

AN EVALUATION OF EFFICIENT USE OF AGRICULTURAL WATERSHED
RESOURCES UNDER FLUCTUATING RAINFALL REGIMES AT MUOONI DAM
SITE, MACHAKOS DISTRICT, KENYA

CUSH NGONZO LUWESI (B. ECON, MBA.FIN.)
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DEPARTMENT OF GEOGRAPHY

A thesis submitted in partial fulfilment of the requirements for the award of the degree of
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Applied Sciences of Kenyatta University

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DECLARATION

This thesis is my original work and has not been presented for a degree or any other award in any other university.

Signature.....Date

Cush Ngonzo Luwesi
Candidate

We confirm that the work reported in this thesis was carried out by the candidate under our supervision

Signature.....Date

Prof Chris A. Shisanya
Associate Professor
Department of Geography
Kenyatta University

Signature.....Date

Dr Joy A. Obando
Senior Lecturer
Department of Geography
Kenyatta University

DEDICATION

To my beloved Jarib, Jeddidah, Jeriah and Jemmimah Ngonzo, Blanche Wetshi, Madeleine Paka, Jacques Ngonzo Gaston Mbu and Jonas Mayala, I dedicate this thesis.

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ABSTRACT

The study objectives were to: (i) assess socio-economic and environmental externalities affecting efficient use of water and land resources in farming activities at Muooni dam site; (ii) determine the extent to which land use activities affect the active water storage capacity of Muooni dam; (iii) simulate the variations of farmers' water demand and related operational costs resulting from rainfall fluctuation in Muooni catchment; (iv) and estimate the farmers' water economic order quantity and limit average cost related to their production efficiency under fluctuating rainfall regimes. To achieve these goals, the following empirical tools were used: an on-farm field survey (involving 66 farmers) and off-farm in-depth interviews (of 60 key informants). Numerical tools of data analysis comprised descriptive, non-parametric and time series statistical analyses along with operational research simulations, utilizing SPSS and MS EXCEL spreadsheets and DOVIEW logic models. The study reveals that land-use activities assessed at Muooni dam site do not have a significant impact on its soil erosion and water over-abstraction (as attested by Mann-Witney U-test and Spearman's rank correlation with 99.8% confidence degree). However, the siltation of the dam reservoir may explain 61% of the total variation of the dam's active water storage capacity decrease (as certified by Spearman's Rho test with 99.5% confidence degree). This is mainly explained by off-site soil erosion impacts (due to external agents like El Niño floods and droughts, heavy winds pressure, footpaths and roadside erosion, sand harvesting and deforestation) and alien trees planting adverse effects on water. Rainfall fluctuation is the main controlling factor of land-use at Muooni dam site. Also, land management is highly correlated with farmers' education and poverty levels. Along with farmlands sub-division, it accelerates the risk of soil erosion and water excess loss in the catchment. These in turn increase water cost (through significant shortage costs) and affect farming yields and incomes. Farmers have therefore adopted multiple cropping of about 9 perennial crops and 6 seasonal species on small farmlands as a strategy for facing poor incomes, especially during unpredictable droughts. Yet, farmers cannot meet their actual crops water requirements. The operational research simulations reveal that LSF, MSF and SSF farmers are ordering respectively 29%, 12% and 4% of their respective actual crops water requirement. An increase of about 175%, 518% and 11,437% of their actual total costs is observed respectively under ANOR, NOR and BNOR scenarios. For efficiency, LSF, MSF and SSF farmers are urged to increase their respective actual water demand by an average of 148%, 142% and 152% to meet their water EOQ. By so doing, they could expect a fall of their operational costs up to 40%, 70% and 98% under the three respective scenarios. The study recommends that they limit their current average costs increase below 100 %, if the viability of their economic activities is to improve. They have also to limit their production under a MES ranging from 68% to 98% of their average costs, especially under NOR and BNOR scenarios, while their water demand variation is limited to 129% and 972% (instead of 518% and 11,437%). The differential rate has to be compensated either by rainfall input or better by hydropolitical strategies, efficient on-farm management techniques and technological innovation. The Government of Kenya was urged to put in place policy intervention measures that back farmers' initiatives within a CMS of the Athi Catchment and a SCMP of Muooni Sub-Catchment.

ACRONYMS AND ABBREVIATIONS

ANOR: Above Normal Rainfall Regime

ASAL: Arid and Semi-Arid Land

BNOR: Below Normal Rainfall Regime

CMS: Catchment Management Strategy

EOQ: Economic Order Quantity

EMCA: Environmental Management and Coordination Act

GIS: Geographic Information System

GoK: Government of Kenya

GPS: Global Positioning System

GSZ: Gradual Silting Zone

ISZ: Immediate Silting Zone

Ksh.: Kenya Shilling Currency

LAC: Limit Average Cost

LSF: Large-Scale Farm

MDGs: Millennium Development Goals

MES: Minimum Efficient Scale

MARCROP: Marginal Cropping Simulation Model

MS EXCEL: Microsoft Office Excel Spreadsheets

MSF: Middle-Scale Farm

NOR: Normal Rainfall Regime

OLS: Ordinary Least Squares

SCMP: Sub-Catchment Management Plan

SPSS: Statistical Package for Social Sciences

SSF: Small-Scale Farm

WOSFOST: Maize Cultivars crop Growth Simulation Model

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CHAPTER ONE

INTRODUCTION

1.1 Background to the Study

The incentive for evaluating efficient use of agricultural watershed resources was driven by recent sensitizations on global changes (Lexén, 2008; Pachauri, 2004; *The Economist*, 2003; IPCC, 2001; Gann, 2001; Brown, 2001; Eriksen, 1998; Armstrong & Castle, 1995). In fact, UNEP (2002a & 2000) notices that land degradation, water scarcity, food insecurity, and poverty alleviation are being hampered by climate change and other environmental changes. Calls are made by the international community to seek strategic actions to overcome those issues (GEF *et al.*, 2008; EES, 2008; Niemczynowicz, 2001). These include water management and hydropolitics, land management and soil fertility improvement, the Millennium Development Goals (MDGs) and other strategies of poverty reduction (Bastiaanssen & Bingfang, 2008; Paglia, 2008; World Bank, 2007; IDRC & DFID, 2007; FAO, 2005; Gathenya, 2005; Faruqui, 2003; Kemper, 2003).

The optimization of watershed resources allocation, use and conservation is not a new issue. Zeiller raised the first flow problem in 1650 at Pregolya Basin, Russia (Swarp *et al.*, 2007). This opened avenues to scientists to look forward for solutions to water stress and scarcity, land resources depletion and degradation, poverty and food insecurity (UNDP, 2007). Clark and King (2004) predict that these problems will affect sustainable development worldwide. They foresee more severe crises over the next 15 years, when the world population is expected to reach the 9.1 billion levels. So, they recommend adequate water management policies for irrigation extension. Other scientists warn that

water and land resources crises will be aggravated by the morphology, topography and geology of catchments (Jansky *et al.*, 2005; Dixon, 2005; Flintan & Tamrat, 2003). The subsequent ecological changes will hinder natural resources productivity, resulting in increasing unit costs per water drop and land parcel for producing the same quantity of crop or meat. Without precautionary measures, this agricultural inefficiency will result in food insecurity and increase in poverty levels with population growth (FAO, 1995).

Recent scientific developments suggest precautionary measures for mitigating risks related to climate change and other global changes, local land-use changes, and maladapted agricultural and irrigation policies (Guthrie, 2008; Obando, 2007). These may consist of “green water credits” and other interventions that determine all fresh water resources in a region (Hoff *et al.*, 2007). However, all communities are mobilized to alleviate food insecurity and poverty vulnerability through skilful control of available watershed resources, particularly in most vulnerable areas (Sylva-Monde *et al.*, 2008).

Another pathway proposed by scientists is the reduction of water consumption in food production. This requires the application of efficient technological means in addition to the principles of management such as hydropolitics. Renault (2002a) observes that virtual water trade has become a substitution to real water savings through food imports and subsequent differential water productivity. Thus, he states:

Impacts of diet changes on water requirements for food are significant but the gain in water productivity for food production is more influent...thanks to the agricultural productivity (Renault, 2002a:iv).

As hydropolicies are being debated worldwide, agreements result in efficient watershed resources allocation and conservation (IOB, 2008; Earle, 2005; UNEP, 1997). Those

measures feature the Millenium Development Goals (MDGs), the Catchment Management Strategies (CMSs) and Sub-Catchment Management Plans (SCMPs) (Olukoye & Mukanga, 2007; Perret *et al.*, 2006; Onyando, 2006; Figueres *et al.*, 2003). The MDGs aim at achieving poverty eradication and sustainable development by rapidly increasing access to basic needs such as food security, clean water, sanitation and infrastructure development, energy, gender strategic needs and healthcare, employment, etc. A target of 66% is to be reached for Sub-Saharan Africa in order to halve by the year 2015 the proportion of populations who, in 1990, had no access to safe drinking water and to adequate sanitation (currently 36%). There is thus need to quadruple efforts to reach the remaining 30% (UNEP, 2002b).

Jaetzold *et al.* (2007) observe that Kenya agricultural sector is highly vulnerable. It relies on marginally degraded lands, whereas water scarcity and land infertility undermine resources productivity. Arid and Semi-Arid Lands (ASALs) in Kenya represent about 85% of the whole country area (GoK, 2007a; MWI, 2007; Agwata, 2006). Therefore, one way of assuring food security and poverty alleviation is to plan the long-term availability of water and land resources through programmes dealing with efficient agricultural production. Efficient farming systems are based on the inventory of available resources and the evaluation of their potential productivity in connection with their physical and operational costs. This helps in determining the economic efficiency of watershed resources use in agriculture. Soil fertility improvement and land management are likewise suggested as basic tools for improving crop production efficiency. They enable the environment for germination, growth and fruition. Accordingly, El-Gamal (2006)

recommends that evaluation of such resources be done with respect to socio-economic, political and biophysical environments to ensure sustainable efficiency. Hence, an integral assortment of those factors enhances the efficiency of watershed resources use in agriculture. Brown (2001: 77-78) finally warns:

If an economy is to sustain progress, it must satisfy the basic principles of ecology. If it does not it will decline and eventually collapse. There is no middle ground. An economy is either sustainable or it is not.

He conveys a balance between the supply and demand of watershed resources for safeguarding both humankind and wildlife (Wahby, 2006).

The Government of Kenya proposes concrete approaches and strategies for poverty alleviation by the year 2030. One of the strategic actions adopted is linked to watersheds management and rehabilitation programmes, and seeks to push the agricultural sector generate some Ksh. 80-90 billion increase in GDP (GoK, 2007a & 2007b). These efforts are the resultant of a long process that led to the release of *The Water Act 2002* of Kenya. The latter promotes a participatory management of watersheds resources, and the use of Catchment Management Strategies (CMSs) and Sub-Catchment Management Plans (SCMPs) in the whole country (MWI, 2007; Ngigi & Macharia, 2007; Förch *et al.*, 2006; MoW, 2005; Cap-net *et al.*, 2005).

1.2 Statement of the Study Problem

The agricultural sector in Machakos District in general and Muooni catchment in particular is facing critical environmental challenges in addition to coping with high population pressure and over-reliance on water and land for livelihood (Nation Media Group, 2007). Like most Arid and Semi-Arid Lands (ASALs) of Kenya, Muooni

catchment has undergone erosional processes, erratic rainfalls, river flows and forests cover depletion, silting dams and other asset investments degradation, and farms subdivision in small parcels for settlement. These factors decrease chances for high yields and good income, resulting in inefficient farming activities (Jaetzold et al., 2007). Thus, water scarcity and the lack of potential irrigable lands appear to be the primary cause of potential yield losses, food insecurity and socio-economic underdevelopment in these Kenyan ASALs. They undermine irrigation systems and foster deficient crops water absorption, leading to significant crop failures. In financial terms, these processes result in high costs of externalities (costs of water saving or water shortage costs) increasing the total farming operational costs under abnormal rainfall regimes (whether above or below normal). For facing poor farming yields and incomes, most farmers have adopted a strategy dealing with multiple cropping of about six seasonal crops and nine perennial crop species (indigenous as well as alien) on small farmlands. They also make use of fertilizers for improving their seasonal crops yields. Yet, these practices do neither improve soil fertility nor reduce its alkalinity, leading thus to a large gap between the actual farmers' water demands and their crops water requirements.

Due to external agents such as El Niño rainfall and other climate change impacts, off-farm effects of winds, water over-abstraction by Eucalyptus and other alien trees, etc. the risk of environmental degradation is imminent. The ongoing farming activities in the catchment have a significant impact on Muooni dam, which is the main source of water. Is Muooni dam storage capacity decreasing each year because of its reservoir siltation by farming activities? Is there any other explanation to water stress and soil infertility facing

Muooni catchment? There is need for water and land resources utilization in agriculture to be optimized in order to improve the efficiency of farming activities. Farmers thus have to minimize their operational costs and maximize their yields sustainable productivity of watershed resources. This study therefore attempts to provide indicators for monitoring and evaluating the efficient use of watershed resources in agriculture, on a regular basis (Petit-Guyot & Rieu, 2006; Vidal *et al.*, 2006; GoK, 2002a & 2002b).

1.3 Justification of the Study

This study was motivated by the need to improve agricultural sustainability in Muooni catchment in general and Muooni dam site in particular. Water and land resources utilization is significantly inefficient for both socio-economic and environmental activities development. One reason is that farming activities affect Muooni dam, which is the main source of water for agriculture in the catchment. Muooni dam reservoir's water storage decline has an impact on the economic viability of farming incomes. It increases farmers' water demand operational costs and enhances the risk of on-farm environmental degradation. The latter enhances the inefficacy of conservation measures practised, resulting in adverse effects on water and land resources, and asset investments. Consequently, food insecurity and inequitable resources distribution will increase, leading to conflicts between water resources users upstream as well as downstream.

Another reason is that the increasing population density in the catchment leads to the subdivision of small farm holdings and the over-exploitation of the available water and land resources through multiple cropping. Given that farming activities are the only viable income-generating enterprises, stakeholders' actual livelihood is affected. As their

food security collapses, poverty spreads in the entire Muooni catchment. The ongoing trends may unexpectedly escalate if no urgent action is taken.

Muooni dam site was mainly chosen because it has not been adequately researched. The scarcity of reliable data on the management of the dam as well as of the catchment itself is a critical gap that needs to be filled, if successful implementation of the 2002 Kenya water sector reform is to be achieved (Ngigi & Macharia, 2007; Bransington *et al.*, 1998). Data availability are thus crucial for developing Muooni Sub-Catchment Management Plan (SCMP). Even where some data exist, Brown (2001:78) observes:

By failing to reflect the full costs of goods and services, the market provides misleading information to economic decision-makers at all levels.

For all these reasons, the evaluation of efficient agricultural use of water and land resources at Muooni dam site could be vital in addressing the issues of food insecurity and poverty in the near future.

1.4 Research Questions

The following questions guided this study:

- (i) What socio-economic and environmental externalities affect farming activities efficient use of water and land resources at Muooni dam site?
- (ii) To what extent are land use activities affecting the active water storage capacity of Muooni dam?
- (iii) What variations of farmers' water demand and related operational costs are expected as a result of rainfall fluctuation in Muooni catchment?
- (iv) What are the farmers' water economic demand and limit costs related to farming production efficiency under different rainfall scenarios?

1.5 Study Objectives

1.5.1 General Objective

The overall objective of this study was to provide socio-economic and environmental cost-effective indicators for efficient use of watershed resources in farming activities around Muooni dam site.

1.5.2 Specific Objectives

This study research consisted of the following four specific objectives:

- (i) To assess socio-economic and environmental externalities affecting efficient use of water and land resources in farming activities at Muooni dam site.
- (ii) To determine the extent to which land use activities affect the active water storage capacity of Muooni dam.
- (iii) To simulate the variations of farmers' water demand and related operational costs resulting from rainfall fluctuation in Muooni catchment.
- (iv) To estimate the farmers' water economic order quantity and limit average cost related to farming production efficiency under fluctuating rainfall regimes.

1.6 Significance and Anticipated Output

Farming activities going on around Kenyan ASALs are highly vulnerable to rainfall fluctuations. To ensure good yields and incomes, farmers need to use water and land resources efficiently, under any rainfall regime. This study provides policy guidelines and some strategic management actions for efficient use of watershed resources in agriculture at Muooni dam site, and their conservation for the whole of Muooni catchment. It also results in an operational evaluation of agricultural water demand by farmers, using

different rainfall scenarios. The simulation model used incorporates a full range of socio-economic and environmental costs and externalities of the farming production. It attempts to achieve food security and poverty alleviation through the monitoring of efficiency indicators of the farming production that relate to Water Economic Order Quantity (EOQ), Limit Average Cost (LAC) and the Minimum Efficient Scale (MES).

1.7 Scope and Limitations of the Study

This study simulated rainfall fluctuation from the variations of Muooni dam's active water storage capacity. When the dam's storage capacity was relatively around the median, it was assumed that the rainfall regime was normal; otherwise it was abnormal (above or below the normal). The analysis did not utilize seasonal rainfall data and meteorological data to establish rainfall fluctuation. Rather, it used the concept of the flood hydrograph to assess Muooni river regime changes through the fluctuations of the active water storage capacity of its dam reservoir (Musy, 2001 and 1998). Yet, the study did not intend to take physical measurements; instead, it used available secondary data. Similarly, socio-economic and environmental ex post impact assessments were restricted to qualitative analysis and non-parametric tests of soil erosion problems and water over-abstraction. Using laboratory tools and field techniques for measuring soil loss, sediment loads and water evaporation in the dam as well as plants water evapotranspiration was also beyond the scope of this study.

The study derived water efficient use indicators by comparing operational costs and the estimated income values obtained on three scales of farms, namely: SSF, MSF and LSF. The latter were demarcated on the basis of their farmland size and farming income only

(see details under sub-section 3.3.1 of sampling methods). The study did also not take into account all farming inputs influencing the total farming cost; the most pertinent cost variable retained by the simulation was water demand. Though no production curve was predicted, an estimate of yield and income was only tailored on questionnaire responses.

In most of the cases, data availability was a major problem due to inadequate dam management by the dam environmental committee, established by the Ministry of Water and Irrigation. Discontinued and scattered data on the dam water storage capacity was assembled through in-depth interview (see appendix 4.7). Accessing this information as well as that from farmers required adequate funding, and overcoming study area terrain, language barrier and inaccurate responses from some respondents. Yet these limitations were overcome by paying two research assistants' allowances and transport fares, and by having access to modern technological means of data collection and analysis.

1.8 Operational Definitions of Terms and Concepts

1.8.1 Agricultural Watershed Resources

Agricultural activities always rely on watershed resources, namely: natural, financial and human resources (Ellis, 1993). This study considered three types of watershed resources contributing to the crops potential growth. They included:

- (i) Farming capital or asset investments (the dam and farming inputs)
- (ii) Natural resources (water and land resources); and
- (iii) Human resources (farmers' know-how).

1.8.2 Efficiency of Agricultural Resources Use

The efficiency of agricultural resources use involved only increased crop yields at a low cost of inputs or with few resources wastage (compared to the production growth). This expression entailed sustainable use of water, land and other resources in agriculture with respect to their thresholds.

1.8.3 Rainfall Regimes Fluctuation

This study used three rainfall regimes scenarios: “normal” (NOR), “above normal” (ANOR) and “below normal” (BNOR). The NOR scenario referred to a dam’s active water storage capacity between the median and the threshold. In such a context, farmers’ water demand was expected to meet the actual water requirement of their crops. Under the ANOR scenario, the dam’s active water storage capacity was supposed to be beyond the median; and under the BNOR scenario, it was assumed to be below the threshold. These two last scenarios represented abnormal rainfall regimes characterised either by water surplus or by a deficit of water in the farming cycle.

1.8.4 Operational Costs and Externalities

The expression “operational costs” referred to the costs of transaction, opportunity costs, costs of water saving and shortage costs. The two last costs were considered as increased costs in the farming production due to “externalities”. The latter were referred to as negative effects of external agents (such as flooding, water shortages and drought, poverty and ignorance, farmland sub-division for settlement, excessive multiple cropping, etc) in the farming production.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

Agriculture is believed to be one of the most ancient activities ever undertaken by human beings (KLB, 2007a). It is acknowledged as the engine of civilizations and economic development; and it is also perceived as a transition between “the primitive tribe and the industrial society” (Ellis, 1993:6). However, due to global changes, agricultural production is disturbed, as are frustrated most of “tenuous production and survival systems” by extreme climatic events (Wambongo, 2007:9). The scientific community even consents that global changes are a resultant of an uncoordinated development of human activities (*Awake!*, 2008; UNEP, 2000, 2002a & 2002b; IPCC, 2001; Demounem *et al.*, 1998). Watershed resources vulnerability and their unsustainable use in marginal (or semi-arid) and dry (or arid) lands are propounded to be the primary causes of agriculture inefficiency in most Sub-Saharan African countries, Kenya included (Rockström, 2003; Shisanya, 1996).

This chapter reviews some empirical literature related to agricultural watershed resources, economics, the theory of externalities, environmental studies and ecohydrology, agro-ecology, eco-economy and resource economics, and watershed management. It focuses on conceptual models, methods of valuation or experimentation used in the evaluation of environmental efficiency, agro-ecological efficiency, socio-economic and hydropolitical efficiency.

2.2 Concept of Agricultural Watershed Resources

Agriculture based activities mainly include crop production (field crops culture, perishable crops culture or horticulture, and tree planting or silviculture), and livestock production (Mammalian livestock farming, fish farming or aquaculture, and bee-keeping or apiculture) (KLB, 2007a). These activities always take place in a small environment within a watershed or catchment area, whereby crops are able to get moisture and nutrients from the soil, and livestock has water and food (KLB, 2007d; FAO, 1995; UNEP, 1989). Therefore, agricultural activities always rely on watershed resources. Ellis (1993) mentions three main categories of them: natural, financial and human resources.

Natural resources include among others: rainfall, surface water, groundwater, soil surface and subsurface, biomass, climate and all other environmental factors contributing to the potential growth of crops and livestock (KLB, 2007c). All these factors are magnificently nested through natural agro-ecological systems (Waswa, 2000; Bøgh, 1995). For instance, the climate, rainfall and soil surface conditions influence the rate at which water and nutrients can be absorbed by plants, though the capacity of the lower soil layers to receive and store additional infiltrating water is another constraint (Jaetzold *et al.*, 2007; KLB, 2007b; Balagopalan, 2001; Shisanya, 1996).

Financial resources comprise the farming capital and all physical investment assets used in agriculture, such as farmland, farming inputs, dams, irrigation schemes and other man-made infrastructures, as well as technological and monetary means (Anandajayasekeram *et al.*, 2004). Waswa (2006) attests that financial means are very crucial in agriculture because they allow farmers to afford effective and efficient technological means for

higher yields and better incomes. Oduol *et al.* (2006) also notice that they bear scale and allocative efficiencies in addition to the technical efficiency.

Finally, farmers themselves play a key role in ensuring efficient use of agricultural watershed resources. They have to combine skilfully natural and financial resources in agriculture so that the costs of production remain within the bearing capacity of natural resources. Douglas (1994) points out that a good management is the most important resource for ensuring agricultural production efficiency. It always takes into account the scale of all costs incurred by the acquisition and use of resources in the production (Lemon, Seaton & Leew, 1993). For instance, it can help farmers make good decisions by reducing useless evaporation and monitoring evapo-transpiration, thus leading to sustainable water use and income raising (Bastiaanssen & Bingfang, 2008). The increase of agricultural production would thence be acquired at lower costs of inputs, below the thresholds of natural ecosystems (Guthrie, 2008; Obando, 2007). If not taken care of, endogenous factors to the management system and exogenous factors from the management environment can threaten the efficiency of watershed resources management (Boseman & Phatok, 1989). Significant losses due to resource wastage above their natural bearing capacity may be the final outcome of such mismanagement (Thompson, 2001). Therefore, farmers' labour, management know-how and technological skills, and other human resources are very critical in efficient use of watershed resources in agriculture.

For the sake of this study, human resources were limited to farmers' management know-how; natural resources particularly encompassed rainfall, water and soil; and financial

resources included especially Muooni dam and farming capital. The efficiency of agricultural watershed resources use was especially simulated from a model evaluating farmers' water demand and subsequent operational costs.

2.3 The Theory of Externalities

As said above, the acquisition and use of watershed resources in agriculture has a cost and benefit. Economists agree that there are some costs or benefits incurred by individual farmers, and some others by the entire community when individuals try to increase their production beyond the threshold of natural ecosystems (GDAE, 2008; Harris, 2008; Coeli, Rao & Battese, 1998). These increased costs incurred in production may be explained by “externalities”. The latter are external effects from the environment. They may be described as either cost of pollution, water shortages and drought, flooding destructions and diseases. They may also be benefits from a new technology acquired by the management for efficient production (Hardwick, Khan & Langmead, 1994; Nicholson, 1992).

Local land-use changes as well as the global climate change, notably characterized by rainfall fluctuations, have an impact on the diffusion of environmental phenomena, socio-political crises and spontaneous economic conjunctures, which are difficult to predict (GEF *et al.*, 2008). These have especially some external costs on the production by rural communities, and on the management of watershed resources (Dixon, 2005; Shisanya, 2005). When those social and environmental costs that accrue to the community are in excess of the internal management benefits, there are “external diseconomies” in the production (Mansfield, 1991; Meier, 1990; Todaro, 1977). Rural farming production

seldom expands by “external economies” (derived from excess external benefits on the management costs) under perturbation of environmental patterns (GDAE, 2008; Goodwin, 2008).

