles were mainly obtained from nearby forest reserve/national park while timber was bought from nearby towns. One and five farmers in Muusini and Bondeni respectively reported to have storage problems with wood and non-wood products. The problems were noted as wood borers, rain that wets wood stored out side, termites, lack of storage facilities, termites that feed on the products and snakes. Furthermore, the interviewees reported the use of their farm resources by other users. The sharing of wood and non-wood products including pasture puts more pressure on the natural woodland and pastures. Only two farmers in Muusini and two in Bondeni sold wood and non-wood products in form of firewood, seedlings, mango fruits and charcoal. They noted market problems to be far market centres and low prices.

In Isara and Erankau wood products in form of poles, posts, firewood and fencing materials were causing over exploitation of trees and shrubs. The species most affected for the different uses were *Acacia mellifera, A. ancistroclada, A. tortilis* (branches cut), *A. drepanolobium, A. Senegal, Cordia quercifolia, Commiphora schimperi, C. baluensis, C. africana* (especially around homesteads in Isara), *Boscia angusitifolia, Boswellia neglecta, Premna resinosa, Grewia biolor, G. tembensis*, *Balanites* spp., *Dichrostachys cinerea* and *Ximenia americana.* (Appendix V).

Five out of the 19 interviewees in Isara and Erankau faced shortages of wood and non-wood products because of the nature of the landscape where their farm are found. (*Vertisols* lowlands and *ferral chromic Luvisols* plains) Consequently they rely on their neighbours farms to access wood and non-wood products.

Using an average data from the household samples interviewed, each household in Isara and Erankau was estimated to use 207.8 and 150 kg of firewood per month, translating to 2,493.6 and 1800 kg/household per annum respectively. In total, 51 and 86 households that occupy the villages were estimated to use 127173.6 kg (127.2 tonnes) and 154800 kg (154.8 tonnes) per year respectively. Firewood was obtained from a distance of less than two km from the homestead. Surplus wood and non-wood products were stored or left in-situ for future use. Three interviewees in Isara and six Erankau noted to have storage problems. They store wood products outside the main house (mostly in the open). As consequence they related their storage problems to rain, termite, and snakes and rats that hide in the woods. Only one interviewee in Erankau admitted to sale the wood as charcoal and therefore except this individual, the rest of the farmers did not identify market as a problem. The agropastoralist noted the market problems as low prices, far market centers and the issue of getting permit from the Forest Department prior to burning charcoal. To curb wanton tree cutting, it is a requirement by the Government to get permit from the Forest Department. Timber was the only wood product the agropastoralists get from outside the village (nearby towns of Emali and Sultan Hamud) for construction of modern roofs and furniture. However, *C. baluensis*, which was significantly present on the Regosols hills of Erankau if sustainably managed and used can be exploited for good timber especially for door frames.

The demand for dead fence (that has to be renewed once every six months) to fence off homesteads, croplands and "olopololi" (Plate 4.2.14) is one of the greatest pressure the local communities impact on the existing woodlands. Five of the interviewees admitted that vegetation cover has decreased mainly due to farming, charcoal burning and cutting for poles/posts and fencing materials. On the other hand the settling down and the realization of the decrease in vegetation cover might have encouraged tree planting by 27 of the interviewes although the number of seedlings they planted in the past five years was few (2 to 100) and their survival rates has been low (less than 50%). The low survival rate can be related to drought, termites, browsing by animal and the planting of exotic species by majority of the farmers.

(iii) Impacts of wild animals on vegetation resources

The impact of wildlife to vegetation resources was lowest in Muusini than the other villages because it is located a bit far from the national parks. However, the few wild animals housed in the woodlands within and around the village is still a big bother to farmers mainly on crops than on pastures. These impacts have been mentioned under the crop section. Moreover, elephants stray from the parks at certain times of the year and destroy crops.

In the current Government policy, all wild animals belong to and are managed by the state except for few licensed large-scale ranches. According to all the the farmers and 18 of agropastoralists, wild animals are a big problem on-farm. The wild animals that have been reported to destroy crops in the villages were porcupine, baboons, monkeys, hare, warthog, wild pigs, squirrels and elephants. Elephant is cited as the most destructive. It was reported to prefer the pods of pigeon peas, pumpkin fruits, banana (whole plant), paw paw fruits, mangoes (whole plant if juvenile or branches/leaves/fruits for mature trees), Leucaena, sugarcane and maize. Other problematic wild animals include birds on millets and sorghum. The Kenya Wildlife Services who are responsible for the wildlife do not compensate for crops and tree damages. This policy has been in place since 1989.

Consequently, they request the Government to take wild animals to parks and electric fence and re-think about compensation policy. The only wild animal the agropastoralists were happy to leave with was Ostrich, which according to them does not compete with livestock in resource use and is harmless to the environment. A part from crop damage, wild animals too compete with livestock for pasture, water and they are reported to be carriers (vectors) of livestock diseases. Carnivorous wild animals like Cheetah, leopard, eagle, fox, lion, python, jackal, and hyena eat livestock too.

While the relationship between local communities and the Kenya Wildlife Service (KWS) was wanting, a new and bright initiative to involve the local communities in wildlife resources has been initiated by the KWS in 2002. The involvement of Merueshi Individual Group Ranch in the wildlife conservation, management and use as a pilot scheme was a step in the right direction. The group members who number 24 (two from Isara village) were already very active protecting and monitoring against poaching. According to Mr. Musa, the group's Chairman, they have received Kshs. 100,000 from the sale of the authorized game meat and each member have at least bought one to two heads of cattle. This is a big motivation and boost for the local economy. A slaughterhouse has been constructed at the site for this purpose (Plate 4.2.17). However, the exercise has been suspended temporarily to reorganize and develop appropriate policy procedures (District Warden Kajiado pers. Comm. 2004).



Photo by A. Mohamed in 2004.

Plate 4.2.17 A pilot community managed slaughterhouse for game meat near Isara, Mashuru, Kenya.

4.2.4.3 Institutional support to woodland, pasture and livestock management

In Muusini four farmers reported to have received support on animal production from the ARIDSAK project and GAA. The support of the ARIDSAK Project was cited to be in form of pasture improvement through reseeding while that of GAA was noted to be in form of disease identification. In Bondeni, one farmer reported to have received support from the Veterinary Department by treating her chicken.

The rest have never got any institutional support citing that there is communication break down between them the institutions that were meant to support them. In Isara Village five farms and a similar number of spillovers have obtained support from the ARIDSAK Project in form of agroforestry, pasture improvement and crop production.

Additionally, Isara Primary School has been used by the project as a model school in agroforestry (Plate 4.2.18) though tree nursery demonstration and tree planting activities.



Photo by A. Mohamed in 2003.

Plate 4.2.18 Isara primary school agroforestry farm. Pupils guard the farm even over the holidays.

Amongst the agropastoralists interviewed, four have reported to benefit from the ARIDSAK Project directly or indirectly in form of trainings, exposure tours, provision of crop seeds, seedlings and minimal agricultural inputs. Above all they appreciated technical advice that they have received. Further, the project has financially supported a livestock based group who are now actively engaged in livestock business. They buy young stock (goats) and resale them after some time. During a feedback meeting the role of KARI-Kiboko in pasture improvement in some farms of Isara have been acknowledged.

Additionally, in Erankau two interviewees have reported receiving seedlings or trainings on tree planting from the ARIDSAK Project. But they noted that they were either not provided with enough seedlings for planting or the seedlings provided were mainly exotics that required a lot of water and was liked by wild animals as browse.

4.2.5 SUMMARY OF THE IMPACT OF EXISTING MANAGEMENT AND USE ON RESOURCE COMPONENTS

Attempts have been made to conserve soil resources on croplands by applying 19 different practices. Physical soil conservation structures were applied most in Muusini and Bondeni though inappropriate and inadequate. Gravitational soil fertility management and "olopololi" fodder reserves were unique to Isara and Erankau. Despite these efforts, soil erosion was most common on croplands of Kibwezi while the woodlands and pastures were severely overgrazed resulting to low crop yields and insufficient pastures respectively.

High value trees and shrubs were also over exploited causing siltations of water sources and gross pollution and contamination.

4.2.6 CONCLUSIONS

The existence of high soil erosion, low soil fertility and inadequate food, wood and fodder/forage and chronic water shortages combined with pollutions and contaminations means the existing management practices are not effective. Further, efforts towards supporting the farmers/agropastoralists were minimal. Consequently, sustainable approaches have to be put in place.

4.3 CONTRIBUTION TO THE DEVELOPMENT OF SUSTAINABLE AND INTEGRATED MODELS FOR THE MANAGEMENT OF NATURAL RESOURCES

4.3.1 INTRODUCTION

Land use systems are integrated systems and their description should include both biophysical and socio-economic characteristics (Mohamed *et al.* 2000). In order to compare how the land is currently used and managed and what it can potentially be used for and managed. Individual management operations are never isolated events but series of activities planned by the farmer, to adapt or modify the biophysical sub-system in such away that the intended goals (crop, livestock, wood and non wood production) are fully attained. In this section, different ecological landscape types were identified based on the characteristics of the soil types, vegetation types, physiographic and water components. Similarly, farms with similar socio-economic characteristics were mapped out in order to obtain harmonized farm types. The overlays of the landscape types and harmonized farm types were undertaken to obtain integrated ecological and farm management units in order to plan for sustainable natural resource conservation in the future.

4.3.2 THE DEVELOPMENT OF INTEGRATED ECOLOGICAL AND FARM MANAGEMENT UNITS, IDENTIFICATION OF THE MAJOR CONSTRAINTS AND ALTERNATIVE OPTIONS

Based on the definition by Wisconsin Department of Natural Resources (2004), ecological landscapes are areas with unique combinations of bio-physical characteristics that make up the ecosystem such as soil, water, natural vegetation types and physiography, which differ in levels of biological productivity and species, and in many others ways affect land use and management opportunities. As per the recommendation of FAO (1989), the foundation of the ecological landscape types in this report is the soil units classified under soil characterization combined with descriptions of slope, water and natural vegetation and existing land uses.

4.3.2.1 Development of integrated ecological and farm management units and identification of their major constraints

(i) Classification and mapping of ecological landscape types and summary description

Muusini Village

There are two ecological landscapes in Muusini, that is the *Ferralsols* and *Luvisols* plains (Fig. 4.1.8).

The *Ferralsols* plains are covered by dark gray sandy loam - loamy sand textured soils with flat slopes. The soil erosion rate was high while fertility of the landscape was low due to low phosphorus, low organic carbon and BSP although the CEC was high. Calcium and magnesium contents were low in the Ferralsols plains but potassium levels were high throughout the landscape and therefore the soils response to NPK fertilizers are likely to be low. The low base saturation is an indication of low fertility caused by moderate to severe erosion that exists in the landscape mainly in form of sheet and rills.

The landscape experiences slight water logging in rainy seasons and its moisture content was low due to the arid environment and the sandy texture. Legume crops performed well on the eroded zones of the landscape while cereals (maize and sorghum) had highest yields on less eroded areas of the landscape. Deforestation of high value trees and shrubs was a concern though not as severe as the *Luvisols* plains. Most of the water ponds and shallow wells are located within the landscape. The only dry riverbed within the village crosses southern edge of these plains. The landscape faces water deficit throughout the year and situation was chronic and the quality grossly polluted and contaminated. The natural vegetation was dominated by *Adansonia digitata-Commiphora africana - Combretum exalatum* wooded bush land thicket reducing grass cover to < 10%. Out of the 60 species were identified within the woodlands and pastures, 21 were high value species that provided multiple uses. Additionally, about 60% of the trees, shrubs, climbers and herbs were regenerating when compared with about 50% of the Luvisols plains. The vegetation had dense under growth of *Barlaria taitensis* exacerbating inadequacy of pasture in dry seasons.

The Luvisols plains are flat to gentle dark reddish brown to red sandy loam landscapes with soils prone to surface crusting and therefore erosion. Fertility of the landscape was low due to low organic carbon, nitrogen and phosphorus levels (except on terraced farm common on farms owned by well off and medium poverty groups). The plains contain few sources of water in form of shallow wells and the water situation is same as the Ferralsols plains if not worse. The natural plant community was composed of *Commiphora* spp. – *Erythrochlamys spectabilis* – *Premna resinosa* wooded bush land thicket with *Grewia bicolor* and *Combretum exalatum* common in depressions. Out of the 48 species occurring in natural vegetation, 17 of them were regarded as high value. Just like Ferralsols plains, the vegetation had dense under growth of *Barlaria taitensis* completely suppressing the growth of grasses to < 3%. As a result there was pasture shortage in dry seasons. Most of the high value species had low regeneration due to overgrazing and over exploitation by man. In terms of crop productivity, cereals such as maize and sorghum performed better than legumes.

The existing land uses in both landscapes were subsistence dryland farming, sedentary livestock keeping and settlements. The major crops grown are maize, cowpea, green grams, sorghum and millet while livestock was composed of cattle, goats, sheep and poultry as explained under characterization section of this document.

Bondeni Village

Volcanic Lava plains, *Ferralsols* plains and *Chernozems* lowlands constituted the Bondeni Village (Fig. 4.1.9). The soils of the Volcanic Lava plains landscape are made up of reddish gray stony, bouldery and rocky sandy loam soils and gentle convex slopes of 2-5%. As a result, its soils are extremely shallow in depth. Furthermore, because of its volcanic nature, the soils are chemically rich with moderate levels of phosphorus, high CEC and moderate BSP but constrained by moisture content. Natural vegetation had been cleared and therefore being bare the soil was exposed to severe erosion. Additionally, due to its spongy nature, the landscape had no water sources. Except for maize and beans the rest of the major crops do not seem to perform well on the landscape. A part from cropping the landscape was also used for settlement.

The *Ferralsols* plains are dark gray sandy loam textured soils with flat slopes. Its descriptions are similar to *Ferralsols* of Muusini. The *Ferralsols* plains were low in soil fertility both in the pastures and croplands due to low phosphorus but CEC was higher in croplands with terraces (owned by the well off) though the BSP was generally low due to erosion. However, the soils were more fertile than the *Ferralsols* of Muusini. Soil erosion was moderate to severe. The landscapes' soils experienced moisture stress due to its sandy nature and limited rainfall. Most of the shallow wells of the village were located within the landscape but the water quantity was inadequate and the quality grossly polluted. Part of the contamination is caused by over use of the remaining natural woodlands and pastures for myriad of uses. The natural vegetation of the existing woodlands was dominated by *Combretum* spp. wooded grassland with *Duosperma kilimandscharica* dominating the under canopy. The vegetation was made up of 46 species out of which 21 were considered as high value susceptible to over use. Fortunately, about 80% of the natural trees, shrubs, climbers and herbs were regenerating although grasses covered about 19% of the landscape. The existing land uses were cropping, settlement, bricks making and sedentary livestock rearing as explained under resource characterization. Except for maize and pigeon pea the rest of the major crops did not perform well on the land unit.

The *Chernozems* concave lowlands cover the valley section of the Bondeni Village. The soils of the landscape are dark gray to brown sandy clay loam and moderately fertile due to relatively higher CEC caused by the high clay and organic carbon contents but the phosphorus was very low just like *Ferralsols*. Soil erosion was moderate to severe. The unit is prone to temporary flooding with runoff from the Chyulu Ranges and Metava Swamp (Fig. 4.1.9) subsequently becoming muddy and sticky. As a result, in rainy periods, cropping is possible using hand tools and not tractor or oxen. Shallow wells and ponds are common within the valley but the water quantity is insufficient and the quality highly contaminated. Just like the *Ferralsols*, deforestation and over grazing were common though the extent was not as severe as Muusini Village. The natural vegetation was *Lannea triphylla - Combretum* spp. wooded grassland with *Acacia drepanolobium* common in some portions. The woodlands and pastures had 58 species out of which 20 were regarded as high value that faced over exploitation. Luckily, over 80% of the trees, shrubs, climbers and herbs were regenerating. Grasses constituted about one third of the cover. The unit is used for cultivation, settlement and sedentary livestock keeping.

Isara village

Six ecological landscapes (Volcanic *Vertisols* lowlands, Basement Vertisols lowlands, *Cambisols* hill, Cambisols foothills, *Ferral Chromic Luvisols* and *Ferric Luvisols* plains) are found in the Isara Village (Fig. 4.1.10).

Chromic & Pellic Vertisols lowlands (basement and volcanic origin) are dark brown to dark gray linear to S-shaped bottomlands with cracking and shrinking sandy clays (clay forming over 30%). The CEC and BSP were high due to high contents of clay, calcium and magnesium but very low phosphorus levels. Furthermore, its stickiness and slippery surfaces reduce its usefulness in rainy seasons. Similarly the cracks formed as a result of shrinking and swelling nature can break livestock especially if covered by dense grasses. Moreover, snakes also like such sites. Moisture stress is another draw back due to low and erratic rainfall. Erosion is excessive in form of sheet, rill and gully. Overgrazing was rampant. The natural vegetation of the basement *Vertisols* was dominated by sparse *Acacia tortilis – Serracocomopsis pallida* open woodlands.

On the other hand, volcanic *Vertisols* were covered by Oloorok kileling - *A. mosambicensis* shrub land and *Cyprus bulbosus* occupies most of the bare grounds in rainy seasons. The *Vertisols* lowlands had a total od 37 species with 17 of them considered as high value and less than half of the trees, shrubs, climbers and herbs were regenerating. Existing land use was restricted to sedentary livestock keeping that graze freely with wild animals. By the time of the study, except for the Olosedeti dry riverbed and the Noulturesh pipeline that crosses the *Vertisols* lowlands of basement origin, there are no sources of water in the landscape due to the cracking and swelling nature. Although river water were unreliable and grossly polluted and contaminated, the pipeline was the source with best water quality though expensive for the agropastoralists and inaccessible for irrigation purpose.

Cambisols hill and foothill ecological landscapes are convex-concave raised undulating grounds with very dark gray to black stony, bouldery and shallow volcanic soils. Although fertile, its hilly nature too restricts the type of land use and erosion was severe due to animal pressure and the deciduous natural vegetation cover. There was also soil moisture stress due to aridity of the area. Due to its volcanic nature water percolates easily into the ground and therefore the units had no water sources. The vegetation on the hill was made up of *Chrysopogon aucheri - Acacia Senegal - Dalbergia melanoxylon* bush grassland while the foothills were occupied by *Pennisetum mezianum* grassland dotted with *A. mosambicensis* and *Acacia mellifera*. *Cambisols* hill and foothills had 36 species out of which 9 were of high value. However, less than half of the trees, shrubs, climbers and herbs were regenerating. The two landscapes were exclusively used for extensive sedentary grazing by livestock and wild animals and provision of wood and non-wood products.

Ferral chromic LUVISOLS plains are gently undulating linear (concave in some sections) landscapes are covered by deep and well drained yellow red to dark reddish brown sandy loam to sandy clay soils. The landscape faced severe sheet and rill erosion due to overgrazing, bush encroachment, surface sealing and lack of soil conservation. Otherwise the soils are moderately fertile with moderate phosphorus, moderate CEC and BSP. The soils of the unit have low moisture percentage due to the dry climate and sandy soils. Three water ponds and a pan (on the border with Vertisols) were the water sources found in the unit while the Noulturesh pipeline crosses the landscape. Maize, beans and green grams had high yields on the landscape although moisture stress, pests, diseases and wild life affected the productivity. The ponds and pans were silting up and provided grossly polluted and contaminated water during the rains and few months after. *Acacia tortilis – Serracocomompsis pallida* open wood grassland dominated the 32 species found in the landscape and grasses covering about a quarter of the area. Sixteen high value species were identified on the landscape though less than half of the trees, shrubs, climbers and herbs had regenerates. The existing land use of the landscape was extensive grazing by livestock and wild animals, dryland farming, settlements and in rare and erratic instances, irrigation with vegetables.

*Ferric LUVISOLS (*Dark brown and Reddish brown) plains are flat to gently undulating landscapes with dark red brown sandy loam to sandy clay loam in some portions to the east of Noulturesh pipeline to dark gray brown sandy clay loam soils (with portions of yellow red of sandy loam and loamy sand) to the west of the pipeline. Soil moisture stress, soil erosion and fertility levels were similar to those of *ferral chromic Luvisols*. Six ponds and two pans are found within the landscape while the Noulturesh pipeline passes through the landscape. Maize and beans performed well on the landscape and their productivity constraints were similar to those of *ferral chromic Luvisols*. The status of the water sources were similar to those of *ferral chromic Luvisols*.

The landscape was covered by *Commiphora africana – Acacia tortilis* bush land on the reddish brown portion while *Grewia bicolor - Commiphora africana* bush land on the dark brown soils. Out of 51 species that constituted the natural vegetation on the landscape 21 were regarded as high value. Grass cover was less than 15% on the landscape while more than half of the trees, shrubs, climbers and herbs regenerated. The current land uses are same as that of the *ferral chromic Luvisols*.

Erankau Village

Erankau Village has six agroecological landscapes constituting the *Regosols* hills, a *Cambisols* hill, *Cambisols* plains, *Luvisols* plains and foothills, *Gleyic Luvisols* lowlands and the *Vertisols* lowlands (Fig.4.1.11).

The Ngama *Regosols* hills have convex-concave steep slopes mostly greater than 16%. The landscape, which is rocky and stony and extremely shallow, is covered by dark yellow brown loamy sand (with few portion of sandy clay loam and sandy loam) soils. The unit has low moisture. Soil erosion was severe due to overgrazing and over exploitation of high value trees and shrubs. The soils too had low fertility (low phosphorus, CEC and BSP) due to the soil erosion. The landscape faces moisture stress due to slope, high sand content and aridity of the climate. Source of water found in the landscape were a shallow well and seasonal watercourses that were unprotected. Watercourses were useful only in rainy seasons and the well had low water yield and quality grossly contaminated due to siltation, infestation by baboons and contamination too from containers and direct drawing by people. *Commiphora baluensis – Acacia brevispica* wooded bushland is dominant along the watercourses while *Combretum apiculatum* wooded grassland occupy the parts away from the streams. Grasses comprised about a quarter of the total cover. *Regosols* hills had 74 species out of which 36 were considered to be of high value and susceptible to over use. Moreover, less than halsf of the trees, shrubs, climbers and herbs were regenerating. The existing land use is predominantly extensive sedentary grazing and woodlands that provide myriad of uses. However, settlements have also started.

Oldonyo Sepa *Cambisols* hill is a concave-convex hilly landscape with steep slopes of 16-30% and is occupied by very dark gray brown loam volcanic soils. The soils too are rocky and stony and extremely shallow. The landscape had moisture stress and had no water sources due the porous nature of the parent material (volcanic). *Digitaria milanjiana - Sprobolus fimbriatus - Themeda triandra - Chrysopogon aucheri* grasslands dotted with *Erythrina abyssinica* and *Sclerocarya birrea* cover the landscape that had a total of 33 species. Seventeen of the species were of high value and faced over exploitation wile about half of the trees, shrubs, climbers and herbs were regenerating. The present land use is exclusively extensive sedentary grazing and as woodland endowed with over exploited medicinal plants. Erosion mainly in form of sheet is excessive due to overgrazing.

The Cambisols plains are linear landscape composed of red to dark brown volcanic moderately deep and relatively fertile sandy clay loam soils but severe to excessive sheet and rill erosion was reducing the fertility. Overgrazing (both wildlife and livestock), settlements and cultivation with no physical soil conservation were the causes of erosion. The landscape has no functional water source due to its permeable volcanic parent material. Two failed dams are located within the plains – failed because of heavy floods from the upper hills and seepage. Green grams, maize and beans had the highest village production on this landscape and performed best on farms of the poor. The plains are covered by *P. mezianum – D. milanjiana – Chloris roxburghiana* grassland dotted with *S. birrea* and *L. stuhlamanii*.

The landscape had 27 species composed of 14 high value plants that faced over use. Further, less than half of the trees, shrubs, climbers and herbs were regenerating. Land use was extensive sedentary grazing both by livestock and wild animals, cultivation and settlements.

The *Luvisols* plains and foothills have gently undulating concave linear slope and is covered by dark gray brown very deep and well-drained sandy loam soils. The soils are moderately fertile soils (both in pastures and woodlands) though highest near settlements and on croplands that used gravitational soil fertility management. Erosion was medium to severe forming gullies on upper part of the plains. Due to high sand content the soil has moisture stress. The high potassium presence means less likely response to fertilizers. Most of the ponds, water pans and earth dams are found within the landscape. The water sources were facing siltation and contamination problem due to over grazing and deforestation in the surrounding areas and inadequate and inappropriate management. Witthin the village green grams performed best on the landscape especially on farms owned by the poor. Other crops such as maize, cowpea and beans had moderate yields though highest on farms owned by the poor. *Acacia mellifera* forests/woodlands dominates the foothills, *A. tortilis – B. aegyptiaca* open woodland on the upper portion while *A. drepanolobium* dominated the lower potion of the plains though in some portions it was substituted by *A. mellifera*, *B. glabra* or *B. aegyptiaca* while *Albizia anthelmentica* and *Cordia ovalis* replaced it along water courses. The Luvisols plains had a total of 64 species in the woodlands and pastures out of which 29 were high value species that were being over exploited. Moreover, less than 50% of these species were regenerating. Except in "olopololi" (dry season fodder/forage reserve), deforestation and overgrazing was common while the foothills and middle zones of the landscape had bush encroachment constraint. Extensive sedentary grazing both by livestock, cultivation and settlements were the major land uses.

Gleyic Luvisols lowlands landscape form part of the bottomlands of the village and is covered by sandy clay soils that become sticky and slippery in rainy seasons. The lowland was prone to seasonal flooding from Matoi seasonal river and runoff from the surrounding hills and plains. Soil erosion in form of sheet, rills and gullies were common. Consequently, it has high CEC but very low BSP and the phosphorus level was also too lowas explained under characterization. A silting water pan and a non-functioning earth dams are located within this ecological landscape. The dam failed due to seepage problem. However, the lowland is endowed with seasonal River Imatoi that has many individually dug "catch pits" or water holes on its floor. The catch pits have to be dug after every rainy season and the water yields though permanent, were low. The quality of the pits and river surface water were highly polluted and contaminated for human consumption. *Acacia mellifera* woodlands dominated the 20 species found in the natural pastures of the unit. Seven high value species found in the landscape face over exploitation while less than half of the trees, shrubs, climbers and herbs were regenerating. The land was extensively used for grazing.

Vertisols lowlands landscape is too part of the bottomlands within the village and it is restricted to along the River Arroi (seasonal). The landscape is covered with black sandy clay loam V*ertisols*. The lowlands were prone to severe soil erosion in form of sheet, rills and gullies. Thus the CEC was very high but the BSP was low. The landscape was also deficient in phosphorus. The unit was also prone to flooding in rainy seasons from the River Arroi. The soils are sticky in rainy seasons and difficult to work. By the time of the study the landscape contained no other source of water except the river whose water was polluted and contaminated.

The natural vegetation of the *Vertisols* lowlands was dominated by *Acacia seyal* var. *Fistula*. There were 16 species on the landscape out of which seven were high value that facing over use. About half of the trees, shrubs, climbers and herbs were regenerating. The landscape was extensively used for grazing.

(ii) Classification and mapping of harmonized farm types and summary description

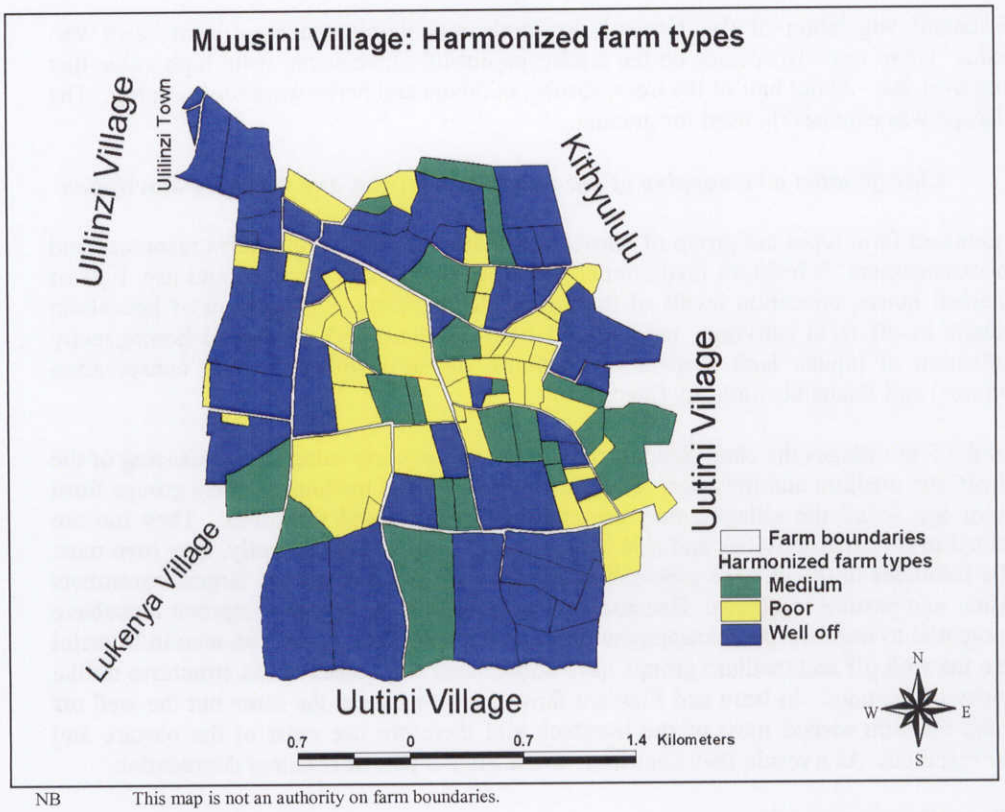
Harmonized farm types are group of households that have similarity in farm resources and their management. It includes institutional similarity (farm sizes, type of land use, type of residential house, education levels of the household members, involvement of household members in off farm activities, number and types of livestock), Technical homogeneity (application of inputs, land preparation methods, physical soil and water conservation structures) and financial similarity (income).

In all the four villages the classification zeroed down to poverty categories consisting of the well off, the medium and the poor. Though the well off and medium poverty groups form 40% or less in all the villages, they are endowed with natural resources. They too are involved in off-farm activities and ride high in social status. Consequently, they own most of the resources in the villages especially land and livestock and are the largest consumers of water and pasture resources. Because they have resources, they too improve most/have the potential to improve the management their natural resources. This was seen in Muusini where the well off and medium groups have constructed soil conservation structures unlike majority of the poor. In Isara and Erankau farm sizes are almost the same but the well off and the medium owned most of the livestock and therefore use most of the pasture and water resources. As a result, they contribute to the greater part of resource degradation.

Well off (Poverty group I)

The well of form 14%, 17% and 12% of the households in Muusini, Bondeni, Isara and Eranakau respectively. Although few in number, they own most of the livestock, pocket most of the income within the villages and in Muusini and Bondeni own most of the land (Figures 4.3.1 to 4.3.4 and Tables 4.1.3 and 4.1.4). They and their children were the most literate (the children go beyond secondary school level because they can afford to finance higher level of education) and household members were involved in off-farm activities increasing income per day to more than two Euros in Muusini and Bondeni and over three Euros in Isara and Erankau. They therefore potentially have resources to purchase more land and livestock, hire labour, fence off farms and improve on their on-farm resource status. The well off too reside in permanent houses and own permanent food stores and so the incidence of store pests and diseases are reduced and exert minimum pressure to harvest shelter materials from the woodlands. The well off household members rarely crop during the unreliable long rains of March/April for fear of crop failure and because they have stored previous seasons' harvest. Moreover, they use most of the pasture resources in the villages because of the large number of livestock they own and therefore contribute to overgrazing. Additionally, they usually use tractor for land preparation and oxen for weeding.

In Muusini and Bondeni, the farms of the well off had better terraces to control erosion, constructed contour ridges and add manure to improve soil fertility and moisture so as to obtain more crop yields. However, the terraces were inadequate and not protected.



NB This map is not an authority on farm boundaries.

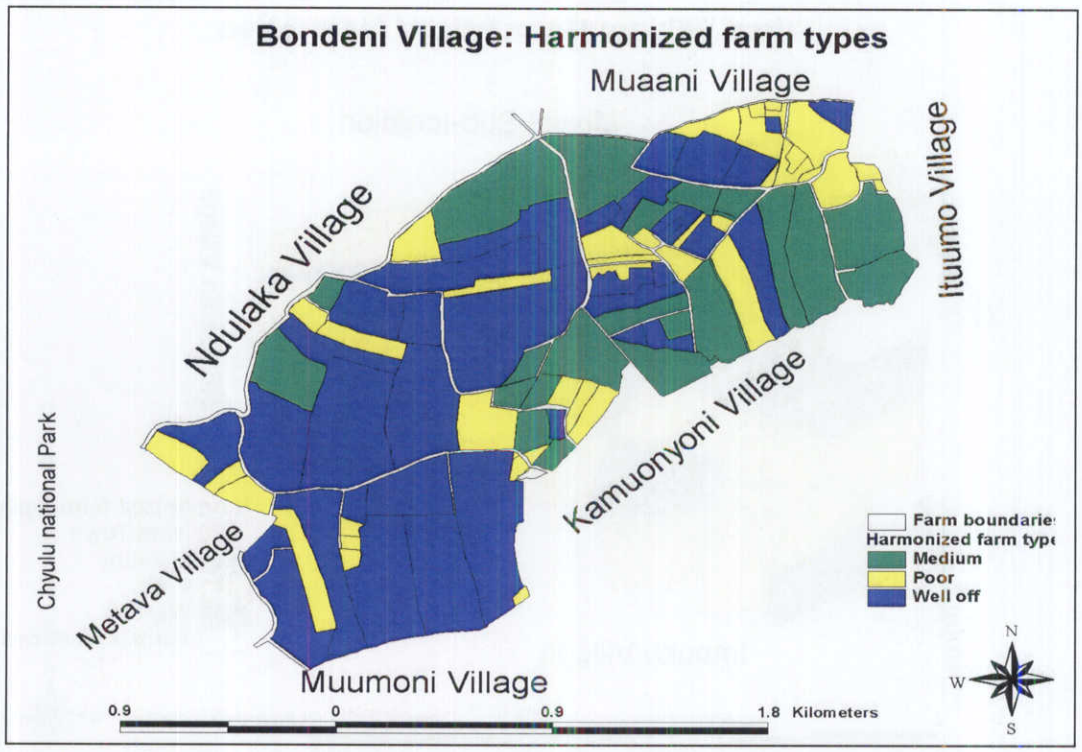
Figure 4.3.1 Harmonized farm types in Muusini Village, Kibwezi Division, Kenya.

Conversely, in Isara and Erankau they rarely constructed physical soil conservation structures but instead used gravitational soil fertility management. The demand for dead fence (that has to be renewed once every six months) to fence off their large farms and pasture reserves is one of the greatest pressure they impact on the existing woodlands.

Socially, their status is high in the villages. They form core members the village elders, some are political leaders while others are working elites and therefore are respected for their socio-economic status.

Medium (Poverty group II)

The medium constituted 26%, 19%, 14% and 12% of the households in Muusini, Bondeni, Isara and Eranakau respectively. A part from owning average farms and livestock numbers (Tables 4.1.4) and moderate farm sizes in Muusini and Bondeni (Table 4.1.6), they too got an average income of 1-3 and 2-4 Euros per day in the Kibwezi and Mashuru villages respectively. Most of the income was remittance from household members involved in off-farm/business activities. Such income means the group can moderately improve their farms and accumulate more livestock resources. In fact they owned about 20-30% of the villages cattle, goats and sheep and therefore like the well off impact a lot of pressure on pasture and soil resources. They are moderately literate and can afford to take their children at least to secondary school level. The poverty II household members reside in semi permanent houses and own semi-permanent food stores.



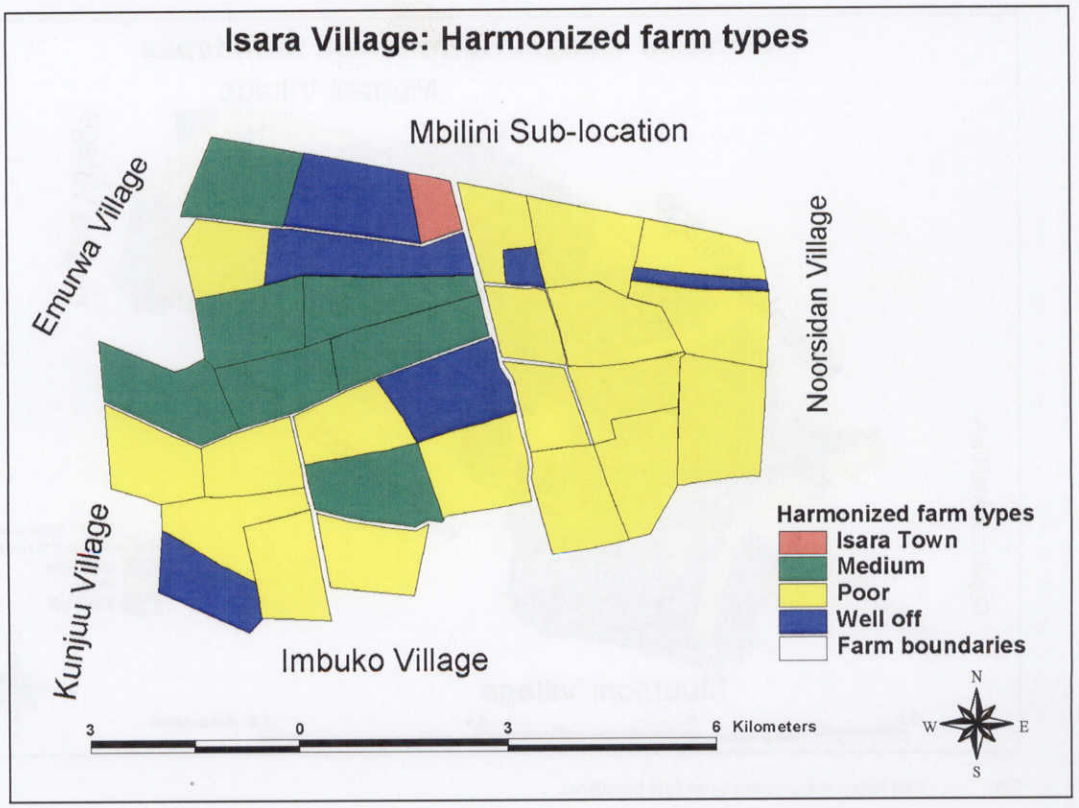
NB This map is not an authority on farm boundaries.

Figure 4.3.2 Harmonized farm types in Bondeni Village, Kibwezi Division, Kenya.

They too require dead fence materials to fence their farms and these means more harvests of wood products and fencing materials from the remaining woodlands of the village. To increase their crop production, some of medium poverty group members in Muusini and Bondeni constructed physical soil erosion control (terraces and cut off drains) and use oxen to prepare their land and in weeding. But, the terraces were inadequate and improperly laid. Similar to the well off, in Isara and Erankau almost all the group members practiced gravitational soil fertility management in order to improve productivity. Unlike the well off, in Muusini and Bondeni the medium poverty group use most of their farmland for cropping in order to target the production of more food for survival and some of them cultivate through out the year. In terms of social status, some members are village elders and also form part of the village committees while most are ordinary village members.

Poor (Poverty group III)

The poor form majority of the village households (average of 66% in all the villages). In Muusini and Bondeni they are crowded in a small portion of the villages area (Fig. 4.3.1 to 4.3.2). Furthermore in the later villages they own less than three hectares virtually forcing them to own too few numbers of livestock. The situation was better for the poor in Isara and Erankau who owned most of the land (Fig. 4.3.3 to 4.3.4) and their farm sizes were similar to those of the well off and the medium. However, in Isara there are tendencies for these categories to sale part of their farm to get income. Just like the poor of Muusini and Bondeni, they too own the least number of livestock in the villages (Table 4.1.4).

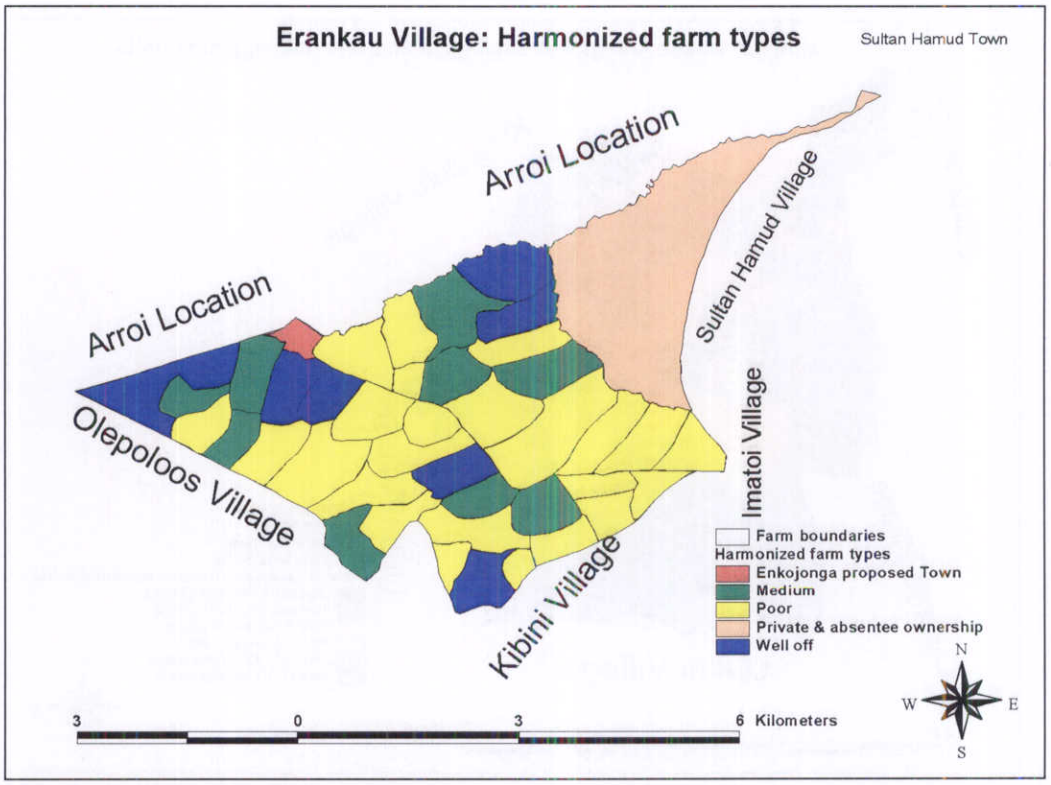


NB This map is not an authority on farm boundaries.

Figure 4.3.3 Harmonized farm types in Isara Village, Mashuru Division, Kenya.

In order to survive the poor in Muusini and Bondeni cultivate almost the whole of their farms and/or throughout year and usually they prepare and weed by the hoe. To conserve their small farms just like the medium poverty group they rarely applied fire in land preparation. Moreover, they get a paltry income of less than a Euro per day though their equals in Isara and Erankau were estimated to get about 2 Euros or less. The low income coincides with their rare involvement in off-farm activities and their limited farm products hardly fetch good market prices.

Consequently, the group members were the most illiterate and their children rarely go beyond primary school level unless supported through the "Harambee spirit". In fact their children are lucky to benefit from the Governments' free primary education. They reside in temporary houses and either have no store or own temporary ones. Temporary shelter and store means more pressure on the already over exploited woodlands. They also get from these woodlands materials to dead fence their farms. Despite this unfortunate status they were not involved in charcoal burning or sale of firewood unlike the well off and the medium. The poor could hardly afford to construct physical soil conservation structures and if any they are inadequate, inappropriate and improperly laid. The poor form ordinary village members.



NB This map is not an authority on farm boundaries.

Figure 4.3.4 Harmonized farm types in Erankau Village, Mashuru Division, Kenya.

(ii) Development of integrated ecological and farm management units, identification of their major constraints and alternative management options

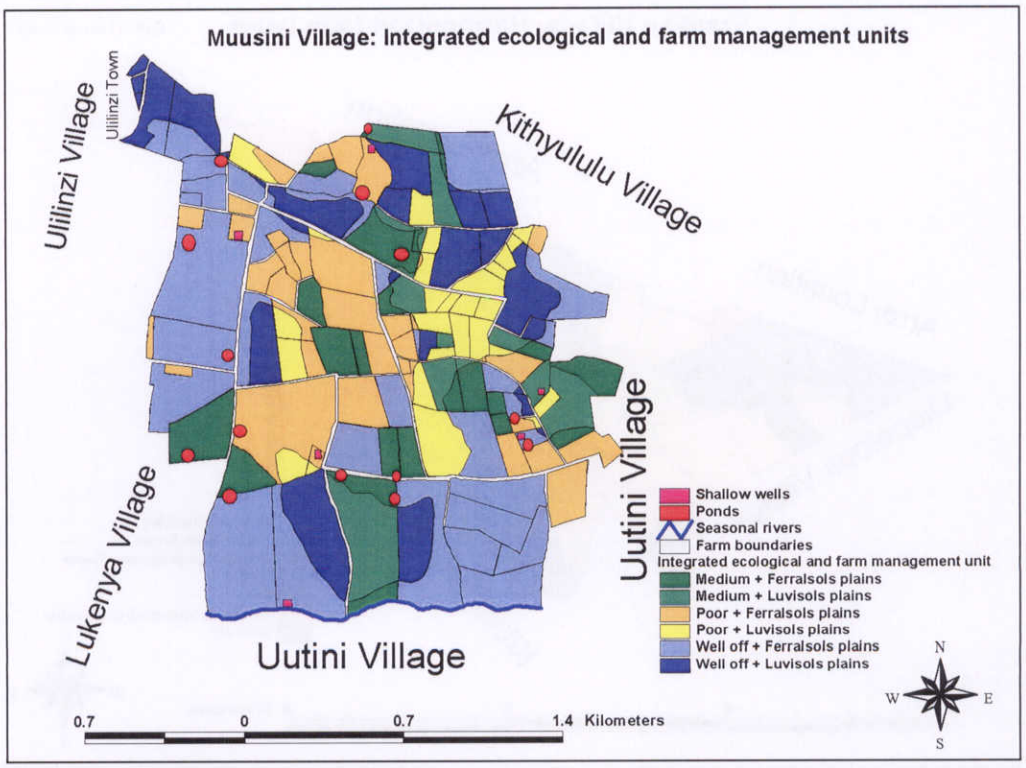
After mapping the farm and landscape types separately for each village, the two layers were overlaid using GIS ARCVIEW to obtain integrated ecological and farm management units. These integrated units formed the basis for analysis of existing land use systems in order to propose appropriate technologies and approaches for sustainable management in the future.

The proposed management options in each unit are guided by three principles of:

- improve and diversify rural income;
- improve yields of food and wood/non-wood products;
- alleviate land degradation.

Muusini Village

Six integrated ecological and farm management units have been identified from the overlay of the ecological landscape types and the harmonized farm types (Fig. 4.3.5). The following are some of the highlights of the current resource status and management on the units.



NB This map is not an authority on farm boundaries.

Figure 4.3.5 Integrated ecological and farm management units in Muusini Village, Kibwezi, Kenya.

Medium + Ferralsols plains

The farm sizes in the unit were small and they were also constrained by financial limitations, inadequate modern technical knowledge and low enrolment of children in schools. Pastures were overgrazed and encroached by bushes/thickets and high value trees and shrubs over exploited for various uses. Additionally, croplands were over cultivated and multi cropped, ponds silted/silting up and chronic water shortage was common compounded by gross pollution and contamination causing health problems. Due to population pressure, most of the unit has been opened up for cultivation with tree cover on cropland < 2%. Soils have temporary water logging problem and they too (both in cropland and woodlands) had relatively higher organic matter content and CEC when compared with other units. However, BSP on cropland was the lowest while it was highest in woodlands and pastures. The low BSP was due to severe soil erosion caused by lack of physical soil conservation structures and application of inadequate and undecomposed manure that comes with chaffer grub pest. Soil moisture stress made crop yields in this dryland-farming zone even lower thereby contributing to lower food nutrition. Farm products within the unit faced market problems related to low prices and transport constraints and outbreaks of pests and diseases. Furthermore, wildlife negatively impacted crop productivity on the unit. Despite the above constraints, farmers within the unit were moderately literate, had average income and therefore with some resources to invest on farm.

Another opportunity is the many variety of livestock the farmers keep though the woodlands and pastures were not sustainably managed. Additionally, the soil, which is the foundation of the unit, is relatively more stable than the Luvisols and therefore easier to manage. In addition, Ferralsols can support relatively optimal production of both cereal and legume crops. Besides, the soils can also be exploited for bricks making and construction of earth dams/pans. Though tree cover was low, croplands within the unit helped in the conservation of some overexploited trees such as *Terminalia prunoides, Boscia anguisitifolia, Senna abbreviata* and *Boscia coriacea.*

Considering the above constraints and opportunities of the unit, we have four alternatives:

- doing nothing policy with continuation of the current management, which means increase in poverty levels, increasing dependence on food aid, decrease in biodiversity and accelerating land degradation, therefore rejected;
- increase of farm production without market and transport consideration – will increase farmers frustrations and collapse of the system and therefore rejected;
- non-land use planning alternatives - population control through family planning and education. However, reduction of fertility rates can have impact on medium and long term only. Food aid will be necessary at critical periods;
- integrated and sustainable management of natural resources with emphasis on appropriate technologies plus market and transport improvements leading to reduced land degradation, conservation of biodiversity and increase in income, food and wood production is the way forward.

Taking into account the above overall alternatives the following technologies are put forward to contribute to the sustainable management of natural resources within the unit:

- awareness creation and training of the farmers on sustainable land management and market intelligence;
- construction of physical soil and moisture conservation structures such as "Fanjuu" terraces and cut off drains and reseeding them with high value grasses such as *Eragrostis superba, Cenchrus ciliaris* and *Panicum maximum*;
- boundary planting with high value multipurpose trees such as *Melia volkensii*;
- planting of living fences and posts of *A. mellifera, A. senegal* and *Commiphora* spp. to crop damages by roaming animals;
- improvement of mixed cropping practices and germplasm for dryland crops;
- fruits production using grafting and budding technique on tree crops known to perform well in the area such as "Apple and Ngowe through dryland farming, Harden, Tommy Atkins, Van dyke and Kent" varieties of mangoes along water courses or under supplementary irrigation for income generation;
- integrated pest management for higher crop, wood, pasture and livestock production;
- bush management and pasture improvement using candidate grasses, legumes, shrubs and high value trees;
- fodder banks with high value indigenous and exotic shrubs mixed with grasses;
- improvement of the productivity of emerging (poultry and bee keeping) and small ruminant conventional livestock (goats and sheep) and the promotion of zero grazing or semi-zero grazing;
- support to prospection, digging and protection of shallow wells through cost sharing arrangements. Coordination with various financial institution will be necessary to achieve this goal;

- improved soil moisture conservation through water spreading, microcatchment, pit planting and tied contour ridges and furrows;
- promotion of roof and rock catchments to directly harvest rain water;
- promotion and planting of natural plants - for example *Moringa oleifera* to treat water;
- promotion of environmentally bricks making techniques by use of compression machines rather than the use of firewood for curing the bricks. Collaboration with financial institutions as mentioned above will be necessary to acquire the machines;
- compensation of damages by wildlife to crops and encouragement of eco-tourism;
- improved production will also require similar progress in transport and communication networks to the markets.

More on some these technologies and their impacts plus ecological advantages and constraints of candidate grasses are in Appendix VI and VII.

Medium + Luvisols plains

Constraints within the unit are similar to those of Medium + Ferralsols plains, except that the situation of land degradation was more severe due to susceptibility of the unit to soil surface crusting and sealing. Furthermore, the unit is less stable than the above due to its nature. Consequently, SOM, P and BSP levels were low both in croplands and woodlands but more severe in the former because of severe erosion caused by same management factors as in Medium + Ferralsols plains. However, unlike in the Medium + Ferralsols plains, farmers constructed few terraces and cut off drains though the structures were in sufficient and inappropriately laid. Most of the opportunities within the unit are same as the above unit but the unique ones to the unit include, that the farmers have the will for soil, plant and water conservation because they constructed some physical soil conservation while retaining some high value over exploited indigenous species such as *Melia volkensii, Boscia anguisitifolia, B. coriacea, Platycleyphium voense, Lannea stuhlmanii* and *Senna abbreviata* on croplands. Based on these pros and cons of the unit, the technologies for sustainable management are the same as those of Medium + Ferralsols plains with more emphasis on increase in vegetation cover especially on croplands.

Poor + Ferralsols plains

The least fortunate members of the community in modern education who own very small farms settle in the unit and they are too constrained by critical financial limitations and inadequate modern technical knowledge. The rest of the constraints within the unit were similar to that of Medium + Ferralsols plains if not worse. In spite of the difficulties, farmers in the unit are desperate for support to improve their farms and there is available labour for application of acceptable technologies. As a result the technologies required in this unit should aim to improve and diversify income while simultaneously improving food, wood and forage/fodder production. Consequently, the following technologies/approaches are recommended:

- diversification of sources income through tree nurseries (sale of seedlings) and off-farm professional training, for example tailoring, masonry and carpentry; and
- promotion of affordable soil conservation structures such as grass strips and trash lines along contours.

The rest of the technologies are same as that of Medium + Ferralsols Plains.

Poor + Luvisols plains

The constraints and opportunities within the unit are similar to those of Poor + Ferralsols plains except that the soils were less eroded due to the establishment of some physical soil conservation structures in form of terraces and cut off. Furthermore, due to very small farm sizes the pressure on the unit was higher than that of Medium + Luvisols plains. Consequently, the suggested technologies are similar to those of Poor + Ferralsols plains but requires more vegetation cover in form of high value trees, shrubs and grasses due the susceptibility related to surface sealing and crusting common within the unit.

Well off + Ferralsols plains

The unit covered the largest part of the village and was mainly under woodlands and pastures. The major socio-economic constraints in the unit were market and inadequate modern technical knowledge in resources management. Other problems include bush encroachment, overgrazing, low quality livestock, low soil fertility especially in woodlands, low crop yields, very low tree cover on cropland (cover of 1%) and the rest were similar to those of Medium + Ferralsols Plains. Opportunities include relatively high income and therefore can afford to improve crop, tree, pasture and livestock production. Additionally, the farmers of the unit were the most literate and constituted village elders/leaders and therefore ease in communicating with them. Moreover, they have already constructed some physical soil conservation structures on cropland yielding moderate erosion status. Consequently, the following technologies and approaches are appropriate to the unit:

- the construction of earth dams and water pans. Because the farmers have plenty of land to accommodate they should be encouraged to excavate pans/dams through cost sharing as explained earlier. Once constructed the runoff harvested water can be a source of income through sale and irrigation of horticultural crops;
- sustainable management and conservation of the indigenous woodlands through a well planned harvesting of wood and non-wood products (for example selective cutting/felling) as incentive to the farmers. A well managed woodlands and pastures will too contribute to better water quality;
- bush management, live fencing and reseeding of parts of the woodlands and pastures; and
- improvement of livestock breeds with high yielding but tolerant to drought, pests and diseases. For example Boran cattle to breed with the local Zebu, Galla goats and Duper sheep with the respective local breeds.

The rest of the technologies are the same as those of Medium + Ferralsols Plains.

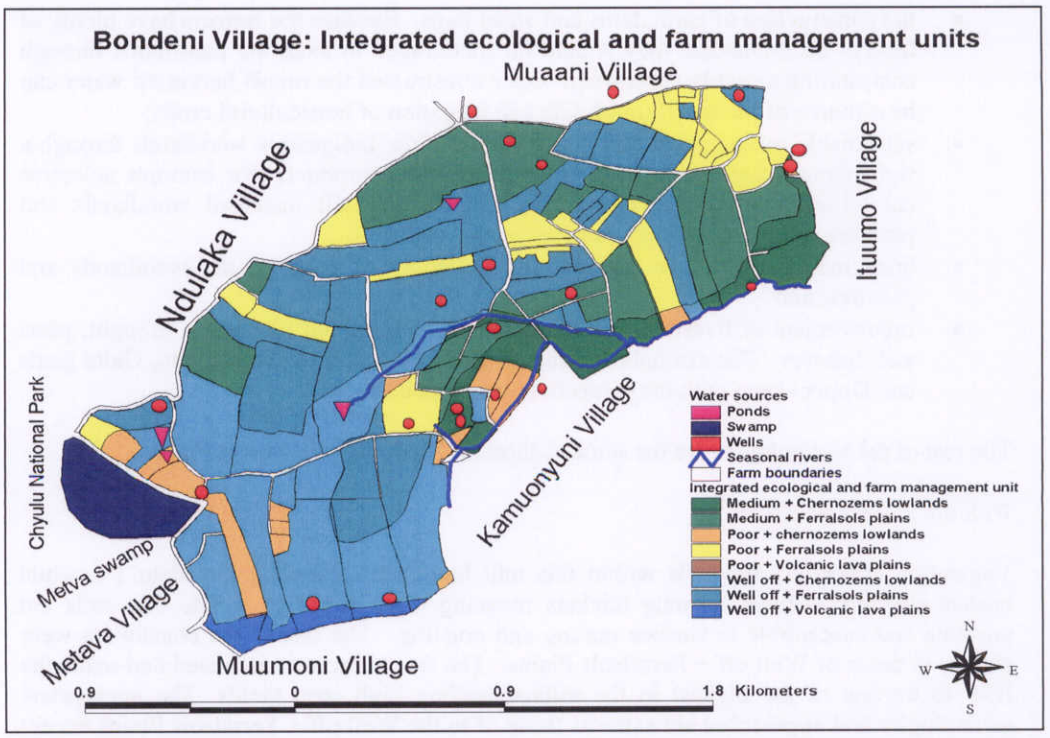
Well off + Luvisols plains

Vegetation cover on croplands within this unit has been cleared to less than 1% while bushes covered pastures forming thickets reducing grass cover to < 3%. The soils are unstable and susceptible to surface sealing and crusting. The rest of the constraints were similar to those of Well off + Ferralsols Plains. The few terraces constructed had made the BSP to be one of the highest in the village leading high crop yields. The appropriate technologies and approaches are same as those of to the Well off + Ferralsols Plains except that more vegetation cover will be required on croplands.

In all the units, soil moisture stress, chronic water shortages/gross contamination and pollution, inadequate fodder and wood and non-wood products, decrease in biodiversity, soil erosion, low soil fertility, poor livestock breed and inadequate modern technical knowledge were the constraints although the impact increased with poverty. Additionally, crop yield were low not only due to low fertility and moisture stress but also due to infestations of pests and diseases and wild animals causing frequent annual food insecurity. The farmers also have no access to irrigation opportunities. In order to feed the ever-increasing population, the farmers are forced to open up more woodlands (especially the Luvisols plains) for cultivation mostly with annual crops and hence, expose more soils to bare surfaces. Moreover, in the good rainy years there is over production in this annual crop based farming system and therefore low and unreliable market prices. To sustainably manage the units, priority of the well off has to be the improvement of woodlands/pasture and livestock due to their importance under this management while crop/tree production has to be priority for poverty groups medium and poor. It is also important to note that the well off have more resources to implement better resource management than the other poverty groups.

Bondeni Village

Because of the occurrence of more ecological landscape types, Bondeni Village has eight integrated ecological and farm management units and therefore more than that of Muusini Village (Fig. 4.3.6).



NB This map is not an authority on farm boundaries.

Figure 4.3.6 Integrated ecological and farm management units in Bondeni Village, Kibwezi, Kenya.

Medium + Chernozems lowlands

The unit's low lying landscape was one of the most severely eroded in the village both in the croplands and woodlands though the impact was most on croplands where fertility was the lowest due to lack of physical soil conservation structures. The CEC was high but BSP was very low. Further, the soils are sticky in rainy seasons and prone to flooding in rainy periods and therefore difficult to till by mechanical means. Possibility of mechanization is further made remote by the small farm sizes. Water sources were grossly contaminated and polluted due to lack of protection and siltation. Socio-economic constraints were similar to that of Medium + Ferralsols plains of Muusini. However, income per day and modern technical knowledge was lower than that of the same poverty group in Muusini. The limited knowledge in agricultural production is as a result of limited technical advice from natural resource management based institutions. Similarly, farm sizes were smaller than that of medium poverty in Muusini. Tree cover on croplands was less than 4% increasing its vulnerability to erosion. Water sources were inadequate, grossly polluted and contaminated. Although land resource degradation was high, croplands have helped conserve some over exploited high value tree species and the lowlands had higher grass cover than Muusini (> 30%). Maize was the candidate crop for the site though green grams and pigeon pea too give average yields. However, wild animals from neighbouring Chyulu National Park negatively impact crop yields especially pigeon pea and maize. Few of the farmers in the unit apply fire in land preparation. Other opportunities were similar that of Medium + Ferralsols Plains of Muusini. Consequently, technologies/approaches are recommended are similar to that of Medium + Ferralsols Plains with exception of bricks making, which is not possible here due to differences in soil types.

Medium + Ferralsols plains

Soil erosion within the unit (both in the woodlands and croplands) was moderate though fertility was low especially in the woodlands due lack of soil conservation and overgrazing. Within the village, the unit had high maize and pigeon pea production. The soil was also used for bricks making. The few wells that fall within the unit had very saline water and were unprotected. Other characteristics were similar to Medium + Ferralsols plains of Muusini, hence with similar proposed technologies.

Poor + Chernozems lowlands

The soils of the unit both in the croplands and woodlands had low P, high CEC and low BSP meaning that it requires a lot of effort to improve the low fertility.
The low fertility was as a result of severe soil erosion due to improperly and inadequately laid physical soil conservation structures. The consequence was dislodging of crops due to the impact of high run off (Plate 4.3.1). Further, maize production within the unit was the lowest within the village. Conversely, soil erosion in the woodlands was moderate due to higher grass cover than Muusini Village and the lower number of livestock. Socio-economically, the poor farmers of the units had similar problem to that of the Poor + Ferralsols plains and the Poor + Luvisols plains of Muusini. In fact their income level was even low than that of Muusini, meaning that they have very limited resource to improve natural resource management. The big advantage of this unit is that they do not use fire in land preparation. The recommended technologies in this unit are the same as those of Poor + Luvisols plains of Muusini.



Photo by A. Mohamed 2004.

Plate 4.3.1 Dislodging of maize crops on Chernozems soils in Bondeni Village, Kibwezi, Kenya. It is caused by the impact of high runoff caused by lack of terraces or inappropriately laid physical soil conservation structures.

Poor + Ferralsols plains

Poor + Ferralsols Plains faced very acute shortage of water resources because there were no water sources were very limited within the units. Farmers were one of the poorest in terms of income and other resources just like Poor + Chernozems Lowlands. Croplands had high CEC and low BSP due to severe erosion (though few improperly laid and eroded terraces existed) while the few remaining woodlands had low CEC and high BSP. However, crop fields had higher crop production (maize and pigeon pea) than the Poor + Chernozems lowlands. Other resource management constraints and appropriate technologies/approaches were similar to those of Poor + Ferralsols Plains of Muusini.

Poor + Volcanic lava plains

The unit covered only a very small portion of one farm south of the village. Currently, it is used for the growing of maize and beans.
The major constraints were severe soil erosion due to bareness and rockiness but relatively fertile due to volcanic nature of the parent material. However, socio-economic constraints were similar to other units owned the poor. The recommended technologies are contour stone bunding and grass strips along the contours to control soil erosion.

Well off + Chernozems lowlands

The unit covers most of the Chernozems lowlands and is owned by the well off farmers endowed with resources similar to those of Well off + Ferralsols plains and Well off + Luvisols plains of Muusini. The wells found within the unit had water that were relatively more fresh than other sources within the village though they were grossly contaminated and polluted due to lack of protection, siltation and use of contaminated containers. The amount of water available was inadequate. Ponds found within the unit were silting/silted up. Croplands had high organic matter and CEC but low P and BSP due the lack of physical conservation of soil erosion. The soils are also sticky and muddy in rainy seasons. However, the situation was better off in the woodlands. Though maize and pigeon pea yields were one of the highest in the village, other crops did not perform well.

The recommended technologies/approaches are similar to those of the Well off + Ferralsols plains of Muusini.

Well off + Ferralsols plains

Well off + Ferralsols plains integrated unit covers the largest part of the village. Although most of the natural vegetation has been cleared, it still retains the large tracts of woodlands and pastures. Socio-economic characteristics of the unit are same as that of Well off + Chernozems lowlands. The wells found in the unit were protected or semi-protected though the ponds were silting/silted up.

Crop yields were relatively moderate when compared with that of Well off + Chernozems lowlands and croplands were the most well conserved with physical soil conservation structures through inadequate. Consequently, though these soils had low P and CEC they had high SOM and BSP. On the other hand the woodlands and pastures had higher CEC but lower SOM and BSP. The recommended technologies/approaches are similar to those of the Well off + Chernozems lowlands. In addition, the promotion of farmer-based eco-tourism will provide incentives to the conservation of wildlife.

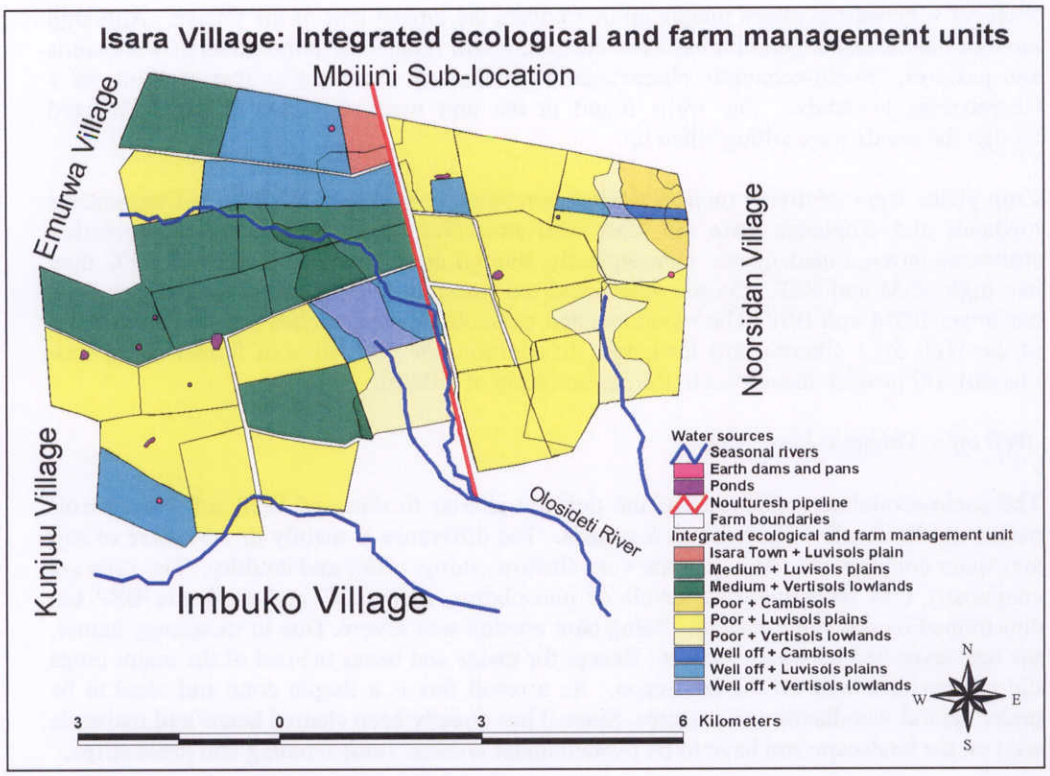
Well off + Volcanic Lava plains

The socio-economic constraints of the unit are similar to those of Well off + Ferralsols plains and Well off + Chernozems lowlands. The difference is mainly in the nature of soil and water components. The soils are very shallow, stony, rocky and bouldry. The soils are chemically rich with moderate levels of phosphorus, high CEC and moderate BSP but constrained by moisture content. Being bare erosion was severe. Due to its spongy nature, the landscape had no water sources. Except for maize and beans the rest of the major crops did not perform well on the landscape. As a result this is a fragile zone and ideal to be under natural woodlands and pastures. Since it has already been cleared beans and maize do well on the landscape and have to be planted under contour stone bunding and grass strips.

In summary all the units faced population pressure, inadequate technical knowledge, water shortages (quantity and quality), financial constraints, soil erosion, negative impacts of wildlife, pests and diseases. The *Chernozems* owned by all the poverty groups are facing erosion problems because there are no or have minimum physical soil and water conservation structures. Even the few that exist were inadequate and improperly laid. Furthermore, the well off applies fire as a land preparation tool. However, under the current management, organic carbon and BSP were still higher on farm owned by the well off (Table 4.3.2) due to more manure application as a result of the high number of livestock owned. Moreover, though high in the landscape soil erosion was also relatively lower in farms of well off. The integrated units on the *Ferralsols* plains had terraces mainly on the farms owned by the well off (though not adequate). Consequently the organic carbon and the BSP were more than double under well off than medium and poor categories. The medium and the poor apply very inadequate conservation measures. The volcanic lava plain both under the poor and well off farmers were over exploited, bare with no soil conservation measures and had severe soil erosion. In woodlands and pastures, the reverse of the cropland was observed. Both in the Ferralsols and Chernozems, BSP was highest on farms owned by the medium and poor, therefore more fertile. This can be related to the few number of livestock owned by the poor that graze on the pastures. The problems/constraints of woodlands and pastures under all the units are similar to those of Muusini Village except that the adversity is less due to grazing opportunities in the nearby Chyulu National Park and Kibwezi Forest Reserve.

Isara Village

Nine integrated ecological and farm management units (one of them covered by Isara Centre) have been identified in the village (Fig. 4.3.7).



NB This map is not an authority on farm boundaries.

Figure 4.3.7 Integrated ecological and farm management units in Isara Village, Mashuru, Kenya.

The Vertisols lowlands includes average data for those of volcanic and basement origins while Luvisols plains include that of ferral chromic Luvisols, reddish ferric Luvisols and brownish ferric Luvisols.

Isara Town + Luvisols

Isara Town houses the office of the area chief. There are also Isara Primary School and churches at the centre. The center acts as the nearest market for farm products. Water to the center is obtained from Noulturesh pipeline (Fig. 4.3.7). The center needs policies that will encourage its growth as market incentive for increased on-farm production.

Medium + Luvisols plains

The unit is under the management of agropastoralists who earn average income (about two Euros) from animal resources especially cattle, sheep and goats. The agropastoralists were also semi-literate, inadequate in scientific technical knowledge and use the existing woodlands to get firewood, fencing and construction materials. Ponds found within the unit silted/silting up and with no management at all. Consequently, water resource was inadequate and grossly polluted. The use of Noulturesh pipeline was expensive and inaccessible for irrigation. Croplands were severely eroded with low fertility (Table) while the woodlands had high P and CEC but too low in BSP due to overgrazing and severe erosion caused by the high livestock and wildlife population. Physical soil conservation was lacking even on cropland and farms were continuously cropped in all rainy seasons with maize and beans. The current production is high but if land degradation continues at this rate, then it is likely to decrease. Crop and pasture yields were further reduced by wild animals, frequent droughts and pests and diseases.
Except the annual crops, the croplands had limited tree cover. Moreover, inadequate pastures were a common problem due to free grazing, sharing of pasture resources and large heads of livestock. The agropastoralists did not use fire in land preparation and the farms have kraals "bomas" full of animal manure that was rarely applied directly into croplands. The strongest tangible resource conservation opportunities were the Masaais not eating game meat, conservation of *Acacia tortilis* trees, planning of goats/sheep breeding for lactation to coincide with rainy seasons, sustainable business with live animals, gravitational soil fertility management and the fencing and management of "Olopololi" individual pasture reserves. As a result the following technologies and approaches are recommended:

- awareness creation and training of the farmers on sustainable land management and market intelligence;
- construction of physical soil and moisture conservation structures such as fanjuu terraces and cut off drains in pastures and croplands and reseeding them with high value grasses such as *Eragrostis superba, Digitaria milanjiana, Cynodon plectostachyus, Cenchrus ciliaris* and *Panicum maximum*;
- woodlots and fodder banks with high value multipurpose trees such as *Melia volkensii* and *Serracocomopsis pallida*;
- fruits production using grafting and budding technique on tree crops known to perform well in the area such as "Apple, Ngowe, Harden, Tommy Atkins, Van dyke and Kent" varieties of mangoes for income generation;
- integrated pest management for higher crop, wood, pasture and livestock production;
- bush management and pasture improvement using candidate grasses, legumes, shrubs and high value trees. See Appendix for more details;
- improvement of the productivity of small ruminants (goats and sheep) and cattle with Galla, Duper and Boran breeds respectively;
- improved soil moisture conservation in pastures through water spreading and microcatchment;
- promotion of roof catchments;
- promotion and planting of natural plants - for example *Moringa oleifera* to treat water;
- promotion of environmentally bricks making techniques by use of compression machines rather than the use of firewood for curing the bricks.

Collaboration with financial institutions as mentioned above will be necessary to acquire the machines;

- compensation of damages by wildlife to crops and promotion of agropastoralist based eco-tourism and involvement of local communities in wildlife management similar to that of Merueshi Individual Group Ranch; and
- upgrading of "olopololi" indigenous fodder reserves through species and management diversifications.

Medium + Vertisols lowlands

The socio-economic constraints within the unit was same as that of Medium + Luvisols. The unit was solely used as pastures and there were no ponds, dams or water pans due to the occurrence of shrinking and swelling clays. In rainy seasons, the landscape too becomes sticky and muddy and the soils had high SOM, CEC and BSP but P was low. Due to these constraints, shrub and annuals covered the unit's landscape with exception of *Acacia tortilis* woodlands along seasonal watercourses.
Other constraints and opportunities are similar to those pf Medium + Luvisols plains. Consequently, this is a fragile zone, severely eroded and ideal to be under natural pastures. It can too be used for subsistence dryland farming but with water harvesting structures such as bunds and drainage furrows to improve water percolation into the soil and remove excess water. The unit can also be used for pasture improvement with suitable grasses and shrubs such as *Sporobolus helvolus* and Oloorok kileling.

Poor + Cambisols hills

The unit is owned by resource poor agropastoralists with very low income per day. Consequently, finance compounded by modern illiteracy is big constraint. They own large farms but with few livestock hence their pastures are exploited by well off and medium that own large herds. The unit is excessively eroded not only due to overgrazing but also its stony, bouldery, shallow and hilly nature. The hills were also covered by deciduous natural vegetation an the soils are faced by moisture stress due to aridity. The unit has no water sources due to its volcanic nature. But the zone has unique vegetation and therefore is important for biodiversity conservation. The appropriate technologies/approaches include:

- ecotourism as explained under Medium + Luvisols plains;
- biodiversity conservation through sustainable management and harvesting of wood and non-wood products. The unit is a fragile zone and ideal to be under natural woodlands and pastures and for recreation. It has special plant species and therefore deserves to be conserved as a biodiviersity conservation and catchment protection zone;
- farming is possible only under contour stone bunding and grass strips; and
- pasture improvement can also be undertaken with appropriate species such as *Chrysopogon aucheri* and *Grewia* spp.

Poor + Luvisols

Socio-economic constraints are same as those of Poor + Cambisols hills and the soils within the unit are susceptible to surface sealing and crusting hence prone to severe soil erosion both in the croplands and woodlands. SOM and BSP both on cropland and woodlands were low while P and CEC were high. Therefore a lot of effort is needed to conserve the soils.

Moreover, *Commiphora africana* bushes and *Ipomea kituiensis* pasture weed have encroached the unit and are limiting coverage of grasses especially in the ferric Luvisols plains. Overgrazing and lack of physical soil conservation structures were the most important factors that were encouraging the degradation. Ponds found within the unit were too silting/silted up and water grossly polluted and contaminated.
The opportunities that exist include availability of land and the rest of the opportunities plus technologies and approaches are the same as those of Medium + Luvisols plains.
However, here emphasis will have to be given to diversification of sources of income as explained under Poor + Ferralsols plains of Muusini.

Poor + Vertisols lowlands

Management and socio-economic obstacles and land use were similar to that of Poor + Cambisols hills leading to excessive erosion. The biophysical constraints and proposed technologies were similar to those of Medium + Vertisols.

Well off + Cambisols hills

The unit is owned and managed by well off agropastoralist who owns large herds of diverse livestock. The well off also formed elders/leaders and the most literate in terms of modern education. They too had the highest income and therefore have the resources to improve their farm resources. The unit was under woodlands and pastures. Although the CEC was high the BSP was low due excessive erosion. Other biophysical constraints and recommended technologies were same as those under Poor + Cambisols hills.

Well off + Luvisols plains

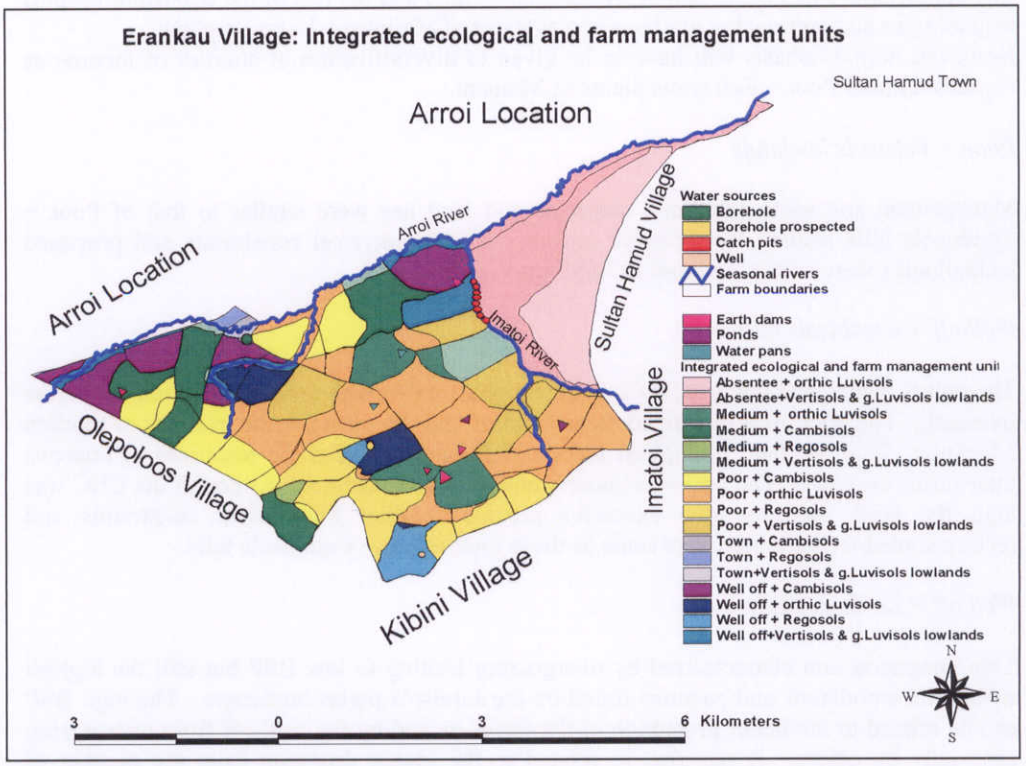
This integrated unit characterized by overgrazing leading to low BSP but still the highest within the woodlands and pastures found on the Luvisols plains landscape. The high BSP can be related to the better protection of the farms owned by the well off from overgrazing especially by others. It can also be related to the higher dropping from the number of livestock grazing in the unit. Overgrazing is causing sitation of the existing ponds and dams within the unit. Other constraints are encroachment by bush and invader plants as explained under Medium + Luvisols plains.
Similarly, the technologies are the same but in addition, the construction of earth dams and water pans has to be supported. Because the agropastoralists have financial resources they should be encouraged to excavate pans/dams through cost sharing as explained earlier. The dams/pans should then be well fenced with live fences of *Commiphora* spp and its inlets and compounds reseeded with appropriate grasses like *Digitaria milanajiana* and *Cynodon plectostachyus*.

Well off + Vertisols lowlands

The constraints, opportunities and technologies of the well off + Vertisols lowlands are similar to that of medium + Vertisols lowlands except that overgrazing pressure is more causing the BSP to be lower and it is likely increase with increase in human and livestock population.

Erankau Village

Eleven integrated ecological and farm management units (one them covering a combination of proposed town centre and three on land owned by a long time absentee farmer) have been identified (Fig. 4.3.8).



NB This map is not an authority on farm boundaries.

Figure 4.3.8 Integrated ecological and farm management units in Erankau Village, Mashuru, Kenya.

In this analysis, the three units under the town and the three under absentee farmer will be treated as one. Though they are potentially to be put to different land uses and management, currently, they are free for all to use. This reduces the units technically to 11. Additionally, although each agropastoralist knows the extent of his farm and the final authority of its use lies with the owner, the village is under group ranch. However, its is currently earmarked for sub-division and this may change some of existing farm boundaries. Group ownership also means village members have to share the pastures and wood products but not the individually owned water, croplands and "Olopololi" resources. Consequently, the study is based on the assumption that the boundaries will the same even after subdivision and that the existing status of the woodland and pasture resources is not only caused by the activities of an agropastoralist but also neighbours with his authority.

Absentee + orthic Luvisols plains, Absentee + Vertisols and gleyic Luvisols lowlands, Town + Cambisols, Town + Regosols and town + Vertisols and gleyic Luvisols lowlands

The unit is currently free for all to graze and benefit from its wood and non-wood products. As a result, high value plants such as *Balanites* spp, *Acacia* spp and *Grewia* spp., *Combretum apiculatum* and *Terminalia brownii* have been overused. The pastures were overgrazed causing excessive soil erosion. A sample from Absentee + orthic Luvisols plains indicated sand to be forming 90% of the texture (Appendix II Ref No. 10). SOM, P and CEC were low but BSP was high due to impact of droppings from the large livestock population grazing on the unit. The unit houses the only reliable water source in the village, that is, the Erankau borehole. The borehole attracts large concentration of livestock and people and has caused soil and plant degradation. An interim way forward for the site is placing it under the village committee to sustianably managing it through a well-planned resource use. The products from the site can be an incentive. The Rivers Arroi and Matoi seem to lie along fault line and therefore more ground water sources could be prospected.

Medium + orthic Luvisols plains

The income and management constraints are similar to those Medium + Luvisols plains of Isara. Furthermore, Marketing of milk products and wood products were unique constraints in the village. Additionally, the croplands here have high SOM, P and CEC but BSP was average.
The high fertility is explained by the application of gravitational soil fertility management giving moderate crop yields. The pastures and woodlands had moderate fertility but highly encroached by *Acacia* spp – *Premna resinosa* bushes/thickets reducing grass cover to an average cover of 21%. Earth dams/pans were grossly contaminated and pollution and silted/silting up. The opportunities and technologies are similar to those of Medium + Luvisols plains of Isara.

Medium + Cambisols plains/hills

Socio-economic constraints were same as those of Medium + Luvisols plains of Isara. Croplands were severely eroded making the BSP to be low though the P and CEC were very high. Maize production was the highest in the village. In the woodlands, the unit housed unique and high value species such as *Rhamnus staddo* and *Sclerocarya birrea*. erosion was moderate to severe. Consequently, the BSP was low. P was also low. Grass cover was over 70% though overgrazed. Consequently, we either have to reduce the number of animals or increase production of forage and fodder.
Other opportunities and technologies are similar to those of Medium + Luvisols plains of Isara. Additionally, conversion of the hill sites into community based biodiversity conservation and catchment zones while tapping the high value species and forage through well-planned sustainable harvesting and resource use is the way forward.

Medium + Regosols hills

The unit had similar socio-economic constraints to those of Medium + orthic Luvisols plains. The unit was covered by rocky and stony and extremely shallow soils on steep slopes and with extreme moisture stress. Soil erosion was severe due to overgrazing and over exploitation of high value trees and shrubs leading to low soil fertility. The woodlands are only over exploited without management. A well in the zone was grossly polluted and contaminated because it was not protected. Grasses comprised 24% of the total cover. As a result, the unit is ideal for biodiversity conservation explained as above.

Medium + Vertisols and gleyic Luvisols lowlands

The unit had similar socio-economic constraints to those of Medium + orthic Luvisols plains. The sites are overgrazed and under excessive erosion translating into the lowest BSP within the village. No management was in place though it is a fragile zone and therefore ideal to be under natural woodlands and pastures. It may be used for subsistence cereal growing but has sticky and slippery properties.

Poor + Cambisols hills/plains

Socio-economically, the unit has similar limitations similar to Poor + Cambisols hills of Isara and biophysical constraints similar to Medium + Cambisols hills/plains of Erankau. The low income especially for the units on the hills means more erosion and loss of soil fertility. Therefore, support to the agropastoralists to conserve the fragile environment is requires as explained under Medium + Cambisols plains/hills.

Poor + orthic Luvisols plains

Socio-economically, the unit has similar limitations to Poor + Luvisols of Isara and biophysical constraints similar to Medium + Cambisols hills/plains of Erankau.

Technical support similar to that of the Poor + Luvisols of Isara is necessary especially on soils and water conservation, promotion of the planting of high value trees, bush management and reseeding.

Poor + Regosols hills

A part from income and illiteracy limitations, the steep slopes and other biophysical problems indicated under Medium + Regosols hills retard development in the unit. The proposed solutions are same as those of the Poor + Cambisols hills/plains.

Poor + Vertisols and gleyic lowlands

A part from more financial support in form of diversification of income, other technologies are same as those of Medium + Vertisols and gleyic Luvisols lowlands

Well off + Cambisols hills/plains

The unit is under the management of agropastoralists with high annual income, the most literate and who socially hold high status within the village. They too own large number of livestock and are involved in livestock business. Consequently, they have resources to improve their farms. The large numbers of livestock are responsible for overgrazing in the village pastures and the resource managers have inadequate modern technical knowledge. Biophysical constraints and technologies are similar to that of Medium + Cambisols hills/plains of Erankau. Additionally, the promotion of eco-tourism and compensation for wildlife damages need to be pursued.