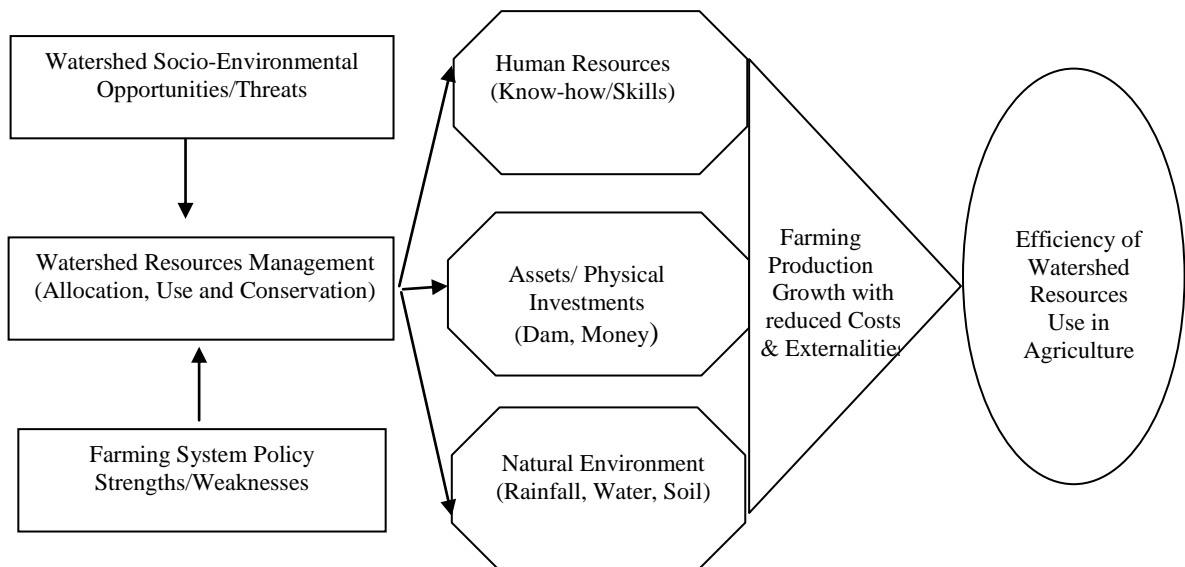
Rosanvallon (1992) refers to the theory of externalities to justify the relentless public expenses growth by deficient market rules and market system dysfunction. These, in turn, increase the economic inefficiency and social injustices. In the same breath, Ngonzo (1999) explains the impact of monetary financing of the state treasury budget, within a lower economic conjuncture, on the salary of civil servants and other state agents. He uses a hybrid model adapted after Baumol deterministic monetary model and Beranek dynamic treasury model to determine the “Spontaneous Credit Salary” (SCS) and the “Minimum Cash Salary” (MCS) in both normal and abnormal economic conjunctures.

The theory of externalities was used in this study to justify external impact of farming activities and their immediate environment on the dam’s water storage capacity. The latter explained the decreasing farmers’ water demand due to higher operational farming costs at Muooni catchment under abnormal rainfall regimes. The total farming cost under above normal and below normal rainfall regimes was respectively overloaded by the cost of water saving and the shortage cost. These outcomes of the theory of externalities were originated from a hybrid operational model shaped after Wilson deterministic stock inventory model, Baumol deterministic monetary model and Beranek dynamic treasury model (Ngonzo, 1999). The latter provided useful indicators of the farming production efficiency through comparison of its original values (or actual farmers’ water demand and related costs) with operational ones. It came up with farmer’s water demand “Economic

Order Quantity” (EOQ) and Limit Average Costs (LAC), and a farming production “Minimum Efficient Scale” (MES).

This study also adopted Thompson (2001) conceptual framework for evaluating the economic growth and welfare efficiency. Figure 2.1 presents the adjusted framework that fit the objectives of this study.

Figure 2.1: Efficient watershed resources management framework



Source: Adapted after Thompson (2001)

This flow diagram summarizes the process leading to efficient management (allocation, use and conservation) of watershed resources and its relevant factors. It shows how on-farm management may either be weakened (or strengthened) by endogenous factors pertaining to its resources allocation and use, or threatened (or may be given opportunities) from outside by exogenous (socio-environmental) factors affecting resources conservation (Boseman & Phatok, 1989). Endogenous factors impacting

directly on resources productivity may aggravate the gaps between resources allocation and their use (or improve their conservation). They may also weaken (or strengthen) the farming production through its system policy implementation effectiveness (strong or weak system). However, exogenous factors have an indirect impact on the farming system through efficient (or deficient) watershed resources availability and management opportunities (such as funding from the international community). They may also rise up threats through water pollution and siltation (due to storms, El Niño floods and droughts, and socio-economic activities going on around the watershed), socio-political clashes, conflicting laws, for instance. If the management takes into account the full range of endogenous and exogenous factors, it will certainly come up with ‘more crop produced per drop’ and enhanced soil resilience (Clarke & King, 2004; Lal, 1993).

2.4 Evaluation of the Environmental Efficiency

Today’s economy has been shaped by market forces, not by the principles of ecology. Unfortunately, by failing to reflect the full costs of goods and services, the market provides misleading information to economic decision-makers at all levels. This has created a distorted economy that is out destroying its natural support systems. The market does not recognize base ecological concepts of sustainable yield nor does it respect the balances of nature, observes Brown (2001:78).

Eco-Economy is thus an alternative to the market economic system, which is jeopardizing the capacity of future generations to meet their needs (Koech & Kinoti, 2007; Waswa *et al.*, 2006). Similarly, the Kenya vision 2030 associates economic prosperity with “social equity in a clean and secure environment” as well as individual freedom and accountability in a democratic political system (GoK, 2007a: 2). Therefore, sustainable farming activities should not only fit the socio-political context and cultural

habits of stakeholders, but also respect the thresholds of natural ecosystems with regard to croplands, rangelands, fisheries, and forests.

As indicated above, this study aimed at assessing and justifying externalities of farming activities and their immediate environment on Muooni dam's water storage capacity, and their subsequent operational costs variation. Such a study needed to rely on a strong scientific background on environmental costs and externalities valuation for efficient natural resources management.

It is in favour of such a background that Rietbergen-McCracken and Abaza (2000) apply various economic methods on environmental valuation. For instance in their collection, Angeles *et al.* (2000) evaluate the profitability of forest plantations in the Philippines using a replacement costs approach. This involves the computation of the costs due to soil fertility removal by soil erosion; agricultural loss of earnings due to the impact of soil erosion on the dam reservoir siltation and irrigation system inefficacy; and an opportunity cost of constructing a large non-productive sediment pool to prevent the adverse effects of sedimentation. In the same collection, Fürst *et al.* (2000) estimate the willingness to pay water services from other vendors than institutional ones in urban Haiti by a cost-savings approach. Yet, these extended cost-benefit analyses did not provide a clear indication of efficient agricultural production scale under specific farming periods. Similarly, Shakya (2001) evaluates the impact of farming activities' deforestation on water flow at the Khageri River and Chitwan district irrigation system in Nepal. Nonetheless, the study does neither value water shortage cost due to deforestation nor relates it to water productivity and profitability in the farming activities under different

rainfall regimes. On the other hand, Gonzalez *et al.* (1995) propose a methodology enabling the assessment of geomorphologic factors impacting on the environment degradation. But they provide indicators that mostly fit to the evaluation of Master Plans activities rather than Sub-Catchments' Management plans.

The present study clearly differentiates operational costs as normal (costs of transaction and opportunity costs) and abnormal ones (costs of water saving and shortage costs), according to their periods of occurrence. It helps in computing the total farming cost variations under fluctuating rainfall regimes, and thus evaluating farmers' water use efficiency in the farming production at the catchment area level.

2.5 Evaluation of the Agro-Ecological Efficiency

Efficiency agriculture relies on balanced interrelations between different natural resources and their environments: soil erosion and new soil formation, biomass removal and regeneration, carbon sequestration (emission) and carbon sinking (fixation) (Brown, 2001). If sufficient conditions are not filled for agro-ecological systems to be well nested, on-farm environment can easily threaten the potential growth of farming products through deficient water and nutrients absorption by plants, crops or livestock.

When assessing chances and risks of maize and beans growth in the semi-arid areas of south-eastern Kenya, Shisanya (1996) observes that fluctuating rainfall conditions have an impact on the yielding of different crop cultivars. He uses MARCROP and WOSFOST agro-ecological models for evaluating the efficiency of beans and maize farming under different rainfall regimes of the short rainy seasons. Though chances and risks of such a business are successfully simulated under "expected deficient, normal and

above normal” rainfall of the short rainy seasons, the study does not provide a cost-benefit analysis. Likewise, Jaetzold *et al.* (2007) present exhaustive information on the natural farming potential of Kenya, including the Machakos District. The study is based on small farm surveys, using agro-ecological and crop growth models. Waswa (2000 and 2006) gives a comprehensive environmental impact assessment of marginal agricultural land management in Kenya. Based on prerequisites provided by Douglas (1994) for preventing in-farm soil degradation in some agro-ecosystems in Africa, he looks at physical impact of land resources misuse on the sustainability of on-farm management. He assesses the factors limiting sustainable use of agricultural soils in African resource-poor farms and sorted out both the selection of a specific land-use and appropriate form of land management as key means of preventing soil erosion problems. This study, like those preceding it, does not attempt to provide a valuation of costs due to the effect of soil erosion problems on farming activities. The present study fills that gap by providing an operational costing method of factors prone to soil erosion externalities. It also simulates the extent to which farmers’ water use in cropping could be efficient under such agro-ecological conditions.

2.6 Evaluation of the Socio-Economic and Hydropolitical Efficiency

Environmentalists nowadays believe that environmental trends are difficult to predict, though forecasting patterns guide human predictions and their activities (GEF *et al.*, 2008; Phillips, 2003). Brown (2001) observes no linear cause-effect relationships and no through-flow situations in the natural ecosystem whereby resources go in one end and wastes come out on the other. To quote John R. Christy (Director of the Earth System

Science Center at University of Alabama, Huntsville, USA), the magazine *Awake!* (2008: 6-7) notes the following:

One scientist who participated in the IPCC discussions said: ‘There are some of us who remain so humbled by the task of measuring and understanding the extraordinarily complex climate system that we are skeptical of our ability to know what it is doing and how’.

The third and fourth IPCC express similar sentiments when they assert that the impacts of climate fall disproportionately upon world’s poorest, most vulnerable people, while both their exact causes and consequences are not certainly certified (*Awake!*, 2008; Lexén, 2008; Pachauri, 2004). Therefore, efficient watershed resources use in farming is more a question of management of social, economic and political factors affecting resources availability, rather than an issue of managing its environmental determinants.

A study by Shisanya and Kwena (2005) shows that the lack of technical know-how, and of sufficient means of transport and finances for assuring permanent water supply, especially during the dry season, are major factors increasing socio-economic externalities that impact on the environment in Kakamega District (Kenya). It reveals that people spend an enormous amount of time (an average of two hours) fetching water from unprotected springs. They have, therefore, to queue and wait for silt to settle before fetching, and have to face crude methods of drawing water from wells and springs. Sometimes, they have to traverse long distances mostly in accidental terrains (lands with steep slopes), and to pay for some repair services by a mason (for springs and wells) or a pump technician (for boreholes). The authors use a series of statistical tools to assess the type of costs and externalities impacting on water accessibility in rural Kenya.

Nevertheless, they do not reveal how cost-effective is agricultural water use at Kakamega District.

Mutisya (1997) uses a “humanistic approach” for assessing soil erosion problem (rather than analysing its physical process) in the Masinga dam catchment. The study focuses on the explanation of the human environment deterioration by soil erosion. It is based on agronomic and socio-economic factors contributing to soil erosion. It reveals that human induced activities contribute to the soil erosion problem through the modification of physical processes occurring on soil composition, land topography, vegetation and climate. The latter either accelerate the erosion process or reduce it, thus making mankind the key agent of soil erosion problem. Yet, no opportunity cost or cost of replacement of eroded soil is provided to value human activities externalities on farmlands and the dam reservoir capacity. However, Bremer *et al.* (2003) attempt to fill in that gap by using an econometric approach. They evaluate the impact of sanitation and education on improved spring water and children performance at school, using “Intention-To-Treat” (ITT) and “Treatment-effect-On-the-Treated” (TOT) methods. Nevertheless, their methods do not directly concern the evaluation of farmers’ productivity efficiency in a watershed. Using a conventional cost-benefit analysis or the operational cost-efficiency approach applied in this study may have improved that study.

Talking about water scarcity, Clark and King (2004), and Flintan and Tamrat (2003) express the need for efficient water management. Yet, their projected water crises are neither directly linked to rainfed farming and small-scale irrigated farming activities, nor valued by actual or operational costs of inefficiency of technological farming methods.

Predicting higher water demands for irrigation and food production with a yearly world population growth of 4.623%, Clark and King (2004) present a three-scenario simulation of the world water withdrawals by sector by the year 2025. The latter is based on populations and business activities growth, and policy interventions effectiveness, using available data from 1950 to 2003. The simulation outcome is an unprecedented water crisis in 2025 without adequate policy intervention. Flintan and Tamrat (2003), on the other side, observe that efficient water resource management practices are found in the history of Ethiopian stakeholders. They include afforestation, pollution control, general good land husbandry and conflict resolution on the resource. If guided by a philosophy that values such practices, peoples are eager to protect their watershed resources. Yet, due to high population growth and subsequent increasing food demand and water scarcity, traditional water technology becomes rudimentary. Due to climate change disasters, they are susceptible to important water evaporation, frequent damage by floods and constant repair costs. The present study provides an adequate simulation method based on the valuation of such external costs on farming activities taking place within a catchment area.

For addressing water stress or scarcity issues, Earle (2005 & 2001), Renault (2002a & 2002b) and Allan (1999 & 1998) recommend hydropolitical measures. Earle (2005) notes that alternating dry and humid conditions result in aridity and climate variability in Southern Africa. These climatic factors conditions combined with the past conflicts and economic development problems make the region hydropolitically vulnerable. To ensure a sound ecology, social welfare and a wealthy economy, he suggests trade and benefit-sharing activities that enhance water availability and cooperation between communities

sharing the same water resources in the region. Virtual water import is thus a hydropolitical option opened to them with support of economic resources for sustainable use of their water resources. In achievement to Earle's strategy, Renault and Wallender (2000) provide some useful principles and concepts that promote virtual water trade. He presents some benefits of importing virtual water in terms of improved water savings (resulting from differential in water productivities), reduced water consumption in food production, and additional agricultural water productivity. Nonetheless, for assessing efficient watershed resources use in agriculture, the present study suggests an analytical tool based on operational costs and benefits, and allowing decision-makers value virtual water imports efficiency. Table 2.1 below presents main findings, methods and gaps identified from some selected key empirical studies relevant to the present study.

Table 2.1: Key empirical literature selected and gaps identified

No	Author	Year	Methods	Summary of Findings	Gaps Identified
1	Jaetzold et al.	2007	Agro-ecological and crop growth modelling	Good land management database can help preserving the natural potential of Kenya.	The study does not address cost-efficiency of farming land use.
2	Waswa	2006	Agro-ecological systems approach	Land degradation in Kenya is the fact of farmers' ignorance, poverty, and lack of technological innovation.	The analysis does not consider the cost of water and related losses.
3	Shisanya & Kwena	2005	Descriptive & Inferential statistics	Socio-environmental externalities in rural Kenya are due to the lack of technical know-how and adequate means of storing water, esp. during dry periods.	The study does not consider the costs of externalities in agriculture in rural areas.
4	Clark & King	2004	Statistical simulation	Worldwide water demand by the year 2025 depends on irrigation, food production and population policies efficiency.	The projection is not specific to farming and investment in a water-saving technology.
5	Renault	2002	Water Economics	Virtual water imports can reduce significantly water consumption and increase agricultural water productivity.	There is need to consider virtual water and its values in the total water footprint.

Source: Literature Review (2008)

Table 2.1, Continued

No	Author	Year	Methods	Summary of Findings	Gaps Identified
6	Brown	2001	Eco-Economic systems approach	A sustainable economy should be compatible to the natural ecosystems thresholds with regards to their exploitation.	The study is not completed with analytical tools.
7	Rietbergen-McCracken & Abaza	2000	Economic valuation methods	Environmental externalities can be valued by economic approaches such as opportunity costs, replacement costs, loss of earnings, cost-savings, etc.	The study needs to consider time scales and an approach to operational cost efficiency.
8	Mutisya	1997	Nonparametric tests	Human induced activities	The study needs to consider the impact of human induced activities on the environment.

			& Agronomic survey	contribute to the soil erosion problem through the modification of physical processes pertaining to it.	valuation replacement c externalities activities asses
9	Shisanya	1996	Agro-ecological & Crops growth modelling	Assessment of chances and risks of maize and bean yields in semi-arid areas under fluctuating rainfall regimes.	Assessment efficiency is ne activities cost-l
10	Boseman & Phatok	1989	SWOT analysis	The efficiency of any system of management depends on endogenous and exogenous factors pertaining to it.	There is lack indicators o efficiency i endogenous costs of impact

Source: Literature Review (2008)

CHAPTER THREE

MATERIALS AND METHODS

3.1 Introduction

This study aimed at assessing external impacts of farming activities and their immediate environment on the dam's water storage capacity, using on-farm field survey methods for collecting data and statistical analyses for valuing the impacts assessed. It will thereafter apply an operational research simulation for computing farmers' water demand and subsequent farming costs, and efficient water use scales as well, under different rainfall regimes. Figure 3.1 presents a flow chart of the methodology adopted in the study, while Table 3.1 links study objectives with corresponding materials and methods used.

3.2 Study area

3.2.1 Location

Muooni catchment is a small catchment of 25 km² situated in Mitaboni location of Kathiani Division in Machakos District (Eastern Province of Kenya). It is shared by three

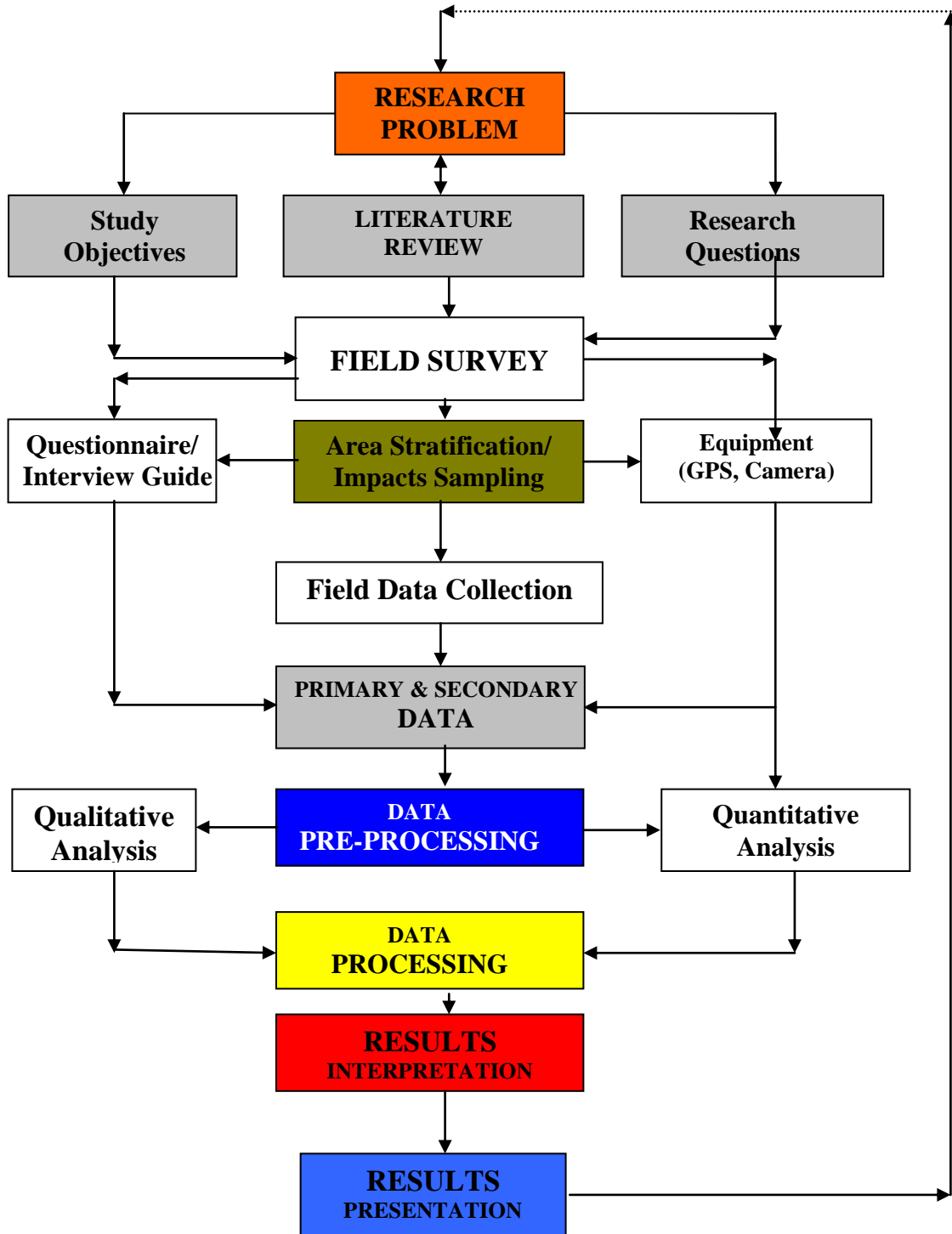
sub-locations, namely Isyokone, Mbee and Kaewa, and bounded by latitudes $37^{\circ} 16' 30''$ E and $37^{\circ} 20' 30''$ E, and longitudes $1^{\circ} 24' 30''$ S and $1^{\circ} 28' 15''$ S in the 37^{th} Meridian (Figure 3.2). It is mainly a dry and hilly land with small plateaus rising between 1,434 and 2,005 metres, within the upper midland agro-ecological zone. Coffee, maize, banana, and cowpeas are the most preferred crops, and are supplemented by livestock products. Water for agriculture is mainly supplied by Muooni Water Project, which relies entirely on Muooni River and its dam. Many homes harvest rainwater from shallow ponds and/or roof catchments (Oduor, 2003). Others pump water directly from the dam and store it.

Table 3.1: Research methodology summary

No	Objectives	Data Required	Source of Data	Statistics	Type of Analysis
1	To assess socio-economic and environmental externalities affecting Muooni dam site.	Farms position Farming activities types - Farming activities hydro-geomorphologic impacts	Questionnaire Site visit –Photo Maps - GPS -GIS	Frequencies /Mean Standard deviation U-test statistics Spearman’s rank correlation Z-score	Descriptive statistics Non-parametric statistics
2	To determine the extent to which land use activities affect the active water storage capacity of Muooni dam.	Dam design patterns Dam active water storage capacity time series	In-depth interview Records from the dam management	Regression A and b coefficients Standard deviation and Error term Rho test t-statistic	Time series analysis Quality control Correlation analysis
3	To simulate farmers’ water demand and operational costs variations related to rainfall regimes fluctuation.	Income - Expenses Crops water requirement Water demand turnover Output from objective 2	Questionnaire Time series analysis output	Total Cost (TC) Average Cost (AC) Marginal Cost (MC)	Operational Research simulation
4	To estimate the farmers’ water Economic Order Quantity (EOQ) and Limit Average Cost (LAC) related farming efficiency under fluctuating rainfall regimes.	Output from objective 3	Questionnaire In-depth interview Operational research output	Water EOQ, LAC and Minimum Efficient Scale (MES)	Operational Research simulation

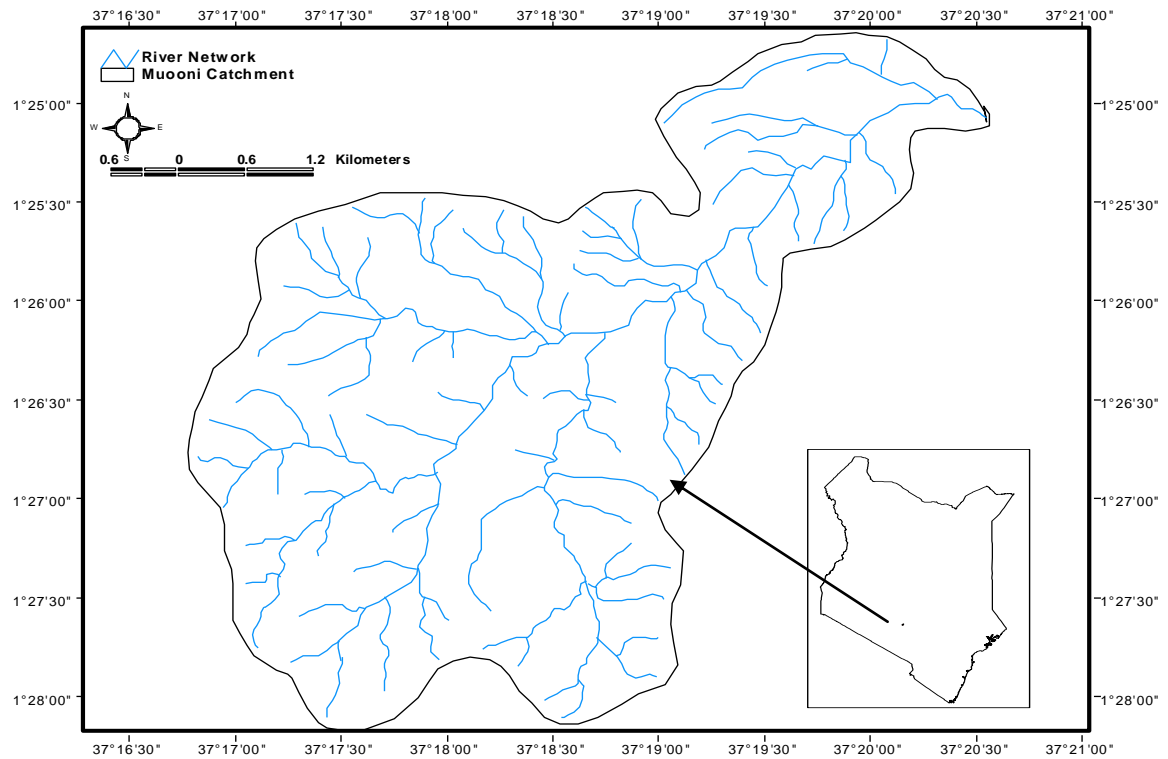
Source: Author (2008)

Figure 3.1: Research methodology flow chart



Source: Author (2008)

Figure 3.2: Muooni catchment area



Source: Author (2008)

3.2.2 Population

The population comprises mainly the Akamba people, who are predominantly agriculturalists. During the 1999 census projections, the population at Kathiani division (Muooni included) was estimated at about 18,997 persons with a density of 462 persons /km² (Jaetzold *et al.*, 2007). However, the average population density at Muooni catchment is estimated at about 3 persons each 100 metres; that is about 900 persons /km² (Phillip's-E.A.E.P., 2002).

3.2.3 Geology and Soil

Athi WRMA (2008) reveals that the geology of the catchment consists essentially of pre-cambrian basement complex (crystalline rocks) and intrusive granites (igneous rocks) of the Pleistocene Age. The geological formations overlaying the basement complex vary between alluvial deposits at the valleys to undifferentiated tertiary sediments, except for the deeply forested parts having poorly developed soils. The soil in the catchment is dominated by the nitisols in the wetlands with some ferrasols and vertisols on hillslopes and some forested areas (Phillip's-E.A.E.P., 2002). Because of climatic variation with altitude (high rainfall at the hill tops and low rainfall at the low plains), variable soils have developed. Those soils are poorly consolidated; and combined with the steep slopes, they are highly susceptible to erosion (MoW, 1987).

3.2.4 Topography

Muooni catchment belongs to the eastern highlands topographic area, one of the most important hills of Kenya (Phillip's-E.A.E.P., 2002). It is characterised by steep slopes which are intensively cultivated. The area is sandwiched between the Iveti forest (at Muooni River source) and Kyevaluki and Uuni hills (situated to the east). Altitudes range from 2,005 m a.s.l. at Mutondoni to 1,434 m a.s.l. near Kathiani divisional headquarters (Athi WRMA, 2008). The catchment is traversed by the West-East running Machakos-Kathiani tarmac road, and Muooni River which cuts across the three main hills of the location (Iveti, Kyevaluki and Uuni hills).

3.2.5 Hydrological Conditions

Hydrologically, Muooni sub-catchment is part of the Athi catchment, administered by the WRMA Regional Office in Machakos. Muooni River is the only perennial water course in the catchment. It is a tributary of Thwake which in turn is a tributary of the Athi River. At this upper reach, Thwake is perennial while Muooni becomes seasonal. Nevertheless, its water resource serves for both domestic and commercial needs of the population, especially for agriculture. Table 3.2 gives an idea of Muooni catchment hydrological patterns. With the development of the Catchment Management Strategy (CMS) initiated by the Athi WRMA last year, there is hope that some of the major issues and challenges raised may be soon addressed in the whole Athi catchment, Muooni watershed included.

3.2.6 Climatic Conditions

The catchment lies within a medium potential zone : the upper midland agro-ecological zone 4 (UM4). Climatic conditions in the catchment range from humid to semi-humid. Rainfall is bimodal falling during the long rains (from April to May) and short rains seasons (from November to December) (Athi WRMA, 2008). Annual temperatures range from 10⁰ to 30⁰ C, and annual rainfall from 626 mm to 783 mm (Figure 3.3).

On a small scale map, Muooni catchment appears as a dot in the map of Kenya. Its long term rainfall fluctuations, temperatures and evapotranspiration patterns are similar to those of south-eastern Kenya. The area being situated few degrees south of the equator, rainfall distribution is highly influenced by the seasonal movements of the African “Inter Tropical Convergence Zone” (ITCZ) (Wambongo, 2007). Table 3.3 provides average

annual rainfall, temperatures and average potential evapotranspiration (PET) data at Katumani Agricultural Resource Station (from data recorded on a period of at least 15 years). It shows that climatic conditions in south-eastern Kenya do not show a regular trend of average rainfalls and temperatures. That denotes the influences of the area topography on the intensity and diffusion of the ITCZ influences.

Table 3.2: Muooni catchment characteristics

No	Characteristics	Values
1	Catchment area ¹	25 km ²
2	Muooni dam reservoir area ³	15. 2 Hectares
3	Annual average rainfall ¹	~ 705 mm
4	Estimated evapotranspiration ²	~ 1,720 mm
5	Surface water abstractions rates.	Not known
6	Groundwater abstractions rates.	Not known
7	Average Muooni dam yield ³	~ 500 m ³ /day
8	Muooni dam specific capacity (at Spillway level) ³	~836,000 m ³ /year
9	Average borehole yield	Nil
10	Borehole specific capacity	Not known
11	Average discharge during high flow ³	99 m ³ / sec
12	Altitude at spillway level ³	1614 m a.s.l
13	Catchment altitude ¹	1602-2,005 m a.s.l.
14	Average temperature ²	20.2-18.6° C
15	Water demand	Not known
16	Estimated water demand by 2030 ¹	~ 800 m ³ /day
17	Population ²	~ 22,500 pers.
18	Population density ²	~ 900 pers./km ²

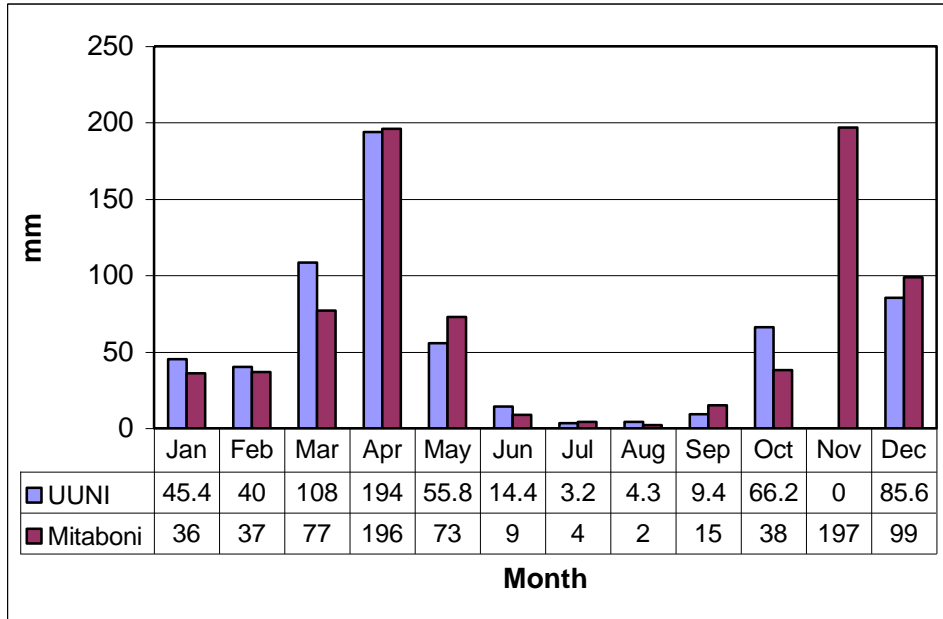
Source: *Estimated and/or compiled after:*

¹Athi WRMA (2008)

²Phillip's-E.A.E.P.. (2002) and Jaetzold et al. (2007)

³MoW (1987)

Figure 3.3: Muooni catchment seasonal rainfall 2007



Source: Athi WRMA (2008)

Figure 3.4 below shows that rainfalls in extreme periods (of drought and wetness) are spatially uniform, although rainfall distribution is highly variable, and drought is a recurrent phenomenon. The rainfall regime is dominated by two mainly dry “monsoon” seasons (from January to February, and from June to September); and two rainy seasons are associated with the movement of the ITCZ (in March, April and May, and from October to December). Total annual averages range between 500 and 1,300 mm, with 66% of reliability. Additional rainfall in that part comes from the trade effects of south-eastern winds blowing on slopes. Yet, Jaetzold *et al.* (2007) notice that the El Niño Southern Oscillation (ENSO) affects the kind of agricultural water and land use in the catchment, in terms of rainfed and irrigated agricultures, and crop treatments. It enhances the short rainy season wetness or makes it become extremely dry.

Table 3.3: Average annual rainfall, PET and temperatures in south-eastern Kenya

N ^o	Kind of Records	J	F	M	A	M	J	J	A	A	S	O	N	D	Year
1	Aver. rainfall (mm)	42	41	81	144	63	8	5	4	4	0	40	157	88	673
2	Reliable rainfall	13	9	59	108	37	1	0	1	1	0	7	118	60	582
3	Aver. PET (mm)	164	158	167	133	120	104	103	114	114	100	173	141	145	1622
4	Rainfall % of PET	41%	41%	41%	41%	41%	41%	41%	41%	41%	41%	41%	41%	41%	41%
5	Mean Max t ^o .	25.8	27.1	26.4	25.1	24.2	23.0	22.1	22.6	25.8	27.1	26.4	25.1	24.2	23.0
6	Mean Average t ^o	19.8	20.7	20.9	20.4	19.3	17.5	16.9	17.1	19.8	20.7	20.9	20.4	19.3	17.5
7	Mean min t ^o .	13.8	14.3	15.3	15.7	14.3	12.0	11.6	11.6	13.8	14.3	15.3	15.7	14.3	12.0
8	Abs. min t ^o .	8.1	5.6	8.6	10.0	7.8	6.7	6.1	3.4	8.1	5.6	8.6	10.0	7.8	6.7

Source: Jaetzold et al. (2007)

Notice: Belt Limits: 1,800 m-1,300 m UM

3.2.7 Agro-ecological Patterns and Land Use Activities

As said above, Muooni catchment is under the Upper Midland Agro-Ecological Zone 4 (UM4). Its soils are potentially suitable for sunflower and maize cropping, expected rainfall ranging between 700 mm and 950 mm per year with 66% reliability (Jaetzold *et al.*, 2007). As most areas receive less than 1,000 mm of mean annual rainfall, the catchment is not generally favourable for intensive rainfed agriculture. The high soil moisture and cool climate of the hill tops make them favourable for cropping wheat, maize and pyrethrum. However, due to the shortness of the rainy seasons and small size of farms, those crops most likely fail. Farming income is thus supplemented by the cropping of potatoes, coffee (in altitudes ranging from 1,650 to 1,800 m), early maturing sorghum and foxtail millet, and “marginal crops” (like Tepary beans and Tohono Z16 maize), most of the time associated with livestock farming.

Most farmers practise irrigation for commercial and/or subsistence agriculture, using Muooni dam water. Those farming activities have resulted in erosive processes, though the majority of farmers practise soil conservation measures. Soil erosion in the dam site is always propounded to be the primary cause of siltation of the dam reservoir. The ultimate effect of soil loss from farms is thus reduced land productivity, food shortage and desertification. Consequently, sand harvesting and quarrying have become important sources for livelihood in some parts of the catchment. Figure 3.4 gives a better understanding of spatial patterns of land-use in different agro-ecological zones of Machakos and Makueni districts through the distribution of rainfall. The main economic

activities in the catchment are subsistence and commercial farming. Commercial farming mainly involves the growing of coffee, tea, agro-forestry (especially eucalyptus and grevillea species) and horticulture. Subsistence farming involves the growing of maize, French beans, potatoes, arrow roots, pumpkins, bananas, sugarcane, sweet potatoes, cassava, yams, sorghum, millet and cowpeas.

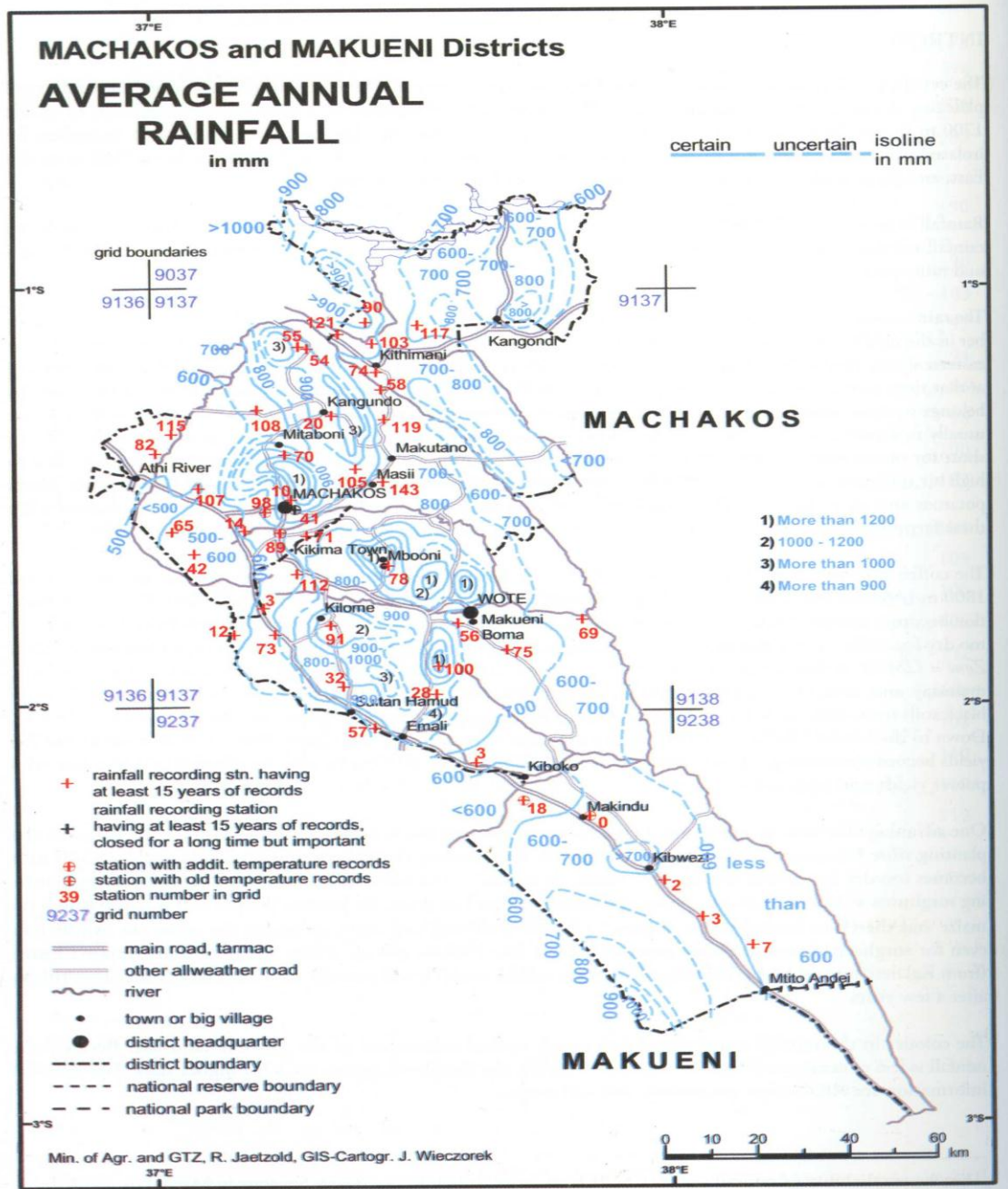
Livestock rearing is another important activity in the catchment and includes cattle, goat, sheep, pig and chicken. Donkeys are sometimes used as means of transport, particularly for supplying firewood, water and other goods for the market. Market centres include Isyekone, Kathiani, Mitaboni, Lita and Nzaikono (in Kathiani Division), Kyevaluki, Kakuyuni and Kawethei (in Kangundo Division) as well as to Vyalya, Masii, Mwala and Makutano (in Mwala Division). Homesteads within the catchment usually use firewood as their main source of energy for cooking. Additional firewood is used for making charcoal, which is an alternative source of energy. The demand for firewood has led to the clearing of Iveti forest in some parts of the catchment. Consequently, indigenous tree species are being replaced by eucalyptus, grevillea and other alien tree species. The scarcity of forest resources justifies high prices of firewood, timber and related products.

3.2.8 Muooni Dam Characteristics

Table 3.4 presents some key characteristics of the Muooni Dam, which is the major water source of the catchment. Water in the catchment is mainly supplied by Muooni Water Project relying totally on Muooni dam. Muooni dam is a small dam built by the Ministry of Water (from April 1986 to June 1987). It is a kind of overflow gravity dam located in a

narrow part of Muooni River deep valley at Isyekone sub-location (Mitaboni location, Kathiani Division).

Figure 3.4 Average rainfall in south-eastern Kenya



Source: Jaetzold et al. (2007)

Its primary function was to fill the gap in the natural reservoir line left by the stream channel in order to supply water to Mitaboni, Kathiani, Lita and Nzaikono (in Kathiani Division), Kyevaluki, Kakuyuni and Kawethei (in Kangundo Division) as well as to Vyalya, Masii, Mwala and Makutano (in Mwala Division). Yet, Muooni dam water is currently supplied only to Kathiani divisional headquarters (including the market centre, the hospital and the high school) and surrounding rural areas to an average distance of 3 kilometres.

Table 3.4: Key features of Muooni dam design

No	Principal Characteristic	Data	Observations
1.1	Dam site area:	15 hectares	Muooni river, Isyekone sub-location
2.1	Reservoir capacity (1)	1,559,400m ³	Maximum capacity
2.2	Reservoir capacity (2)	836,000 m ³	Median capacity, at the spillway level
2.3	Reservoir capacity (3)	119,400 m ³	Minimum capacity, the threshold
3.1	Spillway capacity	99 m ³ /sec	
3.2	Spillway width (1)	20 m	At chute
3.3	Spillway width (2)	30 m	At entrance
3.4	Spillway length	167 m	
4.1	Cutlet tower height	22 m	
4.2	Cutlet pipe diameter	600 mm	
4.3	Cutlet pipe length	132 m	
5.1	Embankment height	22 m	
6.1	Downstream slope	2:1	Protected by grassing
6.2	Upstream slope	3:1	Rip rap protection with filter cloth layer
7.1	Slope channel velocity (1)	2%	Low
7.2	Slope channel velocity (2)	3%	High

Source: Compiled from MoW (1987)

Athi WRMA Regional Manager observes that the dam site has been so highly eroded that it has a significant impact in the siltation of the dam reservoir. This forces women and children to walk long distances (up to 3 km) for fetching water and grazing animals, with some implications on their health. He also asserts that when the Government of Kenya

built the Muooni dam, its minimum capacity was 1,559,400 m³, with a reservoir area of 15.2 hectares containing 836,000 m³ (at the spillway level) and a threshold of 119,400 m³. Yet, its average storage capacity has decreased since its construction in 1987. This must have some implications on other productive sectors of the local economy due to the loss of precious time for other activities.

3.3 Sampling Methods and Techniques

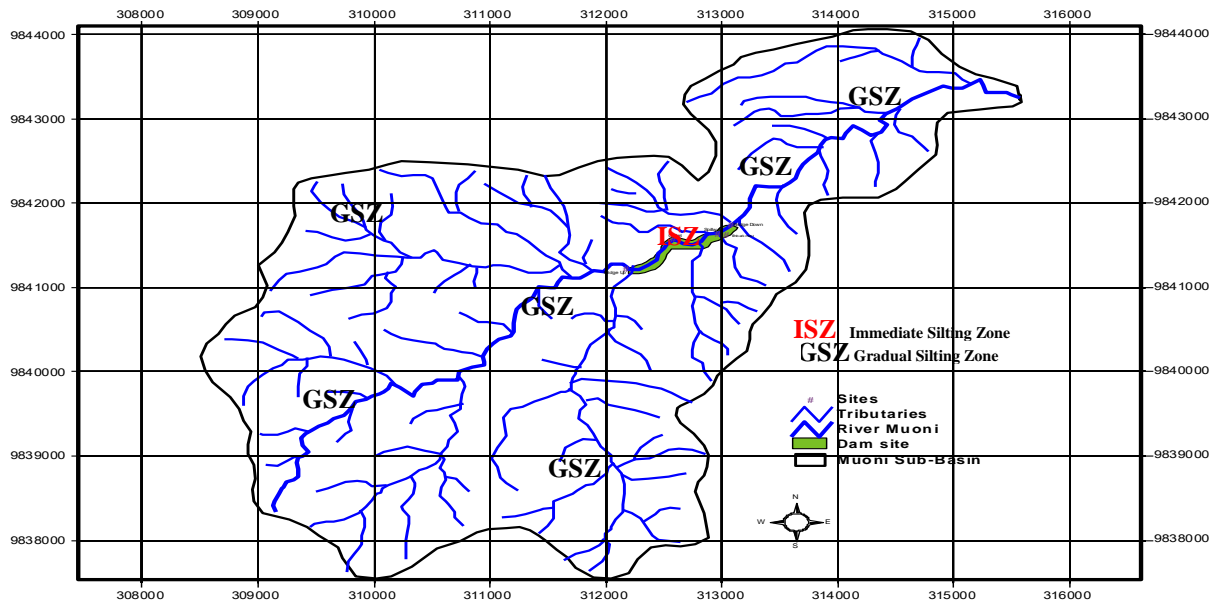
3.3.1 Stratification from Study Area

The study used a stratified random sampling to select farms at Muooni dam site. The site was divided into two zones for easy data collection: Zone 1 was the location of the experimentation group, and Zone 2 encompassed the control group. Zone 1 (the on-farm survey area) was demarcated as the “Immediate Silting Zone” (ISZ) of Muooni Dam, due to its higher altimetry (greater than 1%); and Zone 2 (the interview area) was delineated as “the Gradual Silting Zone” (GSZ), because of its lower altimetry (less than 1%). Figure 3.5 presents the two zones of the study area.

Notice that the two zones were situated within one agro-ecological zone (UM 4) in order to avoid complications due to a wide range of farming practises on the computation of crops water requirements, farmers’ water demand and the subsequent costs. An assumption was made on inputs and outputs prices, that their variations were not significant within the same AEZ. Moreover, farms were classified in three different types for analytical purpose. The first type including “Large Scale Farms (LSF)” referred to all farms having more than 2.5 acres of land area, with a minimum monthly average income of Ksh. 24,000 (i.e. annual income of at least Ksh. 288,000). The “Medium Scale Farms

(MSF)” classification was applied to farms having a land area of between 1 and 2.5 acres, and a monthly average income falling between Ksh. 6,000 and 24,000 (i.e. an annual income falling between Ksh. 72,000 and 288,000). And the last category included “Small Scale Farms” (SSF), which farmlands were less than 1 acre and had a maximum monthly average income of Ksh. 6,000 (i.e. a maximum annual income of Ksh. 72,000). Finally, each zone was allocated a research assistant in order to facilitate communication with local stakeholders through translation. This helped overcome the language barrier.

Figure 3.5: Study area strata



Source: Author (2008)

3.3.2 Impact Assessment Sampling Technique

The research used the impact assessment sampling technique proposed by Gonzalez *et al.* (1995). This technique was particularly useful for recording significant farming activities and their assumed impacts randomly occurring on farming areas. The technique of

sampling was based on the significance of hydro-geomorphologic impacts of each farming activity going on in the Muooni dam site, in terms of sedimentation of the dam and water over-abstraction from the dam reservoir. The weight of each impact on the sedimentation of the dam was represented by a figure (i.e. 1, 2, 3....) indicating the hydro-geomorphologic impact significance (Table 3.5). Figure 3.6 presents the method of mapping farming activities and impacts assessed.

Table 3.5: Key farming activities and hydro-geomorphologic impacts assessed

Weight	Farming Activities	Weight	Hydro-geomorphologic Impacts
1	Tree planting	1	Sheet/ rill erosion in the farm area
2	Intensive cultivation with water pumps/ tanks	2	Agriculture impacts on wetland
3	Subsistence cultivation with limited irrigation	3	Sand harvesting/ quarrying impacts on farms
4	Subsistence cultivation without irrigation	4	Gully erosion in the farm area
5	Livestock keeping with some cultivation	5	Landslide in the farm area
6	Livestock keeping without cultivation	6	Eucalyptus water over-abstraction

Source: Ngonzo (2008)

3.4 Data Collection

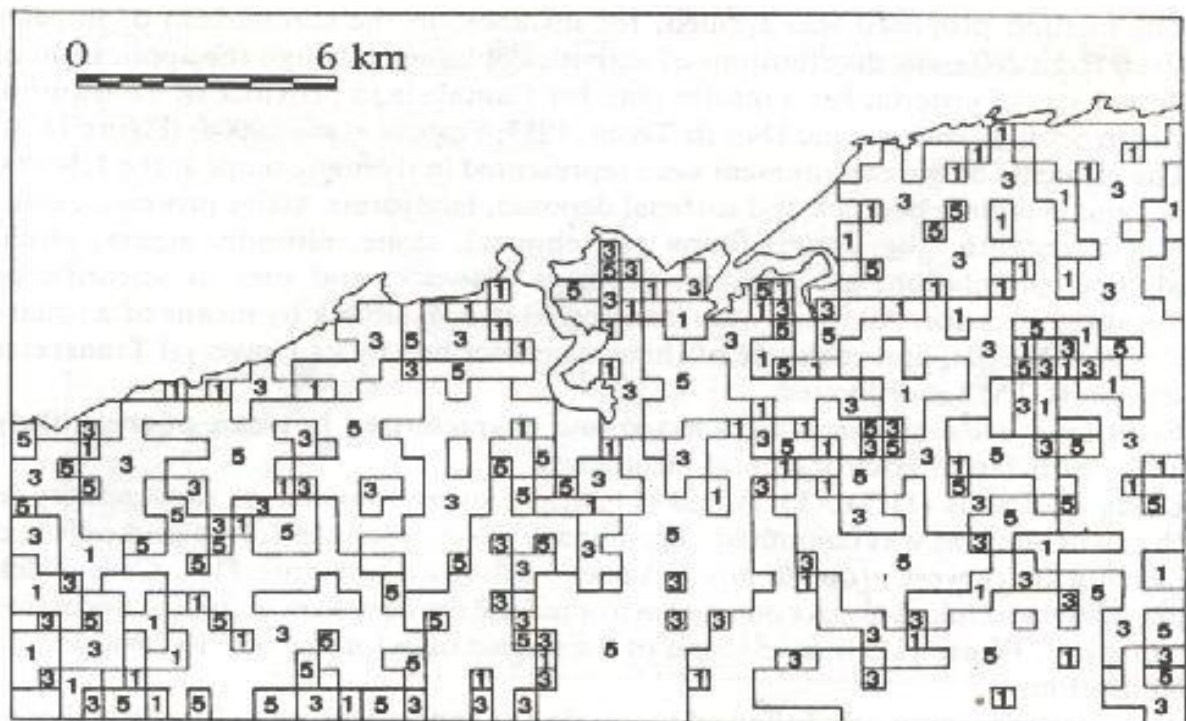
3.4.1 Primary and Computational Data

This study used both primary and computational data (Montello & Sutton, 2006). Primary data were collected using a structured questionnaire for on-farm survey (Appendix 4.6), and institutional interview guides for in-depth interview of the witnessing group (Appendices 4.7 and 4.8). A total of 66 farmers were randomly selected in the ISZ (Zone 1). This helped collecting questionnaires responses from about 70% of the total number of farmers (that is 66 out of 93 farmers). Additional information was collected from an

interview involving some 60 representatives of institutions randomly interrogated through a face-to-face interview in the GSZ (Zone 2). The latter mainly came from the Ministry of Water, Ministry of Agriculture, Ministry of Environment and Mineral Resources, Muooni Water Project, Muooni Treatment Plant, Muooni Coffee Factory, Muooni Dam Site Environmental Committee, NGOs and CBOs, and Kathiani High School.

To collect computational data, technological means were availed. They included a digital camera, Global Positioning System (GPS), Arc View 3.3 Geographic Information System (GIS) and computer machines. These data were particularly processed from the GIS Laboratory of the Geography Department (Kenyatta University) for technical assistance.

Figure 3.6: Catchment hydro-geomorphologic impacts mapping



Source: Gonzalez et al. (1995)

3.4.2 Secondary Data

Primary and computational data were collected, according to the theoretical methods presented in literatures, and in harmony with the study objectives and scope. Secondary data also helped in analysing those data and making a realistic interpretation of the results by triangulation. Secondary data were collected from journals, magazines, books, encyclopaedia, media information, internet browsing and other records or sources of assessment. Thus both official and private sources were consulted. Official sources included governmental reports and laws, as well as documents from other public administrations and international organizations. Private sources consulted were documents from non-governmental institutions and private enterprises. They involved first-hand literature (or original sources of information) and second-hand ones (from “translators” or “encyclopaedists”). The latter covered a collection of information on political economics, eco-economy (or environmental and resource economics), agro-economics, agro-ecology, ecohydrology and integrated watershed management.