Well off + Orthic Luvisols

The socio-economic difficulties are similar to that of the Well off + Cambisols hills/plains while the biophysical limitations and technical solutions are the same as those of the Medium + orthic Luvisols plains though reduction of the number of livestock is paramount.

Furthermore, the unit houses a prospected but untapped borehole. Therefore, there is to technically and financially support its drilling.

Well off + Regosols hills

The grazing of large number of animals on the steep and fragile Regosols hills contributes to soil erosion and catchment degradation. As a result the solutions to Medium + Regosols hills units also apply here but emphasis on destocking, reseeding and soil conservation is very necessary

Well off + Vertisols & gleyic Luvisols lowlands

The unit is fragile and the large number of animals has caused overgrazing that decreased BSP to 10 in parts of the unit. Therefore similar recommendations to that of the medium/poor + Vertisols & gleyic Luvisols lowlands are suggested.

(iii) Synthesis of the major cross cutting constraints in all the ecological and farm management units, projections of their effects and alternative management options

The major constraints cutting most of the units were high poverty levels, population pressure, illiteracy, low and fluctuating prices of farm products and inadequate technical and financial inputs. All these constraints are in one way or the other related to policy issues. Others were high soil erosion and low soil fertility, low crop yields and therefore less food nutrition, inadequate pastures and low quality livestock breeds and over exploitation of high value trees and shrubs and chronic water shortages plus gross pollution and contamination that causes health problems (Fig. 4.3.9). Consequently, under the current trend the rates of these major constraints are likely to increase in the future.

(a) High poverty levels

Over 60% of the households in Muusini and Bondeni are considered as poor. The poor in these villages own an hectare or less of land, not more than two, five and 10 heads of cattle, goats and poultry respectively and shelters in temporary residential houses.

The poor rarely accesses off farm employment and their children hardly ever go beyond primary (elementary) school level as a result of low income (less than Kshs 80 per day, about 0.9 Euros).

Isara and Erankau Villages the agropastoralists consider 70% of their population as poor based on number of animals especially cattle. The poor has less than 20 heads of cattle in both villages and less than 10 and 30 goats/sheep respectively in Isara and Erankau respectively. During the drought periods they are the most affected forcing them to request from the better off milking cows (the example of Erankau). The pastoralists are well off compared to the farmers but only if the drought years/periods are not long enough to kill their stock. Ones the animals die they become destitute very fast and they basically have neither grain stores to fall back to nor alternative sources of income.

The high poverty level was caused by many interwoven socio-economic and biophysical factors. unreliable rainfall, fluctuating prices and inaccessible markets, exploitation by middlemen, lack of alternative sources of income and therefore increase in unemployment, inadequate and poor financial and technical support and shortage of on-farm labour.

Others were low soil fertility and severe soil erosion, frequent outbreaks of pests and diseases (human, crops, trees, livestock), poor storage facilities, expensive and unavailable chemical fertilizers and farm inputs including appropriate seeds, inadequate knowledge on modern farming, population pressure and the subsequent land subdivision. Low crop and livestock yields, the burden of sharing natural resource use, grossly polluted water sources, lack of water for irrigation, destruction of crops by wild animals, frequent shortage of pastures and unemployment were the other causes of the high poverty.

Consequently, the construction of physical soil and water conservation structures is remote and the poor resorts to hoeing as the major alternative to land preparation. Moreover, the yields per hectare of the major income generating crops such as maize, cow pea and green grams is low compared to the well off and medium poverty groups. The low productivity can be related to over cultivation. As a last alternative, they resort to migration to towns in search of jobs and expansion of croplands and therefore contribute to the degradation of the environment.

Further, due to inadequate institutional support they were in a state of desperateness and feel abandoned by the same institutions that were meant to be supporting them. Although few in number, the well off and medium poverty groups use most of the villages' resources. For example, they own most of the livestock resources and therefore most of the pasture degradation in village was by their livestock.

(b) Population trends

By end of 2002, the villages had population densities of 69, 212, 20 and 11 persons per km^2 in Muusini, Bondeni, Isara and Erankau Villages respectively. This means that while villages in Kibwezi are getting saturated while those of Mashuru are relatively sparsely populated. However, at annual population growth rates of 1.94% in Kibwezi and 4.6% in Mashuru (GoK 2001c), in 20 years time, even in Mashuru the densities will double (Table 4.3.1). By 2024, there will be 237,403, 771 and 625 more mouths to feed. To do so, an extra 47400, 80600, 154200 and 125000 kg of cereals will be required per annum (at 200 kg of cereal and legumes grains per person per year - Mergeai Per. Comm.. 2004).

Table 4.3.1 Population projection in four study villages of Eastern Kajiado and southern Makueni, Kenya: 2004 to 2024.

Population indicators	Year/Village											
	2004				2014				2024			
	Muusini	Bondeni	Isara	Erankau	Muusini	Bondeni	Isara	Erankau	Muusini	Bondeni	Isara	Erankau
Population	500	857	527	589	607	1039	826	924	737	1260	1298	1451
No. of households	83	129	53	98	101	157	83	154	123	191	130	242
Density	71	224	12	22	87	266	18	35	105	323	28	54

Since expanding the area under cultivation can no longer increase production, thorough planning and sustainable management technologies and practices have to be in place to avoid more adverse impacts on the already degraded natural resource components. This population trend has two implications in the current scenario: either open up more land to cultivation and degrade further the natural resources or we shall see a second population movement not from the highlands to the drylands (as was the case of 1960s to 1990s) but from rural to urban areas. The last trend has already started especially in Muusini and Bondeni Villages. The household members work in white-collar jobs/business in various towns and cities across the country.

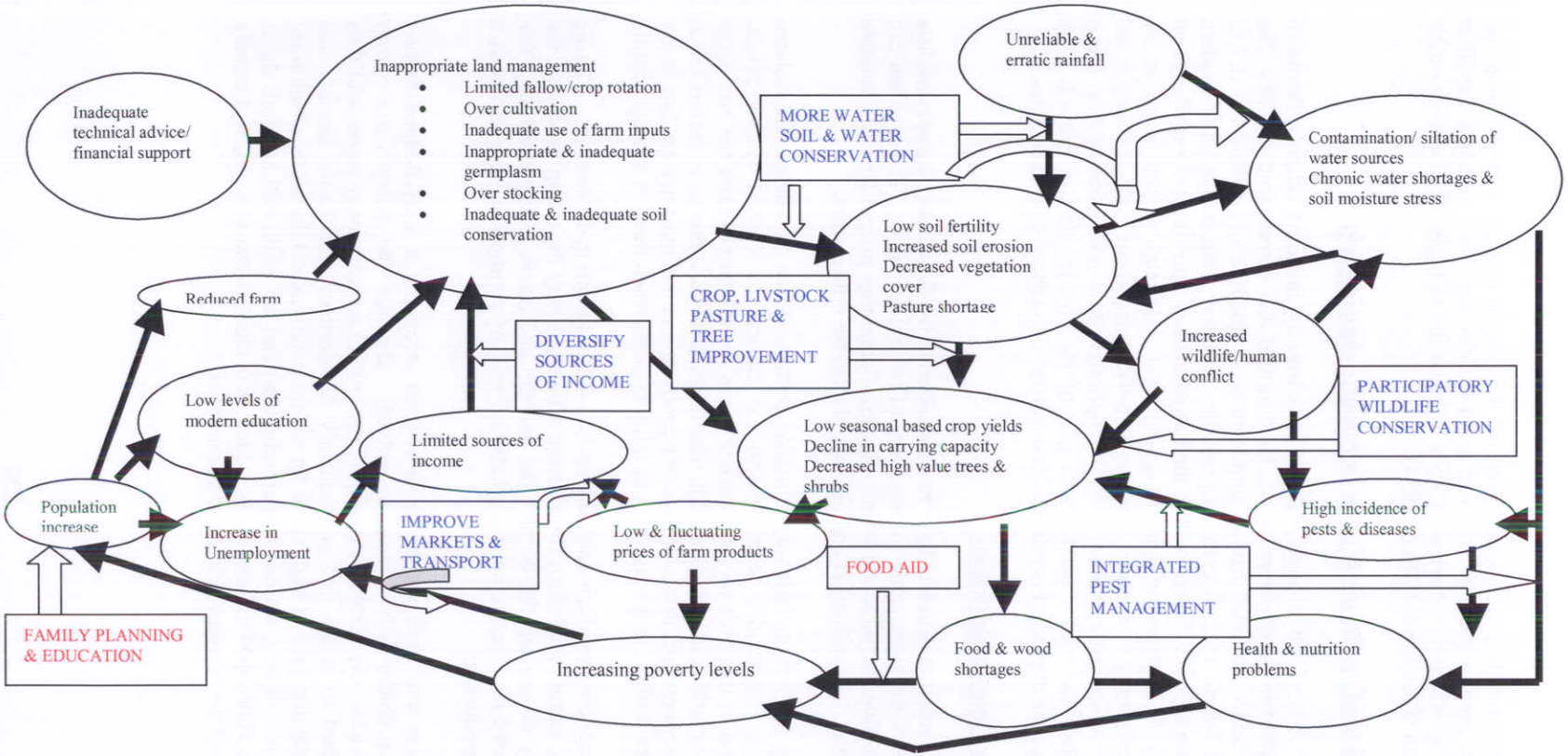


Figure 4.3.9 Cause-effect model land use situation in Eastern Kajiado and Southern Makueni, Kenya: Synthesis of the existing situation and alternative options.

These members send monthly remittance back to the villages and therefore keeping ties home. In case "the greener pastures" in town proof fruitful, then the household members will be compelled to welcome others who wish to leave the villages. Similar cases have also been reported in West Africa (OECD 1994).

(c) Education level and its implication on resource management

An estimated over 50% of school aged children are currently attending schools, thanks to the free primary education programme of the Government that commenced in 2003. The education of the "future farmers" has an implication on resource management – it will potentially lead to hybrid of indigenous knowledge acquired from parents and modern sciences gained from schools. But in reality, the future farmers gains limited knowledge on sustainable resource management at primary school level. Although natural resources are the backbone of the country's economy, emphasis on its management starts at colleges and universities levels. At secondary school level it is optional while at elementary level it is a non-curricular subject and only considered as part of the broader science subject. The scientific knowledge the pupils get is minimal and restricted to school club excursions.

(d) Market and marketing systems

In all the villages, market constraints have been mentioned by the farmers/agropastoralists as a major obstacle to the sustainable management of natural resources. The problem can be summarized into five: Exploitation by middlemen, fluctuating prices, far away reliable markets (inaccessible), lack of market and unavailable market information.

Middlemen way lay farmers on their way to market centres. Since the villages are isolated middlemen take the opportunity to misinform the farmers on current market prices. Trusting him/her and because the way back home too is far, the farmer sales the product at a low price than the market only for the middleman to resale them at the same centers but at a better price. Furthermore, the prices of livestock products and live livestock are low in dry periods (due to impact of drought) and high in rainy seasons when there is enough pasture and water.
The reverse is true for crop products shooting up to 3-4 times more in dry seasons. During the harvest periods, again middlemen flock to the villages to buy the cheap products. On the other hand they do not tell the farmers the demand and prices in urban centres. The farmers also indicated far away reliable markets and lack of appropriate information as a constraint to crop production.

Consequently, unless and until we make subsistence economy a fully-fledged market economy poverty problem will seldom be solved. Because the villages are poorly connected to the market, the surpluses produced are sold at a throw away prices and thus decrease the standard of living and consequently demoralizes sustainable farming and management. No wonder there is high value for off-farm activities. Ultimately if solutions are found, then there will be mass rural-urban migration and the result will be more slums in urban areas. The Nairobi-Mombasa roads, which pass close to the villages, will remain the economic heart of the region but so far under utilized.

(e) ***Inadequate technical and financial support***

Institutional support to the sustainable management of natural resources is wanting within the villages especially in Bondeni and Erankau. Farmers and agropsatoralists in these villages have made it clear that they rarely get services they are expected to receive. Only very few institutions have been acknowledged for their support. The response to the lack of support from the majority sounded desperate. When enquired why they are not getting support, although very few admitted either to be new in the area or have not been attending trainings the following were some of the replies from majority: "we have been forgotten/do not interact with them; we do not see them/they never visited us; they are too far from us; I do not know/relevant institutions know better; the Government does not have enough staff; there is communication break down between us and them; may be due to inefficiency; officers stay only in offices; may be they think we are backward and illiterate to be contacted; and poor leadership/Leaders are discriminating this village".

It shows that there is indeed a big gap between research/extension institutions and majority of the local community in the study villages.

The study went further to ask the farmers which institutions they want to work closely with and currently what they think about them. Using the following scores (a modification of Andiema *et al.* 2003), the farmers in feedback meetings rated various institutions they want to work with/are working with. The four feedback meetings were attended by a minimum of 15 elders coming from all corners of the villages. The scores were:

0 = we need them but so far we do not get support from them/do not see them;
1 = we need them, have seen them but they have no activities on the ground/we do not appreciate their impact;
2 = we need them, have/had activities in the area but with minimum impact;
3 = we need them, have/had activities in the area with average impact; and
4 = we need them, have/had activities in the area with positive impact.

Table 4.3.2 summarizes the findings. Except a few most of the institutions are far from the farmers/agropastoralists and therefore urgent solution is required to reverse the concern. The institutions that were ranked highest in Kibwezi were AMREF and ARIDSAK Project. In Mashuru, the agropastoralists appreciated most the support of Department of Education and ARIDSAK. As indicated in the Table 4.3.2, ARIDSAK Project support cuts across most of the natural resources and is the most integrated institution so far within the study area. On the other hand AMREF in Kibwezi is valued for its active role in water and health sectors. In all the villages, the Departments of Education and Health were highly rated because they stay right at the village with farmers and advice them accordingly. The role of teachers in natural resource management through children and directly with parents during parent meeting needs no emphasis.

On the other hand the natural resource based personnel cited the lack of facilitation (transport, allowances etc.) to deliver the necessary expertise to farmers.

Financial support to the farmers was very minimal, reduced to seven farmers and agropastoralist out of the 36 interviewees in the four villages. Not only do they lack accessibility to loan but they also have "fear fever" because of the unreliable rainfall, low productivity and therefore unconfident to obtain loans. Unless this problem is solved then productivity at the rural farm level is under threat.

Table 4.3.2 Support strength of core institutions in natural resource management in four villages of Eastern Kajiado and Southern Makueni, Kenya

INSTITUTIONS MENTIONED FOR COLLABORATION BY FARMERS	VILLAGE/SCORES						
	MUUSINI	BONDENI	AVERAGE FOR KIBWEZI	ISARA	ERANKAU	AVERAGE FOR MASHURU	TOTAL SCORE
Department of Lands	1	-	**1**	-	-	-	**1**
Department of water	0	1	**1**	0	0	**0**	**1**
Forest Department	1	1	**1**	0	-	**0**	**1**
Department of Agriculture	1	0	**0.5**	0	0	**0**	**0.5**
Department of Livestock	2	3	**2.5**	2	0	**1**	**3.5**
Department of Health	4	2	**3**	2	2	**2**	**5**
Kenya Wildlife Services	0	3	**1.5**	1	0	**0.5**	**2**
Department of Education	2	3	**2.5**	4	3	**3.5**	**6**
ARIDSAK	4	3	**3.5**	4	3	**3.5**	**7**
Public works	1	-	**0.5**	-	0	**0**	**0.5**
County council	2	-	**1**	2	2	**2**	**3**
WINROCK International	2	-	**1**	-	-	**0**	**1**
AMREF	4	4	**4**	-	0	**0**	**4**
Department of Information	0	0	**0**	-	2	**1**	**1**
GAA	4	-	**2**	-	-	**0**	**2**
KEMRI	4	-	**2**	-	-	**0**	**2**
Administration		3	**2**	4	2	**3**	**5**
Cooperatives		0	**0**		0	**0**	**0**
ACTION AID International	-	4	**2**	-	-	**0**	**2**
KARI	-	-	**-**	3	-	**1.5**	**1.5**
ADRA	-	-	**0**	4	-	**2**	**2**
National water & pipeline corporation	-	-	**0**	1	-	**1**	**1**
World Vision	-	-	**0**	3	1	**2**	**2**
Churches	-	-	**0**	4	2	**3**	**3**
SARDEP	-	-	**0**	-	0	**0**	**0**
Department of Mines & Geology	-	-	**0**	-	0	**0**	**0**
East African Portland & Cement	-	-	**0**	-	3	**1.5**	**1.5**

NB ARIDSAK = Kenya/Belgian Agroforestry for Integrated development in the Sem-arid Areas of Kenya Project, GAA = German Agro Action, AMREF = African Medical and Research Foundation, KEMRI = Kenya Medical Research Institute, KARI = Kenya Agricultural research Institute, ADRA = Adventists Development and Relief Agency, SARDEP = Kenya/Netherlands Semi-Arid Rural Development Programme

(f) Policy issues

Existing Government policies in relation to natural resource management are in sectors. The following are some of the major policies in the country concerning natural resource management.

- Forest Act Cap 385 of the laws of Kenya – This is the principle legislation for the conservation, management, and utilization of forests and forest products. Other Acts related to CAP 385 are The timber Act Cap 386 (regulates timber products), Plant protection Act - Cap 324 and the Seed and Plant varieties Act – Cap 326.
- Sessional Paper No. 1 of 1968 on Forest Policy for Kenya – to control wanton destruction of vegetation and emphasizes on reforestation
- Kenya Forestry Master Plan – calls for participatory forest resource management.

- Sessional Paper No. 1of 1986 on Economic Management for Renewed Growth – calls for environmental Protection and recognizes drylands as an important resource
- Agricultural Act Cap 318 of the laws of Kenya – for the promotion of stable agriculture and soil and water conservation.
- Sessional paper No. 4 of 1981 on national food policy – for food sufficiency of the growing population.
- Water Act Cap 372 of the Laws of Kenya – govern the management of water resources
- Sessional Paper No. 1 of 1999 on National Water Resources Management and Development that foresees to meet all the water demands and development towards the year 2010.
- Sessional paper No. 6 of 1999 on Environment and Development – recognizes the importance of sustainable conservation of the environment through an integrated approach and addresses poverty as an obstacle towards this end
- Wildlife Management and Conservation Act Cap 376 of the Laws of Kenya. This Act supported by Sessional Paper No. 3 of 1975 and modified by the Kenya wildlife service Policy Framework 1991-96 gives the Kenya Wildlife Services sole legal mandate to conserve and manage wildlife throughout the country.
- The Local Government Act Cap 265 – mandates local councils to the management of forests and woodlands under their jurisdiction.
- Public Health Act Cap 242 – on environmental health issues.
- Poverty Reduction Strategy 2001-2004. This policy paper reiterates the Governments' commitment to poverty alleviation and gives especial attention to the drylands
- Economic Recovery Strategy for Wealth and Employment Creation 2003-2007 outlines the development strategy and policies of the Government for the stated period. It stresses the promotion of sustainable livelihoods and alleviation of poverty in the arid and semi-arid areas of Kenya.
- Presidential decrees are also important policy references – where the head of state comes in to save resource degradation whenever he feels appropriate
- National Development Plan 2002-2008. Effective management for sustainable economic Growth and poverty reduction. This policy plan to emphasizes the importance of sustainable management of the various sectors of the natural resources with a major aim on poverty alleviation.
- Strategy for Revitalizing Agriculture 2004 – 2014 states the Government policies to achieve a progressive reduction in unemployment and poverty.
- The District Development Plans for Kajiado and Makueni Districts are also another important policy document at the District, divisional, locational and sub-locational levels. Other supportive policy documents at the district levels include Kajiado and Makueni District Poverty Reduction Papers.
- National Annual Tree Planting. Each year the country conduct a national tree planting day. On this day Kenyans of all categories are involved in the activity

Due to so many sector and ad hoc policies and laws that govern natural resources, there are conflicts of interest by the various implementers and therefore retard development. Some of the policies also contradict each other, while others are inappropriate and hard to implement. Other socio-economic constraints include

- limitation of sources of income to few white collar jobs outside the villages to very few small scale business and sale of primary farm products;
- high levels of unemployment – caused by high level of poverty is forcing able bodied men and women to look for jobs in towns as far as Mombasa and Nairobi about 250 – 300 km away;

- food shortage is frequent as the villages receives one good rain in every 3 to 4 years.

Alternative options to the existing socio-economic constraints

- Building a single research and extension approach - the way out is the merge of existing research and extension services of the Government and having one well paid and motivated integrated resource manager close to the farmers at locational level. Here it is assumed that a division will have a maximum of five locations. The locational integrated resource managers will be under one divisional resource manager. Currently, there are 8 – 10 sector based natural resource management officers at divisional level (Agriculture, irrigation, soil and water conservation, water, forest, livestock, veterinary, lands, social services, horticulture) and many research and development based officers in different centers within the region. It is important to have the Department of Public health under natural resources because of its importance in resource management quality especially in water, crops and livestock products. The Locational resource managers will be supported by 1 - 2 Para Natural Resource Managers (literate farmers elected by the local communities and then specially trained on all aspects of natural resources by the resource manager on contractual basis). The participation by the local communities in natural resource management will strengthen local institutions and develop confidence.

- Mobilization, training and awareness creation have to be strengthen and regularly undertaken. Local communities should be thought how to organize themselves and take charge of the management of important changes in the production systems (marketing, legal frameworks, decentralization of agricultural credit structures and concerted land use planning). They should also be enlightened to take part in defining natural policies on par with traders, processors, and consumers of farm products and their market intelligence well improved. Similarly, the resource managers require regular training on the different aspects of integrated management of natural resources

- Strengthening of urban market catchments within the village vicinities for more reliable outlets of farm products (reliable markets) and bringing job opportunities closer to farmers is necessary. Urban markets such as Machakos and Athi River and many in West Africa and throughout the world are known to have contributed to significant role in food and wood production (Peirrera 1997, OECD 1994). The farmers closer to towns earn more income from farm products, for example milk in Erankau Village because it is close to Sultan Hamud Town. Farmers neighbouring towns increase their productivity and yields. They also improve production techniques. In the long run such markets can compensate for part of the goods for export provided the dumping of subsidized low quality products is controlled. Policies are therefore necessary for the expansion and strengthening of centers along the Nairobi – Mombasa Highway market catchment. The catchment is currently under utilized. Potential centres for expansion are Sultan Hamud – Emali – Simba merger town, Makindu, Machinery, Kibwezi, Kambu and Mtito Andei. Except for Machinery, currently water is available in the rest of the named towns but more will required if they are to be expanded. For Machinery, the tapping of Umani Springs will be a potential. These centres currently have 1,000-5,000 inhabitants each. The target should be to have towns with population of 20,000-30,000. Such town will also become shock absorbers for the current population pressure. To achieve this thorough planning will be required in terms of their requirements and possible impacts.
The expected impacts include increased demand for more water, crop, livestock and tree products. Similarly, building materials such as bricks will be necessary. But instead of using fuelwood to burn the bricks, relatively cheap and environmentally friendly

compression machines for brick making are available from firms like Aprotec Kenya. Nevertheless, the use of compressors means much greater investment. Currently, brick makers use the available soil, fetch wood and water but the compressors have to be acquired from Nairobi and therefore needs finance to purchase it plus accessory inputs and transport. The extra incomes generated as a result of the impact of the markets and transport network will facilitate the poor farmers to take their children beyond primary school education, which currently is seldom. Moreover, value added technologies; irrigation, crop and livestock improvement will have to be introduced/up-scaled to diversify income sources.

- Intensification of financial support – The Government, NGOs and the private sector have to develop a harmonized and coordinated plan in assisting farmers/agropastoralists with financial support in order to make rural economy more modern and productive. The availability of loans with very low interest rates, grants and goodwill funding of agriculture based activities to individuals and groups is required.

- The improvement of transport and communication between the market catchments and the villages is necessary. Good transport is too known to improve production as it opens more market opportunities for farmers. An example again is how the tarmac roads have opened markets for Machakos farmers up to Nairobi, Athi River and beyond.

(g) High soil erosion, low soil fertility and low crop yields

Both in the cropland and woodland pastures, soil fertility was low due to erosion, and in most instances with low soil organic matter and consequently the total nitrogen. Furthermore, most of the soils are deficient in phosphorus, which is explained by the high contents of iron, manganese and other cations, therefore fixed.

The high erosion was caused by overgrazing, trampling, footpaths and the cutting of vegetation for charcoal, increases in settlement, over cultivation, bareness, insufficient and inappropriately laid down soil conservation structures causing low crop yields and grass cover. The low crop yields were also related to moisture stress, wild animals, pests and diseases (in the field and in the store), labour constraints and weeds. The most affected are farms owned by the poor. Erosion risks were very high. Conservation efforts were limited to few terraces in croplands. There are minimum management efforts in the woodlands/pastures.

The amount of farmyard manure (animal manure) added was inadequate to replenish the soil fertility. This is because in Kibwezi the average numbers of livestock kept were too few to yield enough manure while in Mashuru direct manure application was minimal despite its abundance. To make the matter worse, chemical fertilizers were not applied in all the farms. Crop rotation and fallow were rarely practiced. Year in year out the farms are cultivated. Furthermore, some of the crops introduced were considered as inferior in quality for example green grams.

Alternatives option to high soil erosion, low soil fertility and low crop yields

- Frequent practical trainings and monitoring on the laying down of technically correct and well maintenance soil conservation structures on cropland will have to be explored.
- The use of less aggressive (as weed) indigenous grasses, which will be used only through cut and carry, has to be encouraged along soil conservation structures – for example *Panicum maximum, Cenchrus ciliaris* and *Eragrostis superba*. The use of promising cover crops will also have to be considered.
- Improvement of mixed cropping practices – research should be based on what the farmers know and for many years now multiple cropping had not been researched on and it is time to do it.
- Addition of adequate and appropriate farmyard manure from the improved livestock. Once the livestock component is improved then the farmers will have more farm yard manure to improve soil fertility. For Mashuru, technologies have to be develop based on the existing soil management practices- for example how best to improve the use gravitational soil fertility management and manure use. Research to develop manure based fertilizers is required.
- Encourage crop rotation and improved short season fallow. Crop rotation is known to increase yields by 20 – 30% (Brady and Weil 1996).
- Improvement and diversification of crop varieties based on local germplasm plus promising ones tested within the region.
- Compensation of destruction by wildlife and maximum incorporation of Kenya Wildlfe Services into integrated programmes in case sector approach continues to hold.
- Growing of fruit trees cash crops such as *Mangifera indica, Psidium guajava, Carica papaya, Annona muricata* and banana. From experience, *M. indica* varieties of Apple and Ngowe do can well in the area under dryland farming while varieties Kent, Haden and Van dyke will perform best with supplementary irrigation.
- Revamping cash crops such as cotton, sisal, sesame, sunflower, castor oil and groundnuts is needed once markets have been established.
- Value addition and aggressive marketing of traditional crops and indigenous fruit plants. Sorghum, millet, cowpea, green grams, lablab, baobab and other wild fruits has to be explored. The resources are in the villages but lack services especially marketing.

For example traditional crops such as sorghum and millet are appreciated by urbanites in big cities and in Western Kenya while lablab has a big demand in Central and Mount Kenya regions yet farmers are living below the poverty line. Something must be done to the following statements of the Bondeni Village during feedback meeting "We have the resources. What we need are people to help us understand how to access the markets".

- Adequate training and mobilization of the communities through awareness creation on sustainable crop production
- Introduction of irrigation (using promising crops) from surplus water harvested as runoff and piping/furrowing from rivers and springs
- Integrated pest management. Collaboration with ICIPE (International Centre for Insect Physiology and Ecology) and other relevant organizations on the use of Neem and research on indigenous species/techniques with potentials will have to be undertaken.
- Participatory wildlife conservation scheme and ecotourism is very necessary. The Kenya Wildlife Services who are responsible for wild animals have to change its current policies of maximum wildlife protection with little regard to the blights of farmers caused by wild animals to crops and livestock. Moreover, the Government needs to re-think and re-introduce compensation scheme for damages caused by wild animals that was scrapped in 1989 if the confidence farmers have to be gained.

Above all, the communities neighboring parks have to get special development programmes per year from the revenues generated from tourism and wildlife. The Merueshi individual group ranch should be a model for the Kenya Wildlife Services to replicate.

(h) Over exploitation of high value trees and shrubs, pasture shortages and low quality livestock breeds

High value trees and shrubs have been over exploited for poles, posts, timber, firewood, carvings, fence, charcoal burning and medicine and their cover and ecological significance reduced. If the population continues to increase at the current rate, the use of firewood is estimated to almost double in the next 20 years within the study villages (Table 4.3.3). Other wood and non-wood products will too have similar trends.

Table 4.3.3 Projected firewood use in four study villages of Eastern Kajiado and Southern Makueni Districts, Kenya.

Villages	Year/Firewood use (Tonnes)		
	2004	**2014**	**2024**
Muusini	281	355	432
Bondeni	504	633	746
Isara	132	207	312
Erankau	174	273	429

The pastures and woodlands had no soil and water conservation structures and their management was restricted to fencing and surveillance. As a result, bush encroachment was noted as a big constraint. Yet in the two sub-regions, every year chronic pasture shortages occur between June – November. Furthermore, there are hundreds of extra livestock units more than the carrying capacity of the existing village pastures. Consequently, overgrazing is rampant within the pastures with grass cover drastically reduced in all the ecological landscapes. Bushes and thickets have too reduced grass cover. Unpalatable species/range land weeds have increased and palatable species have decreased within the pastures. Farmers also mentioned that some of their breeds are of low quality in terms of milk and meat production. They reported to prefer high yielding livestock (both milk and meat).

Alternative options to over exploitation of high value trees and shrubs, pasture shortages and low quality livestock breeds

- Bush management – selective cutting of some of the thick bushes (*A. mellifera, Premna resinosa, Barlaria taintensis* and *Commiphora* spp.)
- Establishment of soil and water conservation structures in the rehabilitated pastures after contour ploughing
- Establishment of multipurpose fodder banks with indigenous palatable species such as *Duosperma kilimandscharica, Acalypha racemosa, Combretum exalatum, Grewia bicolor, Grewia tembensis, Aspilia mosambicensis, Crotolaria goodiformis* and *Indigoera lupatana.* These species were identified through experience and interview with farmers/agropastoralists.

Similarly, Roothaert (2000) while working in the Central semi-arid Embu, Kenya identified *Melia volkensii, Morus alba, Leucaena leucocephala, Leucaena diversifolia* and *Maytenus puttlickioides* as candidate species with crude protein of over 97 in dry seasons. Other known fodder species that can do well in the study area include *Acacia tortilis, A. mellifera, A. Senegal, Balanites aegyptiaca, Boscia anguisitifolia, Cadaba farinosa, Entada leptostachya, Faidherbia albida* and *Combretum aculeatum* (IBPGR 1984). In between the lines of the fodder banks indigenous high value grass species such as *Digitaria milanjiana, Eragrostis superba* (Masaai love grass), *Cynodon plectostachyus* (Naivasha star grass), *Cenchrus ciliaris* (African fox tail), *Panicum maximum* (Guinea grass), *Chrysopogon aucheri* (Aucher's grass), *Entrepogon macrostachyus* (Bush rye), *Andropogon gayanus* (Gamba grass), *Chloris roxburgiana* (Horse tail grass), *C. gayana* (Rhodes grass) should be reseeded (Appendix VII). Because of problems of seed harvesting ants common in the area (Plate 4.3.2), seeds have to be treated with insecticides.



Photo by A. Mohamed in 2003.

Plate 4.3.2 Seed harvesting ants are common in Kibwezi and Mashuru area.

- Pasture improvement in Mashuru should be base on the "Olopololi" practice. Its management and species diversity requires improvement. Improved pastures will generate more forage/fodder and therefore necessitate improvement of local livestock breeds for generation of more income.
- Superior breeds have to be selected from the existing local breeds and then further improved with other local Kenyan breeds. However, care has to be taken not to introduce breeds that demand more forage than the land and management can afford. The animals to be improved include the Zebu cattle, goats, sheep and poultry. Similarly, the improvement/scaling up of bee-keeping practice of the log beehive needs intensification. The use Langstroth beehives or hut apiary generates more honey and income and are gender friendly.
- Woodlots consisting of indigenous and other species with proven performance is necessary. The woods will also provide timber, firewood, poles, posts, medicine and charcoal. Whenever possible underneath the trees grass /forage pastures will be planted. The multiplication of *Melia volkensii* plantations has to be a priority especially on the Luvisols and Ferralsols soils. Other candidate species are *Eucalyptus* hybrid for dry areas, *Eucalyptus cameldulensis* (Kibwezi, Bulawayo and Lupane provenances) and *Senna siamea.*

- Community mobilization through "Harambee" spirit in supporting each other to manage the individual woodland and pastures
- Integrated pest management (IPM) to control pests and diseases of the trees, forage and livestock. As discussed pests and diseases are big problem to the farmers and pastoralists crops, trees and livestock. Controlling them is not easy and it is very expensive to be applying chemicals. As a result, a multiple control methods are necessary including chemical, biological and mechanical and both modern and indigenous methods of control. The development of improved varieties tolerant to pests and diseases plus the improvement of cropping practices are required. Collaboration with ICIPE and other expertise is very necessary. Research into local species and techniques has to be pursued.

(i) Chronic water shortages, contaminated water sources and projections

Currently, there are acute water shortages in the villages due to unreliable rainfall, contamination and siltation of existing water sources (Table 4.3.4).

As a result women and children take many hours every day to get water from far sources outside the villages. Livestock also trek 10 km if not more per day to and from water points. This long distance coupled with reduced pasture make the animals weak and vulnerable to drought that usually occurs July to November. The available water sources are also grossly polluted and contaminated. Above all there are frequent outbreaks of water related diseases such as malaria, bilharzias, amoebiosis and typhoid. As population increases (Table 4.3.1), assuming that household water use will remain constant then the shortage is expected to increase by over 50% Kibwezi and more than double in Mashuru. (Table 4.3.4). Pollution/contamination is also expected to increase due to more erosion, congestion and over use of the resources. Other expected consequence will be more conflict in the use of resource.

Alternatives to water shortages and contamination/pollution

For rural agriculture to stand on its own in the drylands, it is important to avail and diversify water sources. The possibilities explored are supplementary to each other. This is because using all the alternatives together can only solve scarcity of water in the drylands. The alternatives include water harvesting (runoff and roof), tapping of river, ground water exploitation and the use of drought tolerant plants

Water Quantity

Three major possibilities exist in order to improve the availability of water Muusini, that is, intensification of runoff harvesting and roof catchments, tapping of river water and ground water exploitation. Nevertheless, tapping of river water is inhibited by costs while the nature of parent material constraints ground water use. The most reliable and sustainable water source is therefore intensification of run off harvesting. The analysis from the dam and pond samples indicated also that their water contain less chloride, sulphate and sodium salts than the other sources and therefore ideal for irrigation than the more saline rivers and wells.

Table 4.3.4 Projection of annual water use in four villages of Eastern Kajiado and Southern Makueni, Kenya: 2004 – 2014

Type of water use/ households	Year								
	2004			2014			2024		
	Actual Water Use (m^3)	Demand (m^3)	Annual water deficit (m^3)	Actual Water use (m^3)	Demand (m^3)	Annual water deficit (m^3)	Actual Water use (m^3)	Demand (m^3)	Annual water deficit (m^3)
Muusini									
No. of households	83			101			123		
Domestic	2764	7395	4631	3363	8999	5636	4096	10959	6863
Livestock	3860	3860	0	4697	4697	0	5720	5720	0
Trees	498	2328	1830	606	2833	2227	738	3450	2712
Total	7122	13583	6461	8666	16529	7863	10553	20129	9576
Crops	Rain fed								
Bondeni									
No. of households	129			157			191		
Domestic	3677	11236	7559	4218	12891	8673	5130	15678	10548
Livestock	2012	2012	0	2309	2309	0	2808	2808	0
Trees	77	168	84	89	192	103	108	234	126
Total	5766	13416	7650	6616	15392	8776	8046	18720	10674
Crops	Rain fed								
Isara									
No. of households	53			83			130		
Domestic	3342	21823	18481	5234	34176	28942	8198	53529	45331
Livestock	41428	41428	0	64877	64877	0	101615	101615	0
Trees	474	710	236	742	1112	370	1162	1742	580
Crops	3790			5935			9295		
Total	49034								
Erankau									
No. of households	98			154			242		
Domestic	4048	11145	7097	6362	17513	11151	9997	27520	17523
Livestock	69124	69124	0	108624	108624	0	170695	170695	0
Trees	1135	1422	287	1783	2233	450	2802	3509	707
Crops	Rain fed								

Intensification of runoff harvesting, roof and rock catchments:

The annual rainfall of about 500, 700, 400 and 700 mm/year received in Muusini, Bondeni, Isara and Erankau respectively multiplied by the respective village areas translates to millions of metre cubic of water. This excludes other amounts of water that drains from upper catchments. Of this volume of water 10-20% are estimated to be lost as runoff (Rockstrom *et al.* 2002). Similarly, iron sheet roofs and bare rocks (granitic rocks common in the Regosols) can be used to harvest water. Yet people are faced with chronic water shortage. Therefore harvesting of the runoff in form of individually or community owned dams, pans and through the establishment of technically correct and well-maintained soil conservation structures has to be a priority. To reduce seepage, earth dams and pans can be established on Ferralsols and Luvisols plains but not Vertisols and Cambisols unless further treatments are applied.

Soil conservation structures have to include improved pitting (Zai – with manure application), semi-circular or V/W-shaped microcatchments, "fanya juu" terraces and conservation tillage (contour farming and mulch application).

The use of bottle/porous clay irrigation for trees needs to be promoted too to save loss of water through seepage and evaporation. The water poured into the containers seep slowly through made holes direct to plants roots. To succeed in achieving this task community and other resource mobilization and awareness creation is essential.

Tapping of river water and from springs and catchment protection

A more permanent source of water for irrigation is possible by piping or furrowing water from the existing rivers. For example Kibwezi/Yuu and Athi River in the case of Muusini or obtaining water directly from Umani Springs by gravity for Muusini and Bondeni and Ormuuntus Springs for Erankau. The Athi River alternative requires pressure to pump uphill to the village because it is on the lower altitude. Cost involved is an impeding factor to obtaining water from this source. Another problem related to springs as source of water is deforestation of the catchments that houses remnants of highland forests species *Albizia gummifera*, *Neboutonia macrocalyx*, *Syzigium guineese* and *Teclea* spp. for agriculture, charcoal burning and exploitation for other wood and non-wood products. For example Ormuuntus springs are found in an area covered by remnant highland forests but was being cleared for vegetable growing and therefore requires protection (Plate 4.3.3).



Photo by A. Mohamed in 2002.

Plate 4.3.3 The clearing of remnant highland forest on Ormunuus hill catchment for vegetable (kales and tomatoes) growing is threatening springs (lower photo) necessary for sustainable water use.

It is important to empower village committees to help in the conservation of all the units under fragile and hilly catchment zones. The committee should be linked to locational, divisional and district environment committees.

In the current situation, the District Environment Committee is very powerful but field implementation of activities is hampered by many factors including the large areas under their jurisdiction. Therefore, most of the power should be delegated to village committees. Further, annual rewards to the villages that contribute most to sustainable natural resource management at division, district, province and national levels for should be introduced.

Even if quantity of water is increased as it exists know unless treated river/spring water in the study area are contaminated for human consumption. Moreover, Ormuntuus springs contain leeches.

Ground water sources

Large portions of the study villages are covered by basement and therefore ground water potential may be described as low to medium considering the impervious and fresh nature of the compact and crystalline metamorphic rocks found in the area and the low rainfall experienced. Ground water occurrence is restricted to jointed or fractured, broken and faulted zones within the rocks (ACTIONAID Kenya 1993). As a result of weathering minerals break down in these zones creating sufficient storage of water especially where they extend deep into the ground. Some ground water also occurs where the basement rocks are deeply weathered. Zones of broken rock, joints and fractures often optimize storage, transmissivity and recharge, particularly when they occur adjacent to, or within, drainage systems. Within the location several valleys (lineaments) occur.

Consequently, few wells have been identified by the above ACTIONAID study in Muusini area. However, to date no tangible achievement has been obtained in drilling wells in the area. Moreover, the few wells dug by farmers through trial and error and using indigenous technical knowledge have low yields and are saline due to the high evaporation rates in the area and the influence of the parent materials, which are metamorphosed sedimentary rocks. Therefore this source is not sustainable in Muusini. However, local initiatives have proved successful in Bondeni.

Improvement of the substrate of Metava Swamp in Bondeni to hold more water needs to be studied. Piping of water by gravity from Mount Kilimanjaro or revisiting the use of Noulturesh pipeline. A reliable and permanent source of water for irrigation in Isara and Erankau is possible by piping water through gravity system from Mount Kilimanjaro. Already old railway water pipeline is in place without use. Its repair and rehabilitation could cut the costs. Similarly, revisiting the use of Noulturesh pipeline is necessary.

While urban development is a prerequisite it should not be at the expense of rural development otherwise increase in rural - urban migration will take its toll. The prospect of alternative pipelines from the Aberdare ranges or Mount Kenya should be prospected for urban centres while Noulturesh is reinforced for irrigation agriculture within Mashuru and the surrounding divisions that are recurrent drought prone zones.

Drought tolerant crops

Most of the traditional crops currently grown plus the indigenous species of the area are adopted to the dry conditions of the area and therefore use less water.

Irrigation

Once water is availed irrigation of cash crops such as tomatoes, okra, pepper, egg plant, onions and banana can be introduced. But prior to start irrigation, thorough site study will be necessary in order to determine slope and drainage requirements.
Further in order to irrigate efficiently, drip irrigation should be encouraged. For the irrigation of the common crops under sole crop planting (Table 4.3.5), extra irrigation water will be necessary per crop from planting to harvesting (Cropwat modeling was used to obtain the crop water requirement with courtesy of Prof. Xanthoulis).

Table 4.3.5 Irrigation requirements of some candidate crops for drylands of Kajiado and Makueni Districts, Kenya.

Crop type	Amount of water in mm/ha	
	AEZ V (Muusini/Isara)	AEZ (Bondeni/Erankau)
Beans	201	167
Ground nuts	397	293
Maize	375	309
Millet	306	251
Sorghum	294	241
Citrus	631	545
Vegetables	236	193
Sweet potatoes	336	275
Sunflower	346	284
Soya beans	400	328
Pulses	283	235
Banana	584	486
Cotton	627	517
Tomatoes	435	354

The cost of irrigation with modern techniques is estimated at 2500 euros/ha while simple techniques such as gravitional plus furrow irrigation can cost approximately 500 euros/ha (Prof. Xanthoulis pers. Comm. 2004).

Most of the rivers and spring water are saline to some extent and the use of slightly saline water in the region had indicated to increase soil salinity, which in the long term can create salinization of the soils.