3.5 Data Analysis

3.5.1 Data Pre-processing

Data collected were first pre-processed before any quantitative and qualitative analysis. A quality control helped checking their accurateness, reliability and relevance to the study.

Data quantitative analysis in this study essentially dealt with descriptive statistics, time series analysis, a non-parametric test and an operational research simulation. The study used three different computer packages to generate some 1,452 cross-sectional survey data (for a total number of 22 variables), and 840 in-depth interview data (for 14

variables). SPSS-PC and MS EXCEL-PC were used as spreadsheets, and DOVIEW logic models package was utilized for building linkages between different statements. For processing the data, the preliminary requirement involved coding, entering and displaying them for checking and cleaning errors, and finally pre-processing quantitative data and controlling all data quality.

The first step mainly used SPSS spreadsheets (“Data View” and “Variable View”). It was then possible to label the questions and statements on the Variable View spreadsheet, giving them some meaningful values (or codes). This was particularly cumbersome because many statements provided by farmers and institutional representatives were in open-ended questions format. The coding task required a qualitative analysis of statements and their restructuration, and building a coding frame (by grouping all recurrent answers for each open-ended question).

Thereafter came the data entry and display step. Data entry consisted of entering the responses of each respondent into the spreadsheet according to each variable. However, data display was subjected to Data View spreadsheet in order to realize the accuracy of data entry procedure. This exercise led immediately to the checking of errors. Some of the errors detected were related to wrong recording of questionnaire responses, to typing: incorrect input of variable (or a value), to inverting and/or repeating figures (transposing or duplicating successive digits), and to recording deliberate errors (false replies and lies) from respondents. Errors of transcription and omission were noticed on data copied on removable disks. These included corrections made in the removable disk files that were not saved in the hard disk, and vice versa. Sometimes, inattentive data saving led to the

deletion of a number of records in the medium. This enabled cleaning errors and controlling data quality.

Errors were cleaned after checking variables and values row after row and case by case. Then conformity of duplicate data was done in removable disk (with those in the hard disk), and cleaned copies were finally saved. This allowed the quantitative data pre-processing and data quality control to be achieved. Quantitative data pre-processing involved the selection of a descending numeric measuring scale for each type of variables (from ratio and interval values to ordinal and nominal data). A precision was given on the number of figures needed after the comma for ratios and intervals. Data pre-processed had to pass a quality control before any quantitative and qualitative analysis. The very task of research was to confirm whether they were accurate, reliable and relevant to the study, regarding the objectives set beforehand. It was really a fastidious exercise due to the short time of the study, to compile data from 126 respondents and involving 36 variables. However, this step laid a good foundation for the analytical processing of data.

3.5.2 Descriptive Statistical Analysis

Once data were coded, entered and displayed, preliminary checks and quality control performed, statistical spreadsheets (SPSS-PC and MS EXCEL-PC) were able to provide some simple measurements like percentages, averages and dispersion of data around the mean (range and standard deviation). These were used in order to grasp the frequency of farming activities at the Muooni dam site, and their impact on the sedimentation and water excess loss in the dam reservoir.

3.5.3 Non-parametric Tests

The use of non-parametric tests in this study was justified by the fact that there was no factual data on the normality of farming populations in Muooni catchment in general and Muooni dam site in particular. The assumption that farming activities going on in Muooni dam site were causing soil erosion and water over-abstraction was not sufficiently proved by any statistical inference. Since variables tested (farming activities and impacts) were qualitative, there was a need for statistical analysis using ranking techniques. Thus the study used non-parametric tests to determine the relationship between farming activities assessed and the impacts observed in the fields. It made an assumption that the distributions of the two populations (farming activities and impacts) were identical and that there was a strong relationship between the two samples of data collected. That is why, the study needed to confirm those hypotheses through Mann-Whitney U-test and Spearman's Rank Correlation.

First, Mann-Whitney U-test (also known as U-test and Wilcoxon Rank Sum Test) was used to test the null hypothesis that there was no significant difference in the distributions of populations of farming activities and impacts observed at Muooni dam site. Therefore, the following hypotheses were tested:

- $H_0: \mu_1 = \mu_2$, there is no significant difference in the distributions of the populations of farming activities and impacts observed at Muooni dam site
- $H_1: \mu_1 \neq \mu_2$, there is a significant difference in their distributions

The observations from each of the six categories of farming activities and impacts assessed were first ordered and then ranked from lowest to highest. The rankings were

thereafter summed up to yield ΣR_1 , the sum of ranks of farming activities and ΣR_2 , the sum of ranks of impacts. Then Mann-Whitney U-statistic was computed for each sample using the formulae (3.1) and (3.2):

$$U_1 = n_1 n_2 + \frac{n_1(n_1 + 1)}{2} - \sum R_1 \quad (3.1)$$

$$U_2 = n_1 n_2 + \frac{n_2(n_2 + 1)}{2} - \sum R_2 \quad (3.2)$$

The distribution of Mann-Whitney U-statistic was normalized by computing the Z-score value. Mann-Whitney Z-Test was computed according to the relation (3.3):

$$Z = \frac{U_i - \mu_u}{\sigma_u} \quad (3.3)$$

Where,

U_i is the appropriate value for each sample (U_1 and U_2)

μ_u and σ_u are the mean and standard deviation of the sampling distribution computed in the relations (3.4) and (3.5):

$$\mu_u = \frac{n_1 n_2}{2} \quad (3.4)$$

and

$$\sigma_u = \sqrt{\frac{n_1 n_2 (n_1 + n_2 + 1)}{12}} \quad (3.5)$$

By testing the null hypothesis $\mu_1 = \mu_2$ using either U_1 or U_2 in the formula of Z-score, it was possible to reject (or accept) H_0 ($\mu_1 = \mu_2$) if Z_u (Z value in the statistical tables) was inferior or superior to Z_α . The sum $U_1 + U_2 = n_1 n_2$ provided a quick check of the accuracy of the computations.

Using Spearman's Rank Correlation, the analysis tested the following hypotheses:

- $H_0 : \rho_s=0$, there is no significant relationship between the populations of farming activities and impacts assessed at Muooni Dam site
- $H_1 : \rho_s \neq 0$, there is a significant relationship between the two populations

First observations were ordered and then ranked from lowest to highest. Afterwards, the differences between the rankings were calculated and then squared. The latter were summed up to yield $\sum d_i^2$. Then Spearman's Rank Correlation Coefficient (r_s) was calculated using the formula (3.6):

$$r_s = 1 - \frac{6\sum d^2}{n(n^2 - 1)} \quad (3.6)$$

Recalling that the coefficient of correlation falls between -1 and 1 provided a quick check of the statistic accuracy; it also helped deciding on the type of relationship between the two variables (positive or negative, strong or weak). The Z-test value of the sampling distribution was then calculated as follows (3.7):

$$Z_u = \frac{r_s - 0}{1/\sqrt{n-1}} = \dots r_s \sqrt{n-1} \quad (3.7)$$

Using the Z-test value from this relation (3.7), a decision was made for rejecting (or accepting) H_0 ($\rho_s=0$), there is no significant relationship between the two variables.

The decision rule was the following:

If $Z_u > Z_{\alpha}$, rejection of H_0 ($\rho_s=0$), and acceptance of H_1 ($\rho_s \neq 0$), for absolute Z values;

If $Z_u < Z_{\alpha}$, acceptance of H_0 ($\rho_s=0$) and rejection of H_1 ($\rho_s \neq 0$), for absolute Z values.

This meant that the contribution of farming activities to the erosion at Muooni dam site and its reservoir water excess loss were or not strongly correlated.

3.5.4 Time Series Analysis

This study used time series data of Muooni dam's water active storage capacity. They were adjusted according to Ordinary Least Squares (OLS) regression technique. The latter aimed at assessing a trendline predicting the storage capacity by the time. In fact, the main hypothesis retained by most public servants and key informants was that sediment load from farms was decreasing the dam reservoir capacity year after year. To certify that hypothesis, the analysis first minimized it by assuming that the dam's active water storage capacity was totally dependent of its logistics quality to resist the time; and that the obsolescence (or old-age) of its infrastructure affected directly its capacity to retain water in store.

After data collection and pre-process, the next step was to adjust the data to the time (t). The following regression model (3.8) proposed by Gregory (2003) was used:

$$S_t = a * e^{b * t} \quad (3.8 \text{ a})$$

Where,

S was the dam's water active storage capacity

b was considered as the elasticity of the storage capacity by the time; and

a was meant to be the impact of external factors (like sedimentation) on S .

In order to compute the coefficients a and b , the model was first linearized using the Neperian logarithm (ln) (Webster, 1995). After introduction of the natural logarithm, the following linear function was obtained:

$$\text{Ln}(S_i) = \text{Ln}(a) + b * t \quad (3.8 \text{ b})$$

The parameters $\text{Ln}(a)$ and b were computed according to the formulae (3.9) and (3.10):

$$b = \frac{n * \text{Sum}(ts) - \text{Sum}(t) * \text{Sum}(s)}{n * \text{Sum Sq}(t) - \text{Sq Sum}(t)} \quad (3.9)$$

$$\text{Ln}(a) = \text{Mean}(s) - b * \text{Mean}(t) \quad (3.10)$$

The dependant variable S and the constant a were respectively derived from the exponential (exp) function of $\text{Ln}(S_i)$ and $\text{Ln}(a)$. For testing the quality of the adjustment, SPSS provided some details on the mean, the standard error and the error term of the predicted storage capacity. It provided also meaningful figures on the correlation coefficient and the coefficient of determination. The latter helped assessing the extent to which the dam logistics obsolescence and external factors (notably the sedimentation of the dam reservoir from farming activities) impacted each on its storage capacity.

Spearman's Rho Test was used to assert whether the prediction model was sufficiently strong to explain the variation of Muooni dam's active storage capacity by the time.

Using the Rho test, the analysis proceeded to verify the following hypotheses:

- H_0 : $\rho=0$, there is a no strong relationship between the variation of the dam storage capacity and the variation of the time.
- H_1 : $\rho>0$, there is a strong relationship between the variation of the dam storage capacity and the variation of the time.

The t-test statistics mentioned in relation (3.11) was used for testing the null hypothesis.

The result was judged according to the following rule:

If $t_{p;n-2} > t_{\alpha;n-2}$, rejection of H_0 and acceptance of H_1 , for all absolute t values;

If $t_{p;n-2} < t_{\alpha;n-2}$, acceptance of H_0 and rejection of H_1 , for all absolute t values.

Where,

$t_{\alpha;n-2}$ is the theoretic t-test statistic given by statistical tables; and

$t_{p;n-2}$ is the experimental t-test statistic computed as follows:

$$t_{p;n-2} = \frac{r - \rho}{S_r} \quad (3.11)$$

Where,

r is the sample correlation coefficient

ρ is the population correlation coefficient (hypothesised to be equal to zero)

S_r is the standard deviation of the sample correlation coefficient.

After this process, the final decision was made on the kind of relationship that existed between the dam decreasing storage capacity and its logistics obsolescence on one end, and between the decreasing storage capacity and external factors (sedimentation particularly) on the other end.

3.5.5 Operational Research Simulation

As most scholars suggest it, the use of hybrid models help in integrating variables of watershed resources management, economic performance and socio-environmental sustainability to spatially distributed and mathematical descriptions of water discharge and storage (GDAE, 2008; Kasambala *et al.*, 2006; Brown, 2001; Brasington *et al.*, 1998). Two of the objectives of this study were dealing respectively with the computation of farmers' water demand and related costs variations, and the evaluation of their economic water demand, limit costs variations and farming production efficient scales related to subsequent rainfall fluctuations. That is why the analysis used a hybrid operational model to achieve these objectives. The latter was adapted after Wilson inventory model, Baumol monetary model and Beranek treasury model (Ngonzo, 1999). It helped in computing

agricultural production water “Economic Order Quantity” (EOQ), Limit Average Cost (LAC) and “Minimum Efficient Scale” (MES).

The analysis assumed that soil and water losses reduce agricultural efficiency through increased costs of production. The total farming cost function under normal rainfall regimes (NOR) is a combination of respective costs of transaction and opportunity costs. However, under above normal rainfall (ANOR) and below normal (BNOR) regimes, the total cost is respectively overloaded by the costs of water savings and by the shortage costs. Another assumption was that rainfall fluctuation was reflected in the variation of the dam’s active water storage capacity. Therefore, the NOR scenario referred to an active storage capacity relatively equal to engineers’ median capacity. The ANOR and BNOR scenarios indicated an active storage capacity that was respectively above the median and below the threshold.

Crop Water Requirement (W_c) was derived from “Virtual Water Values” (VWV) as:

$$W_c = \frac{ETP_c}{Y_c} \quad (3.12)$$

Where,

ETP_c is the total crops water evapotranspiration (in m^3) during crop growth, computed according to data provided by FAO (2008).

Y_c is the total crop yield (in Kg)

The farmer water demand was given by the relation (3.13):

$$W_f = n \cdot W_c / 2 = r W_c \quad (3.13)$$

Where,

$W_c/2$ was the average daily crops water demand (water withdrawn twice a day)

n was the total number of water withdrawals over a period of time

r was a theoretic water demand turnover, supposed to be equal to $2/n$, and to the

ratio of the active water storage capacity and the median one ($\hat{S}_t/S_{m\acute{e}}$).

The farmers' incomes (Y) and expenditures (E) were standardized as follows:

$$Y = P.W_c/2.Q \quad (3.14)$$

$$E = P.W_c/2.q \quad (3.15)$$

Where,

Q was the farming activity standardized output

q was the farming activity standardized input

P was the standard water price per m^3

To simplify the incremental analysis, three minimum efficient farms were selected, one for each farming scale. The total, average and marginal costs functions for each of the three farming scales were computed under different rainfall scenarios as described below.

Under the NOR scenario, the main hypothesis was that the farming activity was not expected to incur any significant profits nor losses, only farmers bearing normal costs of transaction and opportunity costs. Thus, the following total cost function was computed under the NOR scenario:

$$TC_{no} = C_t (=n.E) + C_o (= r.Y) = Y r + 2E/r \quad (3.16)$$

Where,

C_t , the cost of transaction

C_o , the opportunity cost

Under ANOR scenario, the most important assumption was that the farming activity was resulting in significant profits or losses depending on the impact of rainfall fluctuation on the farming environment and the farmer cost of water savings. If rainfall incurred important cost of water savings (in addition to normal costs of transaction and opportunity costs), there were many chances to see the farming activity resulting in significant yield losses. Otherwise, the farming activity was likely to be more profitable under above normal rainfall regime. The total cost function computed was the following under the ANOR scenario:

$$TC_{an} = C_t (=n.E) + C_s (= r.Y+l\Pi) = (Y+\Pi)r-\Pi + 2E/r \quad (3.17)$$

Where,

C_s , the cost of water savings

Π was the farmer profit, computed in absolute values of $Y-E$.

l was the loss of water profitability under above normal rainfall (equal to $r-1$)

Under the BNOR scenario, it was assumed that the farming activity was expected to result in significant losses. In the absence of rainfall, farmers were to bear the cost of water shortage in addition to normal costs of transaction and opportunity costs. So, the following total cost function was computed under this scenario:

$$TC_{bn} = C_t (=n.E) + C_s^* (= r.Y + l^*\Pi) = (Y-\Pi) r+\Pi+ 2E/r \quad (3.18)$$

Where,

C_s^* , water shortage cost

l^* was the loss of water profitability under below normal rainfall (equal to $1-r$);

The Average Cost (AC) and Marginal Cost (MC) functions were obtained as follows:

$$AC = \frac{TC}{r} \quad (3.19)$$

$$MC = \frac{dTC}{dr} \quad (3.20)$$

And considering the Original Total Cost (OTC) functions (3.16), (3.17) and (3.18), the Original Average Cost (OAC) and Marginal Cost (OMC) functions derived from the relations (3.19) and (3.20) were obtained as follows:

(i) Under the NOR scenario:

$$AC_{no} = \frac{TC_{no}}{r_{no}} = Y^2 + 2E/r^2 \quad (3.21)$$

$$MC_{no} = \frac{dTC_{no}}{dr_{no}} = Y - 2E/r^2 \quad (3.22)$$

(ii) Under ANOR scenario:

$$AC_{an} = \frac{TC_{an}}{r_{an}} = Y + \Pi - \Pi/r + 2E/r^2 \quad (3.23)$$

$$MC_{an} = \frac{dTC_{an}}{dr_{an}} = Y + \Pi - 2E/r^2 \quad (3.24)$$

(iii) Under BNOR scenario:

$$AC_{bn} = \frac{TC_{bn}}{r_{bn}} = Y - \Pi + \Pi/r + 2E/r^2 \quad (3.25)$$

$$MC_{bn} = \frac{dTC_{bn}}{dr_{bn}} = Y - \Pi - 2E/r^2 \quad (3.26)$$

After computing cost values in monetary terms using theoretic water demand turnover (derived from the variations of the dam's active water storage capacity), the analysis proceeded to optimize the said water demand turnover in order to minimize farming costs

for each farming scale and rainfall regime scenario. The following optimized water demand turnover (\bar{r}) values were derived from each marginal cost function:

(i) Under the NOR scenario:

$$\bar{r}_{no} = \sqrt{2q/Q} \quad (3.27)$$

(ii) Under ANOR scenario:

$$\bar{r}_{an} = \sqrt{2q/(2Q - q)} \quad (3.28)$$

(iii) Under BNOR scenario:

$$\bar{r}_{bn} = \sqrt{2} \quad (3.29)$$

Using MS EXCEL datasheet for each optimized \bar{r} values, farmers' EOQ (\bar{W}_f), LAC and MES were computed from their cost functions and crops water requirements values. Water "Economic Order Quantity" (EOQ) was computed as the optimized farmer water demand (\bar{W}_{ff}) as follows:

$$EOQ = \bar{W}_f = \bar{r} W_c \quad (3.30)$$

To compute the LAC, it was hypothesized that farming profitability was the most important economic incentive leading to farmlands subdivision in Muooni catchment. It was assumed that new farmers entering the agricultural industry had less absolute cost advantages than existing farmers, in the short term. So, their average costs were supposed to be significantly higher than the latter. Cost advantages of older farmers' were probably due to land ownership and free water abstraction from the dam reservoir or from the

wetlands. They might also have included technological advantages, farming skills and knowledge of the environment as well as other factors helping them minimize the costs due to externalities. Finally, satisfactory credit ratings and patents allowing them purchase inputs and borrow money at low rates might have been among such advantages attracting new entrants. However, the latter needed first a lot of time for developing such skills and credit relations. Therefore, there was a certain Limit Average Cost (LAC) at which new farmers could enter the industry without making any loss. At that point, existing farmers needed to adjust their prices just below the LAC in order to discourage new comers and conquer definitely the market. Yet, they would have sacrificed some of their short-term benefits if economies of large-scale production were not practised. This might have resulted in high average costs for small-scale production farmers. They might have decided to practise subsistence agriculture and off-farm activities to ensure their livelihood (rather than competing with large and medium scale farmers). However, before deciding to renounce, they needed to agree on a certain size of losses below which they could continue competing. The latter determined their “Minimum Efficient Scale” (MES). The MES thus referred to the smallest size of agricultural production loss that could reap all the available economies of scale. The larger the loss size, the greater the production MES. This was the very dilemma facing most smallholder farms at Muoni dam site: to determine their farming production MES.

The farming production MES was calculated from data collected on farms having incurred the minimum loss at each farming scale. The Minimum Average Cost (MAC) and Marginal Cost (MMC) functions as well as the optimized water demand turnover

value (\bar{r}_{bn}) were obtained under the scenario of below normal rainfall regime. The MES was then computed as the farmer's EOQ (mW_f).

For analytical purpose, the following formulae were used in order to assess the variations of costs, incomes and crops water requirement under different hypotheses of farming production EOQ, LAC and MES:

$$\text{Expected Costs Variation} = \frac{MAC - OAC}{OAC} \quad (3.31)$$

$$\text{Expected Income Variation} = \frac{MAC - Y}{Y} \quad (3.32)$$

$$\text{Expected Water Demand Variation} = \frac{\min W_f - W_f}{W_f} \quad (3.33)$$

3.6 Interpretation and Presentation of Results

After analysis of the data, some findings were tabulated, others presented in graphic and text forms. A triangulation of quantitative results with qualitative outputs from literature was done for assessing the pertinence of the findings. It also helped drawing meaningful conclusions and recommending sustainable farming activities at Muooni catchment in general, and Muooni dam site in particular. A final quality control of findings was made according to recent scientific knowledge on the matter. Using relevant information from literature, the research cross-checked for deviations from similar studies in literature, and provided plausible for such. The results obtained and their discussion along with the conclusions made and policy guidelines recommended are presented in the following chapters.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents the results and discusses findings from the on-farm survey conducted at Muooni dam site and the in-depth interviews involving public officers and other key informants working within Muooni catchment. Results of the ex-post socio-economic and environmental impacts assessment are presented and discussed as well as those of farmers' operational costs and water demand simulations.

4.2. Ex Post Impacts Assessment Results and Discussion

4.2.1 Results of Ex Post Impacts Assessment

During the on-farm survey, the total farming area occupied by smallholder farmers visited was estimated at 31.2 acres. As shown in Table 4.1 and Figure 4.1, the most significant activities noticed on farms were related to agro-forestry (within an average of 45.5% farms), and subsistence cultivation without irrigation (representing 28.8%). Other farming activities included livestock keeping with some cultivation (12.1%), intensive cultivation using water pumping and storing devices (10.6%), and subsistence cultivation with limited irrigation (3%). No one was practising livestock keeping without cultivating.

Farmers were enhancing soil protection using mainly terracing, polyculture and agro-forestry. Some others utilized to their best contouring and cut-off drains. Farming knowledge and some conservation measures taken against soil erosion were an indication of farmers' awareness on environmental degradation problems. This is also reflected in

the distribution of farmers by level of education. Most farmers interviewed have attained some formal education level, with respectively primary (33.3%) and secondary school certificates (30.3%), professional credentials (12.1%) and university degrees (6.1%). Only some 18.2% of the farmers interviewed had no formal education (Figure 4.2).

Table 4.1: Types of farming activities assessed at Muooni dam site

Weight	Farming Activities	Frequency	Percentage
1	Tree planting	30	45.45
2	Intensive cultivation with water pumps/ tanks	7	10.61
3	Subsistence cultivation with limited irrigation	2	03.03
4	Subsistence cultivation without irrigation	19	28.79
5	Livestock keeping with some cultivation	8	12.12
6	Livestock keeping without cultivation	0	0.0

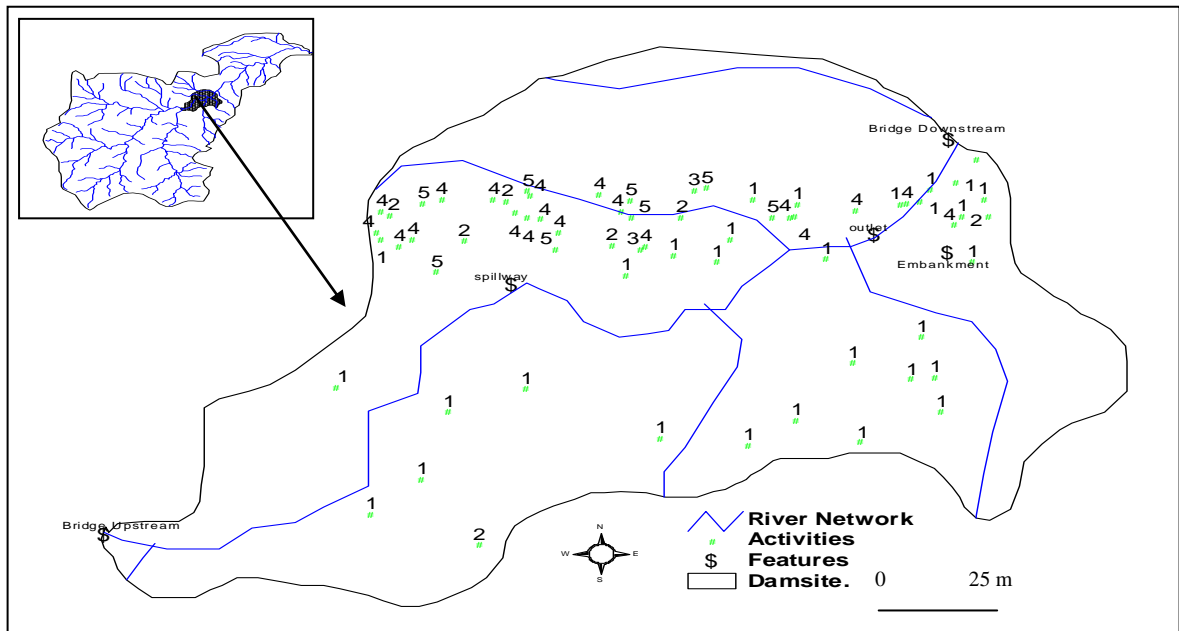
Source: Fieldwork (2008)

According to this table and Figure 4.1, the activities assessed were weighted from 1 to 6 based on the significance of their hydro-geomorphologic impact on Muooni dam site soil erosion and the dam reservoir's water over-abstraction. Sub-section 3.3.2 provides details on the methodology used, and Figure 4.1 presents the spatial distribution of the farming activities assessed according to their respective weights.

It was observed that all farmers had high preference for maize and cowpeas. The main reason is that maize and cowpeas are used to cook the traditional meal of Muthokoyi, and thus have a local market. Cassava, French beans, Irish and sweet potatoes were also important food crops (). The main perennial crops grown in the study area were banana, avocado, coffee, mangoes and sugarcane. Figures 4.3 and 4.4 give an idea about the most important subsistence food and perennial crops grown in Muooni dam site. It can be

noted that a majority of farmers supplement their crop yield with dairy and meat products. Also, only 9.1% of farmers are not keeping any form of livestock (Figure 4.5). The livestock keeping enterprise is composed of goats (69.7%), cattle (54.6%), poultry (48.5%), sheep (24.2%) and pig keeping (15.2%).