For example in Kiboko KARI/ICRISAT research site, Hornetz *et al.* (2001) found that the electrical conductivity of the soils (upper 10 cm) under irrigation was 1760 mmhos/cm while adjacent sites under natural wooded bush land/grasslands had 59 to 165 mmhoscm^{-1}. Therefore it is important also to know the quality of the water for irrigation in order to control salinization.

Water quality

The treatment of domestic water against the high levels of coliforms and *E. coli* is urgent and crucial. The use of chlorine-based chemicals will have to be encouraged. The chemicals are in the market already and at a relatively cheap price (250 ml for Ksh. 35 by 2004).

A household with six members can use a bottle of the chemical "water guard" for almost 6 – 12 months yet few kilometers away farmers have no knowledge about it. What is required here is intensive awareness creation through public meetings. The farmers will at least have to boil to kill the germs or use filtration method to sieve out some of the contaminants.

In future, the staffs of Ministry of Health and natural resource based institution have to collaborate through integrated pest management programmes too for the proper conservation of upper catchments. Research and planting of plants with mollusicidal properties such as *Phytolacca* and *Balanites* species on the Chyulu Hills, along river courses and around dams/pans have be taken up. The use of natural plants to treat water needs too to be intensified. The use of *Moringa oliefera* seeds to purify water needs to be promoted. A decoction from Moringa seeds when added to contaminated water is known to eliminate 99% of bacteria (UNEP 1998) and the plant can grow well in the area. The plants' leaves and immature pods also provide vegetable. The use of *Maerua decumbens* can too be used to purify dirty water (Mohamed 1999).

4.3.3 SUMMARY OF THE CONTRIBUTION TO DEVELOPMENT OF SUSTAINABLE AND INTEGRATED MODELS

The overlays of the ecological and harmonized farm types generated six, eight, nine and 11 integrated ecological and farm management units in Muusini, Bondeni, Isara and Erankau Villages respectively. The units managed by the poor will continue to be the most susceptible to resource degradation due to over cultivation and over use of pastures (by well off who own more livestock) and limitation of resources to improve the status. Additionally, units on the fragile hills and lowlands will also be difficult to sustainably manage if the current scenario of resource continues. Above all various factors including limited technical and financial support, market and policy related constraints, inadequate and polluted/contaminated water supply cut across all the integrated units. As a result different technologies/approaches have been suggested in order to improve the status quo of resource management and use. The options suggested varied with the poverty levels and susceptibility of the units to degradation.

Although many technologies cut across the different poverty levels, technologies that demand less financial resources and diversification of sources of income have been put forward for the poor while technologies for the well and the medium will need financial supplementation. Additionally, technologies for the units that lie on fragile hilly and lowlands units conservation efforts were precedence. The major cross cutting options put forward were merger of research and extension, mobilization, awareness creation and training, strengthening of market catchments along Nairobi – Mombasa road, coordination and intensification of financial support and improvement of transport and communication. Other are soil and water conservation technologies, diversification of crop, grass and tree resources, bush management, value addition to farm products through improved processing, participatory wildlife conservation, integrated pest management, improved water quantity and quality and catchments protection.

4.3.4 CONCLUSIONS

Sustainable resource management can only be achieved through a holistic approach that considers simultaneously the different factors that impact on the resource components right at the farm level. The existing sector approach needs to be reviewed and replaced with integrated resource management approach operated utmost at the locational level. The empowerment of farmers/agropastoralists and creation/accessibility to markets has to be the core to the proposed models. All the units located on fragile and hilly catchment zones should be placed under powerful village community elders.

CHAPTER 5. GENERAL CONCLUSIONS AND RECOMMENDATIONS

The Chapter captures the major outcome of the study and recommendations for the future.

5.1 CONCLUSIONS

Indigenous technical knowledge and modern sciences are supplement of each other. The local communities classify and associate themselves depending on ownership of natural resource components ending up with poverty classification, which is similar to the national classification of poverty.

Over 60% of the population in areas was considered as poor, defined as one with minimal resources to make ends meet. It is as a result of this circumstance that make the poor resort to practices that are likely to degrade the environment, for example over cultivation. However, the study noted that the well off and the medium contribute to degradation through their many livestock that overgraze the existing pastures. Moreover, the well and medium were the ones involved more in deforestation through sale of charcoal and firewood.

The recent Government policy of free primary education is already bearing fruits with over 50% of school age children going to school. Basic education with a strong component of agriculture and environmental education can form a good foundation for integrated natural resource management.

Between 1960s to 1990s there was flow of emigrants into the villages from the Kenya highlands due to population pressure. But now another migration is taking place "from the villages to towns" as a result of increase in poverty at the grass root level. Consequently, in two of the villages, the highest source of income was no longer farm products but off-farm activities in form remittance from household members working in towns. An importance source of income for the poor in the villages but which received limited improvement was poultry.

Market was the major constraint and cause of poverty after drought. Prices of crop products were low after harvest and expensive in dry periods. The exploitation by middlemen and far away reliable markets makes the poverty situation even worse. On the other hand, livestock products are expensive in rainy seasons and cheap in dry seasons.

Farmers and agropastoralists rarely access financial, technical and institutional support. As a result there is desperateness and apathy to institutions that were meant to support them. Therefore a new re-orientation of research and development institutions is necessary.

All the landscapes within the villages were faced erosion problem both in the woodland/pastures and croplands. The soil fertility were also low except on volcanic based soils and well terraced farms mostly owned by the well off. On average all the woodland and pastures had dystric BSP. Moreover, phosphorus rates were low except in soils of volcanic origin or one fertilized by them. The major causes of erosion were over cultivation, bareness, inappropriate and inadequate soil conservation structures, overgrazing and deforestation.

An interesting practice in soil fertility management is gravitational soil fertility management being implemented by the agropastoralists of Mashuru.

The agropasoralists deliberately place cropland down slope the animal kraal "boma" so that when it rains the animal manure is washed down hill into the farm. These agropastoralists reported to have higher yields than most of the others within the villages.

Also the use of various local decoction to control pests and diseases have been documented but the most interesting of all the decoctions was use of *Entada leptostchya* for livestock disease treatment and goats ash for control of the great grain borer beetle that destroys maize grains.

All the major water sources within the villages were bacteriologically, physically and chemically grossly polluted. The contamination is caused by severe soil erosion within the villages leading to heavy siltation into dams, pans and rivers. The levels of iron, colour, fluoride, deposits and odour exceeded WHO limits. Other causes were animal feacal matter, contaminated containers, direct drawing by people and direct drinking by livestock and lack of protection. Consequently, the out breaks of typhoid and amoebiosis were common. There were chronic shortages of even the contaminated water and this deficit is expected to increase in the next 20 years. Water crisis is further exacerbated by deforestation and overgrazing as a result of the erosion of traditional powers that village elders use to wield in natural resource management. In the existing policies, District Environment Committees and executive wield most powers in resource conservation.

A total of 18 crops were grown in the study villages though crop diversity was more in Kibwezi than Mashuru due to differences in cultural backgrounds. The Masaai who settle in Isara and Erankau villages of Mashuru Division started cultivation in the past decade while the Kamba of Muusini and Bondeni are veteran mixed farmers. Multiple cropping was the dominant cropping type in Kibwezi (implemented by all farmers) with variable crop mixtures of two to eleven. In Mashuru, cropping pattern varied from one farm to another. Crop yields varied with poverty groups and soil types. The well off obtained higher yields with crops that fetched better prices in the market. The relatively higher yields were associated with better soil management practices such as the laying down of physical soil conservation structures. Crop productivity also varied with climate and soil types. As expected Bondeni and Erankau, which receive higher rainfall too had higher crop yields. Moreover, soil types that were more fertile such as Cambisols had also higher yields. Crop production was however constrained by multiple factors of pests and diseases, market, storage, moisture and wild animals.

Cattle, goats, sheep and poultry were the major livestock in the villages. The main livestock constraints were market, pests and diseases, shortage of pasture and low quality breeds. In Kibwezi Cattle, goats and sheep were tethered while they moved freely in Mashuru. The pastures in Kibwezi have been highly encroached by bushes and palatable species have decreased in all villages. Overgrazing was rampant especially in Mashuru. Additionally, pastures/woodlands were rarely managed and therefore the range was deteriorating. Wild animals were considered as "Government cattle" and seen to be a big problem destroying crops and sharing the already scarce water and pasture with livestock. However, the empowerment of a group of pastoralists in Merueshi by KWS to sustainably and participatorily manage wildlife was an example for the future.

With poverty being rampant, crop yields low, soils eroded, water sources grossly polluted and contaminated top dressed by frequent shortages of pasture, the resources in the study are degraded and unsustainably managed. Therefore the set hypothesis holds.

5.2 RECOMMENDATIONS

Although there is resource degradation within the study area it is not too late to salvage the situation and this can only be done through integrated approach and dedication. What is required is integrated approach similar to that of the farmer/agropastoralist with one resource manager at the grass root level and the harmonization of all natural resource based policies and approaches. The merger of the existing sector based research and extension is the way forward. Once merged, the integrated team has to plan and implement resource conservation based on the cheapest but the appropriate technologies for each integrated unit. For the units covered by *Ferralsols* and *Luvisols* plains and *Chernozems* lowlands the growing of crops, pastures and high value trees based on the physical conservation of the soils are recommended. The hills and river course should be protected with woodlands and pastures and managed by the local communities under village elders on a sustainable harvesting of wood and non-wood products in order to add value to biodiversity conservation. The located on the *Vertisols* can be farmed if irrigation is available but it should be known that they are very sticky and slippery and therefore have to be drained in rainy seasons. Moreover, sustainable natural resource management and conservation can only be achieved with technically well-trained farmer/agropastoralists and through the empowerment of village committees.

The "future natural resource managers and advisors" (pupils and students) should be well trained in sustainable natural resource management right from primary level. Therefore, natural resource management needs to be incorporated to school curriculum and thought like English and Mathematics subjects. The idea of having natural resource management as non-curricula in schools does not give the subject the seriousness it deserves.

Water has to be availed either by piping from Umani springs or River Kibwezi/Yuu for Kibwezi area or a special pipeline from Mount Kilimanjaro in the case of Mashuru. For Erankau water can also be tapped by gravity from springs on Ormuuntus hills. If piping is costly, then we have to resort to the harvesting of runoff and rain water by digging dams and pans on the *Luvisols* and *Ferralsols* soils but not the porous *Cambisols*, Lava flow nor the shrinking and expanding *Vertisols* or *Vertisols* like *Chernozems*.

Erosion and fertility of soils can also be improved through intensive construction of physical soil conservation structures and by adding adequate animal manure and therefore livestock has to be part and parcel of the land management.

Diversification of income has to be explored by adding value to tree, crop and livestock products at farm level. Above all, market intelligence should be intensified to empower the farmers. They should know where prices are good and where the demands for farm products are high. Therefore they should be well trained and mobilized to understand their rights and opportunities.

The changes has to go hand in hand with the creation and strengthening of market catchments along the Nairobi-Mombasa road as a strategy to market farm products and as a shock absorber for the ever increasing population in the region. Access roads connecting the villages to the catchments have to be well maintained. Unless and until the management of natural resource components at the village are integrated with the development of market catchments centres, sustainability will not be easy. In case the towns grow faster than we anticipate it will definitely too cause environmental degradation.

With the improvement in water quantity and quality, increased crop yields, stable and reliable pasture sources, adequate wood and non wood products coupled with always available market then poverty will be reduced and the pressure on natural resource components will go down.

Further research is required in the following areas:

- seed bank studies to find the level of degradation of the in-situ potentiality of the landscapes. This time the samples will have to be large enough and over along period of study;
- many over exploited species may end up being rare in the area in few years to come, for example *Platycelophium voense* and *Rhamnus staddo*. Detailed research into their ecology, biology and silviculture including seedling production and their performance on croplands should be priority;
- appropriate technologies necessary for on-farm seedling production of *Melia volkensii* and other indigenous high value species;
- nutritive plant analysis of indigenous priority species identified by the study and more research into their performances both at on-station and on-farm should be intensified. *Chrysopogon aucheri* is a candidate species for the dryland pastures but limited/no research has been done on its performances under managed pastures;
- integrated pest management to come up with cheaper alternatives to the problems of the great (large) grain borer, weevils and fungal infections in stores and alternative methods to control field pests and diseases needs to be researched;
- the performances of traditional crops/practices and indigenous high value trees and shrubs under ordinary farm management;
- chemical and biological analysis of water from roof and rock catchments;
- better integration of market catchments towns and villages where natural resource components are produced;
- focused and integrated approach implemented by a resource manager based at the locational level; and
- the socio-economic and environmental aspects of the different agricultural practices implemented by the farmers/agropastoralists over long duration of time (5 to 10 years) in order to understand the underlying factors for their adoption and suggest possibilities of improvement.

The findings of this study could be applicable to other semi-arid areas of Kenya and the region with similar socio-economic and biophysical characteristics. It is most appropriate to situations where agropastoralists are just selling down and with farming communities that settled within two to four decades. It also reflects situations where local communities live side by side with national parks/game reserves.

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APPENDIX I: HOUSEHOLD QUESTIONNAIRE TO ASSESS LANDDEGRADATION AND THE IMPACT OF THE EXISTING PRACTICES/TECHNOLOGIES ON NATURAL RESOURCE COMPONENTS IN EASTERN KAJIADO AND SOUTHERN MAKUENI DISTRICTS, KENYA

Date_____ District_____ Division_____ Location_____

Sub-Location_____ Village_____ Agro-ecological zone_____
Farmer No._____
Farmer's/pastoralist's name_____
Name of Respondent_____
Relationship of the respondent with the farmer/pastoralist_____
Research assistant_____

A. GENERAL INFORMATION

A.1 Sex of the head of the household F ☐ M ☐

A.2 Age (years) < 21 ☐ 21-30 ☐ 31- 40 ☐ 41-50 ☐ >50 ☐

A.3 Years spent in formal school_____

Highest certificate achieved_____

A.4 Marital status: Single ☐ Married ☐ Divorcee ☐ Widow ☐

If married how many wives do you have? _____

If married woman is your husband married to other wives?_____

A.5 Occupation: Farmer ☐ Pastoralist ☐ Farmer and pastoralist ☐
Trader ☐ Employee ☐ Others (specify)

A. 6 Social status of the head of the household

Village elder	☐	Member of any socio-cultural group	☐
Chief	☐	Religious leader	☐
Retired civil servant	☐	Member of village committee	☐
Member of water users association	☐	Civil servant	☐

A.7 Family structure

Age group (years)	Number	Gender		Residing on farm and in school/college	Residing on farm and not in school/college	Not residing on-farm and in school/college	Not residing on farm and not in school/college
		M	F				
<2							
2-5							
5-14							
15-18							
>18							
Total							

A.8 For the children are going to school/college at what levels are they?

Child (No.) Level of education

A.9 What role does each member of the family play in natural resource management?

Children_____
Teenagers (female)_____
Teenagers (male)_____
Adult(s) (Women)_____
Adult(s) (Male)_____

A.10 Are there members of your family who work outside your farm?_____

If yes how do they contribute towards the family income (Please fill in the table below)?

Number	Age	Occupation	Place of work	Income they remit/month
1				
2				
3				
4				
5				

A. 11 What is the estimate of your household monthly income?
Maximum_____ Ksh , Minimum _____ Ksh and average monthly income of _____ Ksh.

What are the major sources of your income per year? Please rank them priority with the most important as 1

Source (Ksh) Estimated production income/year Rank

Livestock
- Live animals/birds:
  - Cattle
  - Goats
  - Sheep
  - Donkey
  - Poultry
- Milk
- Butter/Ghee
- Hides & skins
- Honey
- Eggs
- Traction

Trees
- Timber
- Poles/posts
- Charcoal
- Firewood
- Medicinal plants
- Nursery seedlings
- Fruits

Crops
- Maize
- Beans
- Cowpea
- Pigeon pea
- Sorghum
- Green grams

Salary/wage

Business

B. FARM INFORMATION

B.1 Do you own the land? Yes ☐ No ☐

If yes, how did you acquire? Inherited ☐ bought ☐ Allocated ☐

B.2 What is the total size of your land?_____(Acres)

B.3 When did you settle here? _____

B.4 Where did you migrate from?_____

B.5 Do you have land elsewhere? Yes ☐ No ☐

If yes, what size and where? _____(acres)

B.6 Has your land been surveyed? Yes ☐ No ☐

B.7 Do you have a title deed? Yes ☐ No ☐

C. LAND USE

C.1 Proportion of land use

Homestead (Ha)	Crops (Ha)	Pastures (Ha)	Trees/woodland (Ha)	Total Land area (Ha)

C.2 What do you understand by the terms:

Land degradation

Desertification

Deforestation

Soil erosion

Soil fertility

Sustainable development

Overgrazing

Biodiversity conservation

C.3 What are the natural resource components that sustain your livelihood? Please prioritise starting with the most important as 1:

Crops only ☐

Trees only ☐

Livestock only ☐

Crops and trees ☐

Crops and livestock ☐

Trees and livestock ☐

Crops, trees and livestock ☐

C.4 Which resources do you consider the most crucial in improving your production levels?

Crops ☐

Trees ☐

Livestock ☐

Water ☐

C.5 A part from your household members, are there others from within and outside the village, location, division, district etc. who come to use you land resources (e.g. crops, stover, pastures, trees and woodlands, water etc.)?

Yes ☐ No ☐

If yes who are they?_____

When do they normally come?_____

What resources do they use and under what conditions?

_____

_____

C.6 Are there communally or Government owned land resources in your village?

Yes ☐ No ☐

If yes, who manages the Government resources? _____
and who are entitled to use them?_____
Who manages the communal resources _____ and who are entitled to use them_____

C.7 In which areas do you spend most income in the last 10 years?

Food ☐ Education ☐ Health Livestock ☐

Crops ☐ Building ☐ Clothing Fund raising ☐

Purchase of pasture ☐ Purchase of water ☐

C.8 Have you ever obtained loan(s)? Yes ☐ No ☐

If yes from where and how much?
Institution/organization _____ Kshs _____
If not why not? _____

C.9 Do you employ labourer(s) Yes ☐ No ☐

If yes for which activities in the last two seasons?_____, _____, _____, _____, _____, _____, _____

How many labourer(s) and at what cost_____ at Ksh/month_____
for _____ months

C.10 In your household who makes decision on:

- Cropping_____
- Woodland, pasture and trees management_____
- Water use for: Livestock _____ Crops_____ Trees_____ Domestic_____
- Livestock management_____
- Soil conservation_____
- Sale/purchase of:

Crop products: Stovers _____, grains/seeds_____
Animal products: Live animals (main)_____,
Hides and skin_____ Chicken_____, Milk and milk products_____,
Manure_____, Honey_____
Wood and tree products: Firewood_____, Timber and poles/posts_____,
Fruits_____, Charcoal_____,
Fodder/pasture_____
Water_____
Parcel of land_____

D. CROP PRODUCTION

D.1 What area of your Land is under cultivation? _____ acres

Are you cultivating all of your land? Yes ☐ No ☐

If yes since when _____ and for what reasons?_____
_____
If no what are the reasons?_____
_____

D.2 Are all your fields in one unit? Yes ☐ No ☐

D.3 Has the size of your cultivated land changed?

Yes ☐ No ☐ No change ☐

If yes, has it expanded or decreased in size?_____ _____

If it has expanded or decreased what are the reasons? _____
_____

If your cultivated land has expanded, is the newly cultivated land as productive as the previous one?
Yes ☐ No ☐

What do you think accounts for difference in land production?
_____

How far is this newly cultivated land far from your homestead? _____ km

D.4 How many days does it take you to clear 1 acre of new land?
_____no. of hours/day in _____no. of days with _____ persons

D.5 Is there any part of your farm you leased to other people to farm? Yes ☐ No ☐

If yes how much is paid for an acre per year? _____

D.6 What do you consider as the quality of a good and ideal farm for a sustainable production?

_____

_____

D.7 What do you consider as the quality of a good and ideal crop for a sustainable production?

_____

_____

D.8 List major subsistence and cash crops grown on your farm in order of importance (for each type) and estimated area coverage and yield in Kg per season

Crop Type	Estimated Area (Acres)		Estimated Yield (90 kg bags/Yr)		Use (No. bags)	
	Long rains	Short rains	Long rains	Short rains	Sale	Consumption

D.9 Do you grow each of these crops alone or mix them with other crops?

Mixed ☐ Alone ☐

If mixed which crops do you mix? _____

_____

D.10 Do you grow same crops each season, change to other crops, practice fallow?

_____

D.11 How do you prepare your land?

Oxen plough ☐ Hand tools ☐

Tractor ☐ Family labour ☐

Group labour (relatives, neighbours) ☐

Hired labour ☐

Why do you use the above technologies/technology? _____

D.12 What are the common crop pests and diseases here? Fill the Table below

D.13 List important constraints to crop production (Please rank in order of severity with 1 as the most severe)

Crop type	Pest/Disease	Symptoms	Control Method		
			Conventional	Who taught you	Indigenous methods
Maize	1. 2. 3. 4.				
Beans	1. 2. 3. 4.				
Cowpea	1. 2. 3. 4.				
Pigeon pea	1. 2. 3. 4.				
Green grams	1. 2. 3. 4.				
Sorghum	1. 2. 3. 4.				
Millet	1. 2. 3. 4.				
Cassava	1. 2. 3. 4.				
Pumpkins	1. 2. 3. 4.				
Sweet potatoes	1. 2. 3. 4.				

Pests	☐	Diseases	☐	Labour	☐
Input	☐	Market	☐	Culture	☐
Moisture	☐	Storage	☐	Wildlife	☐
Salinity	☐	Thieves	☐	Weeds	☐
Finance	☐				

D.14 What are the main foodstuffs used by your family? _____, _____,
_____, _____, _____
_____, _____, _____

D.15 What is the estimated kilogram of the foodstuffs (per type) used by your family per day/week?

Foodstuff type	No. of days/week	Kg

D.16 Do you get enough food from your farm throughout the year?

Yes ☐ No ☐

If you get enough food from your farm, what do you do with the surplus?

Sale ☐ Store for future use ☐ Others specify)_____

If No, Where do you get the additional food?

Sources of additional food	Quantity/month (Kg)
Relief	
Purchase	
Neighbours/friends	

How often do you experience food shortage in a year? _____ months

During which month(s) do you experience the most severe shortage? _____

What measures do you take to reduce food shortages in times of drought and famine?

D.17 What type of storage facilities do you have?

Permanent ☐ Semi-permananet ☐ Temporary ☐

Do you have problem (s) with storage of crop products? Yes ☐ No ☐

If yes, list the major five problems stating the most severe as 1.

1. _____
2. _____
3. _____
4. _____
5. _____

D.18 Do you have problem (s) with marketing crop products?

Yes ☐ No ☐

If yes, list the major five problems stating the most severe as 1

1. _____
2. _____
3. _____
4. _____
5. _____

D.19 How do you transport the following products from farm to store/market (feel where appropriate)?

Type	Transport means to	
	Store	Market
Crop products		
Grains		
Vegetables		
Stovers		
Animal products		
Major livestock		
Chicken		
Hides & skins		
Milk and milk products		
Honey		
Manure		
Tree & Pasture products		
Timber		
Poles/posts		
Charcoal		
Fruits		
Firewood		
Forage		

D.20 How do you market your crop products?

Sale on farm ☐ Take products to near by centres ☐

Time market days ☐ Sale along the Nairobi- Mombasa Highway ☐

How far is the nearest major market for your farm products?_____ km

In what form do you sale the crop products? Processed ☐ Unprocessed ☐

Both forms ☐

What is the average price of a 90-kilogram of the products at your nearest main market? (Please fill where applicable)

Crop type	**Weight**	**Just after harvest Estimated Costs (Ksh.)**		**Dry season/drought Estimated cost (Ksh.)**	
		Unprocessed	**Processed**	**Unprocessed**	**Processed**
Maize	90 Kg				
Millet	90 Kg				
Sorghum	90 Kg				
Pigeon pea	90 Kg				
Cow pea	90 Kg				
Green grams	90 Kg				
Tomatoes	A crate				
Onions	A crate				
Okra	A crate				
Beans	90 kg				
Cassava	90 kg				

D.21 Do you think population increase is causing food shortage and famine in your locality?

Yes ☐ No ☐

If yes in your view how do we address population problem? _____

D.22 What do you do with your crop residues?

Burn on farm ☐ Use as feed ☐ Use as fuelwood ☐

Soil fertility improvement ☐

D.23 Do you use fire as part of your land management practices? Yes ☐ No ☐

If yes, name type(s) of use(s)? _____

D.24 Do you use improved seeds/germplasm? Yes ☐ No ☐

If yes, for which crops and where do you get seeds from?

Crop type	Source of seeds/germplasm
Maize	
Beans	
Millet	
Sorghum	
Pigeon pea	
Green grams	
Cowpea	
Tomatoes	
Cassava	
Onions	
Okra	

If Not what do you think are the reasons?_____

D.25 Has there been any institutions/projects that advised/contributed to you on crop or farm management?

Yes ☐ No ☐

If yes which are these institutions/projects (as long as you can remember) and what technologies and advices have they given you?

Name of institution	Type of technology/advice

If No what do you think are the reasons?_____

D.26 What do you think of their advises/contributions?_____

D.27 What do you see as the most tangible impacts of these contributions to your crop and land productivity?

Positive impacts_____

Negative impacts_____

E. SOIL

E.1 Do you experience soil erosion change on your Land? Yes ☐ No ☐

If yes, has it been: Increasing ☐ decreasing ☐ No change ☐

If rising or declining what are the major reasons for these (please prioritise)?

Rise_____

Decline_____

What conservation measures do you use to reduce the problem?

Terraces	☐	Trash line	☐
Contour Ploughing	☐	Grass strips	☐
Reseeding	☐	Pitting	☐
Reforestation	☐	Cut off drains	☐
Contour planting	☐	None	☐
Bush trash	☐		

E.2 Do you observe signs of soil erosion on your farm?

Yes ☐ No ☐

If yes, what are these signs? _____

E.3 Do you experience soil fertility change on your land? Yes ☐ No ☐

If yes, has it been rising or declining? Rising ☐ Declining ☐ No change ☐

If rising or declining what are the major reasons for these (please prioritise)?
Rise_____
_____
Decline_____
_____

If declining what are these signs? _____
_____

If the fertility is declining which practices do you use to maintain or enrich soil fertility of your cultivated farm plots?

Fertiliser ☐ Animal manure ☐
Compost manure ☐ Crop Residues ☐
Terraces ☐ None ☐

E.4 Do you observe appearances of plant species that signify decline in soil fertility?
Yes ☐ No ☐

If yes, what are the names of these species that indicate:

- Decline in fertility? _____, _____, _____, _____,
- That the soil is fertile? _____, _____, _____

E.6 Do you use fertilizer? Yes ☐ No ☐

If yes what kind and how much do you pay for 90 kg of fertilizer including transport?

Type of fertilizer	Price/bag
1 _____	_____
2 _____	_____
3 _____	_____

E.7 Has your fertilizer use increased, decreased or remained the same in the last 10 years?

Increased ☐ Decreased ☐ Remained the same ☐

If it has increased what are the reason for this change?_____
_____
_____
_____

E.8 What do you consider as the quality of a good and fertile soil for a sustainable production?
_____
_____
_____

E.9 Has there been any institution/project that advised/contributed to your soil fertility and soil conservation and management?

Yes ☐ No ☐

E.10 If yes which are these institutions/projects (as long as you can remember) and what technologies and advices have they given you?

Name of institution	Type of technology/advice
1 _____	_____
2 _____	_____
3 _____	_____

If Not what do you think are the reasons? ? _____
_____
_____

E.11 What do you think of their advises/contributions? _____
_____

E.12 What do you see as the most tangible impacts of these contributions to soil conservation and

fertility improvement efforts

Positive impacts_____

_____

Negative impacts_____

_____

F. WATER

F.1 In your opinion has annual rainfall increased or decreased over the years (as long as you can remember)?

Increased ☐ Decreased ☐ No change ☐

In relation to the above, please fill the table below giving scores per season with
1 = Very high 2 = High 3 = Medium 4 = Low 5 = Very low

Year	Seasons									
	Nov. – Dec. rains					March – April rains				
	1	2	3	4	5	1	2	3	4	5
2001										
2000										
1999										
1998										
1997										
1996										
1995										
1994										
1993										
1992										
1991										
1990										
1980										
1970										
1960										
1950										

If yes how many droughts/famine occurred in this area?_____

_____

What do you think are the causes of these frequent droughts/famine?

_____

_____

How do you think we can overcome droughts/famine? _____

_____

Why do you suggest so? _____

_____

F.2 What are your major sources of water, when available and how far?

Fill the Table below

Source	Season		Distance to source (km)		Remarks
	Rainy	Dry	Rainy season	Dry season	
Roof catchment					
Water pans					
Boreholes					
Piped water					
Rock catchment					
Springs					
Wells					
Dams					
Rivers					
Ponds					

F.3 What measures have you undertaken to conserve water/soil moisture for domestic, crop, trees, pastures and livestock uses?

a. Domestic

b. Crop

c. Livestock

d. Trees & Pastures

F.4 What are the sources of water for your trees and crops? _____

_____

F.5 What is the average depth of ground water level in this village? _____

F.6 Do you have enough water supplies through out the year? Yes ☐ No ☐

If yes:

Do you save? Yes ☐ No ☐

How long do you use the saved water? _____ days/months.

Do you sale water? Yes ☐ No ☐

If yes in which month(s) _____ and for how much _____

If no why are you not saving? _____

F.7 Do you use irrigation in any of your plots? Yes ☐ No ☐

If yes, on what trees and crops?

Trees _____, _____, _____, _____, _____, _____, _____

Crops _____, _____, _____, _____, _____, _____, _____

F.8 Is there a permanent source of water for the village? Yes ☐ No ☐

If yes who owns it? _____

What is the quality of the water?

Salty ☐ Soft ☐ Brownish ☐ Clear ☐ Contaminated ☐

What are the common water-borne diseases in the village?

F.9 What do you consider as the quality of an ideal water for a sustainable production?

For Domestic use _____

_____

For Irrigation _____

_____

For Livestock _____

_____

F.10 What is the estimated amount of water you use (in litres) in each of the following use:

Domestic use (per day)_____

Livestock (per day)_____

Irrigation of crops (per week)_____

Trees (per week)_____

Domestic use_____
Livestock _____
Irrigation of crops_____
Trees _____

F.11 Do you have problem in getting quality water for domestic and irrigation?

Yes ☐ No ☐

If yes, which are the critical months of water shortage each year?
_____

F.12 How do you deal with this problem?_____
_____

F.13 What is your suggestion towards the improvement of quantity and quality water availability?

_____
_____
_____
_____
_____
_____

F.14 Has there been any institutions/projects that advised/contributed to your water use, conservation and management?

Yes ☐ No ☐

If yes which are these institutions/projects (as long as you can remember) and what technologies and advices have they given you?

Name of institution	Type of technology/advice
1_____	_____
2_____	_____
3_____	_____
4_____	_____
5_____	_____

If Not what do you think are the reasons?

F.15 What do you think of their advices/contributions?

F.16 What do you see as the most tangible impacts of these contributions to your water quantity and quality?

G. TREES AND WOODLANDS

G.1 Do you have trees/woodlands on your land? Yes ☐ No ☐

If No, why _____

If Yes, fill the following table.

Species	Exotic	Indigenous	Planted	natural	Uses and problem(s)

Categories of uses: 1=Fruit 2=Wood fuel 3=Live fence 4=Aesthetic 5=Charcoal 6=Poles
7=Wind break 8=Shade 9=Tmber 10= Fruits

G.2 What are the common tree pests and diseases here? Fill the Table below

Tree type	Pest/Disease	Symptoms	Control methods		
			Conventional	Who taught you	Indigenous methods

G.3 What do you consider as the quality of an ideal woodland/forest a sustainable production?
_____

G.4 What area of your land is under trees/woodlands? _____acres

G.5 Where do you acquire your tree planting materials?

Forest department Nurseries ☐ School nurseries ☐
Wild seedlings ☐ Own nursery ☐
Individual Nurseries ☐ Women group nurseries ☐
ARIDSAK Nursery ☐ University of Nairobi farm ☐
Natural cuttings ☐ Neighbours nursery ☐

G.6 Have you planted trees and shrubs on your farm? Yes ☐ No ☐

If Not why (please prioritise)?

If Yes out of the total number of seedlings you planted in the last 5 years how many are still surviving? Number planted_____ Number surviving_____

G.7 How do you manage your planted seedlings?_____

G.8 How do you manage your mature trees (both planted and natural)?

G.9 Since you settled on your land, have you noticed any change on the vegetation cover?

Yes ☐ No ☐

If Yes, how?Increased ☐ Decreased ☐

If increased what are the reasons (please prioritise)?

_____
_____

If decreased what are the reasons (please prioritise)?

_____
_____

Which are the preferred species already overexploited for different uses?

_____
_____
_____

G.10 Where do you get your fuelwood, wood and non-wood forest products?

My farm ☐ Neighbours ☐ Government areas ☐

Purchase from neighbours ☐ Communal areas ☐

Purchase from the market ☐

If purchased how much does it cost? _____Kshs for_____ quantity of firewood/ charcoal.

How far is the source of your fuelwood from the homestead? _____ km

How many head loads of firewood do you use per week? _____

G.11 Do you get enough wood and non-wood products from your farm?

Yes ☐ No ☐

If you get enough wood and non-wood forest products what do you do with the surplus?

Sale ☐ Store for future use ☐ In-situ conservation ☐

How do you market your wood and non-wood products?

Product	Price/unit
Timber	_____Ksh/timber
Poles/posts	_____Ksh/pole or post
Fruits	_____ Ksh/ fruit type
Charcoal	_____ Ksh/sack

What income do you earn from sale of wood and non-wood products per month?

_____

G. 12 Do you have any problem (s) with marketing of wood and non-wood products?

Yes ☐ No ☐

If yes, list the major five problems stating the most critical as 1

1. _____
2. _____
3. _____
4. _____
5. _____

G.13 Do you have any problem (s) with storage of wood and non-wood products?

Yes ☐ No ☐

If yes, list the major five problems stating the most critical as 1

1. _____
2 _____
3. _____
4 _____
5. _____

G.14 List important constraints to tree production (Please rank in order of severity with 1 as the most severe)

Pests	☐	Diseases	☐	Labour	☐
Inputs	☐	Market	☐	Culture	☐
Moisture	☐	Storage	☐	Wildlife	☐
Salinity	☐	Thieves		Weeds	☐
Finance	☐	Planting materials	☐		

G.15 Has there been any institutions/projects that advised/contributed to your tree/woodland production management?

Yes ☐ No ☐

If yes which are these institutions/projects (as long as you can remember) and what technologies and advices have they given you?

Name of institution	Type of technology/advice
1 _____	_____
2 _____	_____
3 _____	_____
4 _____	_____
5 _____	_____

If Not what do you think are the reasons?

What do you think of their advises/contributions?

_____

_____

G.16 What do you see as the most tangible impacts of these contributions to your tree/woodland productivity?

Positive impacts_____

_____

_____

Negative impacts_____

_____

G.17 How do you think we can best conserve and manage trees and woodlands?

_____

_____

_____

H. LIVESTOCK PRODUCTION AND WILDLIFE

H.1 Do own livestock? Yes ☐ No ☐ If yes, complete the table below

Livestock type	No. and breed		Total
	Local	Improved	
Cattle			
Goats			
Sheep			
Poultry			
Donkey			
Bee hives			
Dogs			
Cats			

H.2 What area of your Land is under pasture? _____ acres

H.3 What do you consider as the quality of an ideal pasture or range for a sustainable production?

_____

_____

How do you relate range condition in this area over the years?

Improving ☐ Deteriorating ☐

What do you think are the causes for this change _____

_____

What do you consider as the quality of an ideal livestock for a sustainable production?

*For milk*_____

*For Beef*_____

H.4 Do you perceive carrying capacity as an important range factor? Yes ☐ No ☐

If yes what factors determine the carrying capacity of a range?_____

_____

H.5 How do you feed your animals?

Free grazing_____ ☐

Rotation grazing _____ ☐

Zero grazing _____ ☐

Tethering _____ ☐

Semi- zero grazing ____ ☐

H.6 Do you have shortage of pasture or feed for your livestock

Yes ☐ No ☐

If yes what are the critical months?_____

How do you deal with this problem?

Migration ☐ Purchase forage/pastures ☐

Minerals ☐ Crop residues ☐

Concentrates ☐ Lop tree branches ☐

Hay ☐

H.7 If you have shortage of pasture, do you think that decreasing the number of livestock will help solve this problem and why? Yes ☐ No ☐

H. 8 Are there dry season fodder/forage reserves within this area? Yes No

If yes please name them, estimate their distances from your farm

Name of reserve	Estimated distance (km)	Who manages the reserve	Accessible to who
1. _____	_____	_____	_____
2. _____	_____	_____	_____

If no how do you manage your livestock in wet and dry seasons? _____

_____

H.9 Do you have bush problem on your land? Yes ☐ No ☐

If yes, how do you control?

1. None _____ ☐
2. Manual _____ ☐
3. Mechanical _____ ☐
4. Fire _____ ☐

H.10 Do you observe the emergence of unpalatable pasture species and decline of palatable species in the grazing areas?

Yes ☐ No ☐

H.11 If yes, what are the names of the species?

Unpalatable

Local Name

_____

_____

In your opinion why has unpalatable species increased?_____

Palatable

Local Name

_____

_____

In your opinion why has palatable species decreased?_____

H.12 How do you manage your pastures_____

_____

H.13 What is your suggestion towards pasture/livestock improvement?_____

_____

H.14 What are the sources of water for your animals and when do you water them?

Fill the Table below

Animal type	Season	Water source	Distance (km)
Cattle	Dry		
	Wet		
Sheep	Dry		
	Wet		
Goats	Dry		
	Wet		
Donkeys	Dry		
	Wet		
Pigs	Dry		
	Wet		
Chicken	Dry		
	Wet		
Bees	Dry		
	Wet		
Camels	Dry		
	Wet		

Possible sources of water: 1 = Roof catchment 2 = Rock catchment 3 = Earth dams
4 = Springs 5 = Rivers/streams 6 = Wells 7 = Ponds 8 = Boreholes

H. 15 How often do you water your animals during the dry and wet seasons?

Animal type	Season	Frequency of watering				
		Very frequent	Twice a day	Once daily	Once very two days	Once in three days
Cattle	Dry					
	Wet					
Sheep	Dry					
	Wet					
Goats	Dry					
	Wet					
Donkeys	Dry					
	Wet					
Pigs	Dry					
	Wet					
Chicken	Dry					
	Wet					
Bees	Dry					
	Wet					
Camels	Dry					
	Wet					

H.16 How many permanent-watering points for animals do you have in the village? _____ number of points

H.17 What are the most common types of permanent watering points used in your village? Please prioritise them in the order of importance

1 _____ 2 _____ 3 _____ 4 _____ 5 _____

H.18 Do you have problems in getting water for your animals?

If yes, what are the critical months? _____

How do you deal with this problem? _____

_____

_____

_____

H.19 What is your suggestion towards the improvement of water quality and availability for livestock?

_____

_____

H.20 What are the common Livestock diseases/pests here? Fill the Table below

Animal	Disease/pests	Symptoms	Control method		
			Conventional	Who taught you	Indigenous method
Cattle					
Goats					
Sheep					
Donkey					
Poultry					
Bees					

H.21 Do you practice any breeding system? Yes ☐ No ☐

If yes specify Natural ☐ Artificial ☐

Specify the breeding season for;

Cattle _____ Sheep _____

Goats _____ Donkey _____

Poultry _____

Explain your breeding system

H.22 List and priority reasons of keeping animals

Animal	Reasons for keeping livestock										
Cattle											
Sheep											
Goats											
Poultry											
Donkey											
Pigs											
Camel											
Bees											

1 = Milk 2 = Meat 3 = Cash 4 = Hides and Skin 5 = Dowry
6 = Traction 7 = Manure 8 = Blood 9 = Prestige 10 = Security
11 = Eggs 12 = Transport

H. 23 How many animals on average do you milk per season and on average how much do you get from each animal?

Animal	Season			
	Wet		Dry	
	No. of animals milked	Average milk/animal/day (lts)	No. of animals milked	Average milk/animal/day (lts)
Cattle				
Goats				
Sheep				
Camels				

H.24 How many animals and/or animal products on average do you sell per day/month/ season? (fill in the table)

Animal	Products	Method of marketing			Season			
					Wet		Dry	
		Individual	Group	Others (specify)	Av. amount sold	Price/ unit	Av. amount sold	Price/ unit
Cattle	Live animals (No.)							
	Milk (litres/day)							
	Butter/Ghee (litres/day)							
	Hides & skins (No.)							
	Manure (tons)							
Sheep	Live animals (No.)							
	Milk (litres)							
	Butter/Ghee							
	Hides & skins							
	Manure (tons)							
Goats	Live animals (No.)							
	Milk (litres)							
	Butter/Ghee (litres/day)							
	Hides & skins (No)							
	Manure (tons)							
Poultry	Live birds (No./month)							
	Eggs (No./month)							
Bees	Honey (Kg)							

H.25 Do you have any problem (s) with Marketing Livestock and Livestock Products?

Yes ☐ No ☐

If yes, list five major problems stating the most severe problem as 1.

1_____
2_____
3_____
4_____
5_____

H. 26 List important constraints to livestock production (Please rank in order of severity with 1 as the most severe)

Pests ☐ Diseases ☐ Labour ☐

Inputs ☐ Market ☐ Water ☐

Cold storage ☐ Wildlife ☐ Thieves ☐

Forage/pasture ☐ Finance ☐ Transport ☐

Breed ☐

H.27 Has there been any institution/project that advised/contributed to you on pasture or livestock management?

Yes ☐ No ☐

If yes which are these institutions/projects (as long as you can remember) and what technologies and advices have they given you?

Name of institution	Type of technology/advice
1	
2	
3	
4	
5	

If Not what do you think is the reason?

What do you think of their advises/contributions?

H.28 What do you see as the most tangible impacts of these contributions to your livestock productivity?

Positive impacts

Negative impacts

H.29 Explain what do you understand by the word "wildlife"?

H.30 Are there wild animals found on your farm? Yes ☐ No ☐

If yes which are the most common ones?

What social, economic and environmental benefits do wild animals contribute to you, your family and community?

Social

Economic

Environmental

H.31 Do you see them as a benefit or a problem both at farm level and national level?

Farm level

National level

H. 32 If wild animals are beneficial on-farm, which ones have contributed to your livelihood in the last 10 years?

H. 33 If wild animals are more of a problem in views, which ones have caused damage to your farm, crops, trees and livestock in the last 10 years?

H.34 Nationally, wildlife is considered as a national heritage that has to be conserved. How best do you think we should conserve and manage them on-farm as well as in parks?