Figure 4.1: Spatial distribution of farming activities in the dam site



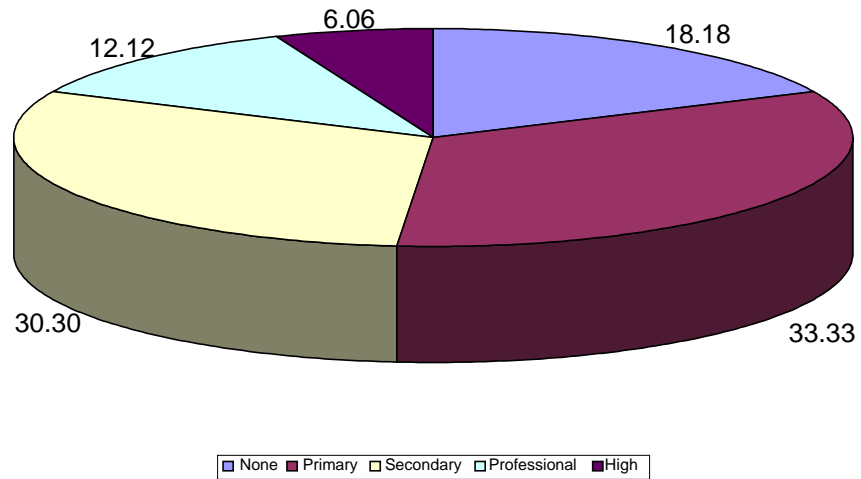
Source: Author (2008)

Notice: Table 4.1 indicates the legend of activities and their weight (1, 2, 3, 4, 5 and 6)

The on-farm survey also revealed that the average annual average income per farm recorded is Ksh. 166,526, which is equivalent to USD 231 per year and less than \$1 per day. Most farms surveyed are Small Scale Farms (SSF)(30.3%), fall between SSF and MSF (30.3%); some 21.2% fall under the category of Middle Scale Farms (MSF), 10.6% between MSF and LSF, and 7.6% under the Large Scale Farms (LSF) category. This distribution of farmers by class of income is dominated by farms earning below Ksh.

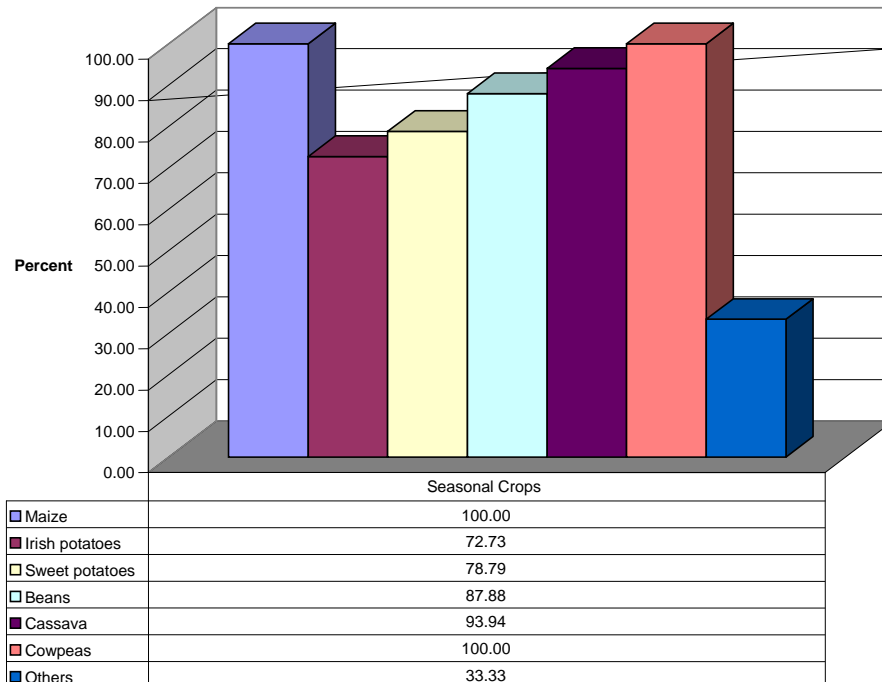
3,000 of monthly income (50% of farms) and those gaining between Ksh. 3,000 and 5,999 per month (10.6%). This confirms that poverty is a reality in the study area.

Figure 4.2: Farmers' level of education



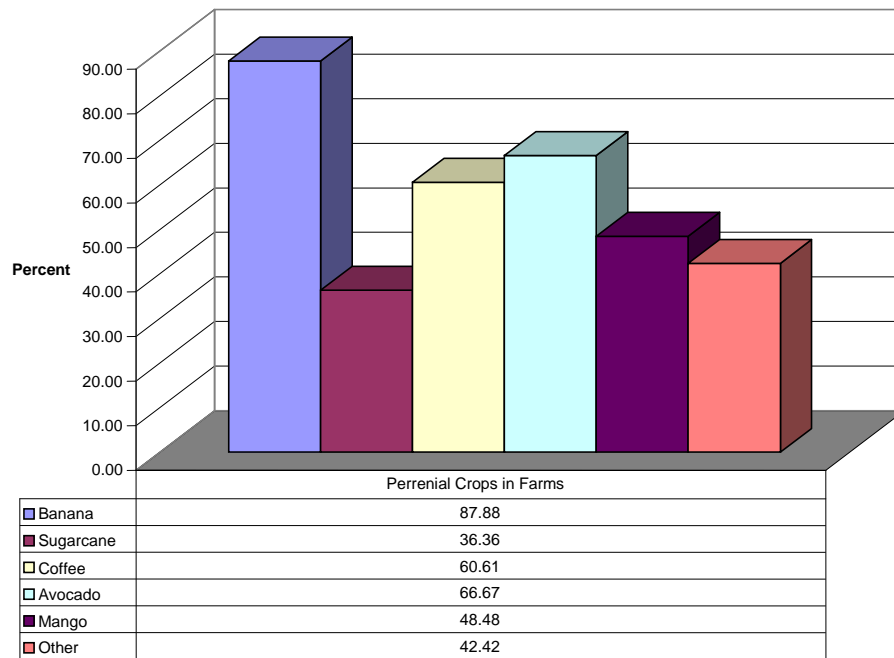
Source: Fieldwork (2008)

Figure 4.3: Subsistence food crops grown



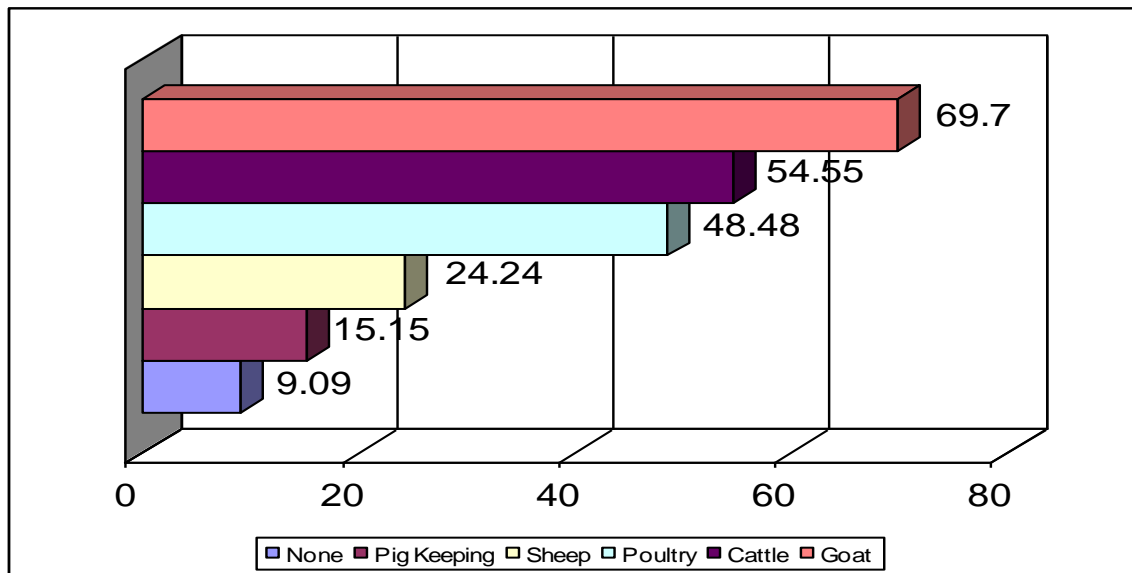
Source: Fieldwork (2008)

Figure 4.4: Main perennial crops grown



Source: Fieldwork (2008)

Figure 4.5: Livestock keeping



Source: Fieldwork (2008)

Table 4.2 illustrates the farmers' annual income, while Figure 4.6 shows farmers' distribution according to their farming category and monthly income. According to their social status, most of the farmers interviewed are workers in private enterprises (36.4%) or full-time farmers (33.3%). Others are self-employed, i.e practising off-farm businesses (21.2%) or are civil servants (9.1%). None of the respondents indicated that he was a school teacher or a lecturer (See Figure 4.7). It should be noted that gender balance is serious issue in the area. No woman was allowed to respond to the survey, unless authorized by the husband. The 2 females (out of 66 farmers) interviewed were widows.

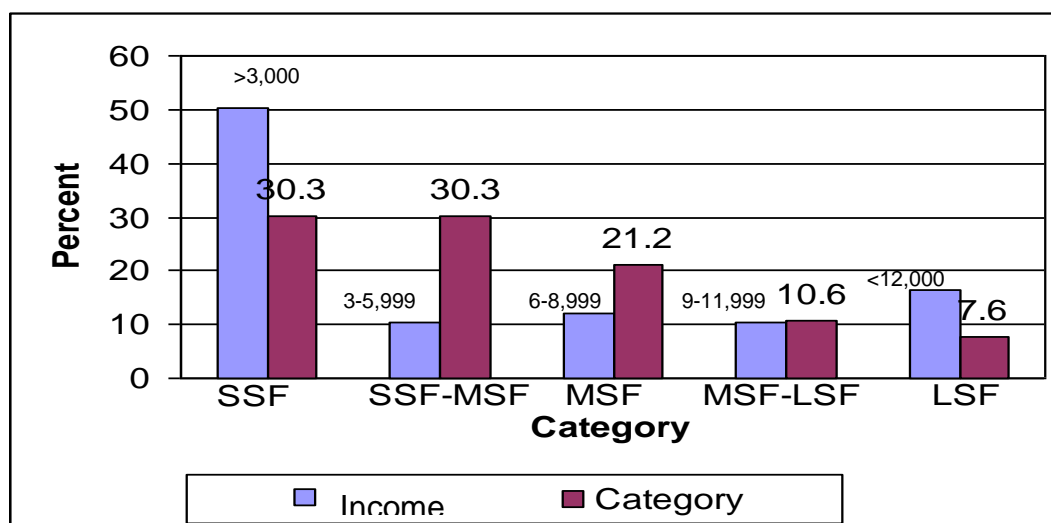
Table 4.2: Allocation of farmers' annual income

N°	Operations	LSF operations Value	MSF operations Value	SSF operations Value
1	Farming Income	428,400	273,600	55,800
1.1	Total Income	428,400	273,600	55,800
1.2	Average Income/m ³	85.84	65.68	51.62
1.3	Marginal Income/m ³	84.84	65.68	51.62
2	Farming Expenditures	569,000	276,500	63,530

2.1	Seeds	10,000	17,500	2,110
2.2	Fertilizers	23,000	0	1,900
2.3	Pesticides	8,000	16,000	0
2.4	Water	0	0	12,000
2.5	Water Pumps Fuel	360,000	135,000	0
2.6	Wages	108,000	81,000	0
2.7	Transport	60,000	27,000	11,520
2.8	Food	0	0	36,000
2.9	Total Cost	569,000	276,500	63,530
2.10	Average Cost /m ³	114.9065	66.3773	58.7648
2.11	Marginal Cost /m ³	114.9065	66.3773	58.7648
3.0	Farming Profit	-140,600	-8.111	-7,730
3.1	Total Profit	-140,600	-8.111	-7,730
3.2	Average Profit/m ³	-28.1725	-0.701	-7.1502
3.3	Marginal Profit/m ³	-28.1725	-0.701	-7.1502

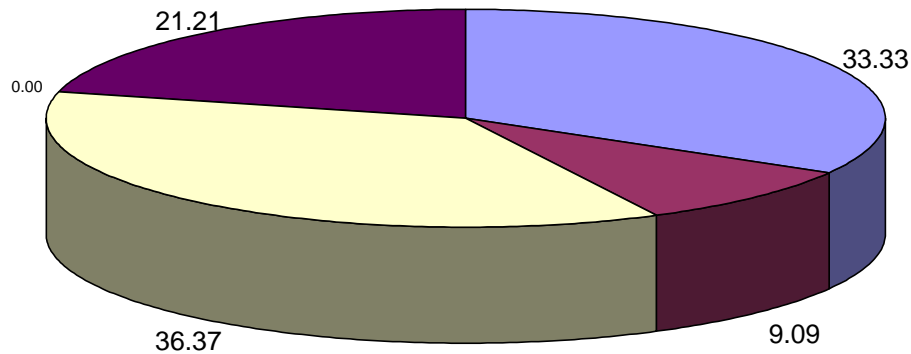
Source: Fieldwork (2008)

Figure 4.6: Farmers' distribution per income class and farming category



Source: Fieldwork (2008)

Figure 4.7: Social categories of farmers



Source: *Review (2000)*

Concerning the environmental impact assessment, the main hypothesis of this study was that the siltation of Muooni dam was a resultant of the effects of farming activities going on around the dam site. The likely significant impacts assessed during the on-farm survey were weighted according to Table 4.3 and illustrated by Figure 4.8. These included: agricultural impacts on wetlands, eucalyptus trees impact on water resources, sheet and rill erosions, sand harvesting and quarrying, gully erosion, and landslides in the farming areas. Notice that rills and sheets represented more than half of the impacts observed on the farms and that 18.2% impacts recorded were coming from the adverse effects of eucalyptus tree planting. Other significant impacts included: agricultural impacts on wetlands, gully erosion and landslides. Although sand harvesting and quarrying are widespread in the catchment, no impact from them was recorded within the dam site.

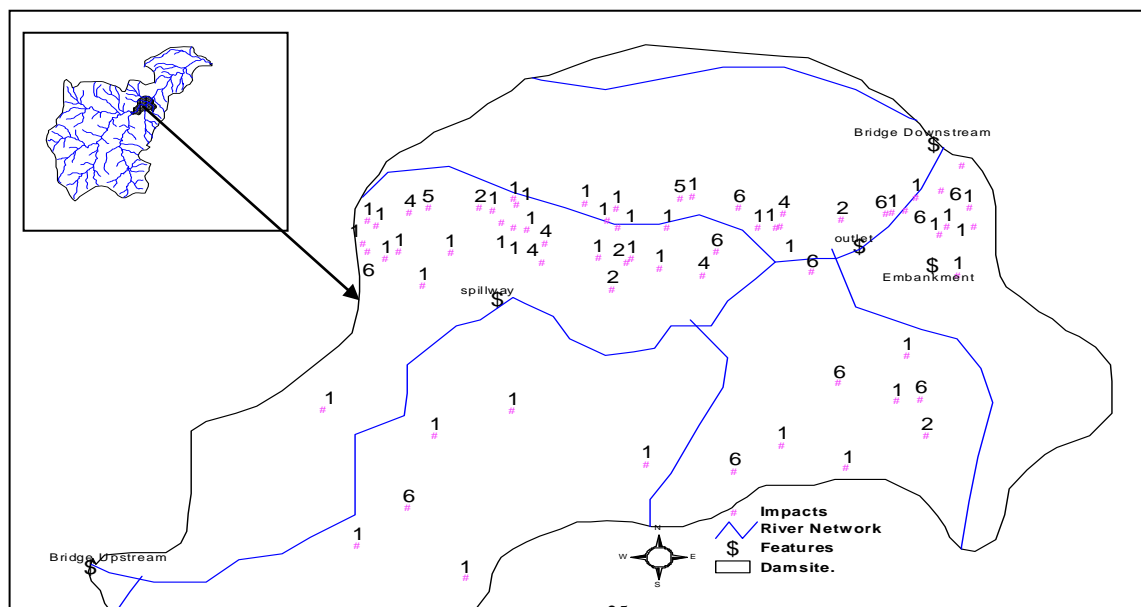
Table 4.3: Environmental impacts of farming activities assessed

Weight	Hydro-geomorphologic Impacts Recorded	Frequency	Percentage
1	Sheet/ rill erosion in the farm area	42	63.63
2	Agriculture impacts on wetland	5	7.575
3	Sand harvesting/ quarrying impacts on farms	0	0.0
4	Gully erosion in the farm area	5	7.575
5	Landslide in the farm area	2	03.03
6	Eucalyptus water over-abstraction	12	18.18

Source: Fieldwork (2008)

A correlation between impacts assessed and the social status of farmers shows that 63.6% of the total number of sheets and rills recorded were observed on lands owned by full-time farmers and farmers employed in private enterprises. They were associated mostly with tree planting, subsistence cultivation without irrigation, dairy farming with some cultivation and intensive cultivation using water pumping devices (Figure 4.9).

Figure 4 8: Spatial distribution of farming environmental impacts in the dam site

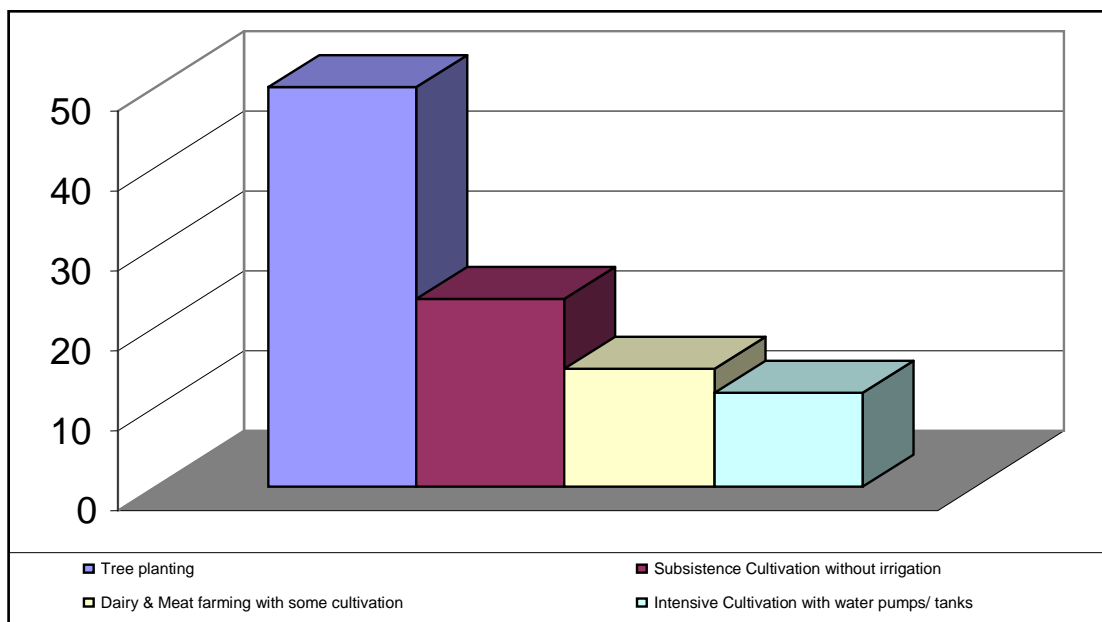


Source: Author (2008)

Notice: Table 4.3 indicates the legend of activities and their weight (1, 2, 3, 4, 5 and 6)

Plate 4.1 gives a view of rill erosion in Muooni dam site. It should be retained that almost all the fields were affected by sheets and rills (maybe because of the topography of the area). The total farming area and income of farms threatened by sheet and rill erosion was respectively equal to 19.9 acres and Ksh. 298,620 (that is approximately 57% of the total monthly income of all the farmers surveyed, and an average of Ksh. 7,110 per farmer).

Figure 4.9: Relation between farming activities and rill-sheet erosion



Source: Fieldwork (2008)

Plate 4.1: Rill erosion in Muooni dam site

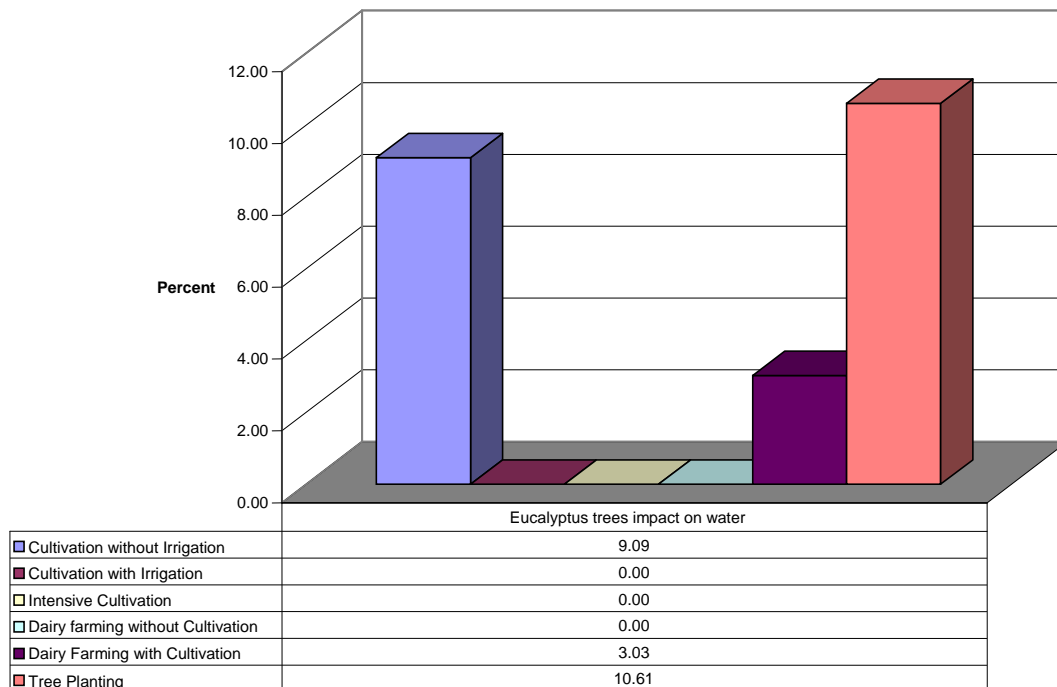


Source: Fieldwork (2008)

A majority among farmers have planted eucalyptus trees in the contour of their farmlands. Yet, the impact of water over-abstraction by eucalyptus trees can only be assessed on 9.1% farms surveyed, which had exclusive syvicultural eucalyptus tree plantations. Among them, 66.7% were employed by the private sector, some even having high level of education. The total farming area exclusively covered by eucalyptus trees is about 2.83 acres, and farmers owning that land gain an average of Ksh. 18,746 monthly. The most favourable farming activities associated with eucalyptus trees planting were fruit trees planting and agro-forestry (46.7%), subsistence cultivation without irrigation (40%) and dairy farming with some cultivation (13.3%). The most dominant crop fields associated with eucalyptus trees compounded bananas, coffee and avocados (for perennial crops), and cowpeas, maize, Irish and sweet potatoes, French beans and cassavas (for seasonal crops). Figure 4.10 and Plate 4.2 summarize these results.

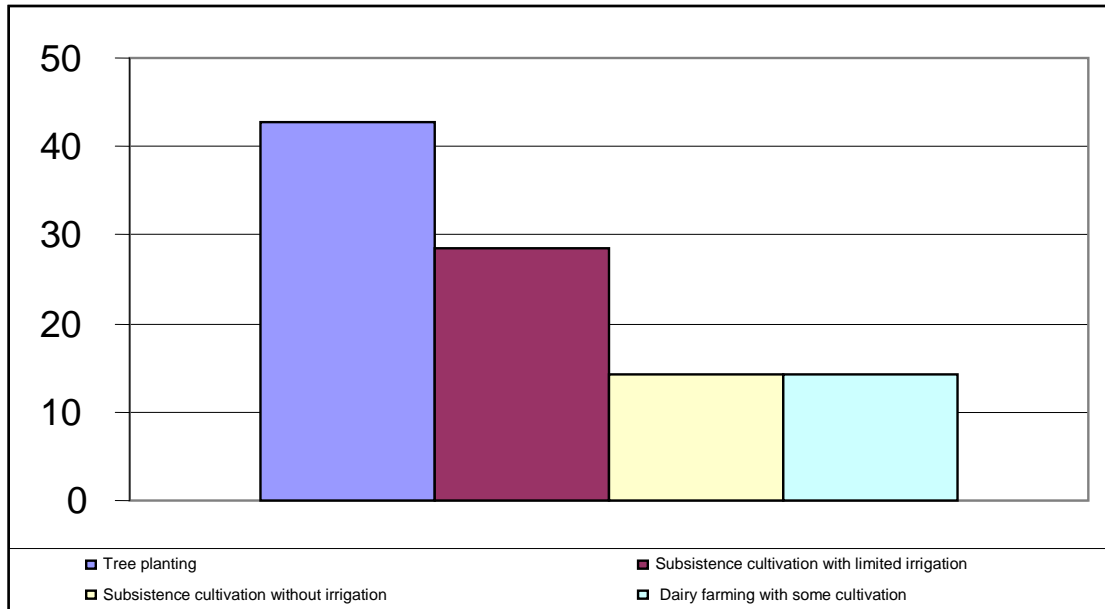
Concerning agriculture impact on wetlands degradation, it was observed that 10.6% of farmers were practising agriculture in wetlands located at Muooni Dam site. Farming activities developed there included tree planting and subsistence cultivation with limited irrigation were represented by 42.8% and 28.5% farmers, respectively. Subsistence cultivation without irrigation and livestock keeping with some cultivation represented each 14.3% of farms in wetlands (see Figure 4.11 and Plate 4.3). It should be noticed that the most dominant crops in the wetlands include bananas, and cowpeas, maize, Irish and sweet potatoes, French beans and cassavas. They cover an average area of about 3.31 acres, essentially belonging to farmers having at least primary education certificates with professional credits and an average monthly income of Ksh. 5,663.