Farm level

National level

Appendix II A: The characteristics of soil resources in Muusini Village, Kibwezi, Kenya

FERRALSOLS (Local Kamba name: Muthangathi ila nziu/Muthangathi ila mbulanu/Ilive)

Ref No	Poverty N	Parent	Slope		Land cover	Colour (Munsell colour chart)					Texture (%)		Texture	Moisture	pH - water	pH -CaCl2	EC	N	OMC	C/N	P	K	Ca	Mg	Na	Sum	CEC	BS	Cu	Zn	Mn	Fe	Erosion	Erosion	Type of
		rock	Shape	%		Wet		Dry			Sand	Clay	Silt	class	%				%	%		ppm	me/100g	me/100g	me/100g	me/100g	bases		%	ppm	ppm	ppm	ppm	status	risk	erosion
Muusini 1	II	Basement	Linear	0 - 2	Cropland	vdaGr	10YR 4/6	Br	10YR 4/4		76	16	6	Sandyloam	3	6,3	5,3	0,03	0,10	2,17	13,00	16,00	0,89	0,60	0,74	0,35	2,59	36,00	7,00	2,00	2,00	118,00	195,00	Severe	V. high	Sheet,rill
Muusini 2	III	Basement	Linear	0 - 2	Cropland	daBr	7,5YR 3/4	vyBr	10YR 3/4		80	8	12	Loamy sand	1	6,2	5,5	0,03	0,04	0,79	12,00	13,00	0,67	1,22	1,08	0,45	3,42	38,00	9,00	2,00	5,00	265,00	218,00	Excessive	V. high	Sheet, rill
Muusini 20	I	Basement	Linear	0 - 2	Cropland	Br	10YR 4/4	Br	10YR 4/4		80	16	4	Sandy loam	1	7	5,4	0,04	0,09	1,50	10,00	4,00	0,69	0,69	0,94	0,55	2,87	32,00	9,00	4,00	3,00	252,00	283,00	Moderate	Severe	Sheet
Muusini 15	III	Basement	Linear	0 - 2	Cropland	vdaGR	10YR 4/6	Br	10YR 5/8		88	6	6	Loamy sand	1	6,8	5,9	0,02	0,03	0,60	12,00	7,00	0,39	2,54	1,22	0,59	4,73	8,00	59,00	2,00	3,25	219,00	258,00	Excessive	V. high	Sheet, rill
											81	11,5	7		1,5	6,58	5,53	0,03	0,07	1,27	11,75	10,00	0,66	1,26	1,00	0,49	3,40	28,50	21,00	2,50	3,31	213,50	238,50			
											5	5	3		1	0,39	0,26	0,01	0,04	0,72	1,26	5,48	0,21	0,89	0,11	0,11	0,95	13,89	25,35	1,00	1,25	66,55	34,18			
Muusini 3	I	Basement	Linear	0 - 2	Woodland & pastures	vdaqrBr	10YR 3/2	daBr	10YR 3/3		88	8	4	Loamy sand	1	7	5,5	0,03	0,82	0,12	12,00	7,00	0,58	0,77	0,87	0,48	2,70	18,00	15,00	2,00	3,00	205,00	248,00	High	Severe	Sheet, rill
Muusini 11	III	Basement	Linear	0 - 2	Wood land & pastures	davBr	10YR 3/4	Br	10YR 5/3		90	8	2	Sand	1	6,8	5,9	0,04	0,06	0,98	10,00	7,00	0,51	0,58	0,74	0,49	2,31	22,00	11,00	2,00	6,00	237,00	270,00	High	Severe	Sheet, rill
Muusini 21	II	Basement	Linear	0 - 2	Woodland & pastures	daBr	7,5YR 3/4	daBr	7,5YR 3/4		88	8	4	Loamy sand	1	6,6	5,7	0,03	0,08	1,46	11,00	4,00	0,82	9,86	2,08	1,15	13,92	30,00	46,00	2,00	2,00	215,00	294,00	moderate	moderate	Sheet, rill
Muusini 14	II	Basement	Concave	0 - 2	Woodland & pastures	vdaqrBr	10YR 3/2	Br	10YR 4/4		84	10	6	Loamy sand	3	6,2	6,2	0,08	0,12	2,37	12,00	4,00	0,70	5,83	1,72	0,61	8,86	10,00	89,00	7,00	3,00	464,00	349,00	Slight	High	Sheet
Muusini 22	III	Basement	Linear	0 - 2	Woodland & pastures	davBr	10YR 3/4		10YR 3/6		74	18	8	Sandy loam	3	6,2	5,1	0,06	0,10	1,88	11,00	10,00	0,70	3,10	1,44	0,64	5,93	12,00	49,00	4,00	4,00	306,00	310,00	Slight	moderate	Sheet
Av				0 - 2							85	10,4	4,8	Loamy sand	1,5	6,56	5,68	0,05	0,24	1,36	11,20	6,40	0,66	4,03	1,37	0,67	6,74	18,40	42,00	3,40	3,60	285,40	294,20	Slight/high	High/mod	Sheet, rill
											6	4	2		1,10	0,36	0,41	0,02	0,33	0,86	0,84	2,51	0,12	3,89	0,57	0,28	4,81	8,05	31,48	2,19	1,52	107,34	38,64			

LUVISOLS (Local Kamba name: Kitune)

Ref No										Sand	Clay	Silt	Texture	Moisture	pH - water	pH -CaCl2	EC	N	OMC	C/N	P	K	Ca	Mg	Na	Sum of	CEC	BSP	Cu	Zn	Mn	Fe			
													class	%				%	%		ppm	me/100g	me/100g	me/100g	me/100g	bases		%	ppm	ppm	ppm	ppm			
Muusini 4	III		Linear	0 - 2	Cropland	daR	2,5YR 3/6	R	2,5YR 5/8	78	16	6	Sandy loam	3	6,7	6	0,04	0,07	1,31	11,00	6,00	0,81	1,31	1,18	0,50	3,79	28,00	14,00	7,00	4,00	356,00	212,00	Severe	High	Sheet, rill
Muusini 6	II		Linear	0 - 2	Cropland	darBr	2,5YR 3/4	darBr	2,5YR 3/4	76	20	4	Sandy loam	5	5,8	6	0,05	0,10	1,96	11,00	7,00	1,16	2,00	1,39	0,50	5,05	36,00	14,00	7,00	8,00	436,00	222,00	Severe	High	Sheet, rill
Muusini 7	III		Linear	0 - 2	Cropland	darBr	5YR 3/4	R	5YR 4/6	84	10	6	Loamy sand	2	6,4	5,6	0,05	0,06	1,22	12,00	4,00	0,96	1,37	1,03	0,51	3,87	26,00	15,00	6,00	10,00	387,00	227,00	Severe	V. high	Sheet, rill
Muusini 9	II		Linear	2 to 5	Cropland	dR	2,5YR 3/6	daR	2,5YR 3/6	80	18	2	Sandy loam	2	6,4	6,2	0,08	0,06	1,05	10,00	10,00	0,93	1,51	1,36	0,51	4,31	20,00	22,00	8,00	5,00	418,00	240,00	Severe	High	Sheet, rill
Muusini 10	II		Linear	0 - 2	Cropland	darBr	2,5YR 3/4	darBr	2,5YR 5/3	78	18	4	Sandy loam	3	6,1	6	0,04	0,08	2,22	16,00	7,00	0,80	1,73	1,16	0,50	4,19	32,00	13,00	9,00	6,00	398,00	324,00	Severe	Moderate	Sheet
Muusini 12	I		Linear	2 to 5	Cropland	yR	5YR 4/6	darBr	5YR 3/4	80	18	2	Sandy loam	3	6,6	6	0,17	0,08	1,45	11,00	12,00	1,05	3,65	1,48	0,59	6,77	10,00	68,00	6,00	17,00	259,00	290,00	Moderate	Severe	Sheet
Muusini 18	III		Linear	0 - 2	Cropland	daR	2,5YR 3/6	R	2,5YR 4/8	74	20	6	Sandy loam	3	5,3	5,2	0,05	0,09	1,57	10,00	8,00	0,89	0,96	0,96	0,39	3,20	40,00	8,00	4,00	3,00	252,00	283,00	Severe	High	Sheet, rill
Muusini 23	III		Linear	0 - 2	Cropland	daR	2,5YR 3/6	R	2,5YR 4/6	78	16	6	Sandy loam	3	6,2	5,8	0,06	0,08	1,48	11,00	7,00	1,59	3,63	0,65	0,99	6,86	8,00	86,00	7,00	3,00	388,00	295,00	Severe	High	Sheet, rill
Av				0 - 2		daR	2,5YR 3/6	R	2,5YR 4/6	79	17	4,5	Sandy loam	3	6,19	5,85	0,07	0,08	1,53	11,50	7,63	1,02	2,02	1,15	0,56	4,76	25,00	30,00	6,75	7,00	361,75	261,63	Severe	High	Sheet, rill
Stdev										3	3	2		0,93	0,46	0,32	0,04	0,01	0,39	1,93	2,45	0,26	1,04	0,27	0,18	1,37	11,61	29,65	1,49	4,72	69,65	41,35			
Muusini 5	III		Linear	0 - 2	Woodland & pastures	R	2,5YR 4/8	daR	2,5YR 3/6	64	26	10	S/C/loam	4	6,2	5,6	0,08	0,07	1,36	11,00	4,00	0,94	1,05	1,16	0,39	3,53	46,00	8,00	5,00	2,00	438,00	219,00	Severe	High	Sheet, rill
Muusini 8	II		Linear	0 - 2	Woodland & pastures	daR	2,5YR 3/6	R	2,5YR 4/6	70	12	18	Sandy loam	4	6,7	5,9	0,07	0,14	2,60	11,00	4,00	1,05	2,56	1,67	0,52	5,80	32,00	18,00	12,00	3,00	416,00	263,00	Moderate	Moderate	Sheet, rill
Musini 16	III		Linear	0 - 2	Woodland & pastures	R	2,5YR 4/8	daR	2,5YR 3/6	50	20	30	Loam	3	6,6	6	0,04	0,10	2,06	11,00	5,00	1,03	1,68	1,74	0,55	5,00	36,00	14,00	8,00	6,00	438,00	274,00	Severe	High	Sheet, rill
Musini 17	I		Linear	0 - 2	Woodland & pastures	R	2,5YR 4/8	duR	2,5YR 3/2	78	16	6	Sandy loam	3	6,9	5,9	0,12	0,09	1,63	11,00	3,00	1,15	1,59	1,15	0,42	4,31	36,00	12,00	10,00	3,00	509,00	282,00	Severe	High	Sheet, rill
Av				0 - 2						65,5	18,5	16	Sandy loam	3,5	6,6	5,85	0,08	0,10	1,91	11,00	4,00	1,04	1,72	1,43	0,47	4,86	37,50	13,00	8,75	3,50	450,25	259,50	Severe	High	Sheet, rill
Stdev										12	6	11		0,58	0,29	0,17	0,03	0,03	0,54	0,00	0,82	0,09	0,63	0,32	0,08	0,97	5,97	4,16	2,99	1,73	40,52	28,10			

NB:

yBr	=	yellow Br
vyBr	=	very yellow brown
vdaGr	=	very dark Gray
Br	=	Brown
vdaGr	=	very dark Gray
daBr	=	dark Br
vdaqrBr	=	very dark gray Brown
davBr	=	dark yellow Brown
darBr	=	dark reddish Brown
yR	=	yellow Red

duR	=	dull Red
R	=	Red
daR	=	dark Red
daR	=	dark Red

Sheet	
Slight	None to very minor exposure
Moder	Minimum to medium exposure
Sever	major exposure & very sandy surfaces
Exces	bare, hard, extremely sandy surfaces

Rill erosion
None to very minor rills
Minor to medium rills
major rills
Many rills

Appendix IIB: The characteristics of soil resources in Bondeni Village, Kibwezi , Kenya

Ref No	Poverty No	Parent	Slope		Land		Colour (Munsell)			Texture				Moisture	pH - water	pH -CaCl2	EC	N	OMC	C/N	P	Ca	K	Mg	Na	Sum of	CEC	BS (%)	Cu	Zn	Mn	Fe	Erosion	Erosion	Type of
		rock	Shape	%	cover	Wet		Dry		class	sand	clay	silt	%				%	%		ppm		me/100g			bases			ppm	ppm	ppm	ppm	Status	Risk	erosion
	a) Volcanic Lava Flow (Local Kamba name: Kivuthi)										%	%	%																					
Bondeni 1	I	Volcanic			Cropland	rGr	5YR 5/2	vdGr	5YR 3/1	Sandy loam	72	16	12	7	7,1	6	0,09	0,07	2,25	19	33	7,66	1,698	1,40	0,27	11,03	32	34,5	10	11	574	474	Severe	V. high	Sheet, rill
	b) Ferralsols (Local Kamba name: Muthangathi ila nziu/Muthangathi ila mbulanu)																																	
Bondeni 6	II	Basement	Convex	2 _ 5	Cropland	BI	10YR 2/1	vdGr	10YR 3/1	Sandy loam	80	16	4	2	6,5	5,8	0,04	0,08	3,32	24	3	2,36	0,81	1,32	0,46	5	20	24,76	3	4	260	161	Moderate	High	Sheet, rill
Bondeni 8	III	Basement	Linear	0 - 2	Cropland	vdaGr	10YR 3/1	daGr	10YR 4/1	Sandy loam	74	18	8	5	6,1	5,7	0,03	0,10	2,77	16	3	2,86	0,89	1,31	0,10	5,2	36	14	3	3	227	129	Moderate	Moderate	Sheet, rill
Bondeni 11	III	Basement	Linear	0 - 2	Cropland	vdaGr	10YR 3/0	vdgrBr	10YR 3/2	Sandy loam	78	16	6	4	6,1	5,9	0,03	0,12	3,39	16	4	4,34	0,87	1,63	0,46	1,72	6	29	3	6	250	162	Severe	V. high	Sheet, rill
Bondeni 13	III	Basement	Linear	0 - 2	Cropland	vdaGr	10YR 3/0	daBr	10YR 3/3	Sandy loam	78	18	4	5	6,1	5,9	0,04	0,10	2,56	15	4	1,71	0,82	1,62	0,46	4,62	54	9	3	4	263	168	Severe	V. high	Sheet, rill
Bondeni 17	I	Basement	Linear	0 - 2	Cropland	vdgrBr	10YR 3/2	Br	10YR 4/2	Sandy loam	78	14	8	3	6,4	5,9	0,04	0,23	5,19	13	4	2,52	0,58	1,43	0,16	4,6	8	57,5	2	8	183	137	Moderate	Moderate	Sheet, rill
Av.								vdgrBr	10YR 3/2	Sandy loam	77	17	6	3,8	6,24	5,84	0,03	0,13	3,45	16,8	3,6	2,76	0,79	1,46	0,33	4,22	24,80	26,85	2,80	5,00	236,60	151,40	Moderate	Moderate	Sheet, rill
Stdev.											2,19	1,67	2,00	1,30	0,19	0,09	0,00	0,06	1,04	4,21	0,55	0,98	0,13	0,16	0,18	1,42	1,42	18,92	0,45	2,00	33,13	17,24			
Bondeni 2	II	Basement	Linear	0 - 2	Pasture	dyBr	10YR 3/4	daBr	10YR3/3	Sandy loam	78	18	4	6	7,1	5,8	0,04	0,14	3,68	15	2	0,79	0,36	0,87	0,00	2	24	8,3	3	4	202	113	Moderate	High	Sheet, rill
Bondeni 5	III	Basement	Convex	2 _ 5	Pasture	vdgrBr	10YR 3/2	Br	10YR 4/2	Sandy loam	78	16	6	3	6,2	6,1	0,04	1,00	3,01	2	3	1,94	0,75	1,32	0,10	4,1	8	51,3	3	4	223	161	Moderate	Moderate	Sheet, rill
Bondeni 14	I	Basement	Linear	0 - 2	Pasture	vdGr	10YR 3/1	Br	10YR 4/2	Sandy loam	76	16	8	7	6,6	5,9	0,05	0,11	3,08	16	2	1,71	0,87	1,72	0,46	4,76	56	9	3	4	290	185	Moderate	Moderate	Sheet, rill
Av.								Br	10YR 4/2	Sandy loam	77,33	16,67	6,00	5,33	6,63	5,93	0,04	0,42	3,26	11,00	2,33	1,48	0,66	1,30	0,19	3,62	29,33	22,87	3	4	238,33	153	Moderate	Moderate	Sheet, rill
Stdev.											1,15	1,15	2,00	2,08	0,45	0,15	0,01	0,51	0,37	7,81	0,58	0,61	0,26	0,43	0,24	1,44	24,44	24,63	0	0	45,96	36,66			
	C) Chernozems (Local Kamba name: Ivoole/Muthangu ula mulu)																																	
Bondeni 7	III	Basement + Volcanic	Convex	2 _ 5	Cropland	BI	10YR 2/1	vdBr	10YR 2/2	Sandy loam	76	16	8	5	6,6	5,7	0,06	0,24	2,97	7	0,06	4,60	1,30	1,12	0,14	7,2	44	16	5	8	348	626	Excessive	V. high	Sheet, rill
Bondeni 12	II	Basement + Volcanic	Convex	2 _ 5	Cropland	vdaGr	2.5YR 3/0	daBr	10YR 3/3	S/L S/C/L	74	20	6	5	6,6	5,9	0,02	0,09	2,29	15	4	1,99	0,92	1,77	0,50	5,17	40	13	3	5	235	148	Severe	V. high	Sheet, rill
Bondeni 9	III	Basement + Volcanic	Convex	2 _ 5	Cropland	vdBr	10YR 2/2	BI	10YR 2/1	Sandy loam	66	18	16	8	6,8	6,1	0,07	0,15	3,80	15	3	9,09	0,54	1,40	0,23	11,3	48	23,54	5	2	310	230	Moderate	V. high	Sheet, rill
Bondeni 16	I	Basement + Volcanic	Convex	0 - 2	Cropland	vdgrBr	10YR 3/2	vdgrBr	10YR3/1	S/C/L	66	24	10	5	6,5	6	0,06	0,15	3,85	15	6	6,48	1,36	2,21	0,18	10,2	53	19,3	6	5	279	275	Severe	V. high	Sheet, rill
Av.						Bl-vdBr	10YR 2/1 -2/2	Bl-vdBr	10YR 2/1 -2	S/L S/C/L	70,50	19,00	10,0	5,75	6,63	5,93	0,05	0,16	3,23	13,00	3,27	5,54	1,03	1,63	0,26	8,47	46,25	17,96	4,75	5,00	293	319,8	Severe	V. high	Sheet, rill
Stdev.											5,26	3,42	4,32	1,50	0,13	0,17	0,02	0,06	0,74	4,00	2,47	3,00	0,38	0,47	0,16	2,80	5,56	4,52	1,26	2,45	47,87	210,83			
Bondeni 3	III	Basement + Volcanic	Convex	2 _ 5	Pasture	drBr	2.5YR 3/3	BI	2.5YR 2.5/0	S/C/L	62	32	6	10	6,6	6,3	0,18	0,09	2,61	17	3	12,49	0,56	1,43	0,44	14,9	40	31,25	6	2	291	186	Slight	Moderate	Sheet
Bondeni 10	II	Basement + Volcanic	S shape	2 _ 5	Pasture	drGr	2.5YR 3/1	daGr	2.5YR 4/0	S/C/L	68	24	8	5	6,7	5,8	0,04	0,14	3,73	16	7	9,75	0,70	1,41	0,17	12	52	23,08	7	5	419	435	Severe	V. high	Sheet, rill, gully
Bondeni 15	III	Basement + Volcanic	Convex	2 _ 5	Pasture	vdgrBr	10YR 3/2	vdgrBr	10YR 3/2	S/L S/C/L	72	20	8	5	6,5	5,7	0,04	0,16	4,25	15	19	2,71	0,99	1,85	0,48	6,02	60	10	4	3	261	313	Moderate	High	Sheet
Bondeni 18	I	Basement + Volcanic	Convex	2 _ 5	Pasture	drGr	2.5YR 3/1	daGr	2.5YR 4/0	S/C/L	70	26	4	5	6,8	6,2	0,12	0,16	3,92	14	3	13,70	0,38	2,41	0,23	16,7	54	30,9	7	5	257	327	Slight	Moderate	Sheet
Av.						drGr	2.5YR 3/1-3/2	daGr	2.5YR 4/0	S/C/L	68,00	25,00	7,00	6,25	6,65	6,00	0,10	0,14	3,63	15,50	8,00	9,66	0,66	1,78	0,33	12,41	51,50	23,81	6,00	3,75	307	315,3	Slight	Moderate	Sheet
Stdev.											4,32	5,00	1,91	2,50	0,13	0,29	0,07	0,03	0,71	1,29	7,57	4,92	0,26	0,47	0,15	8,39	8,39	9,95	1,41	1,50	76,19	102			
				NB		rGr	reddish Gray																											
						vdGr	very dark gray																											
						vdgrBr	very dark grayish Brown																											
						drBr	dark reddish Brown																											
						drGr	dark reddish Gray																											
						dyBr	= dark yellow Brown																											
						daGr	dark Gray																											
						daBr	dark Brown																											
						Br	= Brown																											
						vdBr	= very dark Brown																											
						Bl	= Black																											

APPENDIX IIC: The characteristics of soil resources in Isara Village, Mashuru, Kenya

Ref No	Poverty group	Parent rock	Land cover	Slope Form	%	Land cover	Wet	Colour	Dry		Texture Sand	Clay	Silt	Texture class	Moisture %	pH - water	pH - Cacl2	EC	N %	C %	OMC	C/N	P ppm	K	Ca	Mg	Na	Sum me/100g	CEC	BSP bases	Cu	Zn	Mn ppm	Fe	type	Erosion status	Erosion Risk
			Ferral chromic Luvisols (Local masaai name: Enderit nado/Enderit nanyokie)								%	%	%																								
Isara 8	III	Basement	Cropland	Convex	2 _ 5 (g.und)	Cropland	drBr	5YR 3/3	yR	5YR 4/6	62,0	22,0	16,0	SCL	5,00	6,40	5,80	0,13	0,10	1,40	2,41	14,00	126,0	1,45	3,19	1,76	0,32	6,70	26,00	27,80	10,00	7,00	839,0	476,0	sheet/rill	Severe	V. high
Isara 5	I	Basement	Cropland	Linear	0 - 2 (Flat)	Cropland	drBr	5YR 3/6	rBr	5YR 4/4	74,0	18,0	8,0	SL	3,00	6,70	5,50	0,54	0,08	1,11	1,91	14,00	67,0	1,92	3,40	1,81	0,29	6,70	14,00	47,90	6,00	4,00	411,0	263,0	sheet/rill	Severe	V. high
Isara 12	I	Basement	Grassland	Linear	2 _ 5 (g.und)	Grass lands	yR	2.5YR5/6	yR	2.5YR 4/6	72,0	20,0	8,0	SL/SCL	3,00	7,00	5,50	0,10	0,10	1,10	1,90	11,00	77,0	1,52	3,42	1,89	0,48	7,30	22,00	33,20	6,00	5,00	625,0	350,0	sheet/rill	Severe	V. high
Isara 10	III	Basement	Woodland & g'land	Linear	2 _ 5 (g.und)	G/woodland	drBr	5YR 3/3	yR	5YR 4/6	78,0	14,0	8,0	SL	2,00	5,90	5,80	0,03	0,05	0,61	1,10	12,00	21,0	0,83	1,80	1,50	0,21	4,05	14,00	31,00	5,00	7,00	470,0	171,0	sheet/rill	severe	V. high
Av.								5YR 3/3		5YR 4/6	75,0	17,0	8,0	SL	2,50	6,45	5,65	0,07	0,08	0,86	1,50	11,50	49,0	1,18	2,61	1,70	0,35	5,67	18,00	32,10	5,50	6,00	547,5	260,5	sheet/rill	severe	V. high
Stdev.											4,24	4,24	0,0		0,71	0,78	0,21	0,05	0,04	0,35	0,71	0,71	39,60	0,49	0,81	0,26	0,19	2,30	5,66	1,56	0,71	1,41	109,6	126,57			
			Cambisols - lithic and stony phase (Local Masaai name: Enderit ngiro/Enderit naipoor & some portion were ormurrum)																																		
Isara 14	I	Volcanic	Woodland & g'land	L/concave	5 _8 (undu)	G/bushland	vdGr	5YR 3/1	drBr	5YR 3/4	56,0	24,0	20,0	SCL	6,00	6,60	5,90	0,07	0,33	4,01	6,90	12,00	43,0	1,53	14,31	2,39	0,53	18,80	52,00	36,20	7,00	7,00	682,0	375,0	sheet	Excessive	V. high
Isara 16	I	Volcanic	Grassland	Concave	5 _8 (undu)	Grassland	vdGr	5YR 3/1	Bl	5YR 2.5/1	48,0	40,0	12,0	SC	15,00	7,10	6,20	0,13	0,11	1,81	3,11	16,00	13,0	1,25	27,94	2,69	0,74	32,63	90,00	36,00	13,00	5,00	1622,0	361,0	sheet/rill	Excessive	V. high
Av.							vdGr	5YR 3/1			52,0	32,0	16,0		10,50	6,85	6,05	0,10	0,22	2,91	5,01	14,00	28,0	1,39	21,12	2,54	0,63	25,72	71,00	36,10	10,00	6,00	1152,0	368,0	sheet	Excessive	V. high
Stdev.											5,66	11,31	5,66		6,36	0,35	0,21	0,04	0,16	1,56	2,68	2,83	21,21	0,20	9,64	0,21	0,15	9,78	26,87	0,14	4,24	1,41	664,68	9,90			
			Vertisols - volcanic (Local Masaai name: Enderit ongosero/Enderit narok)																																		
Isara 6	III	Vertisols (V)	Grassland	Linear	2 _5 (g. und)	G/shrubland	vdGr	5YR 3/1	drBr	5YR 3/3	52,0	36,0	12,0	SC	15,00	7,20	6,20	0,14	0,11	1,62	3,34	15,00	5,00	0,56	23,96	2,49	1,48	28,50	64,00	44,50	11,00	5,00	1519,0	345,0	sheet/rill	Excessive	V. high
Isara 18	III	Vertisols (V)	Shrubland & g'land	Linear	2 _ 5 (g.und)	G/shrubland	vdGr	10YR 3/4	vdGr	10YR 3/1	58,0	36,0	6,0	SC	11,00	7,00	6,40	0,07	0,11	1,25	2,15	11,00	8,00	0,76	25,66	2,61	0,98	30,01	56,00	54,00	10,00	3,00	1371,0	294,0	sheet/rill		
			Vertisols - basement (Local Masaai name: Enderit ongosero/Enderit narok)																																gully	Excessive	V. high
Isara 13	I	Vertisols (B)	Woodland & g'land	S shaped	2 _ 5 (g.und)	G/shrubland	vdBr	10YR 2/2	Bl	10YR 2/1	60,0	30,0	10,0	SL/SCL	10,00	6,80	6,30	0,15	0,09	1,26	2,17	14,00	6,00	0,95	20,92	2,29	0,69	24,90	58,00	42,90	10,00	5,00	862,0	231,0	s/rill/gully	Excessive	V. high
Isara 17	II	Vertisols (B)	Woodland & g'land	S shaped	2 _ 5 (g.und)	G/shrubland	dBr	7.5YR 4/4	daGr	7.5YR 4/0	58,0	36,0	6,0	SC	11,00	7,10	6,50	0,14	0,11	2,38	4,10	22,00	6,00	0,88	38,50	2,60	0,75	42,73	56,00	76,00	5,00	6,00	84,0	46,0	s/rill/gully	Excessive	V. high
					Av.		vdBr-vdGr	10YR 2/2-3/4	Bl-vdGr	10YR 2/1-3/1	57,0	34,5	8,5	SC	11,75	7,03	6,35	0,12	0,11	1,63	3,14	15,50	6,25	0,79	27,26	2,50	0,97	31,54	58,50	54,35	9,00	4,75	959,0	229,0	s/rill/gully	Excessive	V. high
					Stdev.						3,46	3,0	3,0		2,22	0,17	0,13	0,04	0,01	0,53	1,36	4,65	1,26	0,17	7,75	0,15	0,36	7,77	3,79	15,24	2,71	1,26	647,66	130,61			
			Ferric Luvisols (Local masaai name: Enderit nado/Enderit narok)																																		
Isara 1	II	Basement	Cropland	Linear	0 - 2 (Flat)	Cropland	vdrBr	2.5YR 3/4	dR	2.5YR 3/6	78,0	16,0	6,0	SL	5,00	6,20	5,50	0,04	0,06	0,98	1,69	12,00	22,0	4,27	0,05	0,01	0,00	4,30	36,00	11,90	8,00	2,00	726,0	255,0	sheet/rill	Severe	V. high
Isara 2	II	Basement	Cropland	Linear	2 _5 (g. und	Cropland	rBr	5YR 4/4	yR	5YR 4/6	78,0	16,0	6,0	SL	13,00	6,20	6,00	0,05	0,07	0,84	1,45	12,00	12,0	1,08	2,39	1,65	0,18	5,30	40,00	13,30	5,00	4,00	385,0	279,0	sheet/rill	Severe	V. high
Isara 3	II	Basement	Cropland	Linear	0 - 2 (Flat)	Cropland	vdGr	10YR 3/1	vdGBr	10YR 3/2	64,0	28,0	8,0	SCL	4,00	6,00	5,60	0,03	0,08	1,13	1,94	14,00	98,0	0,01	0,09	0,01	2,48	2,60	47,00	5,50	6,00	4,00	425,0	348,0	sheet/rill	Severe	V. high
Isara 7	II	Basement	Cropland	Linear	2 _5 (g. und	Cropland	vdGr	10YR 3/1	dyBr	10YR 3/4	74,0	22,0	4,0	SCL	4,00	6,70	5,70	0,06	0,10	1,39	2,39	14,00	76,0	1,40	3,92	1,92	0,22	7,50	18,00	41,70	7,00	7,00	505,0	505,0	sheet/rill	Severe	V. high
Isara 9	III	Basement	Cropland	Linear	2 _5 (g.und)	Cropland	drBr	5YR 3/3	yR	5YR 4/6	76,0	20,0	4,0	SCL/CL	2,00	6,20	5,70	0,03	0,05	0,59	1,02	12,00	33,0	0,97	0,99	1,47	0,48	3,91	48,00	8,00	6,00	4,00	435,0	261,0	sheet/rill	Severe	V. high
Isara 4	III	Basement	Cropland	Linear	2 _ 5 (g.und)	Cropland	drBr	2.5YR 3/4	dR	2.5YR 3/6	72,0	18,0	10,0	SL	4,00	6,60	6,10	0,08	0,08	0,97	1,66	12,00	53,0	1,25	3,17	1,79	0,24	6,50	50,00	13,00	9,00	9,00	628,0	316,0	sheet/rill	Severe	V. high
Av.											73,67	20,00	6,33		5,33	6,32	5,77	0,05	0,08	0,98	1,69	12,67	49,0	1,50	1,77	1,14	0,60	5,02	39,83	15,57	6,83	5,00	517,67	327,33			
Stdev											5,28	4,56	2,34	SL - SCL	3,54	0,27	0,23	0,04	0,03	0,58	0,46	1,03	33,17	1,44	1,63	0,89	0,93	1,79	11,94	13,17	1,47	2,53	133,86	93,90			
Isara 15	I	Basement	Grassland	Linear	2 _ 5 (g. und	Grassland	drBr	5YR 3/4	yR	5YR 4/6	78,00	18,00	4,00	SL	3,00	6,40	5,90	0,04	0,05	0,64	1,10	13,00	74,00	1,16	2,62	1,82	0,48	6,10	18,00	33,90	6,00	7,00	442,00	347,00	sheet/rill	Severe	V. high
Isara 11	I	Basement	Pasture	Linear	0 - 2 (Flat)	P/woodland	drBr	5YR 3/3	yR	5YR 4/6	82,00	12,00	6,00	LS	3,00	5,90	5,70	0,03	0,05	0,66	1,14	13,00	21,00	0,77	1,54	1,24	0,49	4,05	14,00	29,00	2,00	5,00	223,00	151,00	sheet/rill	Severe	V. high
					Av.			5YR 3/3	yR	5YR 4/6	80,00	15,00	5,00		3,00	6,15	5,80	0,04	0,05	0,65	1,12	13,00	47,50	0,97	2,08	2,02	0,49	5,07	16,00	31,45	4,00	6,00	332,50	249,00	sheet/rill	Severe	V. high
					Stdev.						2,83	4,24	1,41		0,00	0,35		0,14	0,00	0,01	0,03	0,00	37,48	0,27	0,77	0,41	0,01	1,45	2,83	3,46	2,83	1,41	154,86	138,59			

Appendix IID: The characteristics of soil resources in Erankau Village, Mashuru, Kenya

Ref No.		Parent	Slope		Land cover			Colour		Texture			Texture	Moisture	pH		EC	N%	C%	SOM	C/N	P	Ca	Mg	K	Na	Sum of	CEC	BSP	Cu	Zn	Mn	Fe	Erosion type
		rock	Shape	%		Wet		Dry		Sand	Clay	Silt	class	%	pH	pH				%				me/100g			bases			(ppm)			
		Orthic Luvisols (Local masaai name: Enderit narok on foothills, Enderit ngiro on middle								%	%	%			water	Cacl2																	
		plains and Enderit Nasonyai on lower plains)																															
Erankau 6	I	Basement	Linear	2 5	Cropland	darBr	5YR 3/3	daBr	5YR 3/4	74	20	6	SL/SCL	3	6,3	5,6	0,076	0,11	1,4	2,41	13	91	2,65	1,88	1,26	0,51	6,3	36	18	5	5	590	396	Moderate (M) sheet/rill
Erankau 13	I	Basement	Convex	2 5	Cropland	vdaGr	10YR 3/1	vdaqrBr	10YR 3/2	76	16	8	Sandy loam	3	6,3	6	0,174	0,23	2,64	4,54	11	82	6,41	2,38	1,45	0,68	10,92	16	68	7	18	687	638	Moderate sheet/rill
Erankau 17	I	Basement	Linear	2 5	Cropland	vdaGr	10YR 3/1	vdaGr	10YR 3/1	76	18	6	Sandy loam	5	6,3	6	0,085	0,1	1,61	2,77	16	5	4,26	2,68	1,46	0,56	8,96	40	22	4	4	408	245	Moderate sheet/rill
Erankau 8	II	Basement	Linear	2 5	Cropland	vdaGr	10YR 3/1	Br	10YR 4/2	66	26	8	SCL	4	6,4	5,7	0,076	0,09	1,26	2,18	14	5	1,77	1,61	1,16	0,46	5,01	40	13	4	8	453	400	Moderate sheet/rill
Erankau 20	II	Basement	Linear	2 5	Cropland	vdaGr	10YR 3/1	vdaqrBr	10YR 3/2	80	12	8	Sandy loam	4	6,4	6	0,111	0,12	1,46	2,51	12	157	1,25	1,16	0,35	0,35	3,11	42	7	5	16	636	724	Moderate sheet/rill
Earnkau 14	III	Basement	Linear	2 5	Cropland	vdaGr	10YR 3/1	vdaqrBr	10YR 3/2	72	18	10	Sandy loam (SL)	5	6,3	6,2	0,134	0,12	1,67	2,87	14	106	5,21	2,43	1,56	0,61	9,81	18	55	6	7	596	536	Moderate sheet/rill
Erankau 16	III	Basement	Linear	2 5	Cropland	darBr	5YR 3/2	vdaqrGr	5YR 3/1	80	12	8	Sandy loam	2	6	5,5	0,062	0,07	1,02	1,75	15	45	1,83	1,64	0,68	0,47	4,62	12	39	5	5	500	357	excessive (E) sheet/rill
Erankau 28	III	Basement	Convex	2 5	Cropland	vdaGr	2.5YR 3/0	darBr	5YR 3/2	84	8	8	Loamy sand (LS)	1	6,8	5,9	0,04	0,03	0,47	0,81	16	12	1,23	0,92	0,58	0,56	3,29	14	23	2	3	361	212	Severe (S) sheet/rill
Av						vdaGr	10YR 3/1	vdaqrBr	10YR 3/2	76,00	16,25	7,75	Sandy loam	3,38	6,35	5,86	0,09	0,11	1,44	2,48	13,88	62,88	3,08	1,84	1,06	0,53	6,50	27,25	30,63	4,75	8,25	528,88	438,5	Moderate sheet/rill
Stdev										5,55	5,60	1,28	Sandy loam	1,41	0,22	0,24	0,04	0,06	0,62	1,06	1,81	55,40	1,97	0,63	0,46	0,10	3,03	13,31	21,45	1,49	5,65	115,95	######	
Erankau 5		Basement	Linear	2 5	Woodlands & pastures	vdaGr	10YR 3/1	vdaqrBr	10YR 3/2	82	16	2	Sandy loam	3	6,6	5,8	0,04	0,07	0,96	1,65	14	40	1,1	1,47	0,82	0,49	3,88	12	32	5	2	278	197	Sheet/rill/qully (E)
Erankau 9		Basement	Linear	2 5	Woodlands & pastures	vdaBr	10YR 2/2	vBr	10YR 5/8	88	6	6	LS	1	6,2	6	0,03	0,04	0,59	1,01	12	2	1,61	1,66	1,13	0,48	4,88	8	61	2	2	285	83	Sheet/rill (E)
Erankau 10		Basement	Linear	2 5	Woodlands & pastures	R	2.5YR 4/8	daR	2.5YR 3/6	90	8	2	Sand	1	5,9	5,4	0,03	0,04	0,55	0,95	14	3	1,34	1,09	0,54	0,57	3,54	6	59	1	1	395	87	Sheet/rill (E)
Erankau 12		Basement	Linear	2 5	Woodlands & pastures	darBr	5YR 3/2	vdGr	5YR 3/1	80	10	10	LS/SL	3	6,9	5,8	0,07	0,08	1,22	2,1	15	57	2,39	1,82	0,92	0,55	5,68	52	11	5	3	449	442	Sheet/rill/qully (E)
Erankau 18		Basement	Linear	2 5	Woodlands & pastures	vdaGr	10YR 3/1	vdqrBr	10 YR 3/2	78	16	6	Sandy loam	4	5,9	5,6	0,08	0,09	1,16	2	13	4	2,66	1,93	0,55	0,75	5,89	26	23	7	8	751	613	Sheet/rill/qully (E)
Erankau 23		Basement	Linear	2 5	Woodlands & pastures	dayBr	10YR 3/4	daBr	10YR 3/3	84	10	6	LS	2	5,7	5,4	0,05	0,06	0,79	1,36	13	2	0,63	1,26	0,67	0,51	3,07	48	6	2	3	473	263	Sheet/rill (E)
Erankau 24		Basement	Convex	2 5	Woodlands & pastures	daBr	5YR 3/3	daBr	5YR 3/2	70	6	24	SCL	1	6	5,7	0,04	0,05	0,68	1,17	14	17	0,76	0,69	0,69	0,48	2,62	16	16	1	7	298	201	Sheet/rill (E)
Erankau 21		Basement	Convex	8 16	Woodland & grassland	yR	5YR 4/6	darBr	5YR 3/4	82	10	8	Loamy sand	2	6,8	5,7	0,05	0,16	1,77	3,04	11	0,26	1,67	1,52	0,87	0,51	4,56	24	19	7	6	475	204	Sheet (minimal)
Av		Basement	Linear	2 5	Woodlands & pastures	vdaGr-dayBr	10YR 3/1-3/4	vdaqrBr-yBr	10YR 3/2-5/8	81,75	10,25	8,00	LS-SL	2,13	6,25	5,67	0,05	0,07	0,97	1,66	13,25	17,86	1,52	1,43	0,77	0,54	4,27	24,00	28,38	3,75	4,00	425,50	######	Sheet/rill (S)
Stdev										6,18	3,92	7,01		1,13	0,46	0,21	0,02	0,04	0,41	0,70	1,28	21,44	0,72	0,41	0,20	0,09	1,19	17,53	21,00	2,55	2,62	155,79	######	
		Regosols (Local masaai name: Enderit naisonyeti/Enderit oseseral)																															
Erankau 1		Basement	Concave	16-30	Woodland & grassland	darBr	10YR 3/2	dayBr	10YR 3/4	82	6	12	LS	2	6,4	5,7	0,043	0,07	1,11	1,91	16	3	1,87	0,87	0,35	0,41	3,5	6	59	2	2	125	113	Sheet/rill (E)
Erankau 2		Basement	Convex	16-30	Woodland & grassland	darBr	5YR 3/4	darBr	5YR 3/4	66	28	6	SCL	6	5,9	5,7	0,042	0	1,19	2,05	1,19	1	2,74	1,62	0,79	0,47	5,62	12	47	6	3	388	140	Sheet/rill/qully (E)
Erankau 3		Basement	Convex	16-30	Woodland & grassland	darBr	5YR 3/4	dayBr	10YR 4/3	84	10	6	LS	2	6,9	5,8	0,075	0,12	1,45	2,49	12	2	1,3	1,34	0,76	0,49	3,9	10	39	4	5	323	154	Sheet/rill (E)
Erankau 15		Basement	Convex	8 16	Woodland & grassland	darBr	5YR 3/4	Br	5YR 3/6	82	8	10	LS	2	6,2	5,3	0,04	0,12	1,44	2,48	12	4	1,37	1,27	0,82	0,46	3,92	40	10	3	2	403	132	Sheet/rill (S)
Erankau 4		Basement	S-shaped	8 16	Woodland & grassland	vdaBr	10YR 2/2	dayBr	10YR 4/3	86	8	6	LS	4	6,6	5,8	0,043	0,12	1,36	2,34	11	4	2,65	1,24	0,55	0,4	4,84	14	35	3	7	369	161	Sheet (M)
Erankau 27		Basement	S-shaped	16-30	Woodland & grassland	daBr	10YR 3/3	vdaqrBr	10YR 3/2	82	12	6	LS/SL	3	6,5	6,1	0,131	0,13	1,48	2,55	11	26	2,16	1,9	0,94	0,52	5,52	28	20	6	6	479	407	Sheet (M)
Av.		Basement	Convex	16-30		daBr	5YR 3/4-10YR 3/3	darBr to dayBr	5YR 3/4-10yr4/3	80,33	12,00	7,67	Stony, gravelly LS	3,17	6,42	5,73		0,09	1,34	2,30	10,53	6,67	2,02	1,37	0,70	0,46	4,55	18,33	35,00	4,00	4,17	347,83	184,5	Sheet/rill (M and E)
Stdev.										7,20	8,10	2,66		1,60	0,34	0,26		0,05	0,15	0,26	4,94	9,54	0,62	0,35	0,21	0,05	0,83	12,99	16,26	1,53	2,14	120,48	######	
		Cambisols (Local Masaai name: Enderit narok)																															
							Hill -- lithic and stony																											
Erankau 29		Volcanic	Concave	16-30	Woodland & grassland	vdaGr	10YR 3/1	vdaqrBr	10YR 3/2	62	20	18	SL/SCL	1	6,3	5,9	0,07	0,25	3,37	5,8	13	25	8,71	3,75	0,92	0,56	13,94	80	17	10	6	335	542	Sheet (E)
							Plain - stony phase																										
Erankau 7		Volcanic	Convex	2 5	Grassland	daBr	7.5YR 3/2	daBr	7.5YR 3/4	54	22	24	SCL	9	6,9	5,7	0,506	0,11	1,23	2,1	11	86	3,77	1,9	1,25	0,53	7,45	72	10	10	3	943	765	Sheet/rill (E)
Av.										58,0	21,0	21,0	Stony, gravelly SCL	5,00	6,60	5,80	0,29	0,18	2,30	3,95	12,00	55,50	6,24	2,83	1,09	0,55	10,70	76,00	13,50	#####	4,50	639,00	653,5	
Stdev.										5,66	1,41	4,24		5,66	0,42	0,14	0,31	0,10	1,51	2,62	1,41	43,13	3,49	1,31	0,23	0,02	4,59	5,66	4,95	0,00	2,12	429,92	######	
		Cambisols - stony phase (Local Masaai name: Enderit nanyokie)																															
Erankau 25	II	Volcanic	Linear	2 5	Cropland	darBr	2.5YR 2.5/4	R	2.5YR 2.5/6	66,0	18,0	16,0	SCL	7,00	6,00	5,90	0,08	0,11	1,45	2,49	13,00	149	3,30	2,01	1,27	0,51	7,09	74,00	10	12	7	1494	772	Sheet/rill (E)
Erankau 11	III	Volcanic	Linear	2 5	Cropland	darBr	5YR 3/3	daBr	7.5YR 3/2	52,0	24,0	24,0	SCL	13,00	6,60	5,80	0,15	0,14	1,57	2,70	11,00	145	3,27	1,89	1,47	0,53	7,15	70,00	10	11	10	1408	651	Sheet/rill (S)
Av.						darBr				59,0	21,0	20,0	SCL	10,00	6,30	5,85	0,12	0,13	1,51	2,60	12,00	147	3,29	1,95	1,37	0,52	7,12	72,00	10,00	#####	8,50	1451	711,5	
Stdev.										9,90	4,24	5,66		4,24	0,42	0,07	0,05	0,02	0,08	0,15	1,41	2,83	0,02	0,08	0,14	0,01	0,04	2,83	0,00	0,71	2,12	60,81	85,56	
		Vertisols (Local Masaai name: Enderit ongosero)																															
Erankau 22		Vertisols	S-shaped	2 5	Woodland & grassland	vdaGr	5YR 3/1	Bl	5YR 2/1	54	30	16	SCL	15	7,1	6,1	0,103	0,14	1,88	3,23	13	44	9,68	2,11	1,22	0,58	13,58	82	17	11	7	1490	496	Sheet/rill/qully (E)
		Gleyic Luvisols pasture (Local Masaai name: Enderit ongosero)																															
Erankau 26		Sedimentar	Linear	0-2	Woodland & grassland	brGr	10YR 4/1	Bl	10YR 2/1	54	40	6	Sandy clay	9	6,6	6,3	0,067	0,08	1,38	2,37	17	7	0,49	1,31	0,6	0,48	2,88	86	3	9	4	1038	458	Sheet/rill/qully (E)