Figure 4.10: Farming activities associated with eucalyptus tree planting



Source: Fieldwork (2008)

Figure 4.11: Farming activities impacting on wetlands at Muooni dam site



Source: Fieldwork (2008)

Plate 4.2: Eucalyptus tree planting and terracing at Muooni dam site



Source: Fieldwork (2008)

Plate 4.3: Some farming activities in the wetland near Muooni dam

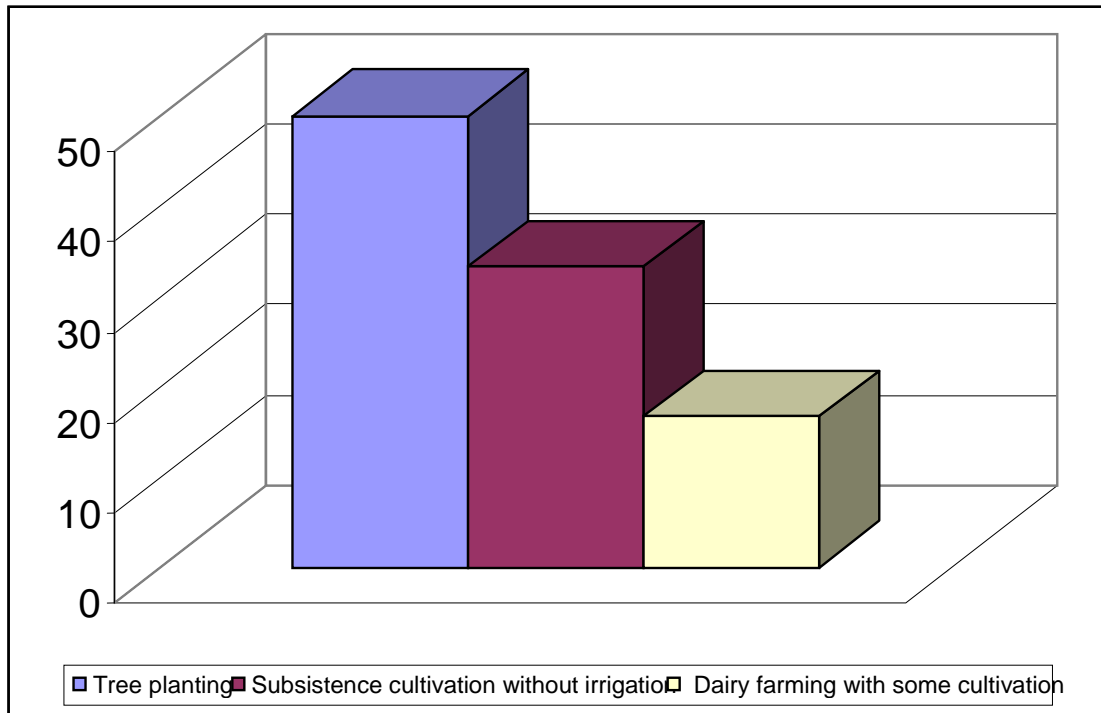


Source: Fieldwork (2008)

Regarding gully erosion in farmlands, five cases of gullies were recorded on farms (that is 7.6% of farms surveyed). Few gullies were observed in farms owned by full-time farmers. Farms with gullies covered about 4.11 acres of farmlands and their owners yield on average Ksh. 2,638 each month. Their formal education level ranged from none up to secondary education with some professional credits. Half of the farms with gullies were practising tree planting, 33.3% subsistence cultivation without irrigation, and 16.7% dairy farming with some cultivation. Figure 4.12 and plate 4.4 illustrate these findings.

Two cases of landslides established a relationship between land-use activities and mass movements at Muooni dam site. They affected one full-time farmer without formal education and a farmer employed in off-farm sector with primary education, and mainly practising subsistence cultivation without irrigation and tree planting

Figure 4.12: Farming activities threatened by the presence of gullies



Source: Fieldwork (2008)

Plate 4.4: Gully erosion at Muooni dam site



Source: Fieldwork (2008)

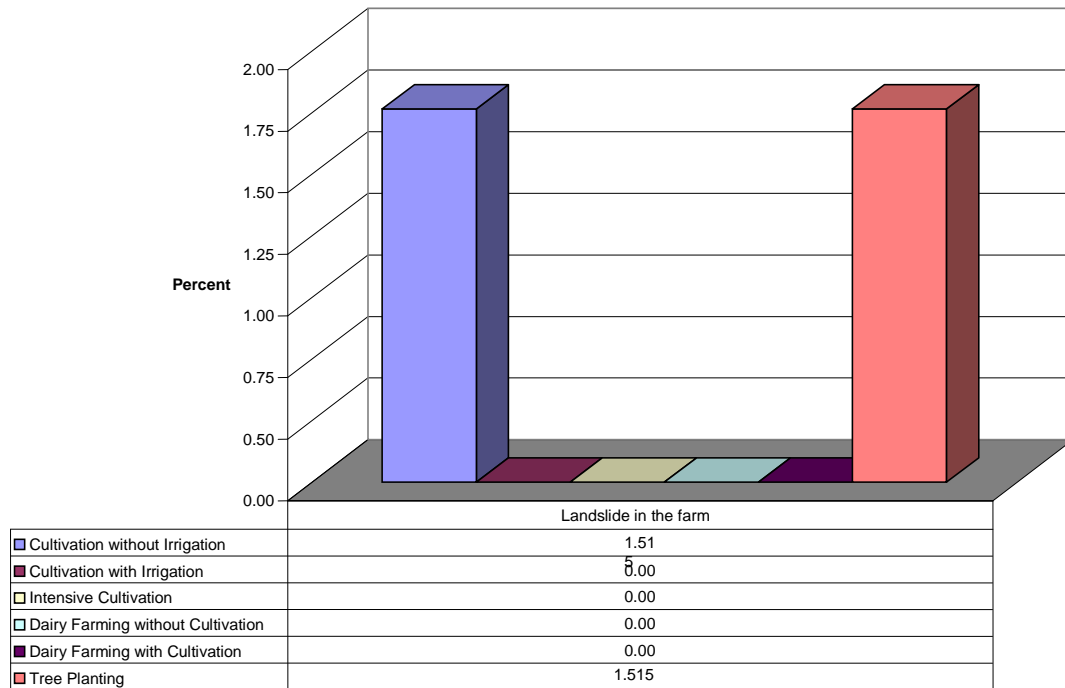
Plate 4.5 and Figure 4.13 illustrate the impact of landslides assessed.

Plate 4.5: A landslide at Muooni dam site



Source: Fieldwork (2008)

Figure 4.13: Farming activities associated with landslides at Muooni dam site



Source: Fieldwork (2008)

Notice that the two farmers affected were females, earning an average income of Ksh. 9,068 per month with a total farming area of about 1.64 acres. Almost all kinds of crops were found in their farmlands, except sugarcane.

Finally, concerning sand harvesting and quarrying, no impact of them has been recorded in the study area. Yet, that land-use was widespread in the riverbeds, the dam site valley and other parts of the catchment (see Plate 4.6). This may be explained by the fact that there is no sand reserves for harvesting in the farmlands; or maybe that all farmers are aware of their negative impact on farmlands; or finally that sand harvesting and quarrying tend to be done traditionally on communal lands.

Plate 4.6: Sand harvesting in Muooni dam site valley



Source: Fieldwork (2008)

The analysis tested the assumption that land-use activities going on around Muooni dam site were causing soil erosion and water over-abstraction, using Mann-Whitney U-test statistical inference. The latter rejected the null hypothesis stating that there was no significant difference between the populations of the two samples. Table 4.4 provides a synopsis of results from Mann-Whitney U-test.

Table 4.4: Summary of the Mann-Whitney U-test results

N°	Decision Parameters		Decision
1	$U_1= 2,178$	$n_1= n_2=66$	The differences between the two samples are far significant rather than the deviations.
2	$\mu_1=1,089$	$\sigma_1 =219.725$	
3	$Z_u= 4.9562$	$n= 66$	$H_0 (\mu_1=\mu_2)$ Rejection: There is no significant relationship between the two populations.
4	$Z_{p; }= 3.99$	$\alpha = 0.002$	

Source: Fieldwork (2008)

The Z value in the table being above 3.99, the null hypothesis $H_0 (\mu_1=\mu_2)$ was rejected at 99.8% confidence degree. The two random samples were considered as being drawn independently from continuous variables. Land-use activities assessed and their presumed impacts were thus not coming from the same population. They might have originated from different sources within or outside Muooni dam site.

Spearman's rank correlation confirmed that result. It accepted the null hypothesis stating that there was no significant relationship between the populations of land-use activities and impacts assessed (see Table 4.5). The Z value being above -3.99, the null hypothesis $H_0 (\rho_s=0)$ was accepted at 99.8% confidence degree. The two random samples were considered as behaving independently one from another. Therefore, there was no strong relationship between land-use activities assessed and the impacts recorded on farms. Those impacts might have come from various sources, some being drawn from the ISZ effects of on-site soil erosion, and others originating from the GSZ effects of off-site soil erosion (El Niño floods and droughts, heavy winds pressure, footpaths and roadside erosion, sand harvesting and deforestation).

Table 4.5: Results of the Spearman's rank correlation

Nº	Decision Parameters		Decision
1	$\Sigma d_i^2 = 52,081.5$	n= 66	There is a weak correlation between land-use activities and impacts assessed.
2	$r_s = - 0.08718$	n= 66	
3	$Z_u = - 0.01081$	n-1=65	$H_0 (\rho_s=0)$ Acceptance: There is no significant

4	$Z_p = -3.99$	$\alpha = 0.002$	relationship between the two populations.
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Source: Fieldwork (2008)

Nevertheless, it was ascertained that environmental impacts assessed were threatening Muooni dam storage capacity, and that they were affecting the rational use of its water and land resources for farming.

4.2.2 Discussion on Ex Post Impacts Assessment

The fact that only 33.3% of farmers interviewed were full-time farmers shows that Muooni catchment is no more an exclusive farming area. Most of the farmers interviewed were just residents working in off-farm sectors. Yet, they were employing farmland caretakers in order to conserve their soil and supplement their livelihood. The mean monthly average income of Ksh. 13,877 per farmer does not reflect the reality on the ground. In fact, a full-time farmer's income was less than Ksh. 6,000 with a monthly income of Ksh. 3,409 (i.e. equivalent of 56.8\$ per month). Actually, this farming income represents less than a quarter of all farmers' average income, more than half of full-time farmers living under the poverty threshold of \$1 per day (that is Ksh. 60). Consequently, true farmers are very poor. Intruders living among them are the ones enhancing the community mean income.

Talking about farmers' living standards and settlement in Machakos and Makueni districts, Jaetzold *at al.* (2007:391) report:

The district has a high population growth due to preference for a large family size, high rate of urbanization in Machakos town, increased settlement in areas that are of marginal agricultural potential; and the sub-division of ranches thereby promoting sedentary small-scale farming practices, and further sub-division of land for settlement.

Yes, the sub-division of land decreases farming areas to the benefit of settlement and therefore, reduces chances for high yields and good income, due to the infertility of soil and water scarcity. The intrusion of no-genuine farmers among full-time farmers has an impact on land good husbandry. Land tenure has thus an impact on land management, particularly for the new comers. One of the key informants of this study stated:

Once they have money, most of farmers who inherited lands from their parents tend to shift away in order to avoid clashes with their kinship. The nearer a person is to his people the more quarrels he gets (Ndonye, 2008).

Although land sales are not very common in the dam site, people have the habit of leasing it. This gives an opportunity to new ones enter the farming community. New land-users are not most likely trained to face with environmental conditions of Muooni dam site, and may ignore some soil conservative measures. Also, since they do not own land, they may not take precautions on the management (Obando, 1995). Yet, Waswa (2006) stresses the fact that land management in Kenya is highly correlated with education and poverty levels. Most land-users are “ignorant and agents of degradation” in pursuit of survival. Using their indigenous knowledge, those farmers look at visible indicators of yield and direct effects on their subsistence without making some innovations (Cheserek, 2005). Sheets, rills and inter-rills tend to pass unnoticed. But later on, when big gullies, difficult to jump over, appear on the farming area, they then come to realize that their activity has threatened the ecosystems functions. Their subsequent interventions could not compensate for the damage that would already have been caused.

When talking about Machakos and Makueni districts, Jaetzold *et al.* (2007) admit that there is evidence of land conservation through terracing in these zones. Tiffen *et al.*

(1994) establish that the high population pressure therein contributes to land husbandry and soil erosion control. Yet, Lal (1993:9) hold back such confidence. He suggests:

In some cases, taking the pressures off marginal lands is probably the best solution. In other cases, intensive cultivation of prime agricultural land, creating off-farm employment and developing income-generating capabilities in non-agricultural sectors can be important options.

Off-farm income-generating activities may seem to be valuable in the case of Muooni dam site, if well-planned along with some capacity building in soil conservation. Otherwise, it can lead to an ecological disaster. However, even where soil conservation is practised, there is no guarantee that farmers are able to prevent environmental degradation. Agro-forestry along with subsistence cultivation without irrigation occurred to be the most significant land-uses at Muooni dam site. Yet, farms are threatened by soil erosion (Obando, 2005a & 2005b). The key informant explained thus:

I was 5 to 6 years old (now I am 47 years old) when the extension officer introduced land conservation measures in this area. People adopted those methods slowly by slowly. Later, fruit trees and the eucalyptus tree planting became important cash crops under the instigation of the forest department. Many people have made it their business from that time on till now. However, subsistence cultivation is just a survival activity for many poor people living in this area while livestock keeping is a symbol of prosperity, especially for cattle and pigs keeping (Ndonye, 2008).

It is not surprising that almost all farms have a tree (for fruit or timber) and/or a small crop field (even under livestock keeping). Tree planting in the catchment is a very old tradition planned by the colonialists and which was backed by the national government to ensure sustainability to the catchment area. People plant trees because of their perennial economic benefits while seasonal crops field can provide food by moment. Farmers know that tree planting contributes to the protection of soil against erosion, though most of them do not explain how those trees are capable of controlling rainfall erosivity and farmland erodibility. The fact is that many do not know much about physical processes

leading to soil erosion. They practise conservation measures by analogy and according to their own understanding.

Waswa (2006) observes that farmers' perception of gully control in Ndome and Ghazi was not unexpectedly part of their soil conservation. Their lack of knowledge was thus apparent through failure to link gully erosion to its main precursors which are rills and inter-rills, and the destruction of ground cover. Although science-based intensive agriculture is being limited to prime agricultural lands, farmers need to consider carefully at least some few factors in their soil erosion control strategy. These may include the soil types, land form and terrain characteristics, rainfall regime and hydrology, cropping patterns and farming systems, and socio-economic factors. Waswa (2006: 57) advises:

Preventive means are better than curative options, especially where land-users are poor and still struggling to meet basic livelihood needs.

Water loss in the dam reservoir was propounded to be the most important factor of environmental degradation at Muooni dam site. The study revealed that sheet and rill erosion were affecting 63.6% of farms surveyed. The latter may have overloaded important sediments into the dam reservoir, reducing its capacity of water storage. At the same time, important water loss may have occurred in the dam reserves due to the practice of overland flow irrigation in wetlands, and to gully erosion and landslides contributing to the decline of the infiltration rate. Eucalyptus trees finally were affecting the dam storage capacity by abstracting more than usual water from the catchment.

High rates of reflected sheets and rills were noticed on lands managed by full-time farmers and farmers employed in the private sector. During the on-farm survey, sheet and

rill erosions appeared in more than half of the fields observed. They affected almost all the farms without exception, especially where shallow topsoil overlies a light soil. The fact that Muooni catchment lands are highly cultivated and that potential rich soils are unavailable are major justifications to soil erosion. Thus, the impact of a raindrop is very obvious through the formation of sheets and rills. The latter contribute to the increase of runoff on the surface and the decrease of water infiltration in the soil. Sheet erosion (also known as “overland flow” erosion) is caused by a mass of water flowing without creating pronounced channels (*Soilerosion.net*, 2007). It detaches earth materials on hillsides during a rainstorm when the soil infiltration capacity is exceeded (KLB, 2005 c). According to the erosivity of the rainfall event and the mass of surface materials overflowing (cobbles, stones and grasses), the flow can be broken up at a certain level. It can also continue through the main channel, leaving some small channels known as “rills”. Whether created by through fall or raindrops intercepted by trees canopy (and dripping from the leaves), sheets and rills can easily lead to gullies and mass movement “when obliterated by weathering and ploughing” (Morgan, 1995). No doubt that any farmer, whatever his education and income can be affected by sheet and rill erosion. Yet, a keen farmer takes adequate measures to correct them once they occur on the surface.

Wetland natural vegetation is generally affected by human induced activities such as agriculture. Its deprivation from the vegetal cover results in the exacerbation of its vital functions when exotic trees, crops and weeds substitute themselves to the natural vegetation (Jansky *et al.*, 2005). In most of the cases, these interlopers do not seem to be water friendly ecosystems (Prasad *et al.*, 2005). Shakya (2001) notices that practising

overland flow irrigation increases the rate of the stream flow evaporation beyond 30% of the total available resource. And this may result on a change of the catchment micro-climate through the variation of its temperatures and rainfall regimes. It may also lead to drought and to the phenomenon of seasonal water courses observed in Muooni catchment. The latter contributes largely to soil loss and sediment load in the drainage systems and the dam reservoir of Muooni River (Benson & Clay, 1998).

The fact that tree planting and subsistence cultivation with limited irrigation contribute to more than 70% of agricultural impacts on wetlands is very significant. Wetlands are invaded by farmers because of the quality of their land resources. In fact, the main tree species planted in Muooni wetlands are eucalyptus, grevillia and other alien tree species. They are mainly cultivated for timber, firewood and charcoal. These are visible indicators of a good livelihood that influence farmers' decision for adopting such types of crops. However, the consequences of these activities on wetlands are usually realized when rills and inter-rills have become gullies and that water resources have shrunk (Waswa, 2000).

Eucalyptus tree planting is another explanation to drought and the phenomenon of seasonal water courses in Muooni catchment. Ojwang (2008:6) expresses eucalyptus impact on water resources in Western Kenya in these terms:

Water shortage is looming in major parts of Kisii region in Western Kenya, with the continued planting of blue gum tree species (eucalyptus) along river banks.

The Athi Catchment Regional Manager stresses on Muooni catchment saying:

Eucalyptus trees have proved to be live pumps of groundwater and true enemies of water resources in the Athi catchment (to which belongs the Muooni catchment). Water has become a scarce commodity since the introduction of eucalyptus trees in this catchment. A small plant pumps about 200 hundreds litres of water each day. It comes to its maturity in less than 3 years, leaving the soil bare and emptied out of all its nutrients (Nzuko, 2008).

Eucalyptus is truly one of the biggest water over-abstractors (from its germination to its maturity), and a contributor to soil loss and sediment load in the drainage systems and Muooni dam (after its harvesting). To summarize the debate, Kitissou (2004: 9) provides evidence from South Africa:

Even more dramatic are reports of a stream in Mpumalanga which, before the clearing of a 500 meter strip of riparian *Eucalyptus grandis*, disappeared within 50 metres of entering the stand. About three weeks after clearing the eucalyptus the stream was visible for 200 metres in the stand, and after one month it was running through the stand. It was postulated that it had taken about a month for the stream and rainfall to recharge the water table, restoring a perennial stream from a dry streambed. The hydrological dangers of invading trees are not just local in their impact. It has been calculated that unless curtailed, invaders will actually reduce the supply to Cape Town by 30 percent. It has also been shown that the cost of water from the best dam option is several times more expensive than the cost of water yielded through clearing invading aliens.

If farmers without formal education as well as those with high-education credits are attracted by eucalyptus tree it is first because of its quick economic returns. Yet, most of them are ignorant of its harmful effects on the environment. Scientific knowledge on eucalyptus trees impact on water resources is a new concept. To make it a true paradigm, it may take a bit of time. For instance, the French research centre for agricultural development (CIRAD) is implementing an important eucalyptus tree plantation project in Pointe Noire, Congo-Brazzaville (Mallet, 2008). Though its valuable economic contribution to biomass energy, the project may cause unknown threats to the Congo River basin (Sinha, 2001). Therefore, we cannot expect more knowledge from farmers operating in Muooni catchment. Their ignorance can be justified and corrected in due time by the Government of Kenya through its agro-forestry policy. However, we can blame farmers experiencing crucial hydro-climatic conditions such as those of Muooni catchment, to take the risk of quarrying and/or harvesting sand on their own farming areas. These practices are known to impact on the farmland productivity (Terer, 2004).

They are likely to appear on communal lands for substantial income. Fortunately, no impact of them has been recorded on farms surveyed. Yet, they may be a source of Muooni dam sedimentation from the main channel of Muooni river valley.

It may be surprising to find that none of the farmers operating in wetlands is uneducated. All of them have a certain level of formal education with professional credits. Yet, literacy without conscience (ethics or moral integrity), and awareness without subsistence can be vain. Poverty and corruption may lead someone to ignore the long-term needs of the community, and take communal resources to his own advantage in a very short time. Since farmers are being directly affected, they ignore the repercussions of their actions. Though being employed elsewhere, some farms are hurrying up to the wetlands for rapid yields and returns. They may be well aware of future impacts on the Muooni River and dam, yet they choose to sacrifice the future generations.

Land and water scarcity in the region is another incentive for farming into the wetlands.

Jaetzold *et al.* (2007:391) notice:

The distribution in the rural areas is influenced by the availability of water and soils to sustain agriculture. There are large inter and intra-divisional variations in population density, and the divisions that consist of zones 2-4 and relatively fertile soils have higher population densities than the rest of the district.

Since some of the sediments loading the dam reservoir come from the wetlands, rills, gullies and slides due to the effect of animals watering and grazing contribute to Muooni dam site degradation. The fact that livestock keeping contributes to 14.3% of agricultural impact on wetlands is explained by KLB (2005c: 160):

One of the main factors of erosion in Kenya is the uncontrolled grazing of large numbers of livestock particularly in the drier areas. When an area is overstocked by cattle, sheep or goats the grass cover is destroyed due to overgrazing leaving the soils surface bare. Generally, destruction starts around watering points. The trampling of

land by animals also has an erosive effect on the soil. Often rill and gully erosion starts with a trail.

Why is it that most of gullies recorded appear in farms owned by farmers employed in the private sector or doing other off-farm businesses? Ndonye (2008) provides an answer:

Many employers in the Ukambani do not pay their workers well. So as an alternative, they use their own children or relatives as land caretakers.

Therefore, many people endowed with the power of land conservation are not motivated for checking daily impacts on the farms. Once they abandon, unskilled workers take the lead in the area. Without knowing exactly the kind of physical processes they are dealing with, they are surprised to realize that gullies on farms are just “difficult to jump over” (Waswa, 2006). It is thus obvious that the small education level of caretakers does not allow them detect early effects of increased runoff on soil erosion and land degradation.

Landslides alike soil erosion contribute to soil loss in farms. Yet, Morgan (1995:22) adds:

The quantity of sediment moved from the hillsides into the rivers by mass movement is far in excess of that contributed by gullies, rills and overland flow.

In fact, continuous exposure of soil to intense rainfall weakens the soil and leads to the formation of sheets and rills. The latter lead to gullies and mass movements (such as soil and mud flows, slide and creep), “when obliterated by weathering and ploughing” (Selby, 1993). In the case of landslides, internal strengths of the land is slowly altered, forcing part of it to fall under gravitation tractive force. The process may take 10 years before it appears naked to our eyes. The two farmers affected by landslides in Muooni dam site had either no formal or a primary education. It cannot be surprising to see that though working full-time (that is not employed elsewhere), they were affected by landslides. Their ignorance could not allow them detect early these processes, nor could their limited

instruction give them insight of taking additional preventive measures to protect their land against most unconscious physical processes going on around the catchment. This consolidates the results from Waswa (2006) and Lal (1993), especially with regard to the high correlation between on-farm land management and farmers' level of education. A vast campaign of sensitization is thus needed to create awareness on land degradation and techniques of soil conservation.

4.3 Results of Muooni Dam's Active Storage Capacity Prediction and Discussion

4.3.1 Prediction of Muooni Dam's Water Storage Capacity

The dam's active water storage capacity was computed according to available official records of the dam management provided by Athi WRMA (2008) and the estimates recorded from the institutional in-depth interview. Table 4.6 presents the average values of the dam storage capacity as displayed by Figure 4.14.

Table 4.6: Muooni dam's active water storage capacity mean values

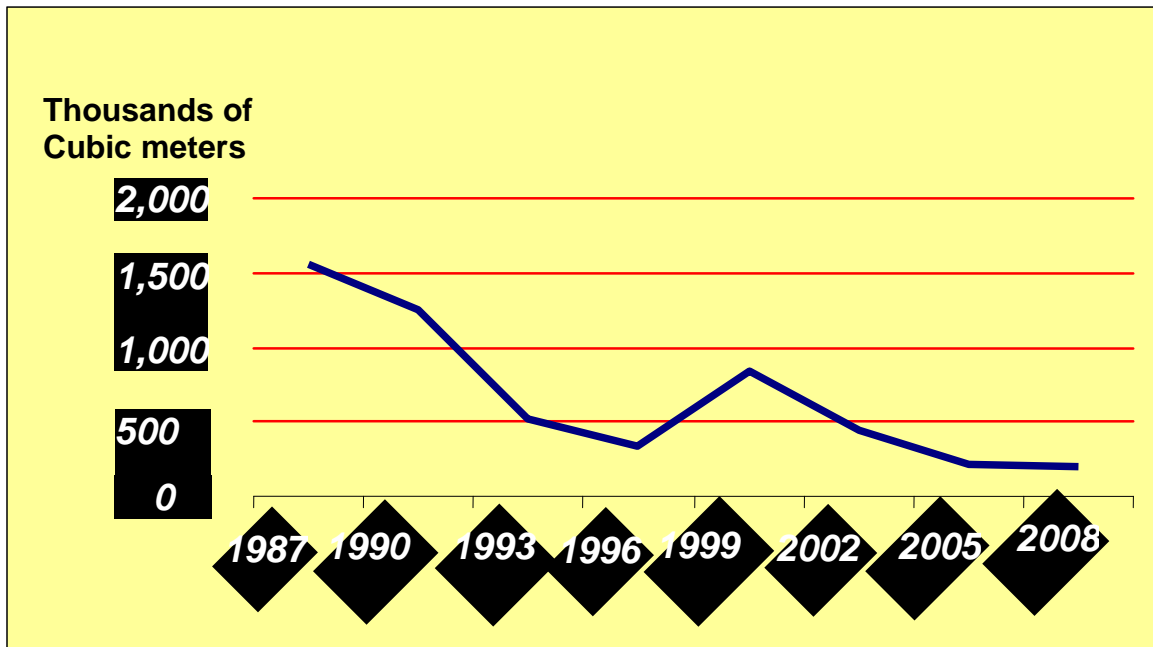
Year	Dam storage Capacity ¹	Comments
1987	1,559	Maximum value determined by engineers
1990	1,250	Mean values from various sources provided by key informants.
1993	525	- -
1996	340	- -
1999	836	- -
2002	440	- -
2005	210	- -
2008	200	- -

Sources: Athi WRMA (2008) and Fieldwork (2008)

Note: ¹ Values in thousands of m³

This table shows that the average storage capacity of Muooni dam has decreased since its construction in 1987. Accordingly, 97% of officers and key informants interviewed believed that the dam decreasing storage capacity is a consequence of its siltation by farming activities going on around the dam site. The uplift observed in 1998 can be explained by the El Niño rainfall, which effect was prolonged until a new decrescendo phase started in 2000. Predictions emphasize that decreasing trend from 2009 and above.