Appendix III A1: Biological and chemical analysis of water samples collected from the major sources of water in Muusini area, Kibwezi Division, Makueni District, Kenya as at April 2004

Parameter	WHO guide line (Ministry of Health Kenya guide line)	Sources of water sample				
		Kiuwani Earth Dam	Athi River	Shallow well near Thange River	Thange River (lower portion)	Pond
Bacteriological tests						
Coliform Count/100 ml of Water	None (0-25)	1800+	1800+	1800+	1800+	61
E.coli Count/100 ml of Water	None	55	1800+	1800+	250	61
Physical tests						
Colour (True colour units)	15	1500	40	20	35	1000
Turbidity	Not turbid	Very turbid	Turbid	Clear	V. turbid	V. turbid
Deposit		Organic matter (OM)/ silt		OM/algae	OM	Silt/OM
Oduor	Should be acceptable	None	Vegetation	Vegetation	Soil smell	Vegetation
Electrical conductivity (mmhos/cm^2) at 25°C		120	490	3600	5800	130
PH	< 8 for effective disinfection with chlorine	7.1	8.5	8.3	7.9	7.6
Chemical tests in mg/l (ppm)						
Total alkalinity as $CaCO_3$		38	120	420	500	40
Phenolphthalein $(CO)_3$		Nil	8	10	66.7	Nil
Methyl orange (HCO_3)		38	112	410	433.3	40
Chloride (Cl)-	250	16	40	712	1416.7	16
Sulphate (SO_4)	250	12.5	45	420	300	40
Nitrate (NO_3)	50	1.1	5.5	4.4	Nil	0.6
Nitrite (NO_3)	3	Nil	1.3	0.08	Nil	Nil
Flouride (F)-	1.5	8.3	0.2	3.3	0.8	0.2
Sodium (Na)+	200	4.5	225	552.6	12.8	1.7
Potassium (K)+		8.6	11.9	11.8	4	19.5
Calcium (Ca) ++		3.2	4.8	16	40	Nil
Magnesium (Mg)++		10.5	13.4	190.1	168	Nil
Iron (Total) (Fe)+++	0.3	1.8	0.005	0.01	0.1	2.1
Manganese (Mn) ++	0.5	0.04	0.009	0.001	0.02	0.03
Ammonia - Free & saline (NH_4)+	200	Nil	Nil	Nil	Nil	Nil
Ammonia- Albuminoid (NH_4)+		Nil	0.2	Nil	0.09	0.05
Zinc, lead, copper		-			-	
Carbonate Hardness as ($CaC0_3$)		38	68	420	500	Nil
Non- Carbonate hardness as ($CaC0_3$)		14	Nil	412	300	Nil
Total hardness as Carbonates ($CaC0_3$)		52	68	832	800	Nil
Free Carbon dioxide		0.4	Nil	0.05	2	0.8
Silica (SiO_2)		45	20	80	10	20
Oxygen absorbed. 4 hr. at 27°C (P.V.)		0.3	1.6	0.5	2.6	5.6
Total Dissolved Solids, residue dried at 180°C		85	340	2500	4100	80
REMARKS	Soft & neutral water Low mineralized. Fe high, very high turbidity due high Fe and silt/organic matter. Biologically contaminated		Mod. soft & alkaline. Polluted with OM and with high bacteria	Excessively hard, alkaline & mineralized with bacteria.	Excessively hard, alkaline mineralized & with excess bacteria	V. soft slightly alkaline. Grossly polluted OM with bacteria

NB: Samples were taken by the participatory team with the support of the Divisional Public Health Officer, Kibwezi put in cooler boxes with ice bags before taking for analysis in The Government Chemist Laboratory, Nairobi

Appendix III A2: The estimated monthly water use in Muusini Village, Kibwezi, Kenya as at end of 2002

Poverty group number *Type of use (monthly in m³)*		**Well off**				**Medium**				**Poor**							***Total water used per Month in the village (m³)***	*Monthly water deficit in the village (m³)*
		Farmer number/amount of water use (m³)																
		1	*2*	Average of samples (m³)	***Sub-total for the better off group***	*3*	*4*	Average of samples	***Sub-total for the medium group***	*5*	*6*	*7*	*8*	*9*	*Average*	***Sub-total for the poor group***		
Domestic (including poultry)	Actual	2.4	3.7	3.1	34.1	3.7	3.7	3.7	77.7	1.2	1.2	3	2.4	3.7	2.3	110.4	222	
	Demand	8.7	11.3	10	110	11.4	5	8.2	172.2	7.4	6.6	6.8	6.7	4.9	6.5	312	594	372
Livestock	Actual	5.8	13.8	9.8	107.8	8.7	1.8	5.3	111.3	1.2	1.1	3.8	2.6	0.8	1.9	91.2	310	
	Demand	5.8	13.8	9.8	107.8	8.7	1.8	5.3	111.3	1.2	1.1	3.8	2.6	0.8	1.9	91.2	310	0
Trees*	Actual	0.4	0.9	0.7	7.7		0.4	0.4	8.4			0.5	0.5		0.5	24	40	147
	Demand	3.8	6.1	5 (33 seedlings per household)	55		1.5	1.5 (10 seedlings per h/hold)	31.5			1.2	3		2.1 (14 seedlings per h/hold)	100.8	187	
Crops	Rain fed																	

NB:

a) Data from the household interviewed were used to estimate the total domestic water use (actual and demand) in the village. For estimation of actual water use the farmers indicated that a head of a zebu cattle/donkey takes 20 litres while one Small East African breed goat/ Fat-tailed brown Masaai breed sheep takes 5 litres per day (because of their small size). This is in line with the KARI recommended rate per animal as indicated below. The poverty classes of well, medium and poor consisted of 11, 21 and 48 households respectively.

b) The number of livestock per individual interviewees per poverty group was used to estimate water use (actual and demand). Water for livestock was obtained free of charge (animals trek to water communal sources). The problem is the quality and the distance especially in dry periods. Therefore actual water use is equal to the demand for livestock (cattle, sheep/goats)

c) Estimate for the water demand per day was based on the rates set by the Kenya Agricultural Research Institute (KARI) of : 1 person (drinking, cooking and washing) = 30 litres, 1 Zebu head of cattle = 20 litres, Donkey* = 20 litres, 1 sheep/goats (small size) = 5 litres, 1 poultry = 0.5 litres,

*1 tree seedling = 5 litres (own experience) in 7 dry months per for one to two years.

Appendix III B1: Biological and chemical analysis of water samples collected from the major sources of water in Bondeni Village, Kibwezi Division, Makueni District as at April 2004

Parameter	WHO guide line (Ministry of Health Kenya guide line)	Sources of water sample					
		Covered well (next to R. Thange – upper)	Metava swamp	Nguku Imwe community well with broken hand pump by elephant	Individual owned well semi-protected	Individually owned fully covered (protected)	Umani springs
Bacteriological tests							
Coliform Count/100 ml of water	None (0-25)	275	1800+	1800+	1800+	31	Contaminated
E. colii Count/100 ml of water	None	20	1800+	1800+	49	7	Contaminated
Physical tests							
Colour (Hazen Units)	15 TCU*	30	15	30	10	Less than 5	5
Turbidity	5 NTU	Clear	Turbid	Turbid	Clear	Clear	Nil
Deposit		Organic matter	Organic deposits	Organic matter (OM)	OM	Little OM	Nil
Oduor (smell)	Should be acceptable	Vegetation	Vegetation	Vegetation	None	None	Nil
Electrical conductivity (mmhos/cm^2) at 25°C		2900	210	3000	1700	2600	542
pH	< 8 for effective disinfection with chlorine	7.4	8.3	8.1	7.4	7.8	7.6
Chemical tests in mg/l (ppm)							
Total alkalinity as $CaCO_3$		790	112	1120	430	280	290
Phenolphthalein $(CO)_3$		Nil	10	60	30	20	15
Methyl orange (HCO_3)		790	102	1060	400	260	275
Chloride (Cl)-	250	440	1	340	230	520	2.5
Sulphate (SO_4)	250	1	Nil	70	10	2	38
Nitrate (NO_3)	50	Nil	0.5	Nil	2.22	1.66	-
Nitrite (NO_3)	3	Nil	Nil	Nil	0.003	0.01	0.004
Flouride (F)-	1.5	1.4	0.4	2.5	2.3	1.5	1.2
Sodium (Na)+	200	458.6	3	702.5	186.3	162.6	55.7
Potassium (K)+		25.8	4.4	9.8	4	6.2	41.8
Calcium (Ca) ++		68	9.6	41.6	76	160	22
Magnesium (Mg)++		67.2	15.4	18.7	48	84	19.2
Iron (Total) (Fe)+++	0.3	0.04	0.07	0.03	0.04	0.02	0.3
Manganese (Mn) ++	0.5	0.02	0.03	0.03	0.03	0.03	Nil
Ammonia - Free & saline (NH_4)+	200	Nil	0.2	Nil	_	-	-
Ammonia-Albuminoid (NH_4)+		Nil	0.6	Trace	_	-	-
Zinc, lead, copper		-	-	-	-	-	Zn 0.01
Carbonate Hardness as ($CaC0_3$)		760	88	182	390	280	135

Appendix III B2: The Estimated monthly water use in Bondeni Village, Kibwezi, Kenya as at end of 2002

Poverty group number *Type of use (monthly in m³)*		**Well off**				**Medium**			**Poor**						***Total water used per Month in the village (m³)***	*Monthly water deficit in the village (m³)*
		Farmer number														
		1	*2*	Average of samples	***Sub-total for the well off group***	*3*	*4*	Average of samples	***Sub-total for the medium group***	*5*	*6*	*7*	*8*	***Average of samples***	***Sub-total for the poor group***	
Domestic (including poultry)	Actual	3.1	3.7	3.4	71.4	2.4	2.4	2.4	57.6	1.2	3.7	1.8	1.8	2.1	168	297	610
	Demand	5.8	10.8	8.3	174.3	9.3	9.6	9.5	228	1.7	9.7	5.4	8.4	6.3	504	907	
Livestock	Actual	2.7	3	2.9	60.9	1.1	0.6	0.9	21.6	0.9	1.5	1.2	0.5	1	80	162	
	Demand	2.7	3	2.9	60.9	1.1	0.6	0.9	21.6	0.9	1.5	1.2	0.5	1	80	162	0
Trees*	Actual		0.3	0.3	6.3										6	6	
	Demand		0.6	0.6	12.8										13	13	7
Crops	Rain fed																

NB:

a) Since the average of the household members per poverty group within the village was available (each household had an average of 8, 10 and 6 for the poverty groups I, II and III respectively) it was used to estimate the total domestic water demand per group. Actual water use data was obtained from sample households
(farmers indicated that a head of cattle/donkey takes 20 litres while a sheep/goat takes 5 litres per day because of their small size). This is in line with the recommended rate per animal as indicated below. The poverty classes of well, medium and poor consisted of 21, 24 and 80 households respectively.

b) The number of livestock per individual interviewees per poverty group was used to estimate water use (actual and demand). Water for livestock was obtained free of charge (animals trek to water communal sources. The problem is the quality and the distance especially in dry periods). Therefore actual water use is equal to the demand for livestock (cattle, sheep/goats)

c) Estimate for the water demand per day was based on the rates set by the Kenya Agricultural Research Institute (KARI) of : 1 person (drinking, cooking and washing) = 30 litres, 1 Zebu head of cattle = 20 litres, Donkey* = 20 litres, 1 sheep/goats (small size) = 5 litres, 1 poultry = 0.5 litres,
*1 tree seedling = 5 litres (own experience) in 7 dry months per for one to two years.

Appendix III C1: Bacteriological and chemical analysis of water samples collected from the major sources of water in Isara area, Mashuru, Kenya as at April 2004

Parameter	WHO guide line (Ministry of Health Kenya guide line)	Sources of water sample		
		Individually owned earth dam	Kuunjuu community earth dam	Noulturesh public water supply pipeline
Bacteriological tests				
Coliform Count/100 ml of Water	None (0-25)	1800+	1800+	45
E.colii Count/100 ml of Water	None	1800+	35	20
Physical tests				
Colour (Hazen Units)	15 TCU*	3500	600	5
Turbidity	5 NTU	Very turbid	Very turbid	Clear
Deposit		Brownish organic matter	Brown organic matter	None
Oduor (smell)	Should be acceptable	Soil	Soil	None
Electrical conductivity (mmhos/cm^2) at 25°C		260	270	220
PH	< 8 for effective disinfection with chlorine	6.9	7.4	7.5
Chemical tests				
Total alkalinity as $CaCO_3$		110	130	108
Phenolphthalein $(CO)_3$		Nil	Nil	6
Methyl orange (HCO_3)		110	130	102
Chloride (Cl)-	250	5	4	4
Sulphate (SO_4)	250	2	3	2.5
Nitrate (NO_3)	50	0.6	0.8	-
Nitrite (NO_3)	3	1.5	Nil	Nil
Flouride (F)-	1.5	0.5	0.4	0.5
Sodium (Na)+	200	6.4	2.1	30.8
Potassium (K)+		44.2	28.1	8.2
Calcium (Ca) ++		12	30.4	8.8
Magnesium (Mg)++		Nil	4.8	1.9
Iron (Total) (Fe)+++	0.3	8.7	0.7	Nil
Manganese (Mn) ++	0.5	0.3	0.05	1.9
Ammonia - Free & saline (NH_4)+	200	0.4	Nil	Nil
Ammonia-Albuminoid (NH_4)+		0.4	1.1	Nil
Zinc, lead, copper		-	-	-
Carbonate Hardness as ($CaC0_3$)		30	96	30
Non- Carbonate hardness as ($CaC0_3$)		Nil	Nil	Nil

Cont. of Appendix III C1				
Total hardness as Carbonates ($CaCO_3$)		30	96	30
Free Carbon dioxide		16	14	Nil
Silica (SiO_2)		7.5	20	35
Oxygen absorbed. 4 hr. at 27°C (P.V.)		14.3	10	Nil
Total Dissolved Solids, residue dried at 180°C		180	190	170
REMARKS	Soft, slightly acidic & fairly well mineralized. The colour and iron exceeds WHO limits for drinking water. Grossly polluted & contaminated. Treatment to lower the colour and iron levels & checks to pollution is recommended		Moderately soft & slightly alkaline. Fairly well mineralized. Colour and iron exceeds WHO limits. Grossly polluted & contaminated. Treatment to lower the colour and iron levels & checks to pollution is recommended	Soft & alkaline. Moderately well mineralized. Chemically suitable for human consumption but Coliform above WHO & the Ministry of Health's (Kenya) limit.

Appendix III C2: The estimated monthly water use in Isara Village, Mashuru, Kenya as at end of 2002

Poverty group number/Type of use		Well off				Medium				Poor							Total water used per Month in the village (m^3)	Monthly water deficit in the village (m^3)
		Farmer number/monthly water used																
		1	*2*	Av. Of samples	*Sub-total for the well off group*	*3*	*4*	Av. of samples	*Sub total for the medium group*	*5*	*6*	*7*	*8*	*9*	*Av. of samples*	*Sub-total for the poor group*		
No. of household members		*5*	*9*	7		*7*	*11*	9		19	*14*	*15*	*9*	*9*	*13*			
Domestic (including poultry and pets)	Actual	6.1	4.9	5.5	33	2.4	4.9	3.7	25.9	7.3	4.9	7.3	3	4.9	5.5	209	268	1482
	Demand	4.6	8.6	6.6	39.6	6.7	10.2	8.2	49.2	174.9	13.1	14	8.2	8.4	43.7	1661	1750	
Livestock	Actual	330.7	328.1	329.4	1976.4	39.5	61.4	50.5	353.5	49.2	17.9	17.9	27.3	18.2	26.1	991.8	3322	
	Demand	330.7	328.1	3294	1976.4	39.5	61.4	50.5	353.5	49.2	17.9	17.9	27.3	18.2	26.1	991.8	3322	0
Trees*	Actual										0.2	0.9	0.6	2.2	1	38	38	
	Demand										0.9	0.2	0.3	4.6	1.5	57	57	19
Crops (Tomato)	Actual	607.6		607.6	3645.6												3646	
	Demand																	

NB:

a) The actual water used and demand data were obtained from members of households interviewed per poverty group. According to the agropastoralists, a head of cattle (average Sahiwal) takes 50 litres per day, donkey takes 20 litres while a sheep/goat (takes 10 litres per day because of their larger size - duper sheep and galla goats found in Erankau are larger than the fat tailed brown Masaai sheep and the small East Africa goats of Kibwezi). The amount of water is in line with the recommended rate per animal as indicated below. The poverty classes of well, medium and poor consisted of 6, 7 and 38 households respectively. According to the farmers, connecting water from Noulturesh pipeline for livestock and domestic use will require monthly payment of Kshs. 2575. Otherwise the animals have to use other sources. In either case with or without cost, animals get their daily water as long as they are within the village and therefore actual water use is equal to the demand.

b) Estimate for the water demand per day was based on the rates set by the Kenya Agricultural Research Institute (KARI) of : 1 person (drinking, cooking and washing) = 30 litres, 1 Sahiwal head of cattle = 20 litres, Donkey* = 20 litres, 1 sheep/goats (large size) = 10 litres, 1 poultry = 0.5 litres, 1 pet** (dog/cat) = 3 litres (own experience), *1 tree seedling = 5 litres (own experience) in 7 dry months per for one to two years

Appendix III D1: Biological and chemical analysis of water samples collected from the major sources of water in Erankau area, Mashuru , Kenya

Parameter	WHO guide line (Ministry of Health Kenya guide line)	Sources of water sample			
		Individually owned unprotected well	Erankau Community borehole	Water holes "catch pits" along River Matoi (unprotected)	Individually owned but used by community -Kimana Dam
Bacteriological tests					
Coliform Count/100 ml of water	None (0-25)	61	95	250	1800+
E.colii Count/100 ml of water	None	35	Nil	39	1800+
Physical tests					
Colour (Hazen Units)	15 TCU*	700	< 5	25	70
Turbidity	5 NTU	Very turbid	Clear	Slightly turbid	Very turbid
Deposit		Blackish organic matter	None	None	Brown organic matter
Oduor (smell)	Should be acceptable	Urea	None	Vegetation	Soil
Electrical conductivity (mmhos/cm^2) at 25°C		810	940	530	97
PH	< 8 for effective disinfection with chlorine	7.1	8	7.9	6.9
Chemical tests in mg/l (ppm)					
Total alkalinity as $CaCO_3$		336	236	266	76
Phenolphthalein $(CO)_3$		Nil	28	Nil	Nil
Methyl orange (HCO_3)		336	208	266	76
Chloride (Cl)-	250	36	68	4	2
Sulphate (SO_4)	250	2.5	150	6	1
Nitrate (NO_3)	50	1.1	-	0.6	Nil
Nitrite (NO_3)	3	1	0.05	Nil	0.9
Flouride (F)-	1.5	0.6	2	3	0.5
Sodium (Na)+	200	59.7	109.4	62.7	10.1
Potassium (K)+		45.2	16.9	4.4	13.2
Calcium (Ca) ++		52.8	41.6	30.4	14.4
Magnesium (Mg)++		26.4	33.1	17.8	2.2
Iron (Total) (Fe)+++	0.3	2.3	Nil	Nil	8.7
Manganese (Mn) ++	0.5	1.6	0.02	0.5	0.1
Ammonia - Free & saline (NH_4)+	200	Nil	Nil	Nil	Nil
Ammonia-Albuminoid (NH_4)+		1	Nil	0.1	0.4
Zinc, lead, copper		-	-	-	-

Cont. of Appendix III D1					
Carbonate Hardness as ($CaCO_3$)		242	236	150	45
Non-Carbonate hardness as ($CaCO_3$)		Nil	6	Nil	Nil
Total hardness as Carbonates ($CaCO_3$)		242	242	150	45
Free Carbon dioxide		15	Nil	2.5	7
Silica (SiO_2)		25	35	15	20
Oxygen absorbed. 4 hr. at 27°C (P.V.)		37.2	0.05	0.9	4.8
Total Dissolved Solids, residue dried at 180°C		570	680	370	68
REMARKS	Hard & neutral. Well mineralized. Colour, iron & manganese exceeds WHO limits. Grossly polluted & contaminated. Treatment recommended		Hard & alkaline. Highly mineralized, contaminated. Flouride & coliform exceeds WHO limits. Treatments recommended	Moderately hard, neutral, contaminated. Well mineralized. Flouride exceeds WHO limits. Demineralization & treatments required	Soft, neutral , grossly contaminated & polluted. Lowly mineralized. Treatments recommended

Appendix III D2: Estimated monthly water use in Erankau Village, Mashuru Division, Kajiado District, Kenya

Poverty group number *Type of use*		**Well off**					**Medium**					**Poor**						***Total water used per Month in the village (m^3)***	*Monthly water deficit in the village (m^3)*
		Farmer number/monthly in m^3																	
		1	*2*	3	Av. of samples	***Sub-total for the well off group***	4	5	*6*	Av. of samples	***Sub total for the medium group***	*7*	*8*	*9*	*10*	***Av. of samples***	***Sub total for the poor group***		
Domestic (including poultry and pets)	Actual	9.7	4.9	4.9	6.5	65	4.9	4.9	4.9	4.9	83.3	2.7	2.4	2.4	2.4	2.5	147.5	296	519
	Demand	7.8	16	8.1	10.6	106	13.2	11.4	11.9	12.2	207	13.5	8.6	4.7	7.1	8.5	502	815	
Livestock	Actual	183.5	124.6	204.9	171	1710	82	72.3	67.4	73.9	1256.3	57.7	24.6	50.4	8.8	35.4	2088.6	5055	0
	Demand	183.5	124.6	204.9	171	1710	82	72.3	67.4	73.9	1256.3	57.7	24.6	50.4	8.8	35.4	2088.6	5055	
Trees*	Actual	0.9			0.9	9		0.2		0.2	3.4				1.25	1.2	70.8	83	21
	Demand	0.5			0.5	5		0.6		0.6	10.2				1.5	1.5	88.5	104	
Crops																			

NB

a) The actual water used and demand data were obtained from members of households interviewed per poverty group. According to the agropastoralists, a head of cattle (average Sahiwal) takes 50 litres per day, donkey takes 20 litres while a sheep/goat (takes 10 litres per day because of their larger size - duper sheep and galla goats found in Erankau are larger than the fat tailed brown Masaai sheep and the small East Africa goats of Kibwezi). The amount of water is in line with the recommended rate per animal as indicated below. The poverty classes of well, medium and poor consisted of 10, 17 and 59 households respectively.

b) Water for domestic and animals is paid for by the East African Portland cement Company that is mining marble within the area

c) Estimate for the water demand per day was based on the rates set by the Kenya Agricultural Research Institute (KARI) of : 1 person (drinking, cooking and washing) = 30 litres, 1 Sahiwal head of cattle = 20 litres, Donkey* = 20 litres, 1 sheep/goats (large size) = 10 litres, 1 poultry = 0.5 litres, 1 pet** (dog/cat) = 3 litres (own experience), *1 tree seedling = 5 litres (own experience) in 7 dry months per for one to two years.

Appendix IV: Types of crops grown and estimated yields in Muusini Village, Kibwezi, Kenya

Poverty group number		Well off (I)				Medium (II)				Poor (III)							*Estimated total yield per year (kg)*
		Farmer number/yield (Kg/ha)															
Crop type	*Season*	*1*	*2*	*Average*	*Sub-total for the well off group*	*3*	*4*	Average	*Sub-total for the medium group*	*5*	*6*	*7*	*8*	*9*	*Average*	*Sub-total for the poor group*	
Maize	SR	585	1233	909	9999	594	810	702	14742	531	450	666	639	1116	680	32640	57381
	LR			NP			450	450	9450					450	450	21600	31050
Beans	SR			NP			100	100	2100	200					200	9600	11700
	LR			NP				NP							NP		
Green grams	SR	250	41	346	3806	882	40	461	9681	216	250	250	250	112	216	10368	23855
	LR			NP				0	0			0	0	225	75	3600	3600
Cowpeas	SR	450	558	504	5544	1098	90	594	12474	216	216	250	333	110	225	10800	28818
	LR			NP				0	0			441	0	441	294	14112	14112
Sorghum	Per	200	56	128	1408	2223	333	1278	26838	675	450	200	441	441	441	21168	49414
	LR			NP				NP					0		0	0	
Pearl millet	SR	NP	225	225	2475	657	450	554	11634	450	675	450			525	25200	39309
	LR			NP				NP							NP		
Finger millet	SR			NP		450		450	9450			450			450	21600	31050
	LR			NP				NP				200			200	9600	9600
Ground nuts (with case)	SR			NP				NP							450	21600	21600
	LR			NP				NP							200	9600	9600
Pigeon pea	Annual	135	657	396	4356	220	657	438	9198	220	220	200	657	657	391	18768	32322
Sweet potatoes (wet)	Annual			NP		NP	225	225	4725	NP	NP	NP	NP	400	400	19200	23925
Pumpkins (wet)	Annual		450	450	4950		450	450	9450	450		450		450	450	21600	36000
Cassava (wet)	Annual		300	300	3300		225	225	4725	200		200			200	9600	17625
Guards (wet)	Annual		200	200	2200		200	200	4200			200		200	200	9600	16000
Dolicos lab lab	Annual			NP		180		180	3780			400		900	650	31200	34980
Cucumbers (wet)	Annual			NP				NP						800	800		

Appendix IV B: The major crops grown and their estimated yields in Bondeni Village, Kibwezi, Kenya

NB: Av. = Average Veges = Leaves for vegetable NP = Not planted 2.4711 acres = 1 ha

Poverty group number		**Well off (I)**					**Medium (II)**					**Poor (III)**								
		Farmer number/yield (Kg/ha/year)																		
Crop type	***Season***	*1*	*2*	***Av. Yield per ha***	***Av. area per crop (ha)***	***Sub-total for the well off group in the village (n=21)***	*3*	*4*	***Av. Yield per ha***	***Av. area per crop (ha)***	***Sub-total for the medium group in the village (n=24)***	*5*	*6*	*7*	*8*	***Av. yield per ha***	***Av. area per crop (ha)***	***Sub-total for the poor group in the village (n=80)***	***Estimated total yield per crop per season (kg)***	***Estimated total yield per year per crop (kg) in Bondeni Village***
Maize	SR	1333	2423	1878	4	157752	2025	2200	2113	1	50712	1800	2250	1543	1800	533	0.6	25584	234048	241346
	LR	33		33	2.7	1871	0	225	113	0.6	1627	NP	500	NP	450	475	0.1	3800	7298	
Beans	SR	450	240	345	0.95	6883	1800	NP	1800	0.1	4320	200	400	2700	900	1050	0.2	16800	28003	35203
	LR	NP	0				0	NP	0	0.1	0	NP	NP	NP	1800	1800	0.05	7200	7200	
Green grams	SR	NP	800	800	0.05	8340	200	NP	200	0.05	240	50	150	NP	NP	100	0.05	400	8980	9780
	LR	NP	NP				NP	NP				NP	100	NP	NP	100	0.1	800	800	
Cowpeas	SR	Veges	160	504	0.3	3175	500	Veges	500	0.1	1200	NP	200	Veges	600	400	0.06	1920	6295	8695
	LR	Veges			0.01	Veges	NP	NP				NP	NP	NP	600	600	0.05	2400	2400	
Sorghum	SR	1000	1800	1400	0.1	2940	200	200	200	0.1	480	NP	200	1200	NP	533	0.08	3411	6831	7041
	LR	1000		1000	0.01	210	NP	NP				NP	NP	NP	NP				210	
Pigeon pea	Year	1000	338	699	1.3	19083	1350	675	1013	0.3	7294	500	1350	1350	2700	1475	0.2	23600	49977	49977
Total grain production (grain cereals + grain legumes) per year						200254 (57%)					65873 (19%)							85915 (24%)	352042	352042
Sweet potatoes (fresh weight)	Year			NP								NP	450	NP		450	0.1	3600		
Cassava (fresh weight)	Year	450	450	450	0.1	945	450		450	0.05	540	NP	450	NP	600	525	0.1	4200		

Demand for food grain per person = 200 kg/year and with household members being: Poverty I = 9, II = 10 and 6 for III. Therefore the amount of grains/year/person (kg) is 179 for III, 275 for II and 1060 in I. So poverty group I facing deficit of 21 kg/person/year. However, these figures are true if and only if there is sufficient rainfall. Therefore there will always be deficit for III with or without rainfall.

Appendix IV C: The major crops grown and their estimated yields in Isara Village, Mashuru, Kenya

Poverty group number		**Well off (I)**					**Medium (II)**						**Poor (III)**								
		Farmer number/yield (Kg/ha/year)																			
Crop type	***Season***	*1*	*2*	***Av. Yield per ha***	***Av. area per crop (ha)***	***Sub-total for the well off group in the village (n=6)***	*3*	*4*	5	*Av. Yield per ha*	***Av. area per crop (ha)***	***Sub-total for the medium group in the village (n=7)***	*6*	*7*	*8*	*9*	***Av. yield per ha***	***Av. area per crop (ha)***	***Sub-total for the poor group in the village (n=38)***	***Estimated total yield per crop per season (kg)***	***Estimated total yield per year per crop (kg) in Isara Village***
Maize	SR	2222	1475	1849	0.7	7766	1098	2195	1475	1589	0.5	5562	1111	300	1537	2195	1286	0.48	23457	36785	41853
	LR	1098		1098	0.4	2635	1098	0	590	563	0.4	1576		110	0		55	0.41	857	5068	
Beans	SR	556	1800	1178	0.5	3534	1350	439	1350	1046	0.3	314	1200	225	1200	900	881	0.2	6696	10544	13734
	LR	556		556	0.8	2669	878	0	450	443	0.3	133		67	0		34	0.3	388	3190	
Green grams	SR												1550		600	450	887	0.1	3371	3371	3371
	LR														0		0	0.2	0	0	
Cowpeas	SR												450		450	450	450	0.2	3420	3420	3420
	LR														0		0	0.1	0	0	
Total grain production (grain cereals + grain legumes) per year						16604						7585							38189		62378

Demand for food grain per person = 200 kg/year and with 483 person in the village, 62378 kg will be enough for 312 persons per year and therefore there will always be deficit of food for 171 persons per year with or without adequate rainfall. Some of the food demands will be meet by milk production but is not enough. Consequently, in current status quo the deficit has to be bought from outside the village.

Appendix IV D: The major crops grown and estimated yields in Erankau Village, Mashuru, Kenya

Poverty group number		Well off (I)						Medium (II)							Poor (III)								
		Farmer number/yield (Kg/ha/year)																					
Crop type	*Season*	*1*	*2*	*3*	*Av. Yield per ha*	*Av. area per crop (ha)*	*Sub-total for the well off in the village (n=10)*	*4*	*5*	6	Av. Yield per ha	*Av. area per crop (ha)*	*Sub-total for the mediu m in the village (n=24)*	*7*	*8*	*9*	*10*	*Av. yield per ha*	*Av. area per crop (ha)*	*Sub-total for the poor in the village (n=80)*	*Estimated total yield per crop per season (kg)*	*Estimated total yield per year per crop (kg) in Erankau Village*
Maize	SR	1667	738	1333	1246	1	12460	1328	4426	2656	2803	0.6	40363	2667	556	1111	5556	2473	0.6	118704	171527	292595
	LR	778	74	889	580	1	5800	450	885	0	445	0.5	5340	889	556		4444	1963	0.7	109928	121068	
Beans	SR	2444	1111	1000	1518	0.5	7590	885	885	1000	923	0.5	11076	1556	887	667	3333	1611	0.6	77328	95994	167791
	LR	1333	0	667	667	0.5	3335	360	148	900	469	0.4	4502	507	887	556	4444	1599	0.5	63960	71797	
Green grams	SR							40	900		470	0.1	1128	222	222	222	3600	1067	0.2	17072	18200	24048
	LR													900	222	900	900	731	0.1	5848	5848	
Cowpeas	SR							90	900		495	0.1	1188								1188	1188
	LR																					
Sorghum	SR								900		900	0.1	2160								2160	2160
	LR																					
Pigeon pea	Annual								800		800	0.1	1920								1920	1920
Total grain production (grain cereals + grain legumes) per year							29185						67677							392840	489702	489702
Sweet potatoes (wet weight)	Annual								450		450	0.1	1080								1080	
Pumpkins (Wet weight	Annual								900		900	0.1	2160								2160	
Cassava (wet weight)	Annual								450		450	0.1	1080								1080	

NB Av. = Average 2.4711 acres = 1 ha

Demand for food grain per person = 200 kg/year. Though it may look that there is enough produced for each person, this figures are only correct when there is pumper harvest, which is very rare. Even then the problem of pests and diseases in store (the great grain borer, rats and fungal) will be a big constraint.

Appendix V A1: The dominant species on the Luvisols plains, Muusini Village, Kibwezi, Kenya (n = 5)

	Species	Life form	Cover (%)	Density	Frequency	Rel cover	Rel density	Rel frequency	IVI	Regeneration	Stems cut
1	*Commiphora africana*	Tree	14,2	320	100	16,5	4,1	4,7	25,3	160	80
2	*Commiphora campetris*	Tree	5	160	100	5,8	2,1	4,7	12,6	20	20
3	*Commiphora boiviniana*	Tree	1,4	20	60	1,6	0,3	2,8	4,7	60	80
4	*Commiphora rostrata*	Tree	0,9	20	40	1,1	0,3	1,9	3,3	20	20
5	*Acacia mellifera*	Tree	0	0	20	0	0	0,9	0,9	20	
6	*Acacia tortilis*	Tree	5,6	160	60	6,5	2,1	2,8	11,4	0	
7	*Sterculia africana*	Tree	0,7	40	20	0,8	0,5	0,9	2,2	0	
8	*Boscia anguisitifolia*	Tree	0	0	60	0	0	2,8	2,8	80	
9	*Senna abbreviata*	Tree	0,4	20	40	0,5	0,3	1,9	2,7	40	20
10	*Boswellia neglecta*	Tree	2	60	20	2,3	0,7	0,9	3,9	125	20
11	*Lannea triphylla*	Tree	0	0	20			0,9	0,9	100	
12	*Melia volkensii*	Tree	1,1	20	20	1,3	0,3	0,9	2,5	0	20
13	*Delonix elator*	Tree	0,4	20	20	0,4	0,3	0,9	1,6	0	
	Other trees within the landscape										
14	*Adansonia digitata*										
15	*Terminalia prunoides*										
	Sub-total trees		**31,7**						**74,8**		
1	*Combretum exalatum*	Shrub	3,8	160	80	4,4	2,1	3,7	10,2	0	80
2	*Combretum aculeatum*	Shrub	0,4	20	20	0,4	0,3	0,9	1,6	0	
3	*Acacia brevispica*	Shrub	0,4	20	20	0,5	0,3	0,9	1,7	0	
4	*Erythroclamys spectabilis*	Shrub	5,1	280	60	5,9	3,6	2,8	12,3	0	100
5	*Grewia tembensis*	Shrub	1,3	60	60	1,5	0,7	2,8	5	280	
6	*Grewia bicolor*	Shrub	4,2	160	100	4,8	2,1	4,7	11,6	440	
7	*Grewia villosa*	Shrub	4,1	220	80	4,8	2,8		7,6	100	
8	*Lantana trifolia*	Shrub	0,2	100	20	0,3	1,3	0,9	2,5	0	
9	*Barlaria taitensis*	Shrub	7,8	3920	60	9	50,5	2,8	62,3	Regenerating	
10	*Premna resinosa*	Shrub	4	180	80	4,7	2,3	3,7	10,7	20	60
11	*Acalypha racemosa*	Shrub	2,6	120	20	3,1	1,5	0,9	5,5	0	Over browsed
12	*Hoslundia opposita*	Shrub	1,4	740	80	1,6	9,5	3,7	14,8	0	Over browsed
13	*Duosperma kilimandscharica*	Shrub	0,3	240	40	0,3	3,1	1,9	5,3	0	
14	*Ochna inermis*	Shrub	0,6	40	40	0,7	0,5	1,9	3,1	140	
15	*Boscia coriacea*	Shrub	1,4	80	80	1,6	1	3,7	6,3	20	80
16	*Boscia sp.*	Shrub	0,4	20	20	0,4	0,3	0,9	1,6	0	
17	*Asparagus africana*	Shrub	0,3	160	40	0,3	2,1	1,9	4,3	0	
18	*Hermannia exappendiculata*	Shrub	0,1	60	20	0,1	0,7	0,9	1,7	0	
	Cont. of Appendix V A1										
19	*Euphorbia cuneata*	Shrub	1,1	60	40	1,2	0,7	1,9	3,8	60	
20	*Solanum renschii*	Shrub	0,1	40	20	0,1	0,5	0,9	1,5	0	20

21	*Pachystigma loranthifolium*	Shrub	0,4	20	60	0,5	0,3	2,8	3,6	100	
22	*Lycium europeaum*	Shrub	0	0	20	0	0	0,9	0,9	20	
23	*Parvonia urens*	Shrub	0,1	40	20	0,1	0,5	0,9	1,5	Regenerating	
	Sub-total shrubs		**40,1**						**179,4**		
1	*Momordica spinosa*	Climber	0,1	40	20	0,1	0,5	0,9	1,5	0	
2	*Vatovaea sp*	Climber	0,8	40	40	1	0,5	1,9	3,4	0	
3	*Tylosema fassoglense*	Climber	0,4	20	20	0,5	0,3	0,9	1,7	0	
4	*Cyphostemma sp.*	Climber	0,4	20	20	0,5	0,3	0,9	1	0	
	Sub-total climbers		**1,7**						**7,6**		
1	*Solanum incanum*	Herb	0,1	60	20	3,5	0,7	3,7	7,9	Regenerating	
2	*Hibiscus pycnostemon*	Herb	3		80	0,1		0,9	1	Regenerating	
3	*Justacia flava*	Herb	7,3		80	8,4		3,7	12,1	Regenerating	
	Sub-total herbs		**10,4**								
1	*Panicum maximum*	Grass	0,9		40	1		1,9	2,9		
2	*Enterepogon macrostachyus*	Grass	1,7		80	1,9		3,7	5,6		
3	*Chloris roxburghiana*	Grass	r		80	r		3,7	3,7		
	Sub-total grasses		**2,6**								
	Total vegetation over		170,4								
	Bare		13,704								

Appendix V A2: The dominant species on the Ferralsols plains, Muusini Village, Kibwezi, Kenya (n = 5)