Figure 4.14: Muooni dam active storage capacity variability



Source: Fieldwork (2008)

After adjustment of all the data, the following Muooni dam's active water storage

capacity line of regression equation (\hat{S}) (Figure 4.15).was obtained:

$$\hat{S} = 8.7253 * e^{-0.0622 * t} \quad (4.1)$$

Where,

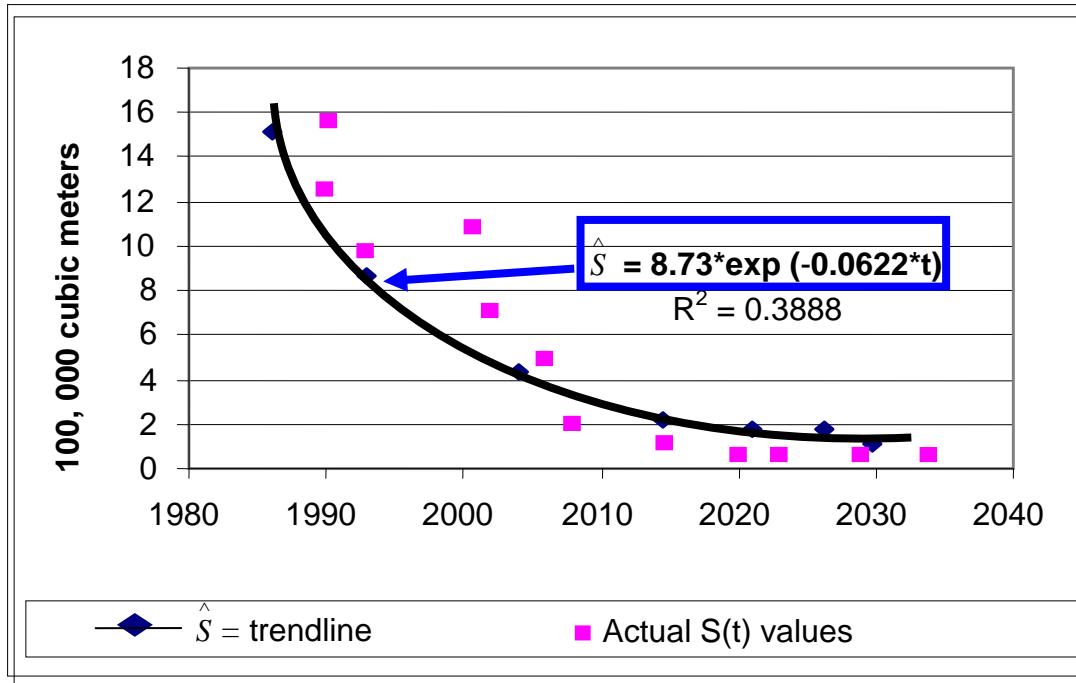
t is the time (in years);

Value 8.7253 (in hundreds of thousands m^3) is the constant and represents the storage capacity threshold fitted to the trendline; and

Value -0.0622 determines the slope of the prediction model which is the elasticity.

The mean annual estimated storage capacity was $336,879.1 \text{ m}^3$ with a Standard Error (SE) of $316,575.5 \text{ m}^3$, an Error Term (ET) of $173,362.1 \text{ m}^3$, a correlation coefficient (r) of 0.6236 and a coefficient of determination (R^2) of 0.3888.

Figure 4.15: Muooni dam active storage capacity trendline



Source: Fieldwork (2008)

The adjustment of the dam's active storage capacity data to the time reveals a yearly decline of 6.2% with an average storage capacity in 2008 estimated at $236,449.7 \text{ m}^3$. If these trends continue, the dam's active water storage capacity will be under its threshold in the year 2020, storing only about $112,093.8 \text{ m}^3$ of Muooni River total flow. The good quality of these previsions was confirmed by the SE and the ET. They revealed that the

deviations around the mean are far less significant than the sample mean itself (ET=173,362.1 and SE=316,575.5 less than Mean = 336,879.1 m³). When the storage capacity was expressed in hundreds of thousands of cubic meters ($\hat{S} * 100,000 \text{ m}^3$), it tended to move towards the very perfect model (with ET equals to zero). Furthermore, the correlation coefficient and the coefficient of determination testified that this model was sufficiently strong to explain the variation of the dam's active water storage capacity by the time. In fact, the correlation coefficient showed that 62.4% of the storage capacity variations were reflected in the change of years. Otherwise, the dam's active water storage capacity variation had the same bearing as its reservoir infrastructures depreciation. The coefficient of determination confirms this result by attributing 38.9% of the total variation of the dam's active storage capacity to the dam storage logistics depreciation over the years. Spearman's Rho test (Table 4.7) certifies these assertions.

Table 4.7: Results of the Spearman's Rho test

N°	Decision Parameters		Decision
01	$r = 0.6236$	$\alpha = 0.005$	There is a strong correlation between S and t
02	$S_r = 0.134073$	$n-2 = 64$	The correlation coefficient has good quality
03	$t_{p;n-2} = 4.650941$	$t_{\alpha;n-2} = 2.576$	Rejection of H_0 ($\rho=0$); So, S is explained by t .

Source: Fieldwork (2008)

This table shows that the prediction model of the dam storage capacity is viable. The Rho Test attests that the prediction model is sufficiently strong to predict the dam storage capacity by its logistics old-age at 99.5% confidence degree and 34 degree of freedom. Thus 62.4% of the variations of the dam's active water storage capacity are reflected in

time (over years), and that 38.9% of its total variation can be explained by the dam infrastructures old-age. The decreasing dam's active water storage capacity may be a consequence of the dam reservoir destruction by its logistics obsolescence and/or no-maintenance. That may have resulted in simultaneous evaporations and seepages from the bottom of the reservoir. Therefore, the study needed to explain the remaining 61.1% of the total variation of the dam's active storage capacity not attributed to obsolescence.

4.3.2 Discussion on Muooni Dam's Active Water Storage Capacity Prediction

When modelling the dam's active water storage capacity, the regression model was said to be well-adjusted for viable predictions. The correlation coefficient and the coefficient of determination confirmed its strength for predicting the decrease of the dam's active storage capacity by its logistics old-age (as certified by the Rho test). Actually, the Rho test proved at 99.5% confidence degree and 34 degree of freedom that 62.4% of the dam's active storage capacity variations were reflected in the variation of the time. As years passed, about 39% of its total variation was due to the decline of the reservoir infrastructures resistance, and/or to its bad or even no maintenance. This may have resulted in a lot of evaporation and seepage at the same time from the dam reservoir. Due to its wooden logistics old-age, some methane and carbon dioxide gases may have occurred from the dam reservoir, contributing thus to the emission of greenhouse gases. The latter must have impacted on the variation of the temperature of water stored, as well as on the variation of the catchment temperature, the whole country's and even the global planet's temperature (GEF *et al.*, 2008; Sylva-Monde *et al.*, 2008; EES, 2008). Referring to a report by the World Commission on Dams, *Wikipedia* (2008) explains such climatic

patterns change by the decay of plant materials in an anaerobic environment of flooded areas. It questions therefore the quality and safety of water as well as the sustainability of energy provided by many dams worldwide (UNEP, 2002a).

The reservoir logistics obsolescence was just one among other factors limiting Muooni dam's active water storage capacity, through water evaporation and seepage. Other socio-economic and environmental externalities were said to result from farming activities, as hypothesized by the majority of key informants interviewed. On-site and off-site environmental impacts assessed above may have loaded a lot of sediments in the dam reservoir and /or resulted in water over abstraction by natural ecosystems. This may be a self-explanatory argument of water scarcity at Muooni dam site. It may also justify some practices observed from farmers, including abstracting and storing water directly from the dam, abuse of wetlands resources through unreasonable multiple cropping, grazing, sand harvesting, and so on. These activities were likely to cause siltation of the dam reservoir and to allow its water over-abstraction by natural ecosystems (notably by eucalyptus trees). They may have explained about 61.1% of the total variation of Muooni dam's active water storage capacity decreasing trend. Concerning particularly water over abstraction, it is mainly a result of excessive multiple cropping in the catchment, intensive cultivation using pumping and storing devices, inadequate irrigation methods in the wetlands, and eucalyptus trees water abstraction.

The assessment of environmental impacts going on around the dam site revealed that farmers' poverty and need of quick gain, their ignorance and unawareness, and population settlements in agro-pastoral lands were some of the socio-economic externalities, which

led to poor land-use practices and to Muooni dam siltation. Douglas (1994) admits that the most significant form of physical land degradation in agro-ecosystems of “resource-poor African farmers” is erosion damage. Under a specific form of land management, the latter may result in the reduction of soil capability to produce benefits from a particular land-use. It is thus obvious that the poverty of full-time farmers is due to the smallness of their benefits. The latter is explained by soil erosion inhibiting soil resilience for sustained yields (Lal, 1993). Waswa (2006) observes that in tropical rural agro-systems food insecurity, poverty and land degradation are closely inter-related.

Another environmental impact externality retained was the sedimentation of the reservoir directly from soil loss on slopes, due to climate and land-use changes. Relating soil erosion to climate and land-use changes Morgan (1995:3-4) states:

Erosion and land-use change are very strongly related. Rates of soil loss accelerate quickly to unacceptably high levels whenever land is misused. The removal of the vegetation cover for cropping or grazing results in rapid declines in organic content of the soil, followed by soil exhaustion and the risk of desertification. A third area of high risk of erosion relates to regions where landforms and associated soils are relics of previous climate. The response of the land to changes in vegetation cover brought about by human influences can depend greatly on geomorphological inheritance from previous climatic conditions.

Jaetzold *et al.* (2007) add that the lengths and intensities of agro-humid periods in south-eastern Kenya are most of the times affected by the El Niño Southern Oscillation (ENSO) phenomenon whereby the short rainy season can become extremely wet (like in 1992-1993 and 1997-1998) or extremely dry (as in 1987-1988 and 1993-1994). The El Niño characterised by extreme moisture deficiencies (called Anti-ENSO) results in plants desiccation due to extreme water stress. When followed by an Into-ENSO (El Niño characterised by extreme intense rainfalls), gullies and landslides are likely to occur in

the farms and elsewhere in the catchment (Shisanya, 1996; Wambongo, 2007). Off-site problems of soil erosion appear then as a result of downstream and downwind sedimentation of rivers and drainage ditches. They enhance the risk of flooding, block irrigation canals and shorten the designed lifespan of dams. Morgan (1995:19) adds:

Due to changing climatic conditions resulting from excess land-uses, runoff can exceed a critical rate increasing its velocity or tractive force. Thence obliterated by weathering and ploughing, water will develop enlarged rills in the soil known as 'gullies' or 'arroyos' in South-East USA,

Global changes have hence a big impact in the decreasing trend of Muooni dam's active water storage capacity over the years. Traditional soil conservation methods become rudimentary for controlling climate change disasters. Therefore, the dam is susceptible to important water evaporation, frequent damage by floods and constant maintenance. This is a tacit fact explaining why there is no significant linkage between land-use activities assessed at Muooni dam site and the siltation of the dam reservoir (in terms of on-site soil erosion effects). The Government of Kenya need to support programme promoting climate change mitigation and adaptation, either through direct investments or policy instruments such as Dams' dredging "Strategic Action Plans" and ENSO "Early Warning Systems" (Benson & Clay, 1998; Uitto & Schneider, 1997).

The following sub-sections focus on the impacts of rainfall fluctuation on the variation of farmers' operational costs (costs of transaction, opportunity costs, cost of water savings and shortage costs) and farmers' water demand under rainfall fluctuations, at Muooni dam site.

4.4 Results of Farmers' Operational Costs Computation and Discussion

4.4.1 Computation of Farmers' Operational Costs

This study aimed at simulating an operational cost function of farmers' production at Muooni dam site. A quick look at the farmers' annual income statement provided above (Table 4.2) gives a good idea of agricultural physical production and costs related to each farming scale at Muooni dam site (SSF, MSF and LSF). To determine operational cost functions of farmers working at Muooni dam site, the analysis first computed crops water requirement and farmers' water demand. It reveals that farmers' water demand is generally not enough to meet their crops water requirement. According to Appendix 4.1 and Table 4.8, there is a large gap between the actual farmers' water demand and their crops water requirement. In fact, LSF farmers order approximately 28.9% of their crops water requirement, while MSF and SSF ones buy just 12.2% and 4.4% respectively.

To determine operational cost functions of farmers working at Muooni dam site, the study used daily observed operations' values of three minimum efficient farmers selected for each farming scale. Data collected helped computing the total, average and marginal cost functions using MS EXCEL-PC. These costs were computed under the hypothesis of rainfall fluctuation in ANOR, NOR and BNOR (Appendix 4.2). The latter represented the simulated climatic conditions in respectively the year 1988, 1998 and 2020.

Under the ANOR scenario, four main variables were fed into the total cost model: the farming income (Y), expenses (E), profit (Π) and water demand turnover (r , expected to be more than 1). The total, average and marginal costs functions computed were as follows:

Table 4.8: Different scales of farmers' water demand at Muooni dam site

No	Water Demand	LSF			MSF			SSF		
		W_c (m ³)	W_f (m ³)	%	W_c (m ³)	W_f (m ³)	%	W_c (m ³)	W_f (m ³)	%
01	Annual Demand	4,990.68	1,440	28.85	4,165.58	540	12.20	1,081.09	48	4.43
02	Daily Demand	13.863	4.0	28.85	11.571	1.5	12.20	3.003	0.133	4.43
.03	Annual W_c Gap	-3,550.68	-	-71.15	-3,625.58	-	-87.80	-1,033.09	-	-95.57
04	Daily W_c Gap	-9.863	-	-71.15	-10.071	-	-87.80	-2.87	-	-95.57

Source: Fieldwork (2008)

For the minimum efficient LSF Selected:

- $TC_{an} = 800.83 r + 99.17 + 1,998.34/r$ (4.2)

- $AC_{an} = 800.83 + 99.17/r + 1,998.34/r^2$ (4.3)

- $MC_{an} = 800.83 - 1,998.34/r^2$ (4.4)

For the minimum efficient MSF Selected:

- $TC_{an} = 751.94 r + 8.06 + 1,536.12/r$ (4.5)

- $AC_{an} = 751.94 + 8.06/r + 1,536.12/r^2$ (4.6)

- $MC_{an} = 751.94 - 1,536.12/r^2$ (4.7)

For the minimum efficient SSF Selected:

- $TC_{an} = 133,53 r + 21,47 + 352.94 /r$ (4.8)

- $AC_{an} = 133,53 + 21,47 /r + 352.94 /r^2$ (4.9)

- $MC_{an} = 133,53 - 352.94 /r^2$ (4.10)

Cost values from these functions were calculated after inclusion of the ANOR theoretic water demand turnover value (supposed to be equal to the ratio of the 1988 dam's active water storage capacity by the median capacity, and equal to $r=1.04351$).

Under the NOR scenario, the total cost function was dependent of three variables: the farming income (Y), expenses (E) and the farmer water demand turnover (r , expected to be relatively equal to 1). The analysis computed the following operational cost functions using MS EXCEL:

For the minimum efficient LSF selected:

- $TC_{no} = 900 r + 1,998.34/r^2$ (4.11)

- $AC_{no} = 900 + 1,998.34/r^2$ (4.12)

- $MC_{no} = 900 - 1,998.34/r^2$ (4.13)

For the minimum efficient MSF selected:

- $TC_{no} = 760 r + 1,536.12/r$ (4.14)

- $AC_{no} = 760 + 1,536.12/r^2$ (4.15)

- $MC_{no} = 760 - 1,536.12/r^2$ (4.16)

For the minimum efficient SSF selected:

- $TC_{no} = 155 r + 352.94 /r$ (4.17)

- $AC_{no} = 155 + 352.94 /r^2$ (4.18)

- $MC_{no} = 155 - 352.94 /r^2$ (4.19)

Monetary cost values were obtained after insertion of the 1998 theoretic water demand turnover (equal to $r=0.6169$).

Under the BNOR scenario, the total cost function maintained the same variables of the model under the ANOR scenario (though the farmer water demand turnover was expected to be less than 1). The analysis came up with the following specific operational costs functions:

For the minimum efficient LSF Selected:

- $TC_{bn} = 999.17r - 99.17 + 1,998.34/r$ (4.20)

- $AC_{bn} = 999.17 - 99.17/r + 1,998.34/r^2$ (4.21)

- $MC_{bn} = 999.17 - 1,998.34/r^2$ (4.22)

For the minimum efficient MSF Selected:

- $TC_{bn} = 768.06 r - 8.06 + 1,536.12/r$ (4.23)

- $AC_{bn} = 768.06 - 8.06/r + 1,536.12/r^2$ (4.24)

- $MC_{bn} = 768.06 - 1,536.12/r^2$ (4.25)

For the minimum efficient SSF Selected:

- $TC_{bn} = 176.47 r - 21.47 + 352.94 /r$ (4.26)

- $AC_{bn} = 176.47 - 21,47 /r + 352.94 /r^2$ (4.27)

- $MC_{bn} = 176.47 - 352.94 /r^2$ (4.28)

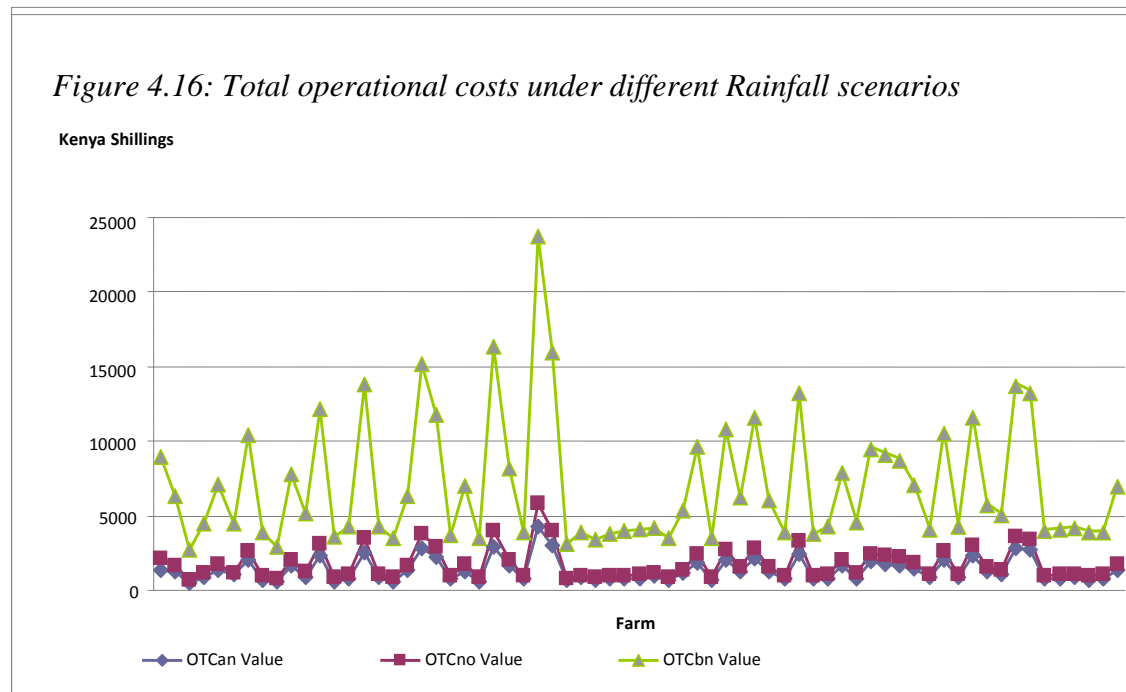
Costs values of these operational functions were estimated after inclusion of the 2020 theoretic water demand turnover (equal to $r=0.1319$).

Figures 4.16, 4.17 and 4.18 present respectively, the total, average and marginal operational costs values computed from data collected on all the farms surveyed. From costs values obtained above, Table 4.9 computed the rate of costs variability under different rainfall regime scenarios. The analysis reveals that farmers' operational costs were highly variable under the BNOR scenario than any other rainfall regime. And all types of farms are vulnerable to costs' variability under rainfall fluctuations. However, no significant variations of operational costs had been recorded amongst different rainfall regimes (see Figure 4.19). Notice that operational costs variations are mostly pulled up under the BNOR scenario, when driven by the cost of water shortage. It can be concluded that farming activities economic viability is really threatened by rainfall fluctuations at Muooni dam site.

Table 4.9: Farmers' costs variability under different rainfall regime scenarios

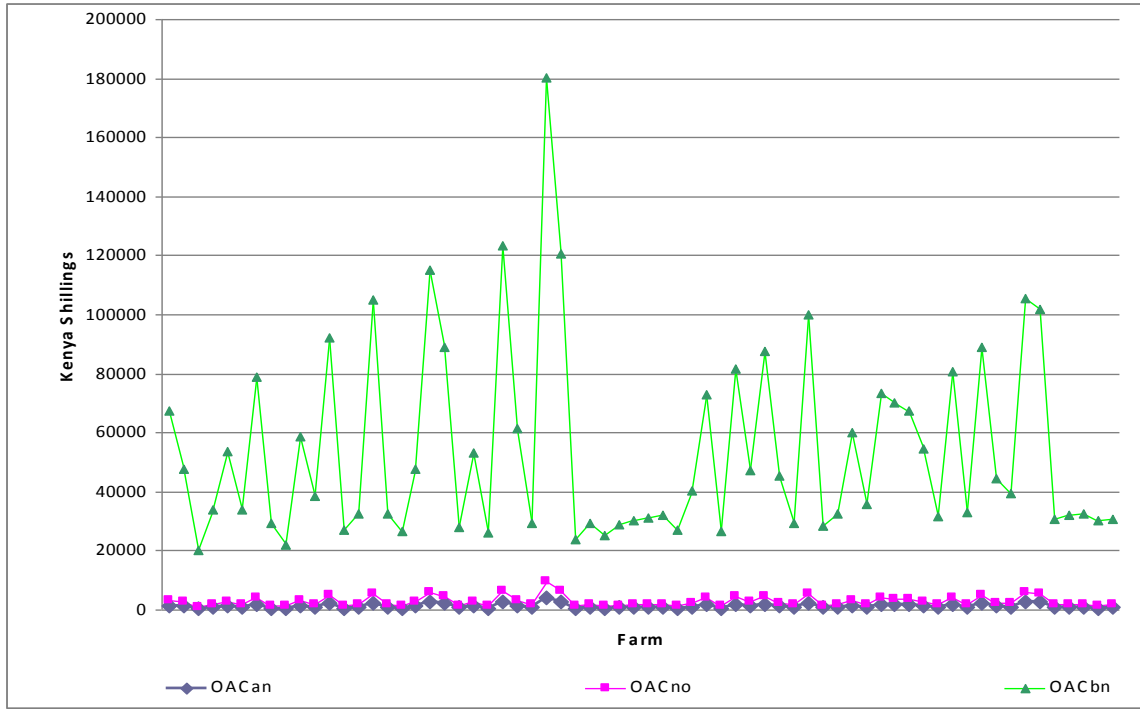
No	Farm Size	Observed AC Daily Values	ANOR		NOR		BNOR	
			OAC	Variation (%)	OAC	Variation (%)	OAC	Variation (%)
1.1	LSF	999.17	2,731.03	173.33	6,150.97	515.61	115,110.22	11,420.58
1.2	MSF	768.06	2,170.35	182.58	4,796.41	524.48	89,001.84	11,487.88
1.3	SSF	176.47	478.23	171.00	1,082.41	513.37	20,300.39	11,403.59

Source: Fieldwork (2008)



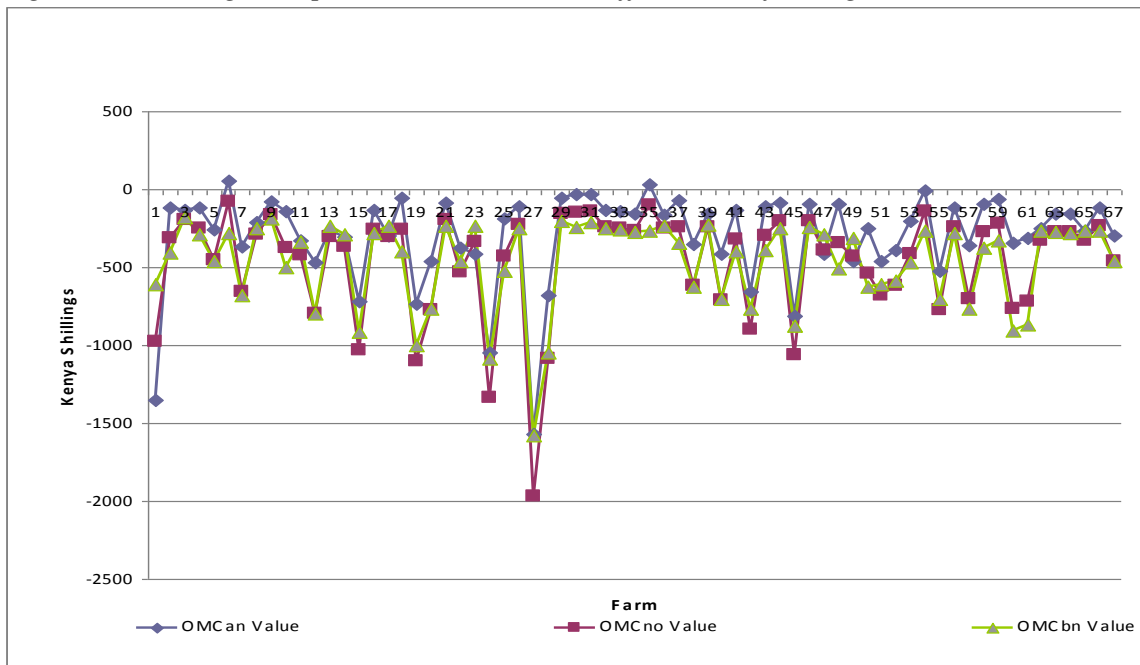
Source: Fieldwork (2008)

Figure 4.17: Average operational costs under different rainfall scenarios



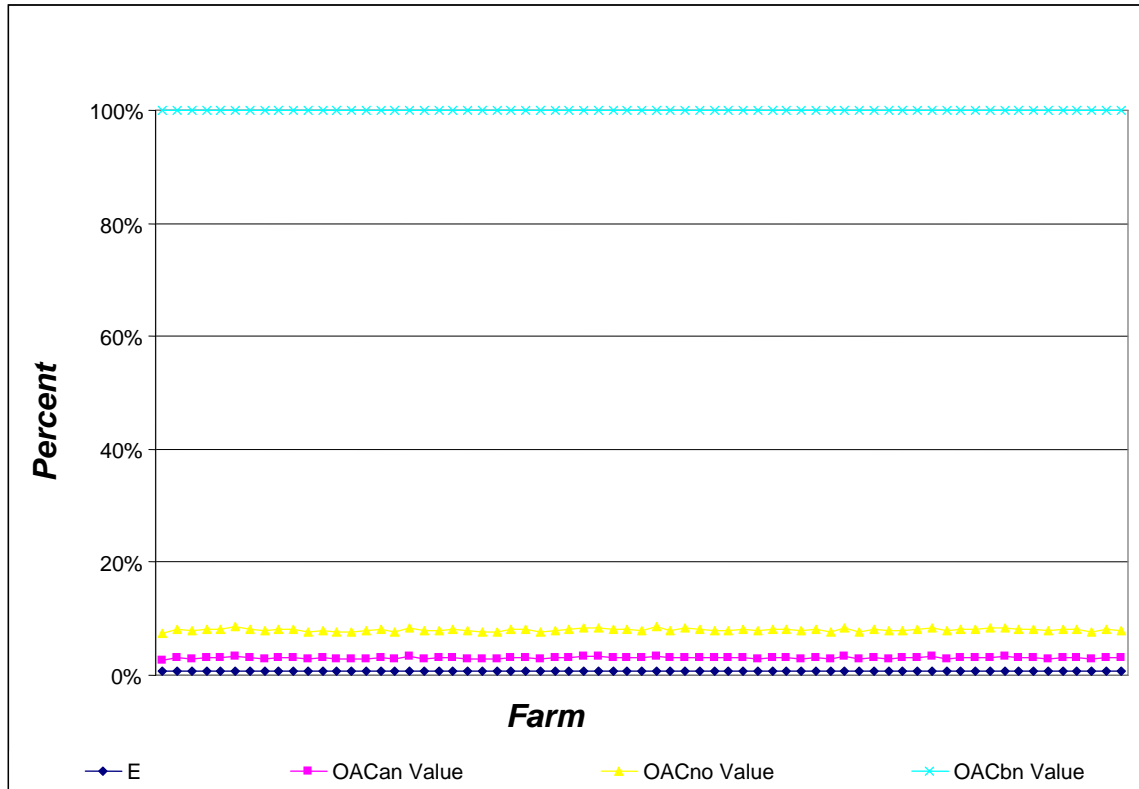
Source: Fieldwork (2008)

Figure 4.18: Marginal operational cost under different rainfall regime scenarios



Source: Fieldwork (2008)

Figure 4.19: Observed and operational costs variation under rainfall fluctuation



Source: *Fieldwork (2008)*

4.4.2 Discussion on Farmers' Operational Costs Computation

There is evidence that farmers' operational costs are highly variable under the BNOR scenario rather than under the NOR and the ANOR scenarios. Rainfall fluctuation is thus the main controlling factor of efficient use of agricultural watershed resources under any farming scale considered at Muooni dam site. The extreme variability of farming operational costs under the BNOR scenario is an expression of external costs significance (especially shortage costs) in the on-farm management. The influence of the El Niño droughts and floods are therefore to be taken into consideration when allocating watershed resources, though the El Niño flooding does not have a significant impact on crop yield losses and operational costs variation (under the ANOR scenario).