	Species	Life form	Cover (%)	Density	Frequency	Rel cover	Rel density	Rel frequency	Important value index (IVI)	Regeneration	Stems cut
1	*Commiphora africana*	Tree	3	180	80	3,3	2,4	4,4	10,1	60	
2	*Commiphora campetris*	Tree	1,2	40	40	1,3	0,5	2,2	4	60	
3	*Commiphora boiviniana*	Tree	1	80	60	1,2	1,1	3,3	5,6	40	
4	*Commiphora rostrata*	Tree	0,9	80	20	1	1,1	1,1	3,2	0	
5	*Acacia tortilis*	Tree	0,4	40	40	0,5	0,5	2,2	3,2	0	20
6	*Boscia anguisitifolia*	Tree	0,6	40	60	0,7	0,5	3,3	4,5	20	20
7	*Senna abbreviata*	Tree	1,5	60	60	1,7	0,8	3,3	5,8	140	300
8	*Boswellia neglecta*	Tree	1,1	80	20	1,3	1,1	1,1	3,5	0	
9	*Lannea triphylla*	Tree	2,4	40	40	2,7	0,5	2,2	5,4	120	
10	*Terminalia brownii*	Tree	2,3	100	40	2,6	1,3	2,2	6,1	80	
11	*Lannea alata*	Tree	2,9	160	20	3,3	2,1	1,1	6,5	100	
12	*Dalbergia melanoxylon*	Tree	0,4	20	20	0,4	0,3	1,1	1,8	0	20
13	*Lannea stuhlmanii*	Tree	1,2	20	20	1,3	0,3	1,1	2,7	0	
14	*Adansonia digitata*	Tree	10,8	60	60	12,1	0,8	3,3	16,2	0	
15	*Lonchocarpus eriocalyx*	Tree	0,3	20	40	0,3	0,3	2,2	2,8	20	
	Other trees within the landscape										
16	*Lawsonia inermis*										
17	*Ormocarpum kirkii*										
	Sub-total trees		**30**						**81,4**		
1	*Combretum exalatum*	Shrub	10,1	420	60	11,3	5,6	3,3	20,2	60	120
2	*Acacia brevispica*	Shrub	1,3	120	60	1,4	1,6	3,3	6,3	20	
3	*Erythroclamys spectabilis*	Shrub	0,8	60	40	0,9	0,8	2,2	3,9	0	
4	*Grewia tembensis*	Shrub	1,3	60	40	1,5	0,8	2,2	4,5	40	
5	*Grewia bicolor*	Shrub	1,1	100	20	1,2	1,3	1,1	3,6	0	
6	*Grewia villosa*	Shrub	0	0	20	0		1,1	1,1	80	
7	*Barlaria taitensis*	Shrub	2,1	1500	20	2,4	20,1	1,1	23,6	Regenerating	
8	*Premna resinosa*	Shrub	9,4	240	40	10,6	3,2	2,2	16	20	
9	*Acalypha racemosa*	Shrub	2,5	1820	60	2,8	24,3	3,3	30,4	0	
10	*Hoslundia opposita*	Shrub	0,3	220	40	0,3	2,9	2,2	5,4	0	
11	*Duosperma kilimandscharica*	Shrub	0,8	640	60	0,9	8,6	3,3	12,8	0	
12	*Ochna inermis*	Shrub	1,1	80	40	1,3	1,1	2,2	4,6	0	20
13	*Pachystigma loranthifolium*	Shrub	1,6	140	40	1,8	1,9	2,2	5,9	0	
14	*Boscia sp.*	Shrub	0	0	20	0		1,1	1,1	20	
15	*Phyllanthus sepialis*	Shrub	1,5	80	20	1,6	1,1	1,1	3,8	80	
16	*Dichrostachys cinerea*	Shrub	1,8	100	20	2,1	1,3	1,1	4,5	100	
	Cont. of Appendix V B										
17	*Combretum contractum*	Shrub	0	0	20	0		1,1	1,1	20	80
18	*Grewia fallax*	Shrub	1,4	40	20	1,5	0,5	1,1	3,1	0	60

19	*Indigofera lupatana*	Shrub	0,4	200	20	0,4	2,7	1,1	4,2	200	
20	*Cordia ovalis*	Shrub	0	0	20	0		1,1	1,1	20	
21	*Parvonia urens*	Shrub	0,1	100	20	0,2	1,3	1,1	2,6	Regenerating	
	Sub-total shrubs		**37,6**						**159,8**		
1	*Entada leptostachya*	Climber	0,7	20	20	0,8	0,3	1,1	2,2	0	
2	*Tylosema fassoglense*	Climber	0,3	20	20	0,3	0,3	1,1	1,7	0	
	Sub-total climbers		**1**						**3,9**		
1	*Solanum incanum*	Herb	0,1	60	20	0,1	0,8	1,1	2	Regenerating	
2	*Abutilon hirtum*	Herb	0,3	200	20	0,3	2,7	1,1	4,1	0	
3	*Hibiscus pycnostemon*	Herb	2,7		20	3,1		1,1		Regenerating	
4	*Trichodesma zeylanicum*	Herb	0,3	240	20	0,3	3,2	1,1	4,6	Regenerating	
5	*Justacia flava*	Herb	4,1		40	4,6		2,2		Regenerating	
6	*Achyranthes aspera*	Herb	3,9		20	4,4		1,1		Regenerating	
7	*Commelina sp.*	Herb	0,4		20	0,5		1,1		Regenerating	
	Other herb within the landscape										
8	*Spaeranthus ukambensis*										
	Sub-total herbs		**11,8**								
1	*Panicum maximum*	Grass	2,1		60	2,4					
2	*Cenchrus ciliaris*	Grass	r		20						
3	*Chloris roxburghiana*	Grass	0,5		20	0,6					
4	*Enterepogon macrostachyus*	Grass	0,2		40	0,3					
5	*Dactyloctenium aegyptium*	Grass	r		20						
6	*Setaria pumila*	Grass	0,1		20	0,2					
7	*Urocloa oligotricha*	Grass	6		40	6,7					
8	*Digitaria abyssinica*	Grass	r		20						
9	*Aristida kenyensis*	Grass	r		20						
10	*Eragrostis sp*	Grass	0,5		20						
	Other grasses within the landscape										
11	*Sporobolus* sp										
12	*Echinocloa colona*										
	Sub-total grasses		**9,4**								
	Total vegetation cover		89		1780						
	Bare		11								

Appendix V B1: The dominant species on the Ferralsols plains, Bondeni Village, Kibwezi, Kenya (n = 4)

	Species	Life form	Cover	Density	Frequency	Rel cover	Rel density	Rel frequency	Important value index (IVI)	Regeneration	Stems cut per ha
1	*Combretum apiculatum*	Tree	31,5	1500	100	34,5	30,9	4,8	70,2	250	900
2	*Zanthoxylum chalybeum*	Tree	1	25	50	1,1	0,5	2,4	4	75	25
3	*Acacia mellifera*	Tree	1	25	25	1,1	0,5	1,2	2,8	0	25
4	*Combretum collinum*	Tree	3,3	300	50	3,6	6,2	2,4	12,2	75	25
5	*Lannea triphylla*	Tree	2	475	75	3	9,8	3,6	16,4	450	175
6	*Lonchocarpus eriocalyx*	Tree	1,3	50	50	1,4	1	2,4	4,8	25	25
7	*Terminalia brownii*	Tree	0,3	25	75	0,3	0,5	3,6	4,4	225	25
8	*Acacia nilotica*	Tree	0,3	50	75	0,4	1	3,6	5	225	25
9	*Strychnus spinosa*	Tree	0,3	25	25	0,3	0,5	1,2	2	25	0
10	*Dalbergia melanoxylon*	Tree	1,4	475	50	1,5	9,8	2,4	13,7	200	825
11	*Combretum zeyheri*	Tree	3,4	225	100	3,8	4,6	4,8	13,2	100	800
12	*Acacia tortilis*	Tree	0	0	25	0	0	1,2	1,2	150	0
13	*Ormocarpum kirkii*	Tree	0	0	25	0	0	1,2	1,2	50	0
14	*Steganottaena aralacia*	Tree	0	0	25	0	0	1,2	1,2	100	0
	Sub-total trees		**45,8**						**152,3**		
1	*Commiphora oblongifolia*	Shrub	0,8	75	100	0,9	1,6	4,8	7,3	4075	125
2	*Hoslundia opposita*	Shrub	0,2	175	75	0,2	3,6	3,6	7,4	0	25
3	*Cissus aphyllantha*	Shrub	0,1	25	25	0,1	0,5	1,2	1,8	75	50
4	*Duosperma kilimandscharica*	Shrub	1,3	1100	75	1,4	22,7	3,6	27,7	350	over browsed
5	*Acalypha racemosa*	Shrub	0,1	25	25	0,1	0,5	1,2	1,8	0	over browsed
6	*Clerodendrum eriophyllum*	Shrub	0,2	125	100	0,2	2,6	4,8	7,6	100	0
7	*Cassia bicapsularis*	Shrub	0,1	50	25	0,1	1	1,2	2,3	0	0
8	*Lantana trifolia*	Shrub	r	25	50	r	0,5	2,4	2,9	75	0
9	*Maytenus putterlickioides*	Shrub	0	0	25	0	0	1,2	1,2	25	0
10	*Grewia bicolor*	Shrub	0,1	50	25	0,2	1	1,2	2,4	0	50
11	*Tephrosia villosa*	Shrub	0,1	4	25	0,1	0,1	1,2	1,4	0	0
12	*Thunbergia holstii*	Shrub	r	25	25	r	0,5	1,2	1,7	0	0
13	*Vangueria apiculatum*	Shrub	0	0	25	0	0	1,2	1,2	25	0
14	*Clerodendrum myricoides*	Shrub	0	0	25	0	0	1,2	1,2	175	0
15	*Flueggea virosa*	Shrub	0	0	25	0	0	1,2	1,2	25	0
16	*Aspilia mosambicensis*	Shrub	0	0	25	0	0	1,2	1,2	150	0
17	*Asparagus africana*	Shrub	r	0	25	0	0	1,2	1,2	150	0

	Sub-total shrubs		**3**						**71,5**		
1	*Entada leptostachya*	Climber	0	0	25	0	0	1,2	1,2	100	0
	Sub-total climbers		**0**						**1,2**		
1	*Justacia flava*	Herb	10		50	10,9		2,4		Regenerating	
2	*Acanthospermum hispidum*	Herb	1,3		25	1,4		1,2		Regenerating	
3	*Hibiscus pycnostemon*	Herb	0,3		100	0,3		4,8		Regenerating	
4	*Cyphostemma sp. (Ngalatimia)*	Herb	6,3		75	6,8		3,6		Regenerating	
5	*Ithilunzu*	Herb	5		50	5,5		2,4		Regenerating	
6	*Crotolaria polysperma*	Herb	0,1		25	0,1		1,2		Regenerating	
	Sub-total herbs		**23**							Regenerating	
1	*Panicum maximum*	Grass	6,3		25	6,8		1,2			
2	*Cenchrus ciliaris*	Grass	3,8		25	4,1		1,2			
3	*Enterepogon macrostachyus*	Grass	2		50	2,2		2,4			
4	*Themeda triandra*	Grass	0,8		25	0,8		1,2			
5	*Digitaria ciliaris*	Grass	1,3		50	1,4		2,4			
6	*Setaria pumila*	Grass	1,3		50	1,4		2,4			
7	*Eragrostis superba*	Grass	2,5		25	2,7		1,2			
8	*Rottboellia cochinchinensis*	Grass	1,3		25	1,4		1,2			
	Sub-total grasses		**19,3**		**2075**			**99,6**			
	Herb and grass cover										
	Vegetation cover		91,5								
	Bare		8,5								

Appendix V B2: Common species on the Chernozems lowlands in Bondeni Village, Kibwezi, Kenya (n=4)

	Species	Life form	Cover	Density	Frequency	Rel cover	Rel density	Rel freq	Important value index (IVI)	Regeneration	Stems cut
1	*Combretum apiculatum*	Tree	2	40	40	2,5	0,2	2,3	5	20	160
2	*Combretum collinum*	Tree	0,5	20	20	0,6	0,1	1,1	1,8	40	20
3	*Combretum zeyheri*	Tree	2,1	160	40	2,6	0,8	2,3	5,7	0	0
4	*Acacia tortilis*	Tree	0,2	140	20	0,3	0,7	1,1	2,1	100	20
5	*Acacia mellifera*	Tree	0,2	20	20	0,3	0,1	1,1	1,5	20	20
6	*Acacia drepanolobium*	Tree	2,4	440	75	3	2,3	4,2	9,5	220	40
7	*Acacia seyal*	Tree	0,1	20	20	0,1	0,1	1,1	1,3	20	0
8	*Albizia anthelmentica*	Tree	r	20	20		0,1	1,1	1,2	40	20
9	*Lannea triphylla*	Tree	3,3	800	75	4,1	4,2	4,2	12,5	660	20
10	*Terminalia brownii*	Tree	0,4	80	20	0,5	0,4	1,1	2	0	0
11	*Ormocarpum kirkii*	Tree	0		40			2,3	2,3	120	
12	*Adansonia digitata*	Tree			20			1,1	1,1	20	
13	*Staganotaenia araliacia*	Tree	0		20			1,1	1,1	400	
14	*Commiphora habessinica*	Tree	0		20			1,1	1,1	20	
15	*Acacia nilotica*	Tree	0		20			1,1	1,1	20	
16	*Strychnus spinosa*	Tree	0		20			1,1	1,1	20	
17	*Dalbergia melanoxylon*	Tree	0		40			2,3	2,3	60	
18	*Albizia amara*	Tree	0,4	100	75	0,5	0,5	4,2	5,2	40	0
	Sub-total trees		**11,6**						**57,9**		
1	*Commiphora oblongifolia*	Shrub	0,2	40	20	0,3	0,2	1,1	1,6	40	20
2	*Hoslundia opposita*	Shrub	r	220	40		1,2	2,3	3,5	0	0
3	*Cissus aphyllantha*	Shrub	r	20	20		0,1	1,1	1,2	0	0
4	*Duosperma kilimandscharica*	Shrub	2,9	7260	75	3,6	38,4	4,2	46,2	0	Over browsed
5	*Cassia bicapsularis*	Shrub	0,3	100	40	0,4	0,5	2,3	3,2	160	0
6	*Gardenia volkensii*	Shrub	0,1	25	20	0,1	0,1	1,1	1,3	40	0
7	*Flueggea virosa*	Shrub	0,6	150	20	0,8	0,8	1,1	2,7	0	0
8	*Maytenus putterlickiodes*	Shrub	0,6	100	40	0,8	0,5	2,3	3,6	20	0
9	*Grewia tembensis*	Shrub	0,1	25	20	0,1	0,1	1,1	1,3	100	0
10	*Euclea racemosa*	Shrub	2,1	350	20	2,6	1,9	1,1	5,6	180	60
11	*Triumfetta flavescens*	Shrub	3,7	7575	40	4,6	40,1	2,3	47	Regenerating	Over browsed
12	*Indigofera volkensii*	Shrub	1,4	900	75	1,8	4,8	4,2	10,8	Regenerating	
13	*Combretum contortum*	Shrub	0,4	100	20	0,5	0,5	1,1	2,1	0	40
	Cont. of Appendix V B2										

14	*Combretum aculeatum*	Shrub	0,5	75	40	0,6	0,4	2,3	3,3	20	20
15	*Cordia ovalis*	Shrub	0,1	25	20	0,1	0,1	1,1	1,3	20	20
16	*Clerodendrum eriophyllum*	Shrub	0		20			1,1	1,1	20	
17	*Asparagus africana*	Shrub	0		20			1,1	1,1	100	
18	*Aspila mossambicensis*	Shrub	0		20			1,1	1,1	20	
19	*Solanum renschii*	Shrub	0		20			1,1	1,1	40	
20	*Lantana trifolia*	Shrub	0		20			1,1	1,1	20	
21	*Thunbergia holstii*	Shrub	0		20			1,1	1,1	60	
	Sub-total shrubs		**13**						**141,3**		
1	*Bleripherispermum zanguebarium*	Climber	r	75	20		0,4	1,1	1,5	20	0
2	*Vatovoea sp*	Climber	r	25	20		0,1	1,1	1,2	0	Over browsed
	Sub-total climbers		**r**						**2,7**		
1	*Justacia flava*	Herb	2,8		40	3,5		2,3		Regenerating	
2	*Anthericum venilosum*	Herb	12		40	15		2,3		Regenerating	
3	*Occimum kilmandscharicum*	Herb	0,6		20	0,8		1,1		Regenerating	
4	*Hibiscus pycnostemon*	Herb	1		60	1,3		3,9		Regenerating	
5	*Cyphostemma sp (Ngalatimia)*	Herb	0,6		20	0,8		1,1		Regenerating	
6	*Aspila sp.*	Herb	0,4		20	0,5		1,1		Regenerating	
7	*Trichodesma zeylanicum*	Herb	r		20			1,1		Regenerating	
	Sub-total herbs		**17,4**								
1	*Cenchrus sp.*	Grass	13,6		20	17		1,1			
2	*Panicum maximum*	Grass	2,5		40	3,1		2,3			
3	*Enterepogon macrostachyus*	Grass	1		20	1,3		1,1			
4	*Pennisetum mezianum*	Grass	r		20			1,1			
5	*Bothriochloa insculpta*	Grass	r		40			2,3			
6	*Echinocloa colona*	Grass	15		60	18,7		3,9			
7	*Chloris roxburghiana*	Grass	r		20			1,1			
8	*Themeda triandra*	Grass	2		20	2,5		1,1			
9	*Heterepogon contortus*	Grass	4		20	5		1,1			
10	*Sporobolus indicus*	Grass	r		20			1,1			
	Sub-total grasses		**38,1**								
	Herbs and grass cover				1775						
	Vegetation cover		80								

Appendix V C1: The dominant species on the Cambisols hills & foothills, Isara Village, Mashuru, Kenya (n = 3)

	Species	Life form	Cover	Density	Frequency	Rel cover	Rel density	Rel Frequency	Important values index (IVI)	Regeneration	Stems cut
1	*Acacia senegal*	Tree	13,3	300	67	17,4	8,3	6,3	32	167	67
2	*Ormocarpum kirkii*	Tree	2,7	200	33	3,5	5,5	3,1	12,1	200	0
3	*Boswellia neglecta*	Tree	4,2	33	33	5,5	0,9	3,1	9,5	0	0
4	*Lannea stuhlmanii*	Tree	1,1	33	33	1,4	0,9	3,1	5,4	0	0
5	*Dalbergia melanoxylon*	Tree	4,3	133	33	5,6	3,7	3,1	12,4	133	0
6	*Acacia mellifera*	Tree	7,5	67	33	9,8	1,8	3,1	14,7	200	67
	Other trees within the landscape										
7	*Acacia drepanolobium*		9	*Albizia anthelmentica*							
8	*Balanites glabra*		10	*Cussonia holstii*							
	Sub-total trees		***33,1***						***86,1***		
1	Ngaimurunyai	Shrub	1,9	67	33	2,5	1,8	3,1	7,4	67	0
2	*Grewia tembensis*	Shrub	10,5	333	100	13,7	9,2	9,4	32,3	267	over browsed
3	*Asparagus africana*	Shrub	r	633	33		0,9	3,2	4,1	500	over browsed
4	*Aspilia mossambicensis*	Shrub	2,6	33	67	3,4	17,4	6,3	27,1	0	0
5	*Maerua* sp	Shrub	1,4	33	33	1,8	0,9	3,1	5,8	0	0
6	*Lantana trifolia*	Shrub	0,3	100	67	0,4	2,8	6,3	9,5	0	0
7	*Grewia villosa*	Shrub	1,9	67	33	2,5	1,8	3,1	7,4	0	0
8	*Phyllanthus sepialis*	Shrub	0,4	100	33	0,5	2,8	3,1	6,4	33	0
9	*Rhus natalensis*	Shrub	4,3	100	33	5,6	2,8	3,1	11,5	0	0
10	*Indigofera lupatana*	Shrub	4	400	67	2,1	11	6,3	19,4	Regenerating	over browsed
11	*Acalypha racemosa*	Shrub	r	167	33	1	4,6	3,1	8,7	Regenerating	
	Other shrubs within the landscape										
12	*Grewia bicolor*		14	*Combretum aculeatum*							
13	*Cordia ovalis*										
	Sub-total shrubs		**27,3**						**139,6**		
	Ngatia mongi	Climber	0,1	33	33	0,1	0,9	3,1	4,1	0	0
	Other climbers within the landscape										
1	*Klienia squarrosa*										
	Sub-total climbers		**0,1**						**4,1**		
2	*Indigofera spinosa*	Herb	1,6	767	33	0,1	21,1	3,1	24,3	Regenerating	
2	*Bleripheris sp*	Herb	0,2	33	33	0,3	0,9	3,1	4,3	0	0
3	*Hibiscus pycnostemon*	Herb	0,1		33	13,5		3,1		Regenerating	

	Cont. of Appendix V C1										
	Other herbs within the landscape										
4	*Occimum* sp		6	*Cyathula* sp							
5	*Heliotropium* sp		7	*Pupalia* sp							
	Sub-total herbs		**1,9**						**28,6**		
1	*Pennisetum mezianum*	Grass	0,8		100	9,2		9,4			
2	*Chrysopogon aucheri*	Grass	10,3		67			6,5			
	Sub-total grasses		**11,1**								
	Total vegetation cover		7		1063						
	Bare		23,3								
	Other life forms within the landscape										
1	*Cyperus bulbosus*										

Appendix V C2: The dominant species on the Vertisols lowlands, Isara Village, Mashuru, Kenya
Volcanic Vertisols (n = 3) and Basement Vertisols (n=4)

	Vertisols - volcanic										
	Species	**Life form**	**Cover**	**Density**	**Frequency**	**Rel cover**	**Rel density**	**Rel Frequency**	**Important value index (IVI)**	**Regeneration**	**Stems cut**
1	*Balanites glabra*	Tree									
1	Oloorok kileling	Shrub	22,6	2633	100	33,1	40,7	33	106,8	1067	over browsed
2	*Aspilia mossambicensis*	Shrub	18,5	2167	67	27,1	33,5	22	82,6	1167	over browsed
3	*Cordia quercifolia*	Shrub	0,5	67	33	0,7	1	11	12,7	67	
4	*Bleripheris* sp	Shrub	11,5	1333	33		2,1	11		Regenerating	
	Other shrubs within the landscape										
5	*Asparagus africana*										
	Sub-total shrubs		**53,1**						**202,1**		
1	*Abutilon mauritianum*	Herb	0,7	267	67	1	4,1	23	28,1	Regenerating	
	Other herbs within the landscape										
2	*Occimum* sp	4	*Cyathula* sp								
3	*Heliotropium* sp	5	*Pupalia* sp								
	Sub-total herbs		**0,7**								
1	*Pennisetum mezianum*	Grass	14,5			16,8					
	Other grasses within the landscape										
2	*Sporobolus helvolus*										
	Sub-total grasses		**14,5**								
	Other life forms outside the plots										
1	*Cyperus bulbosus*	Sedge									
	Bare		31,7								
	Vertisols - basement										
			Cover	Density	Freq	Rel cover	Rel density	Rel Frequency	IVI	Regenerating	Stems cut
1	*Acacia tortilis*	Tree	23,6	375	100	33,2	12,8	11,8	57,8	575	100
2	*Acacia drepanolobium*	Tree	2,4	75	25	3,4	2,5	2,9	8,8	150	0
3	*Acacia mellifera*	Tree	1,1	25	25	1,6	0,9	2,9	5,4	0	0
4	*Acacia senegal*	Tree	0,8	25	25	1,1	0,9	2,9	4,9	150	0
5	*Commiphora africana*	Tree	4	125	50	5,6	4,3	5,9	15,8	0	0
6	*Lonchocarpus eriocalyx*	Tree	3,3	125	25	4,7	4,3	2,9	11,9	0	25
7	*Balanites aegyptiaca*	Tree	1,6	50	25	2,3	1,7	2,9	6,9	50	50

	Cont. Appendix V C2										
	Other trees scattered in the landscape										
8	*B. glabra*										
9	*Albizia anthelmentica*										
	Sub-total trees		**36,8**						**111,5**		
1	*Grewia villosa*	Shrub	7,1	225	50	10	7,7	5,9	23,6	300	167
2	*Cordia quercifolia*	Shrub	0,9	200	25	1,3	6,8	2,9	11	175	50
3	*Sericocomopsis pallida*	Shrub	2	625	50	2,8	21,4	5,9	30,1	25	Over browsed
4	*Vernonia aemulens*	Shrub	1,3	325	50	1,8	11,1	5,9	18,8	33	Over browsed
5	*Lycium eauropeaum*	Shrub	4,8	150	25	6,8	5,1	2,9	14,8	525	0
6	*Lantana trifolia*	Shrub	0,2	50	25	0,3	1,7	2,9	4,9	400	0
7	*Maerua sp*	Shrub	0,8	100	25	1,1	3,4	2,9	7,4	0	0
8	*Grewia bicolor*	Shrub	3,2	100	50	4,5	3,4	5,9	13,8	50	50
9	*Grewia fallax*	Shrub	0,8	25	25	1,1	0,9	2,9	4,9	0	0
10	*Ipomea kituiensis*	Shrub	0,1	25	25	0,1	0,9	2,9	3,9	0	0
11	*Phyllanthus sepialis*	Shrub	0,1	25	25	0,1	0,9	2,9	3,9	0	0
12	*Solanum* sp	Shrub	2,3	75	25	3,2	2,5	2,9	8,6	50	0
13	*Acalypha racemosa*	Shrub	0,2	75	25	0,3	2,5	2,9	5,7	0	Over browsed
	Sub-total shrubs		**23,8**						**151,4**		
1	Orkalay	Climber									
1	*Bleripheris* sp	Herb	0,4	125	25	0,6	4,3	2,9	7,8	0	0
2	*Hibiscus pycnostemon*	Herb	0,1		50	0,1		5,9			
	Sub-total herbs		**0,5**								
1	*Pennisetum mezianum*	Grass	7,5		25	10,6		2,9			
2	*Sporobolus fimbriatus*	Grass	1,3		25	1,8		2,9			
3	*Cynodon plectostachyus*	Grass	1,3		25	1,8		2,9			
4	*Sporobolus helvolus*										
	Sub-total grasses		**10,1**								
1	***Cyperus bilbosus***	Sedge									
	Total veg cover										
	Bare		29								

Appendix V C3: The dominant species on the Ferral chromic Luvisols Plains, Isara Village, Mashuru, Kenya (n= 3)

	Species	Life form	Cover	Density	Frequency	Rel cover	Rel density	Rel Frequency	Important value index (IVI)	Regeneration	Stems cut
1	*Commiphora africana*	Tree	5,2	267	67	6,6	4,3	5,6	16,5	133	67
2	*Acacia mellifera*	Tree	1,7	67	67	2,2	1,1	5,6	8,9	0	167
3	*Acacia tortilis*	Tree	26,3	6,7	67	33,6	11,2	5,6	50,4	500	333
4	*Balanites aegyptiaca*	Tree	0,7	67	33	0,9	1,1	2,8	4,8	67	Over browsed
	Other trees scattered in the landscape										
5	*Balanites glabra*	9	*Commiphora* sp.								
6	*A. drepanolobium*										
7	*Boswelia neglecta*										
8	*Commiphora sambarensis*										
	Sub-total trees		**33,9**						**80,6**		
1	*Grewia tembensis*	Shrub	2,2	100	67	2,8	1,6	5,6	10	0	Over browsed
2	*Cordia quercifolia*	Shrub	8,6	367	67	11	5,9	5,6	22,5	200	133
3	*Serracocomopsis pallida*	Shrub	2,7	1100	100	3,4	17,6	8,3	29,3	800	Over browsed
4	*Ipomea kituiensis*	Shrub	1,9	1333	100	2,4	21,4	8,3	32,1	400	0
5	*Lantana trifolia*	Shrub	0,2	100	33	0,3	1,6	2,8	4,7	67	0
6	*Grewia bicolor*	Shrub	0,7	33	33	0,9	0,5	2,8	4,2	0	133
7	*Euphorbia cuneata*	Shrub	0,7	33	33	0,9	0,5	2,8	4,2	267	0
8	*Serracocomopsis hildebrandtii*	Shrub	0,5	200	33	0,6	3,2	2,8	6,6	67	Over browsed
9	*Vernonia aemulens*	Shrub	0,8	367	33	1	5,9	2,8	9,7	267	Over browsed
	Other shrubs scattered in the landscape										
10	Oloorok kileling	14	*P. resinosa*								
11	*A.cacia paolii*										
12	*Cadaba farinosa*										
13	*A. mosambicensis*										
	Sub-total shrubs		**18,3**						**123,3**		
1	*Waluuuwi*	Climber	0,1	33	33	0,1	0,5	2,8	3,4	0	0
	Sub-total climbers		**0,1**						**3,4**		
1	*Talinum portulacifolium*	Herb	1	500	67	1,3	8	5,6	14,9	300	Over browsed
2	*Occimum* sp	Herb	0,1	967	100	0,1	15,5	8,3	23,9	Regenerating	
	Other herbs scattered in the landscape										
3	*H. pycnostemon*										
	Sub-total herbs		**1,1**								

	Cont. of Appendix V C3										
1	*Pennisetum mezianum*	Grass	8,3		100	10,6		8,3			
2	*Sporobolus fimbriatus*	Grass	8,3		67	10,6		5,6			
3	*Digitaria milanjiana*	Grass	3,3		33	4,2		2,8			
4	*Cynodon plectostachyus*	Grass	5		67	6,4		5,6			
	Other grasses scattered in the landscape										
5	*Letepes senegalensis*										
	Sub-total grass		**24,9**								
	Bare		21,7								

Appendix V C4: The dominant species on the Reddish Ferric Luvisols Plains, Isara Village, Mashuru, Kenya (n= 2)

	Species	Life form	Cover	Density	Frequency	Rel cover	Rel density	Rel Frequency	Important value index (IVI)	Regeneration	Stems cut
1	*Commiphora africana*	Tree	21,3	750	50	29,4	15,5	4	48,9	1000	0
2	*Acacia tortilis*	Tree	15,8	400	100	21,8	8,2	8	38	100	50
3	*Boswellia neglecta*	Tree	3,2	100	50	4,4	2,1	4	10,5	0	0
4	*Acacia mellifera*	Tree	0,8	50	50	1,1	1	4	6,1	0	50
5	*Acacia senegal*	Tree	0,8	50	50	1,1	1	4	6,1	0	50
	Other trees within the landscape										
6	*Acacia seyal*										
7	*Commiphora holtziana*										
8	*Commiphora* sp. (Angalobai)										
	Sub-total trees		**41,9**						**109,6**		
1	*Serracocomopsis pallida*	Shrub	1,5	150	100	2,1	37,1	8	47,2	0	Over browsed
2	*Cordia quercifolia*	Shrub	5,3	600	100	7,3	12,4	8	27,7	700	250
3	*Grewia tembensis*	Shrub	3	300	100	4,1	5,2	8	17,3	350	Over browsed
5	*Grewia bicolor*	Shrub	1,5	100	50	2,1	2,1	4	8,2	100	100
6	*Grewia villosa*	Shrub	1,5	100	50	2,1	2,1	4	8,2	100	50
7	*Vernonia aemulens*	Shrub	0,8	100	50	1,1	2,1	4	7,2	400	Over browsed
	Sub-total shrubs		**14,1**						**130,7**		
1	*Momordica spinosa*	Climber	0,7	250	50	1	3,1	4	8,1	0	Over browsed
2	*Klienia squarrosa*	Climber	0,8	50	50	1,1	1	4	6,1	0	Over browsed
	Sub-total climbers		**1,5**						**14,2**		
1	*Bleripharis linariifolia*	Herb	2,5		50	3,4		4			
2	*Abutilon mauritianum*	Herb	r	50	50		1	4		Regenerating	
3	*Hibiscus pycnostemon*	Herb	r		50			4		Regenerating	
4	*Talinum portulacifolium*	Herb	0,5	1800	100	0,7	6,2	8	14,9	750	Over browsed
	Sub-total herbs		**2,5**								
1	*Cynodon plectostachyus*	Grass	2,5		50	3,4		4			
2	*Pennisetum mezianum*	Grass	5		50	6,9		4			
3	*Sporobolus fimbriatus*	Grass	5		50	6,9		4			
	Sub-total grasses		**12,5**								
	Bare		27,5		1250						

	Other shrubs scattered in the landscape										
15	*Maerua* sp.										
16	*Cordia quercifolia*										
17	*Sesamothamnus rivae*										
	Sub-total shrubs		**29,9**						**135,3**		
1	*Mormodica spinosa*	Climber	0,4	23	15,4	0,5	0,4	1,3	2,2	0	
	Sub-total climbers		**0,4**						**2,2**		
1	*Talinum portulacifolium*	Herb	0,7	323	38,5	0,9	5,9	3,1	9,9	339	8
2	*Occimum* sp	Herb	0,5	254	46,2	0,5	1,1	3,6	5,2	Regenerating	
3	*Solanum incanum*	Herb	0,1	38	7,7	0,1	0,8	0,6	1,5	62	
4	*Abutilon mauritianum*	Herb	r	39	15,4		0,1	1,3	1,4	Regenerating	
5	*Euphorbia* sp	Herb	r	8	7,7		0,1	0,6	0,7	0	Over browsed
6	*Bleripharis linariifolia*	Herb	0,2		7,7	0,3	0,7	0,6		Regenerating	
7	*Hibiscus pycnostemon*	Herb	0,1			0,1		1,6		Regenerating	
	Sub-total herbs		**1,6**								
1	*Sporobolus fimbriatus*	Grass	1,7		53,9	2,1		4,4			
2	*Eragrostis superba*	Grass	0,3		15,4	0,4		1,3			
3	*Enterepogon macrostachyus*	Grass	0,3		30,8	0,4		2,5			
4	*Pennisetum mezianum*	Grass	0,3		23,1	0,4		1,9			
5	*Digitaria milanjiana*	Grass	0,1		7,7	0,1		0,6			
	Sub-total grasses		**80**								
	Other life forms scattered in the landscape										
1	*Sansivaria intermedia*										
	Bare		20								

Appendix V D1: The dominant species on the Regosols hills, Erankau Village, Mashuru, Kenya (n= 7)

	Species	Life form	Cover	Density	Frequency	Rel cover	Rel density	Rel frequency	Important value index (IVI)	Regeneration	Stems cut
1	*Dalbergia melanoxylon*	Tree	2,3	200	28,6	2,6	2,9	1,7	7,2	57	0
2	*Dombeya kirkii*	Tree	0,8	29	57,1	0,9	0,4	3,3	4,6	43	0
3	*Sclerocarya birrea*	Tree	1,5	14	28,6	1,7	0,2	1,7	3,6	14	0
4	*Stagenotaenia araliacea*	Tree	0,2	14	42,9	0,2	0,2	2,5	2,9	900	0
5	*Ormocarpum kirkii*	Tree	0,6	72	57,1	0,7	1,1	3,3	5,1	457	0
6	*Combretum apiculatum*	Tree	5	200	71,4	5,6	2,9	4,1	12,6	186	29
7	*Commiphora baluensis*	Tree	6,6	143	42,9	7,4	2,6	2,5	12,5	729	14
8	*Ochna ovata*	Tree	1,2	57	28,6	1,3	0,2	1,7	3,2	114	0
9	*Zanthoxylum chalybeum*	Tree	0,2	29	28,6	0,2	0,8	1,7	2,7	14	0
10	*L.annea stuhlmanii*	Tree	0,7	14	14,3	0,8	0,4	0,8	2	0	0
11	*B.oscia anguisitifolia*	Tree	0,2	14	14,3	0,2	0,2	0,8	1,2	0	0
12	*Papea capensis*	Tree	1,2	14	28,6	1,3	0,2	1,7	3,2	29	0
13	*Commiphora rostrata*	Tree	0,2	14	14,3	0,2	0,2	0,8	1,2	0	0
14	*Terminalia brownii*	Tree	3,7	114	28,6	4,1	1,7	1,7	7,5	0	0
15	*Synadenium pereskiifolium*	Tree	1,2	14	14,3	1,3	0,2	0,8	2,3	0	0
16	*Brucea antidysenterica*	Tree	1	57	28,6	1,1	0,8	1,7	3,6	0	0
17	*Teclea nobilis*	Tree	0,9	43	28,6	1	0,6	1,7	3,3	57	0
18	*Teclea simplicifolia*	Tree	1,2	71	14,3	1,3	1	0,8	3,1	0	0
19	*Commiphora habessinica*	Tree	0,2	14	14,3	0,2	0,2	0,8	1,2	0	0
20	*Acacia nilotica*	Tree	1,6	43	14,3	1,8	0,6	0,8	3,2	0	0
21	*Nuxia oppositifolia*	Tree	0,2	14	14,3	0,2	0,2	0,8	1,2	0	0
22	*Lannea triphylla*	Tree								100	
23	*Lonchocarpus eriocalyx*	Tree								14	
24	*Commiphora* sp	Tree								29	
25	***Sub-total***		***30,7***						***87,4***		
	Other trees wihin the landscape										
26	*Acacia tortilis*		29	*Ficus sp.*							
27	*Acacia mellifera*		30	*Cussonia holstii*							
28	*Balanites aegyptiaca*										
1	*Clerodendrum mycriodes*	Shrub	0,7	57	14,3	0,8	0,8	0,8	2,4	0	0
2	*Ximenia americana*	Shrub	1,3	14	28,6	1,4	0,2	1,7	3,3	14	0
3	*Croton dichogomus*	Shrub	1,2	57	28,6	1,3	0,8	1,7	3,8	0	0
4	Ngaiurur	Shrub	0,5	100	14,3	0,6	1,4	0,8	2,8	0	0
	Cont. Appendix V D1										
5	*Thunbergia holstii*	Shrub	0,2	71	28,6	0,2	1	1,7	2,9	14	0

6	Emame	Shrub	0,7	29	28,6	0,8	0,4	1,7	2,9	29	14
7	*Premna resinosa*	Shrub	1,8	86	14,3	2	1,3	0,8	4,1	0	0
8	*Aspilia mosambicensis*	Shrub	1,4	714	71,4	1,5	10,4	4,1	16	129	0
9	*G.rewia forbesii*	Shrub	1,3	14	14,3	1,4	0,2	0,8	2,4	0	0
10	*Asparagus africana*	Shrub	0,1	14	14,3	0,1	0,2	0,8	1,1	29	0
11	*I.ndigofera lupatana*	Shrub	0,2	814	14,3	0,3	11,8	0,8	12,9	0	0
12	*Acalypha racemosa*	Shrub	1,2	100	28,6	1,3	1,4	1,7	4,4	0	0
13	*Acacia seyal* var *seyal*	Shrub	0,8	157	57,1	0,9	2,3	3,3	6,5	186	14
14	*Solanum renchii*	Shrub	0,1	14	14,3	0,1	0,2	0,8	1,1	29	0
15	*G.rewia tembensis*	Shrub	2,1	200	28,6	2,3	2,9	1,7	6,9	0	0
16	*Commiphora oblongifolia*	Shrub	6,1	43	42,9	6,8	0,6	2,5	9,9	443	0
17	*Grewia bicolor*	Shrub	0,2	29	14,3	0,2	0,4	0,8	1,4	0	0
18	*Acacia brevispica*	Shrub	6,3	543	42,9	7	7,9	2,5	17,4	86	0
19	*Zizyphus mucronata*									14	
20	*Cassia bicapsularis*									29	
21	*Maytenus putterlickiodes*									14	
22	*Lantana trifolia*									14	
	Sub-total		**26,2**						**102,2**		
	Other shrub wihin the landscape										
23	*Osyris lanceolata*				27	*Occimum americanum*					
24	*Crotolaria goodiformis*				28	*Dichrostacys cinerea*					
25	*Xerophyta spikei*				29	*Euclea divinorum*					
26	*Gnidia latifolia*										
1	*Cyphostemma sp*	Climber	2,6	157	28,6	2,9	2,3	1,7	6,9	0	0
2	*Bleripherispermum zanguiberium*	Climber	1,1	271	42,9	1,2	3,9	2,5	7,6	14	0
	Sub-total		**3,7**						**14,5**		
	Other climbers within the landscape										
3	*Entada leptostachya*										

	Cont. Appendix V D1										
1	*Solanum incanum*	Herb	1,6	857	42,9	1,8	12,4	2,5	16,7	Regenerating	0
2	*I.ndigofera spinosa*	Herb	2,1	629	14,3	2,3	9,1	0,8	12,2	Regenerating	0
3	*Occimum kilimandscharicum*	Herb	0,6	729	14,3	0,7	10,6	0,8	12,1	Regenerating	0
4	*H.ibiscus pycnostemon*	Herb	r		14,3			0,8		Regenerating	0
5	*J.ustacia flava*	Herb	1		28,6	1,1		1,7			
			5,3								
1	*Digitaria milanjiana*	Grass	10,4		57,1	11,6		3,3			
2	*Themeda triandra*	Grass	5		71,4	5,6		4,1			
3	*Panicum maximum*	Grass	0,3		28,6	0,3		1,7			
4	*Enterepogon macrostachyus*	Grass	0,6		28,6	0,7		1,7			
5	*Chrysopogon aucheri*	Grass	1		28,6	1,1		1,7			
6	*E.ragrostis superba*	Grass	1,5		42,9	1,7		2,5			
7	*Sporobolus fimbriatus*	Grass	5		42,9	5,6		2,5			
			23,8					**17,5**			
	Bare		10,7								

Appendix V D2: The dominant species on Orthic Luvisols upper plains, Erankau Village, Mashuru, Kenya (n= 4)

	Species	Life form	Cover	Density	Frequency	Rel cover	Rel density	Rel frequency	Important value index (IVI)	Regeneration	Stems cut
	Upper plains										
1	*B. aegyptiaca*	Tree	4	50	50	4,5	0,8	3,6	8,9	25	25
2	*A. tortilis*	Tree	9,6	350	100	10,8	5,6	7,3	23,7	150	0
3	*Ochna holstii*	Tree	1,1	50	25	1,2	0,8	1,8	3,8	75	0
4	*A. mellifera*	Tree	2,8	175	75	3,2	2,8	5,5	11,5	100	0
5	*Commiphora habessinica*	Tree			25			1,8		50	25
6	*Boscia anguisitifolia*	Tree								50	0
	Other trees within the landscape										
7	*Commiphora schimperi*										
8	*Acacia senegal*										
9	*Lannea stuhlmanii*										
10	*Balanites glabra*										
	Sub-total trees		**17,5**						**47,9**		
1	*C.dichogomus*	Shrub	3,2	413	25	3,6	6,6	1,8	12	150	0
2	*P. resinosa*	Shrub	1,3	150	25	1,5	2,4	1,8	5,7	25	100
3	*G. bicolor*	Shrub	0,7	25	25	0,8	0,4	1,8	3	50	0
4	*G.tembensis*	Shrub	17,1	475	100	19,3	7,6	7,3	34,2	100	0
5	*A. racemosa*	Shrub	1,1	825	25	1,2	13,2	1,8	16,2	0	0
6	*A. brevispica*	Shrub	0,2	25	25	0,2	0,4	1,8	2,4	300	0
7	*C. goodiformis*	Shrub	0,2	25	25	0,2	0,4	1,8	2,4	0	0
8	*A. africana*	Shrub	0,1	50	75	0,1	0,8	5,5	6,4	100	0
9	*O. americanum*	Shrub	0,8	300	25	0,8	4,8	1,8	7,4	0	0
10	*T. holstii*	Shrub	0,5	25	25	0,6	0,4	1,8	2,8	0	0
11	*P. urens*	Shrub	1,6	25	25	1,8	0,4	1,8	4	Regenerating	
12	*H.opposita*	Shrub	0,7	25	50	0,8	0,4	3,6	4,8	0	
13	*Tephrosia villosa*	Shrub	0,1	25	25	0,1	0,4	1,8	2,3	0	
14	*Indigofera volkensii*	Shrub	0,1	50	25	0,1	0,8	1,8	2,7	0	
15	*Olorundoi*	Shrub	1,3	525	25	1,5	8,4	1,8	11,7	0	
16	*R. natalensis*	Shrub	0,3	25	25	0,3	0,4	1,8	2,5	0	
17	*Hermania expaendiculata*	Shrub	0,1	75	25	0,1	1,2	1,8	3,1	0	
18	*D.cinerea*	Shrub	1,4	100	25	1,6	1,6	1,8	5	0	
19	*S. pallida*	Shrub	0,3	175	25	0,3	2,8	1,8	4,9	0	
20	*Phyllanthus sepialis*	Shrub	0,1	75	25	0,1	1,2	1,8	3,1	0	
	Other shrubs within the landscape										
21	*Grewia fallax*										
	Sub-total shrubs		**31,2**						**136,6**		
1	*Cyphostemma sp*	Climber	0,3	25	50	0,3	0,4	3,6	4,3	0	
	Cont. of Appendix V D2										

	Sub-total climbers		**0,3**						**4,3**		
1	*S.incanum*	Herb	2,8	2025	25	3,2	32,5	1,8	37,5	Regenerating	
2	*O.kilimandscharicum*	Herb	r	25	25		0,4	1,8	2,2	Regenerating	
3	*I. spinosa*	Herb	0,2	125	25	0,2	2	1,8	4	Regenerating	
4	*Anthericum venilosum*	Herb	0,5		25	0,6		1,8			
5	*H. pycnostemon*	Herb	0,9		50			3,6		Regenerating	
	Sub-total herbs		**4,4**								
1	*Chloris roxburghiana*	Grass	0,8	6238	25	0,9		1,8			
2	*E. macrostachyus*	Grass	7,9		25	8,9		1,8			
3	*S. fimbriatus*	Grass	1,8		25	2		1,8			
4	*D. milanjiana*	Grass	6,4		50	7,2		3,6			
5	*Cynodon plectostachyus*	Grass	8,8		50	9,9		3,6			
6	*P.mezianum*	Grass	1,3		25	1,5		1,8			
	Sub-total grasses		**27**								
1	*Sedge*	Sedge	6,2		50	7		3,6			
	Sub-total sedge		**6,2**								
	Bare		11,3								

Appendix V D4: The dominant species Orthic Luvisols foothills, Erankau Village, Mashuru, Kenya (n= 4)

	Species	Life form	Cover	Density	Frequency	Rel cover	Rel density	Rel frequency	Important value index (IVI)	Regeneration	Stems cut
1	*B.aegyptiaca*	Tree	2,9	75	50	3,2	1,6	4,1	8,9	0	
2	*A.tortilis*	Tree	0,8	150	75	0,9	3,2	6,1	10,2	100	
3	*A. mellifera*	Tree	29,3	850	100	32	18,2	8,2	58,4	275	250
4	*L. stuhlmanii*	Tree	3,7	75	25	4	1,6	2	7,6	0	
5	*Commiphora habessinica*	Tree			25			2		25	
6	*Boscia anguisitifolia*	Tree			25			2		50	
7	*Zanthoxylum chalybeum*	Tree			25			2		25	
	Sub-total trees		**36,7**						**85,1**		
1	*T. holstii*	Shrub	0,2	150	25	0,2	3,2	2	5,4	0	
2	*G. bicolor*	Shrub	0,8	50	50	0,9	1,1	4,1	6,1	0	
3	*H.opposita*	Shrub	0,4	25	25	0,4	0,5	2	2,9	0	
4	*A. brevispica*	Shrub	1,9	125	50	2,1	2,7	4,1	8,9	1625	
5	*S. renchii*	Shrub	0,1	125	50	0,1	2,7	4,1	6,9	0	
6	*A. mosambicensis*	Shrub	0,1	75	25	0,1	1,6	2	3,7	0	
7	*G. fallax*	Shrub	0,4	25	25	0,4	0,5	2	2,9	25	
8	*A. africana*	Shrub	0,2	100	25	0,2	2,1	2	4,3	175	
9	*G. latifolia*	Shrub	1,6	50	50	1,7	1,1	4,1	6,9	25	
10	*A. racemosa*	Shrub	1,6	1050	75	1,7	22,5	6,1	30,3	0	
11	*G. tembensis*	Shrub	1,9	100	50	2,1	2,1	4,1	8,3	0	
12	*P. resinosa*	Shrub	6,2	100	25	6,8	2,1	2	10,9	0	
13	*Phylanthus sepialis*	Shrub			25			2		175	
14	*Croton dichogomus*	Shrub			25			2		50	
15	Emame	Shrub			25			2		25	
	Other shrubs within the landscape										
16	*Maytenus putterlickioides*										
17	*Crotolaria goodiformis*										
	Sub-total shrubs		**15,4**						**97,5**		
1	*C. fascicularis*	Climber	2,9	75	25	3,2	1,6	2	6,8	0	
2	*B. zangueberium*	Climber	0,4	25	25	0,4	0,5	2	2,9	0	
3	*Cyphostemma sp*	Climber	0,4	25	25	0,4	0,5	2	2,9	0	
	Other climbers within the landscape										
4	*Entada leptostachya*										
	Sub-total climbers		**3,7**						**12,6**		
1	*S. incanum*	Herb	2,2	1425	50	2,4	30,5	4,1	37	Regenerating	
	Cont. of Appendix V D4										

2	*H.pycnostemon*	Herb	0,1		25	0,1		2			
3	*Justacia flava*	Herb	3,25		50	3,5		4,1		Regenerating	
4	*B. pilosa*	Herb	0,75		25	0,8		2		Regenerating	
	Sub-total herbs		**6,3**					**12,2**			
1	*P. maximum*	Grass	1,6		25	1,7		2			
2	*E. macrostachyus*	Grass	10,5		50	11,5		4,1			
3	*E. superba*	Grass	8,75		25	9,5		2			
4	*D. milanjiana*	Grass	8,75		25	9,5		2			
	Sub-total grasses		**29,6**								
	Bare		8,3								

Appendix V D4: The dominant species on Orthic Luvisols lower plains, Erankau Village, Mashuru, Kenya (n= 4)

	Species	Life form	Cover	Density	Frequency	Rel cover	Rel density	Rel frequency	Important value index (IVI)	Regeneration	Stems cut
1	*A. drepanalobium*	Tree	23,5	850	75	26,4	14,5	6	46,9	150	
2	*A.anthelmentica*	Tree	5,2	100	25	5,8	1,7	2	9,5	0	
3	*B. aegyptiaca*	Tree	6,4	125	50	7,2	2,1	4	13,3	25	25
4	*A. mellifera*	Tree	2,3	50	75	2,6	0,9	6	9,5	550	
5	*B.glabra*	Tree	2,8	350	25	3,2	6	2	11,2	250	25
6	*C. schimperi*	Tree	1,1	50	25	1,2	0,4	2	3,6	50	75
	Other trees within the landscape										
7	*Boscia anguisitifolia*										
	Sub-total trees		**41,3**						**94**		
1	*P. urens*	Shrub	1,4	125	50	1,6	2,1	4	7,7	Regenerating	
2	*A. brevispica*	Shrub	1,8	25	25	2	0,4	2	4,4	0	
3	*G. fallax*	Shrub	1,7	25	25	1,9	0,4	2	4,3	0	
4	*G. tembensis*	Shrub	1,1	50	75	1,2	0,9	6	8,1	75	
5	*P. resinosa*	Shrub	0,6	50	50	0,7	0,4	4	5,1	75	
6	*Zizyphus mucronata*	Shrub	0,6	50	25	0,7	0,4	2	3,1	0	25
7	*Hermania exapendiculata*	Shrub	0,2	275	25	0,2	4,7	2	6,9	0	
8	*Rumex usambarensis*	Shrub	0,6	25	25	0,7	0,4	2	3,1	0	
9	*A. africana*	Shrub	0,6	25	50	0,7	0,4	4	5,1	25	
10	*C. ovalis*	Shrub	7	75	50	7,9	6	4	17,9	50	
11	*Phyllanthus sepialis*	Shrub	7	800	50	7,9	1,3	4	13,2	100	
12	*A. racemosa*	Shrub	7,9	900	25	8,9	15,3	2	26,2	0	
13	*A. mosambicensis*	Shrub	0,4	175	50	0,4	3	4	7,4	0	
14	*C. goodiformis*	Shrub	0,2	25	25	0,2	0,4	2	2,6	175	
15	*G. bicolor*	Shrub								75	25
	Other shrubs within the landscape										
16	*Rhus natalensis*										
17	*Solanum renschii*										25
	Sub-total shrubs		**31,1**						**115,1**		
1	*Cyphostemma* sp	Climber			25			2	2		
	Sub-total climbers								**2**		
1	*O. kilimandscharicum*	Herb	0,7	75	50	0,8	1,3	4	6,1	Regenerating	
2	*S. incanum*	Herb	3,8	1725	50	4,3	29,4	4	37,7	Regenerating	
3	*H. pycnostemon*	Herb	1,1		50	1,2		4		Regenerating	

	Cont. of Appendix V D4										
4	*Justacia flava*	Herb	4,2		75	4,7		6		Regenerating	
	Sub-total herbs		**9,8**								
1	*E. macrostachyus*	Grass	4,6		75	5,2		6			
2	*D. milanjiana*	Grass	0,4		50	0,4		4			
	Sub-total grasses		**5**								
1	*Sedge*	Sedge	1,7		50	1,9		4			
2	*Kyllinga erecta*	Kyllinga	0,1		25	0,1		2			
	Sub-total sedge/kyllinga		**1,8**								
	Bare		11								

Appendix V D5: The dominant species on Cambisols hill, Erankau Village, Mashuru, Kenya (n= 3)

	Species	Life form	Cover	Density	Frequency	Rel cover	Rel density	Rel frequency	Important value index (IVI)	Regeneration	Stems cut
1	*Sclerocarya birrea*	Tree	2,8	33	33	3,2	1,1	3	7,3	67	
2	*Erythrina abyssinica*	Tree	6,4	167	67	7,4	5,6	6,1	19,1	133	
3	*A.cacia nilotica*	Tree	1,7	67	33	2	2,2	3	7,2	67	
4	*C.apiculatum*	Tree	0,9	67	33	1	2,2	3	6,2	0	
5	*O. kirkii*	Tree								167	
6	*A. tortilis*	Tree								33	
	Other trees within the landscape										
7	*Lannea stuhlmanii*										
8	*Balanites aegyptiaca*										
	Sub-total trees		**11,8**						**39,8**		
1	*O. americanum*	Shrub	2,1	800	33	2,4	26,7	3	32,1	0	
2	*Rhamnus staddo*	Shrub	1,7	67	33	2	2,2	3	7,2	0	67
3	*A.mosambicensis*	Shrub	0,2	67	33	0,2	2,2	3	5,4	100	
4	*Carissa edulis*	Shrub	8,7	333	33	10	11,1	3	24,1	0	
5	*Maytenus putterlikoides*	Shrub	1,7	67	33	2	2,2	3	7,2	0	
6	*A. africana*	Shrub								400	
7	*Clerodendrum mycricoides*	Shrub	1,7	133	33	2	4,4	3	9,4	0	
8	*L. trifolia*	Shrub	0,3	67	67	0,4	2,2	6,1	8,7	0	
9	*Rhus natalensis*	Shrub	1,7	67	67	2	2,2	6,1	10,3	500	
10	*C. oblongifolia*	Shrub								267	
11	*P. resinosa*	Shrub								100	
12	*Hermannia exappendiculata*	Shrub								67	
	Other shrubs within the landscape										
13	*Osyris lanceolata*										
14	*Euclea divinorum*										
15	*Dichrostachys cinerea*										
	Sub-total shrubs		**18,1**						**104,4**		
1	*B. zangueberium*		2,6	100	33	3	3,3	3	9,3	0	
2	*Rubus pinnatus*									33	
	Sub-total climbers		**2,6**						**9,3**		
1	*O. kilimandscharicum*		2,2	833	67	2,5	27,8	6,1	36,4	Regenerating	
2	*H. aponerus*		0,4	133	33	0,5	4,4	3	7,9	Regenerating	
3	Ithilunzu		5		33	5,2		3			
	Cont. of Appendix V D5										
4	*Cyphia glandulifera*		r		100	r		9,1			

	Sub-total herbs		**7,6**							
1	*S.fimbriatus*		25		67	28,8		6,1		
2	*Themeda triandra*		13,33		100	15,4		9,1		
3	*D. milanjiana*		30		67	34,6		6,1		
4	*C. aucheri*		10		100	11,5		9,1		
	Sub-total grasses		**78,33**							
	Bare		13,3							

Appendix V D6: The dominant species on Cambisols plains, Erankau Village, Mashuru, Kenya (n= 2)

	Species	Life from	Cover	Density	Frequency	Rel cover	Rel density	Rel frequency	Important value index (IVI)	Regeneration	Stems cut
1	*S. birrea*	Tree	1	150	50	1,1	2,3	3,2	6,6	0	
2	*L. stuhlmanii*	Tree	0,7	100	100	0,8	1,5	6,5	8,8	50	
3	*B.aegyptiaca*	Tree	0,5	100	100	0,5	1,5	6,5	8,5	50	150
4	*A.tortilis*	Tree	0,1	50	50	0,1	0,8	3,2	4,1	50	
5	*C. schimperi*	Tree			50			3,2		150	
6	*A. nilotica*	Tree			50			3,2		50	
7	*L.triphylla*	Tree	0,1	50	50	0,1	0,8	3,2	4,1	0	
	Other tree speies within the landscape										
8	*Terminalia brownii*		9	*Azanza garckeana*							
	Sub-total trees		**2,4**						**32,1**		
1	*O.americanum*	Shrub	r	50	50	r	0,8	3,2	4	0	
2	*A. mosambicensis*	Shrub	r	50	50	r	0,8	3,2	4	0	
3	*R.natalensis*	Shrub			50			3,2		50	
4	*G. villosa*	Shrub			50			3,2		50	
5	*A. africana*	Shrub	0,1	50	50	0,1	0,8	3,2	4,1	0	
6	*P.resinoa*	Shrub			50			3,2		50	
7	*L. trifolia*	Shrub			50			3,2		150	
8	*Naigong undenyo*	Shrub			50			3,2		2500	
	Sub-total shrubs		**0,1**						**12,1**		
1	*S. incanum*	Herb	6,8	850	50	7,4	13,2	3,2	23,8	Regenerating	
2	*O. kilimandscharicum*	Herb	19,7	2500	50	21,3	38,8	3,2	63,3	Regenerating	
3	*I. spinosa*	Herb	0,5	2500	50	0,5	38,8	3,2	42,5	Regenerating	
4	*Commelina sp*	Herb	r		50			3,2			
	Sub-total herbs		**27**						**129,6**		
1	*T. triandra*	Grass	5		50	5,4		3,2			
2	*D.milanjiana*	Grass	20		100	21,6		6,5			
3	*Chloris roxburghiana*	Grass	10		100	10,8		6,5			
4	*P.mezianum*	Grass	25		100	27		6,5			
5	*S.fimbriatus*	Grass	3		100	3,2		6,5			
	Sub-total grasses		**63**								
1	*Kyllinga erecta*	Kyllinga	r		50			3,2			
	Sub-total Kyllinga										
	Bare		7,5								

Appendix V D6: The dominant species on Vertisols lowlands, Erankau Village, Mashuru, Kenya (n= 2)

	Species	Life form	Cover	Density	Frequency	Rel cover	Rel density	Rel frequency	Important value index (IVI)	Regeneration	Stems cut
1	*A. seyal*	Tree	13	117	100	16,8	8,6	9,1	34,5	250	
2	*B. aegyptiaca*	Tree	1	50	50	1,3	3,7	4,5	9,5	0	
3	*A. mellifera*	Tree	1	50	50	1,3	3,7	4,5	9,5	0	
	Sub-total trees		**15**						**53,5**		
1	*A. paolii*	Shrub	5,3	150	50	6,8	11	4,5	22,3	0	
2	*A. mossambicensis*	Shrub	0,9	450	100	1,2	32,9	9,1	43,2	0	
3	*G. bicolor*	Shrub	1	50	50	1,3	3,7	4,6	9,6	0	
4	*C.ovalis*	Shrub	1		50	1,3		4,5	5,8	50	
5	*T. flavescens*	Shrub	r		50	r		4,5	4,5	Regenerating	
6	*A. racemosa*	Shrub	r		50	r		4,5	4,5	300	
	Sub-total shrubs		**8,2**						**89,9**		
1	*O. kilimandscharicum*	Herb	1	150	50	1,3	11	4,5	16,8	Regenerating	
2	*H. pycnostemon*	Herb	r		50	r		4,5	4,5	Regenerating	
3	*Bleripheris sp*	Herb	0,7	350	50	0,9	25,6	4,5	31	0	
4	*S. incanum*	Herb			50			4,5		Regenerating	
	Sub-total herbs		**1,7**								
1	*P. mezianum*	Grass	30		100	38,7		9,1			
2	*S. helvolus*	Grass	10		50	12,9		4,5			
3	*D. milanjiana*	Grass	5		50	6,5		4,5			
	Sub-total grasses		**45**					**18,1**			
1	*Sedge*	Sedge	7,5		50	9,7		4,5			
	Sub-total sedge		**7,5**					**4,5**			
	Bare		22,5								

ıx V D8: The dominant species on Gleyic Luvisols lowlands, Erankau Village, Mashuru, Kenya (n= 1)

	Species	Life form	Cover	Density	Frequency	Rel cover	Rel density	Rel frequency	Important value index (IVI)	Regeneration	Stems cut
1	*A. mellifera*	Tree	23,7	500		31,24	3,1		34,34	100	1000
2	*B. glabra*	Tree	1,9	100		2,48	0,6		3,08	600	100
	Other trees scattered within the landscape										
3	*Acacia drepanolobium*										
	Sub-total trees		**25,6**						**37,42**		
1	*A. mossambicensis*	Shrub	1,9	1000		2,48	6,2		8,7		
2	*A.africana*	Shrub	1,9	1000		2,48	6,2		8,7		
3	*C.quercifolia*	Shrub	1,9	100		2,48	0,6		3,1		300
4	*G.tembensis*	Shrub	0,2	100		0,25	0,6		0,9		
5	*T. flavescens*	Shrub	3,4	1800		4,46	11,2		15,7	Regenerating	
6	*Euphorbia sp*	Shrub	r	100		r	0,6		0,6		
7	*Aloe sp*	Aloe	0,4	200		0,49	1,2		1,7		
	Other shrubs scattered within the landscape										
8	*Acacia paolii*										
	Sub-total shrubs		**9,7**						**39,4**		
1	Orkalay	Climber	3	1600		3,97	37,3		41,27	Sprouting	
	Sub-total climbers		**3**						**41,7**		
1	*H. pycnostemon*	Herb	0,2	100		0,25	0,6		0,9	Regenerating	
2	*A.mauritianum*	Herb	0,9	500		1,24	3,1		4,3	Regenerating	
3	*Bleripheris sp*	Herb	15	6000		8,89	9,9		18,8	Regenerating	
4	*S. incanum*	Herb	5,6	3000		7,44	18,6		26		
	Sub-total herbs		**21,7**						**50**		
1	*D.milanjiana*	Grass	5			2,96					
2	*P.mezianum*	Grass	10			5,93					
3	*Chloris roxburghiana*	Grass	r			r					
	Sub-total grasses		**15**								
1	Sedge	Sedge	5			2,96					
	Sub-total sedge		**5**								
	Bare		20								

Appendix VI A: Intervention options to solve chronic water shortages and contaminated water sources in Eastern Kajiado and Southern Makuen, Kenya

Contraints	Strategies to address constraint	Intervention options	Description	Requirements of the options	Effectiveness of the options	Cultural acceptability	Suitability to the landscape types	Impacts of the options	
								Positive	Negative
Chronic water shortages & contaminated water sources + excessive to severe soil erosion	Increase water quantity, improve water use efficiency and conserve soil moisture	Water spreading	Channel runoff from hill sides, open grounds, roads into farms	Time, labour and tools for digging	Improves crop and pasture production	No cultural resistance reported	Vertisols Chernozems Luvisols Ferralsols	Improve crop and pasture production	Flood can destroy soil conservation structures
		Micro-catchments	Building of lunar, circular, V or W shaped catchments basin around a plant to direct rain water	Time, labour and tools for digging (10 persons days/ha). Cost estimate: $ 150/ha	Improves tree establishment on degraded sites in arid areas, increases pasture production	Widely accepted in Kenya, Niger	In all the agro-ecological landscapes of the study area	Improves grass and tree production	Vulnerable to breakages due to run off and livestock trampling
		Pit planting	Planting pits constructed in farmlands to improve captured runoff. Manure too applied into pits to improve fertility.	Time, labour for digging and filling (30-70 person days for digging & 20 person days/ha). Tools, manure. Cost estimate: $ 8/ha	100% increase in yield (0.7-1 tons/ha for sorghum)	Accepted where practiced (Burkina, mali) and few farmers in Kibwezi (study area)	Vertisols Chernozems Luvisols Ferralsols	Improves soil fertility and moisture, ground water recharge, crop yields	Demand for maintaining the hole, subject to water logging in very wet years, encourages breeding of mosquitoes
		Trashlines	Placement of crop residues and weeds along contours to form run-off barrier strips	Time, labour and materials (residues)	Returns of up to 300-500% reported in Embu, Meru areas of Kenya	Widely accepted in Kenya	In all the agroecological landscapes of the study area	Improves soil fertility and moisture, crop yields	Have to be frequently replaced Can harbours pests and diseases Eaten by livestock and termites
		Fanya juu terrace	Terraces constructed by throwing soil up slope from a ditch to form a bund along a contour	Time, labour for digging the terrace plus accompanied cut off drain (150-300 person days/ha), tools. Regular up keep cost: $ 60-460 per ha	Increased crop yields (40% or 400 kg/ha in Machakos)	No cultural resistance reported	Chernozems Luvisols Ferralsols Regosols and Cambisols	Effective control of soil erosion, improved soil fertility. Reliability of crop production increased. If a whole catchment is terraced it can increases river water flow	If terraces bunds are protected the structure is susceptible to erosion

Cont ; of Appendix VI A									
Constraints	**Strategies to address constraint**	**Intervention options**	**Description**	**Requirements of the options**	**Effectiveness of the options**	**Cultural acceptability**	**Suitability to the landscape types**	**Impacts of the options**	
								Positive	Negative
Chronic water shortages & contaminated water sources + excessive to severe soil erosion	Increase water quantity, improve water use efficiency and conserve soil moisture	Tied Contour ridges and furrows	Construction of ridges and furrow along the contours followed by creation of depressions within the furrows	Time, labour for digging plus tools	Conserves soil moisture and enhances crop yields	Contour ridges using oxen are widely practiced in the study area	Luvisols Ferralsols Vertisols Chernozems	Improve soil moisture, soil drainage and crop yields Reduces soil erosion	Water logging can become a problem
		Contour stone bunding & grass strips	Laying of stone bund(s) along contour	Time, labour, tools and money for collection, transport and laying	Increased crop yields by 40%. Former barren fields in Burkina Faso and Mali yielding up to 1200 kg/ha	Accepted Burkina Faso and Mali	Cambisols hills/plains and Regosols hills where stones are available	Rehabilitation of degraded lands and reduces soil erosion, increases Crop yields	Causes shortage of stones
		Stone/rock mulching + Microcatchment	The use of stones as a mulch around planted trees and shrubs to conserve moisture harvested in the microcatchment	Time, labour for digging microcatchments + collection and arrangement of the stones	Conserves moisture by reducing evaporation and wind impact, increases species survival (80%)	No known cultural barrier	All the landscape types where stones and rocks can be available	Increased soil moisture and species growth	Can causes shortage of stones
		Intensification of runoff water harvesting	Harvesting runoff from concentrated flows and storing it in farm ponds and dams of 150 to 300 m^3 capacities	Time, tools, money, labour and expertise for digging and maintaining the sources	Increased availability of water for domestic, livestock and in few instances for irrigation	Accepted throughout Kenya	Luvisols and Ferralsols	Improves availability of water for dual purposes, help conserve energy (getting water from far sources to be put to farm production) The fresh water can be used for irrigation	For human consumption requires further treatments for possible biological, physical and chemical contamination. Encourages the breeding of water borne diseases such as mosquitoes

Cont ; of Appendix VI A									
Constraints	**Strategies to address constraint**	**Intervention options**	**Description**	**Requirements of the options**	**Effectiveness of the options**	**Cultural acceptability**	**Suitability to the landscape types**	**Impacts of the options**	
								Positive	Negative
Chronic water shortages & contaminated water sources		Promotion of drought tolerant crops, shrubs, grasses and trees	Planting of high yield/fast growing drought tolerant plants in all increases farm productivity	Germplasm and technical advice	Very effective in land reclamation and increased farm products	Local communities can have low perception on some species but can be overcome through sensitization	All landscape types	More wood/non wood products, pasture/fodder, food and biodiversity conservation	Some species are slow growing, germplasm not easily available
		Roof and rock catchments	Harvesting of water from bare rock inselbergs/roof into tanks. Catchment area has to be regularly maintained and avoid harvesting "first rain" flash	Finance, skilled labour to construct tanks. $ 852per 20 m³ ferro-cement storage to $ 1016 for storage constructed by masonry	Used widely in Kenya (roof catchment) and provides less contaminated water for domestic, livestock & irrigation	None reported	All landscape types though more appropriate in Erankau and Bondeni – with higher rainfall	Provision of more water at household level saving energy and time for fetching water	Difficult to control water quality, high per capita cost of investment, tanks can be breeding sites for mosquitoes
	Improve the quality of water	Conservation and protection of water sources and catchments	Delineation and conservation of local water catchments and protection of water sources/vulnerable species and planting of species that decrease bilharzias incidences e.g *Balanites* spp along water courses and in woodlands/pastures	Goodwill by all stakeholders, identification of fragile sites and potential sources of contamination and appropriate conservation (e.g protection of springs, covering of wells), mobilization of communities, experts and donors	Effective in catchment and biodiversity conservation while providing quantity and quality water sources	Acceptable once they accruing benefits become tangible	Cambisols and Regosols hills and isolated pockets in the other landscapes	More quality water, wood products, pasture/fodder, food and biodiversity conservation	Sacrificing the land to be put to water catchment and biodiversity conservation will not be easy for the owners
		Use of natural plants to treat water	Planting and promotion of plants that help improve water (seeds of *Moringa oliefera* and roots of *Maerua decumbens*)	Germplasm, expertise Land to plant the species	*Moringa* is known to eliminate 99% of bacteria found in water. The plants leaves and pods are vegetables too	Moringa and Maerua grow in Kibwezi and Mashuru.	The species can grow on Luvisols and Ferralsols plains	Decreases incidence of water borne diseases Improves health of the communities Biodiversity conservation	Extraction of the necessary chemical detergents require training

Appendix VI B: Intervention options to solve food and wood insecurity in Eastern Kajiado and Southern Makuen, Kenya

Constraints	Strategies to address constraint	Intervention options	Description	Requirements of the options	Effectiveness of the options	Cultural acceptability	Suitability to the landscape types	Impacts of the options	
								Positive	Negative
Food and wood insecurity and environmental degradation		Promotion of drought tolerant crops, shrubs, grasses and trees	Planting of high yield/fast growing drought tolerant plants in all increases farm productivity	Germplasm and technical advice	Very effective in land reclamation and increased farm products	Local communities can have low perception on some species but can be overcome through sensitization	All landscape types	More wood/non wood products, pasture/fodder, food and biodiversity conservation	Some species are slow growing, germplasm not easily available
		Roof and rock catchments	Harvesting of water from bare rock inselbergs/roof into tanks. Catchment area has to be regularly maintained and avoid harvesting "first rain" flash	Finance, skilled labour to construct tanks. $ 852per 20 m³ ferro-cement storage to $ 1016 for storage constructed by masonary	Used widely in Kenya (roof catchment) and provides less contaminated water for domestic, livestock & irrigation	None reported	All landscape types though more appropriate in Erankau and Bondeni – with higher rainfall	Provision of more water at household level saving energy and time for fetching water	Difficult to control water quality, high per capita cost of investment, tanks can be breeding sites for mosquitoes
	Improve the quality of water	Conservation and protection of water sources and catchments	Delineation and conservation of local water catchments and protection of water sources/vulnerable species and planting of species that decrease bilharzias incidences e.g *Balanites* spp along water courses and in woodlands/pastures	Goodwill by all stakeholders, identification of fragile sites and potential sources of contamination and appropriate conservation (e.g protection of springs, covering of wells), mobilization of communities, experts and donors	Effective in catchment and biodiversity conservation while providing quantity and quality water sources	Acceptable once they accruing benefits become tangible	Cambisols and Regosols hills and isolated pockets in the other landscapes	More quality water, wood products, pasture/fodder, food and biodiversity conservation	Sacrificing the land to be put to water catchment and biodiversity conservation will not be easy for the owners
		Use of natural plants to treat water	Planting and promotion of plants that help improve water (seeds of *Moringa oliefera* and roots of *Maerua decumbens*)	Germplasm, expertise Land to plant the species	*Moringa* is known to eliminate 99% of bacteria found in water. The plants leaves and pods are vegetables too	Moringa and Maerua grow in Kibwezi and Mashuru.	The species can grow on Luvisols and Ferralsols plains	Decreases incidence of water borne diseases Improves health of the communities Biodiversity conservation	Extraction of the necessary chemical detergents require training

Appendix VI B: Intervention options to solve food and wood insecurity in Eastern Kajiado and Southern Makuen, Kenya

Cont ; of Appendix VI B									
Constraints	**Strategies to address constraint**	**Intervention options**	**Description**	**Requirements of the options**	**Effectiveness of the options**	**Cultural acceptability**	**Suitability to the landscape types**	**Impacts of the options**	
								Positive	**Negative**
Food and wood insecurity and environmental degradation	Improve dryland farming	Improved mixed cropping practices and yields of traditional crops	Study existing practices, enrich and enhance yields of the species, arrangements and management for better income, soil cover and production. Value addition to the product is necesary	Indigenous knowledge and expertise, germplasm, finance	Improved crop production and soil and water conservation	It is an improvement to already popular practice	In all the agroecological landscapes with cropland	Improve crop and soil and water conservation, increase in food security, biodiversity conservation	Yield per crop per ha may be reduced, time is required to understand the practice
		Crop rotation	To improve the low soil fertility communities be enlightened to adopt crop rotation (rotating cereals with legumes)	Good will of the farmers, expertise	Increase productivity by 20-30%	Practiced by few farmers in the study are	In all the agroecological landscapes with cropland	Improvement in soil fertility and crop yields	Not known
		Improved fallows	Planting of nitrogen fixing legumes to improve low fertility status	Expertise, germplasm, finance	Increases soil carbon and total nitrogen and enhanced crop yields	Accepted in western Kenya	In all the agroecological landscapes with low fertility (Luvisols, Ferralsols, Chernozems)	Enhanced soil fertility, soil moisture and crop yields; Provision of fodder and firewood	Not known
		Fruit tree cash crops	Planting/promotion of fruit trees (indigenous and exotic) and value addition to products	Market, expertise, germplasm	Income generation and improves nutrition status	Acceptable	In all the agroecological landscapes with cropland	Increase in household income and heath, soil and water conservation, biodiversity conservation	Competition with crops for water and nutrients, roasting sites for birds that eats the fruits and crops
		Revamp cash crops	Revamping cash crops such as cotton, sisal, sesame, sunflower, castor oil and groundnuts	Market, germplasm, expertise	Generates income	Acceptable provided there is market	Ferralsols and Luvisols for all the crops, cotton, sisal, sesame can also grow in Chernozems and Vertisols with irrigation supplement	Brings in much needed cash	Can exhaust soil (except ground nuts) and requires fertilizers/manure input

Cont. of Appendix VI B									
Constraints	**Strategies to address constraint**	**Intervention options**	**Description**	**Requirements of the options**	**Effectiveness of the options**	**Cultural acceptability**	**Suitability to the landscape types**	**Impacts of the options**	
								Positive	**Negative**
Food and wood insecurity and environmental degradation	Improved management of woodlands, pastures and livestock	Bush management + soil water conservation	Selective cutting of dense stems/unwanted species to open up crown and encourage grass cover establishment. Soil and water structure be laid to increase moisture and reduce erosion	Expertise, tools and labour	Increases grass cover	No known cultural hindrance	In landscapes with bush thickets (Ferralsols, Luvisols, Regosols, Vertisols)	More milk and meat as a result of more grass. Cut materials used as fence, building materials and fuelwood	Demands labour in the initial stage
		Reseeding with high value grasses	Once bush managed/soil conserved high value grass species adapted to the area be planted	Germplasm, expertise, tools and labour, insecticides	Increases grass productivity	Acceptable	In landscapes with bush thickets (with specific species to the different landscapes see Table)	More milk, income and meat as a result of more grass, soil and water plus biodiversity conservation.	Some grasses can become crop weeds
		Establishment of multipurpose fodder banks	To increase crude protein content of forage in dry seasons the establishment of indigenous and exotic trees and shrubs is necessary as feedlot (sole crop) or mixed with high value grasses	Germplasm, expertise, tools and labour, training	Increase in livestock production and soil and water conservation	Acceptable	In all landscapes especially in croplands and "olopololi"	More livestock production, income and improves soil, water and biodiversity conservation	Excess intake of some fodder species can have adverse impact on livestock (e.g mimosine with Leucaena, Gliricida poisonous to donkey and horses)
		Improvement of livestock breeds and honey production	The improvement of fodder/forage availability has to simultaneously go with livestock improvement (keeping few dual purpose animals e.g Galla breed, Boran cattle, langstroth beehives/hut apiary, semi-zero grazing, silk worm production)	Expertise, germplasm	Increase in livestock productivity	No known cultural hindrance	In all villages	More milk and meat, income, more animal manure to be ploughed back into the pastures and croplands, no over grazing and therefore better soil and water conservation	More inputs and intensive management

Cont. of Appendix VI B									
Constraints	**Strategies to address constraint**	**Intervention options**	**Description**	**Requirements of the options**	**Effectiveness of the options**	**Cultural acceptability**	**Suitability to the landscape types**	**Impacts of the options**	
								Positive	**Negative**
Food and wood insecurity and environmental degradation	Improved management of woodlands, pastures and livestock	Establishment of multipurpose woodlots	To increase wood and nonwood products the establishment of indigenous and exotic trees in pure woodlot stands or as wind breaks/shelter belts	Germplasm, expertise, tools and labour, training	Increase in wood production and soil and water conservation	Acceptable	In all landscapes both in croplands and pastures	Extra wood and livestock production, income and improves soil, water and biodiversity conservation	Some trees can have allelopathic (suppression) effect on crops and pastures
	Improved dryland farming, management of woodlands, pastures and livestock	Compensation of damages by wild animals to crop and livestock	Wild animals (especially elephant) destroy crops of the poverty stricken farmers and the re-introduction of compensation by the Kenya Wildlife Services is necessary to reduce human wildlife conflict	Review of Government policy	Will motivate demoralized farmers and the compensation will enhance towards wildlife conservation	Farmers welcome such policy	In all the agroecological landscapes	Increase in household income and wildlife conservation enhanced	Costly for the Goverment
		Integrated pest management (for crops, trees/shrubs, grasses, livestock)	The destruction by wild animals, pests and diseases on farm and in stores is enormous and a cheap and available technologies at farm level is required. The development of improved varieties resistant to pests and diseases plus the improvement to cropping, woodlands, pastures and livestock practices are required.	Indigenous knowledge, expertise, inputs	Less pests and diseases means more food at household level	Acceptable	In all the agroecological landscapes	Food security improved plus income	Takes long time before appropriate technology is identified, can be costly
		Creation/strengthen market catchments and improve market intelligence	Creation/strengthen existing major centres and empower farmers with market knowledge	Review of Government policy, expertise, training and exposures to farmers	Have worked well in Machakos/ Nairobi are, West Africa	Acceptable to farmers	Along Nairobi-Mombasa road (10-30 km from the study villages)	More income, improved farm productivity and livelihoods	Enlarged centres will demand more resources and can negatively impact on the environment unless well planned

Cont. of Appendix VI B									
Constraints	**Strategies to address constraint**	**Intervention options**	**Description**	**Requirements of the options**	**Effectiveness of the options**	**Cultural acceptability**	**Suitability to the landscape types**	**Impacts of the options**	
								Positive	**Negative**
Food and wood insecurity and environmental degradation		Merger of research and extension	Merger of all natural resource based sectors (research and extension + public health) to form an integrated resource management unit with one head at division and a resource manager at locational level	Review of Government policy and expertise	Reduces duplications of activities, consolidates resource management efforts	May not be acceptable to many sectors	Suitable to farmers	Creates team spirit and united efforts to implement activities, imitation of farmers situation, cuts on costs and close to the farmer	Training costs on INRM, staff overloaded with many disciplines
		Participatory wildlife management and promotion of ecotourism	Increased community participation in wildlife management is required. The communities should see wild animals as theirs and not "government cattle" through ecotourism and support community development projects	Goodwill and full participation of Kenya Wildlife Services in all research and extension activities in INRM, training and mobilization, expertise	Increased income and wildlife conservation	Acceptable	In all the villages	Additional income and better attitude to wildlife resources	More resources required

Source: UNEP (1998) and own experience

Appendix VII: The performances and management of the identified high value candidate grasses for Eastern Kajiado and Southern Makueni, Kenya

Species	Suitability to the landscapes	Yields (dry matter)	Advantages	Ecological needs	Management
Eragrostis superba	Regosols, Luvisols, Ferralsols, Chernozems	24000 kg/ha (Australia) 114.3 kg (Himachal Pradesh, India) 3104 kg/ha (wet biomass – Gujurat, India)	Very palatable, good hay, high reseeding capacity, controls soil erosion, fast growing, recovers easily from intensive grazing, drought tolerant and germinates well	Gets stemmy and unpalatable near maturity with a drop in its nutritive value. Problems of seed harvesting ants	Avoid overgrazing, ploughing land prior to planting increases germination, sow enough seeds for good germination
Cenchrus ciliaris	Regosols, Luvisols, Ferralsols, Chernozems, Vertisols	4.8 t/ha (Australia) 18800 kg/ha (Ghana) 2010 kg/ha (India). All no fertilizer	Tolerant to drought, fire, seed with good vigour, with stands constant grazing, good quality hay when cut in early flowering age, seed viable for 2-3 years, deep rooting, free seeding habit, compete well with weeds, soil conservation	Slow to establish on Vertisols, seed easily carried by wind and liked by seed harvesting ants, attacked by cut worms and caterpillars, becomes stemmy with age, bid head disease to horses due to oxalate content, not tolerant to floods, suppresses legume mixtures	For good germination moisten seed for 5 days, ploughing increases germination, manure increases productivity
Themeda triandra	Cambisols, Regosols and chernozems		Moderately tolerant to drought, recovers after fire, good palatability when young	Not tolerant to overgrazing, hay with insufficient crude protein, susceptible to fire, palatability decreases with maturity, not tolerant to flooding, low production of seeds, germinates well after 12 months of sowing	Frequent cutting shortens its life span. Stocking rate should not exceed 1 head/ha
Digitaria milanjiana	Regosols, Luvisols, Ferralsols, Cambisols	Fresh grass with crude protein of 8.1% DM (Kenya) and in hay 12.5% DM (Malawi) Yield: 6328 kg DM/ha (Fiji)	Fairly high yielding, suitable for hay and silage, recovers very fast after extreme drought, remains green throughout the year, extremely palatable, combines well with legumes, excellent drought tolerant	Susceptible to overgrazing and therefore common undisturbed sites, poor seed producer	
Cynodon plectostachyus	Regosols, Luvisols, Ferralsols, Cambisols, Veritsols	1300 kg DM/ha (Australia)	Very good drought tolerant, good in soil conservation, excellent to with stand grazing, excellent ability to cope with weeds, extremely palatable, tolerates temporary flooding	Prefers high fertility soils (that is why it is common near animal boma), crop weed on cultivated lands, suppresses legumes, presence of cyanogens and low iodine can cause Thyroid disfunction in sheep	Full land preparation is required, establishes from seed and splits. Seeds/ha: 6.5 kg, treat seeds with insecticide
Entrepogon macrostachyus	Regosols, Luvisols, Ferralsols		Good tolerant to drought, palatable, germinates readily and grows vigorously, good seeder, excellent grass for reseeding Kenyan range lands, tolerates shade		Sown in wet season at 7 kg/ha, lends easily to mechanical harvesting
Chrysopogon aucheri	Regosols, Cambisols, Ferralsols Luvisols		Excellent tolerance o drought, leafy grass highly palatable and nutritious	Poor seeder because it shades ripe spikelets	Planting seeds/ha: 2.5 kg

Cont. of Appendix VII					
Species	**Suitability to the landscapes**	**Yields (dry matter)**	**Advantages**	**Constraints**	**Management**
Panicum maximum	Regosols, Luvisols, Ferralsols	Cv Makueni: 60000 kg DM/ha (Australia)	Fairly tolerant to shading, competes with weeds, very palatable, very compatible with legumes, erosion control, tolerant to fire, good hay and silage, quick growth, ease of establishment, establishes from seed and clumps, good seedling vigour, with stands defoliation	Does not tolerate drought, poor production on infertile soils, seeds liked by birds and ripen unevenly, with 0.28% oxalic acid in DM but not toxic, not tolerant to floods, bunts affect seeds, leafy spot, fusarium and smut on inflorescence	Ploughing needed, sowing depth not > 1.5 cm, germinates well with straw mulch, Rotational grazing needed
Chloris roxburghiana	Regosols, Luvisols, Ferralsols	16% crude protein at early flowering stage	Drought tolerant, v. palatable, seeds well, reseeds well on degraded sites,	Severely affected by fire, seeds harvested by ants, blown by wind and susceptible to overgrazing	100-200g/ha. Free seeds from spikelets before sowing and treat with insecticides
Chloris gayana	Regosols, Luvisols, Ferralsols, Cambisols plains	5800 kg DM/ha (Zambia)	Digestibility 40-60% of the DM, good drought tolerant as it can extract water from a depth of 4.25 m, spreads by stolen excellently, abundant seeder, compatible with maize and provide fodder after harvest of maize, excellent vigour- ready for grazing after 6 months, with stands defoliation, does well with legumes, competes well with weeds, tolerates seasonal water logging, excellent to salinity tolerance, restores soil structures and organic matter content and controls soil erosion. Recovers well after fire	Feeding value low at flowering stage, old pastures with poor hay, liked by seed harvesting ants, susceptible to Helminthosporium and smut while thrips attack seeds	Makes good hay just as it begins to flower
Andropogon gayanus	Regosols, Luvisols, Ferralsols	3800 kg/ha (Nigeria)	Excellent to drought tolerance due to deep rooting, tolerant to fire, good vigour, excellent growth, excellent seeder, high palatability, suppresses weeds, combines well with legumes, good fertility builder under crop rotation , stems used for weaving grass mats and for thatching, good for reclamation of degrade lands	Cannot withstand heavy grazing until it is well established, looses nutritive value with age and becomes course, low in nutrient as hay	Spreads slowly by seed, sow at onset of rains (5 kg/ha or 35-70 kg/ha for un cleaned), cutting interval 6 weeks, use while juvenile, germination improves for a time with storage
Sporobolus helvolus	Vertisols and gleyic Luvisols Chernozems		Excellent tolerance to drought and salinity, very palatable in all seasons, tolerates flooding	Not good seeder. If seeds could be found it is the most useful grass for ASALs	

Source: : FAOSTAT 2004, Stricland (1973), Humphreys (1967), Toledo et. al. 1990, Buldgen *et. al* (1995), Herrington *et. al.* (1971)