As indicated in the sub-section 3.2.6, the rainfall regime in south-eastern Kenya is dominated by two mainly dry “monsoon” seasons and two rainy seasons associated with the movement of the ITCZ. The annual average rainfall fluctuates between 500 and 1,300 mm, with 66% of reliability and part of coming from the trade effects of south-eastern winds blowing on slopes. (Jaetzold *et al.*, 2007). These rainfall fluctuations affect water and land resources efficient use in agriculture, in terms of crops water requirements and crop treatments, due to the shortness of the rainy seasons. Farming income is thus insignificant if not supplemented by off-farm incomes. The introduction of “marginal” crops (some bean and maize species), with lower diurnal potential evapotranspiration, have proved to be a salvation for farmers under extreme water stress conditions (Jaetzold *et al.*, 2007). Yet, chances for high yields are reduced soil moisture declining so quickly due to prolonged droughts and smallness of farmlands. The analysis has shown that all farms types were highly vulnerable to inefficiency under rainfall fluctuation. The main reason is that they utilize much water through multiple cropping, some crops over-abstracting water deep in the soil.

The fact that smallholder farms practising multiple cropping (of about 8 seasonal crops and 6 perennial crops within a small plot area of 1.5 acres) are inefficient in such a hostile environment is elucidated by Jaetzold *et al.* (2007). Talking about agriculture in Machakos and Makueni districts, they report:

The typical characteristic of agriculture in this region i.e. small farms, dominates the district. Within this context, it should be remembered that land-use potentials vary considerably in the district. For instance, 1 ha of agricultural land in UM3, i.e. Marginal Coffee Zone is equal to about 10 to 15 ha in LM5, the Lower Midland Livestock-Millet Zone. Thus these big differences can occur from location to location, depending on the Agro-Ecological Zones. A district average of 6.79 ha per household (5.68 people) and 1.23 ha per person was available

in 1979. This can be compared with the 1999 figure of 3.37 ha per household, i.e. 4.40 persons. In other words, the available agricultural land per person is continuously decreasing, from 1.23 ha in 1979 to 0.75 ha per person in 1999 (Jaetzold *et al.*, 2007:391)

It is deplorable to realize a decrease of about 62% of habitable land in 20 years. Yet it should not be surprising to see farming areas declining to a rate of 40% (1.5 acres compared to 0.75 ha) in about 10 years (1999-2008) at Muooni dam site. Excessive multiple cropping in such circumstances could be a kind of “land harassment”.

It is this mismatch of crops against the suitability of the agro-ecological zone that contributes to persistent crop failures in these areas (Jaetzold *et al.*, 2007: 419).

The Government of Kenya recognizes that fact in its vision 2030. It proposes therefore a new strategy for poverty alleviation by the year 2030. One of the strategic actions consists of increasing agricultural resources productivity mainly through “increased smallholder specialisation (2-3 crops per plot), utilising a million hectares of currently idle land, a new cultivation of up to 1.2 million hectares of newly opened lands” (GoK, 2007). In the meantime, Muooni dam site farmers take advantage of reduced water shortage costs and increased yields opportunity to engage in multiple cropping, with regard to the hostility of the climate. Accordingly, “Economic circumstances can force farmers adopt some practices. Mixed farming with excessive stocking rates and uncontrolled grazing is usually unsuccessful and degrades the soil and the environment, as is the case in the African Sahel” (Lal,1993:12).

4.5 Farming Production EOQ, LAC and MES Simulation Results and Discussion

4.5.1 Simulation of Farming Production EOQ, LAC and MES

After optimization of water demand turnover for each farming scale and rainfall regime scenario, the analysis revealed that farmers’ water orders were insufficient for meeting

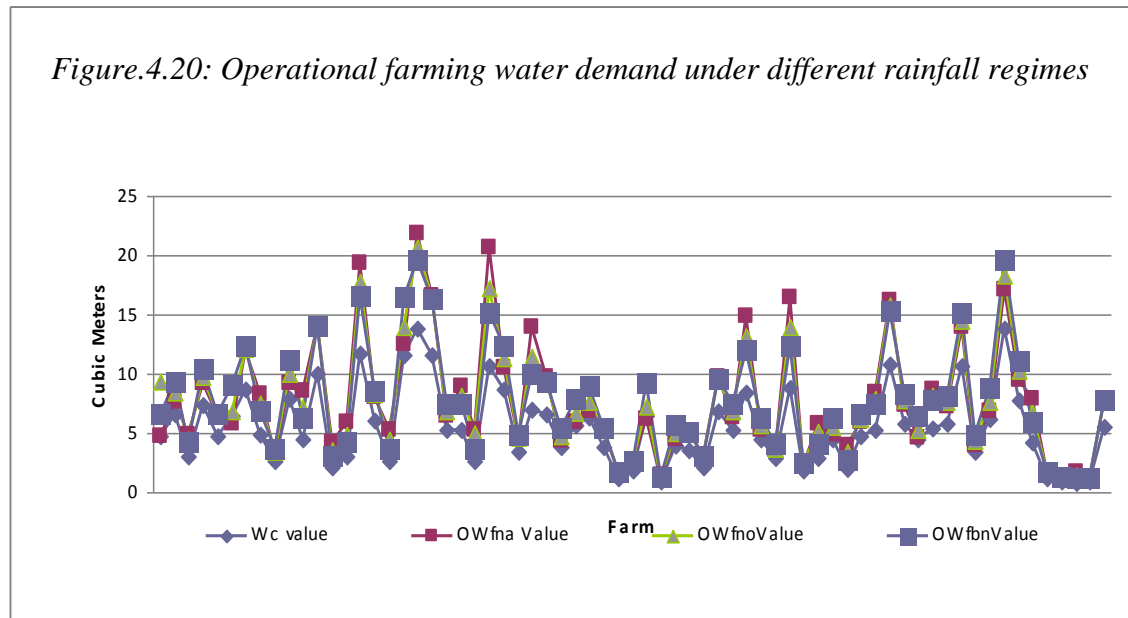
their crops natural water requirements. Table 4.10 summarises the results of EOQ analysis found in Appendix 4.3 under each rainfall regime scenario. It shows that the required agricultural water order (EOQ) is a little bit beyond the normal crops water requirement. LSF farmers, who afford 13.86 m³ per day, need rationally to order respectively 21.9 m³, 20.66 m³ and 19.61 m³ under the ANOR, NOR and BNOR scenarios. Likewise, a rational medium scale farmer needs to order approximately 16.54 m³, 16.45 m³ and 16.36 m³ under respectively the ANOR, NOR and BNOR scenarios in order to meet the 11.57 m³ daily water requirements of his crops. Finally, Water EOQ values under different rainfall regime scenarios for a small scale farm using 3 m³ per day was estimated to 4.88 m³ (under ANOR), 4.53 m³ a (under a NOR) and 4.25 m³ daily (under the BNOR scenario). Observed crops water demand for each farm and farmers' optimum water demand (or EOQ values) are represented in Figure 4.20. Therefore, LSF, MSF and SSF farmers had to increase their respective actual water demand by an average of 147.9%, 142.2% and 152.2% to meet their water EOQ. By so doing, they could avoid more shortage costs and losses due to crops failure.

A comparison of the original operational costs with the optimized ones resulted in a significant reduction of costs under the BNOR scenario. Table 4.11 shows that operational costs can fall up to 40% in SSF and LSF under the ANOR scenario. That is how minimum efficient farmers could improve their water use efficiency in farming. Figure 4.21 presents the same result for the entire study area. Table 4.12 and Figure 4.21 present the gaps between original and minimum operational costs of farms under the NOR scenario. They show an average cost fall ratio of about 70% in the three farms.

Table 4.10: Water economic order quantity under different rainfall regime scenarios

No	Farm Size	Daily Observed W_c Values	ANOR		NOR		BNOR	
			Optimized r	EOQ	Optimized r	EOQ	Optimized r	EOQ
1.1	LSF	13.863	1.5797	21.9	1.4901	20.66	1.4142	19.61
1.2	MSF	11.571	1.4293	16.54	1.4217	16.45	1.4142	16.36
1.3	SSF	3.003	1.6258	4.88	1.509	4.53	1.4142	4.25

Source: Fieldwork (2008)

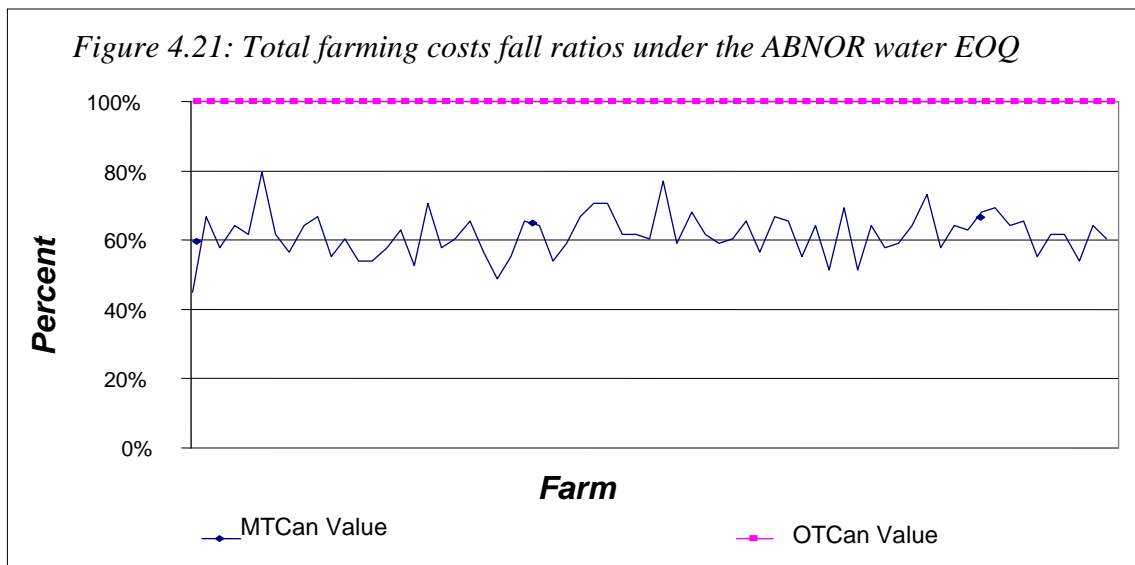


Source: Fieldwork (2008)

Table 4.11: Minimum efficient farms cost fall ratios under ANOR water EQQ

No	Farm Size	Daily OAC Values	MAC	Variation
1.1	LSF	2,731.03	1,664.40	- 39.06 %
1.2	MSF	2,170.35	1,509.51	- 30.45 %
1.3	SSF	478.23	280.26	- 41.40 %

Source: Fieldwork (2008)

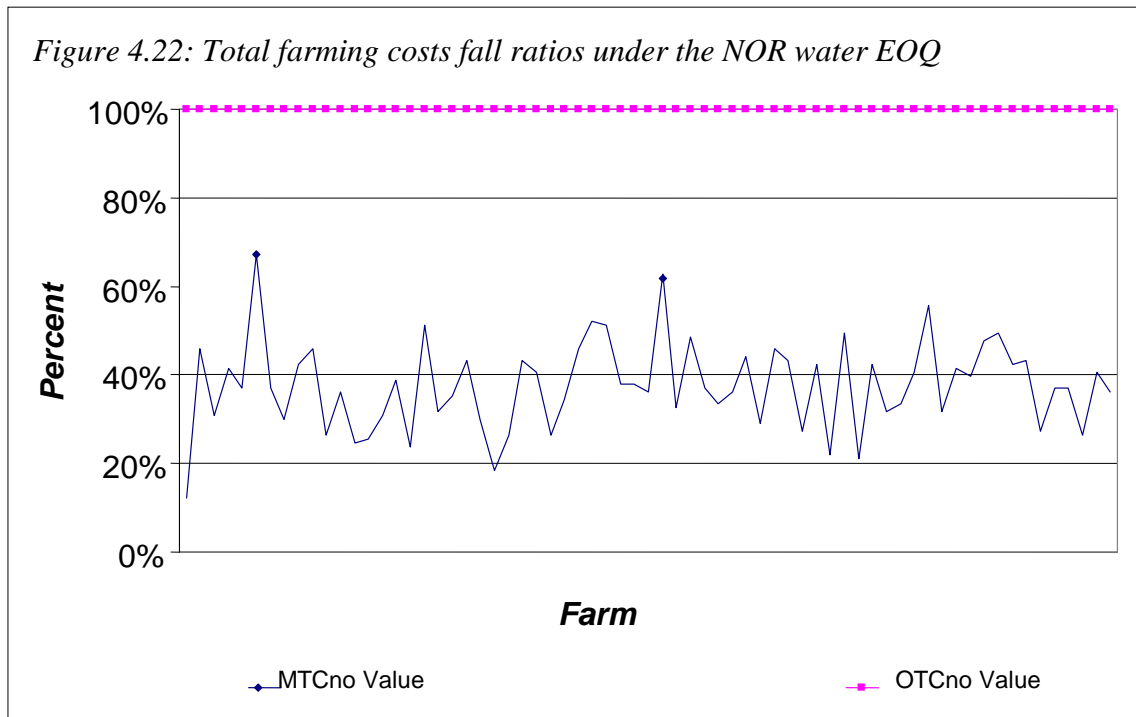


Source: Fieldwork (2008)

Table 4.12: Minimum efficient farms cost fall ratios under NOR water EQQ

No	Farm Size	Daily OAC Values	MAC	Variation
1.1	LSF	6,150.97	2,682.17	- 70.74%
1.2	MSF	4,796.41	2,160.97	- 68.31%
1.3	SSF	1,082.41	467.78	- 71.36 %

Source: Fieldwork (2008)



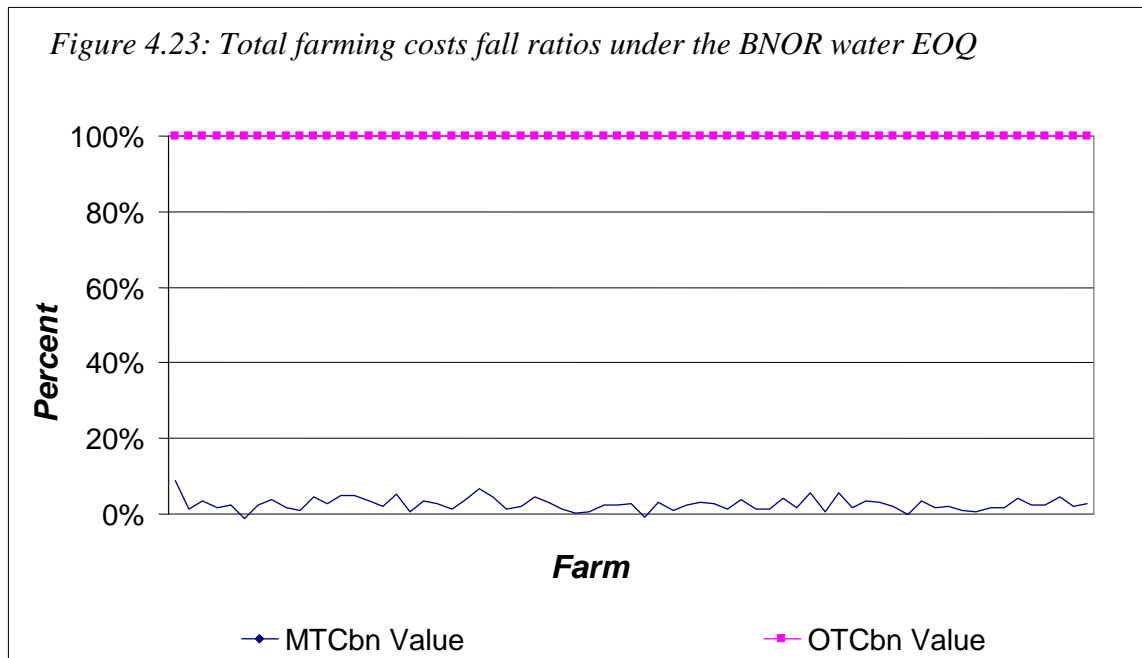
Source: Fieldwork (2008)

According to Table 4.13 and Figure 4.23, operational costs reductions of about 98% are expected at all farming scales under the BNOR scenario, if farmers use efficient methods of watershed resources management backed by technological innovation.

Table 4.13: Minimum efficient farms cost fall ratios under the BNOR water EOQ

No	Farm Size	Daily OAC Values	MAC	Variation
1.1	LSF	115,110.22	2,726.91	- 98.33 %
1.2	MSF	89,001.84	2,164.34	- 98.28 %
1.3	SSF	20,300.39	499.13	- 98.26 %

Source: Fieldwork (2008)



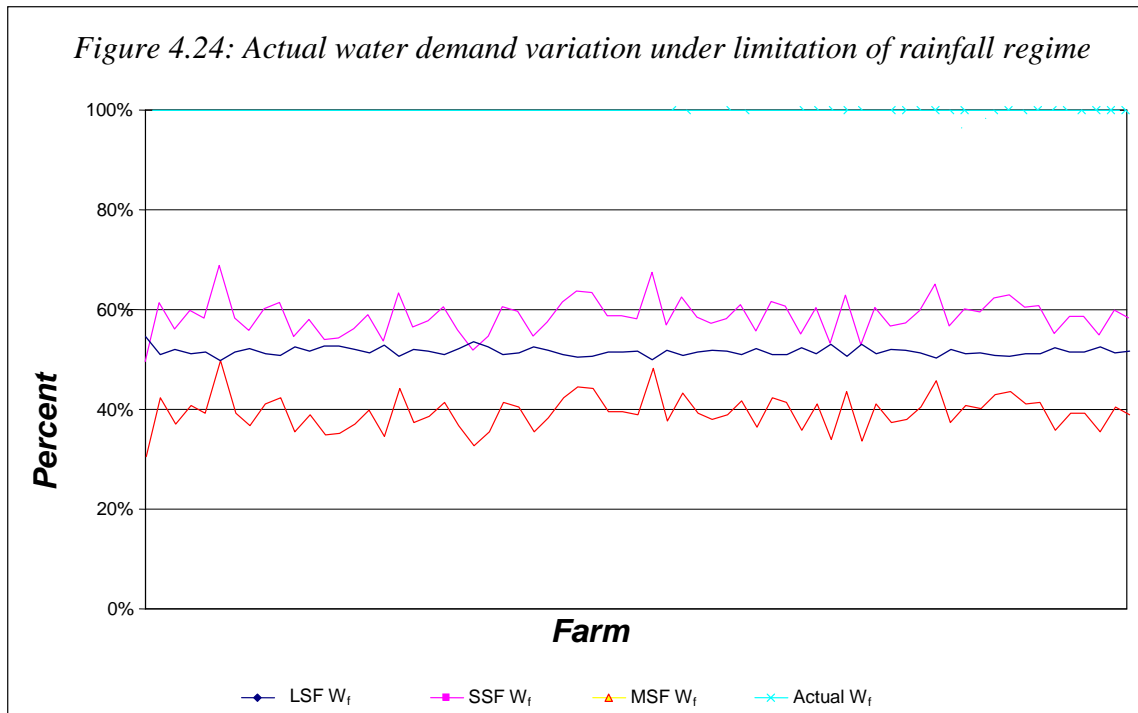
Source: Fieldwork (2008)

The analysis of farmers' water EOQ has shown that farmers needed first to increase sufficiently their water orders to avoid crops failure. Yet, there is a certain Limit Average Cost (LAC) beyond which they cannot go to avoid any loss. The LAC hereby refers to an average cost computed under limitation of rainfall regimes to a normal one. Table 4.14 presents the results of actual average costs variation under the production LAC.

Table 4.14: Actual average costs variation under limit average costs

No	Farm Size	Actual Values		LAC		Limit W_f	
		AC	W_f	Cost	Variation	min W_f	Variation
1.1	LSF	999.17	13.863	1,799.99	100 %	20.66	49.01 %
1.2	MSF	768.06	11.571	1,519.99	100 %	16.45	42.17 %
1.3	SSF	176.47	3.003	310.00	100 %	4.53	50.9%

Source: Fieldwork (2008)



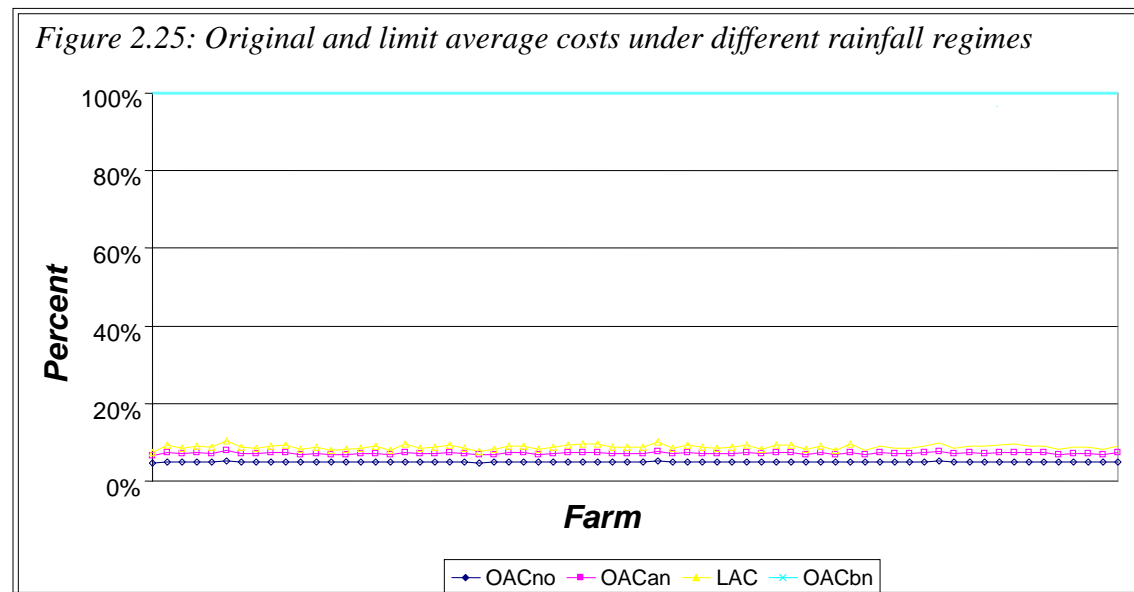
Source: Fieldwork (2008)

As illustrated by Figure 4.24, Table 4.14 shows that all smallholder farms are very sensitive to costs limitation. Their average operational costs may escalate up to 100 % of their current average costs without incurring losses. To improve the economic viability of their farming activities, they need to increase their actual water demand by 50% (for SSF and LSF) or at least by 40% (for MSF). Un less increase of farm size, operations above that limit may result in inefficient use of agricultural watershed resources at Muooni dam site (see also Figure 4.24). Therefore, half of the farming water consumption variation would be compensated by rainfall input, hydropolitical strategies and some other innovative measures helping in decreasing agricultural water consumption. Yet, additional costs of technological innovation should be expected under any rainfall scenario. Table 4.15 and Figure 4.25 provide an analysis of operational costs variation under limitation of rainfall fluctuation.

Table 4.15: Original average costs variation under limitation in different scenarios

No	Farm Size	LAC Values	ANOR		NOR		BNOR	
			OAC	Variation (%)	OAC	Variation (%)	OAC	Variation (%)
1.1	LSF	1,799.99	2,731.03	- 34.09 %	6,150.97	- 70.74 %	115,110.22	- 98.44 %
1.2	MSF	1,519.99	2,170.35	- 29.97 %	4,796.41	-68.31 %	89,001.84	- 98.29 %
1.3	SSF	310.00	478.23	- 35.18 %	1,082.41	- 71.36 %	20,300.39	- 98.47 %

Source: Fieldwork (2008)

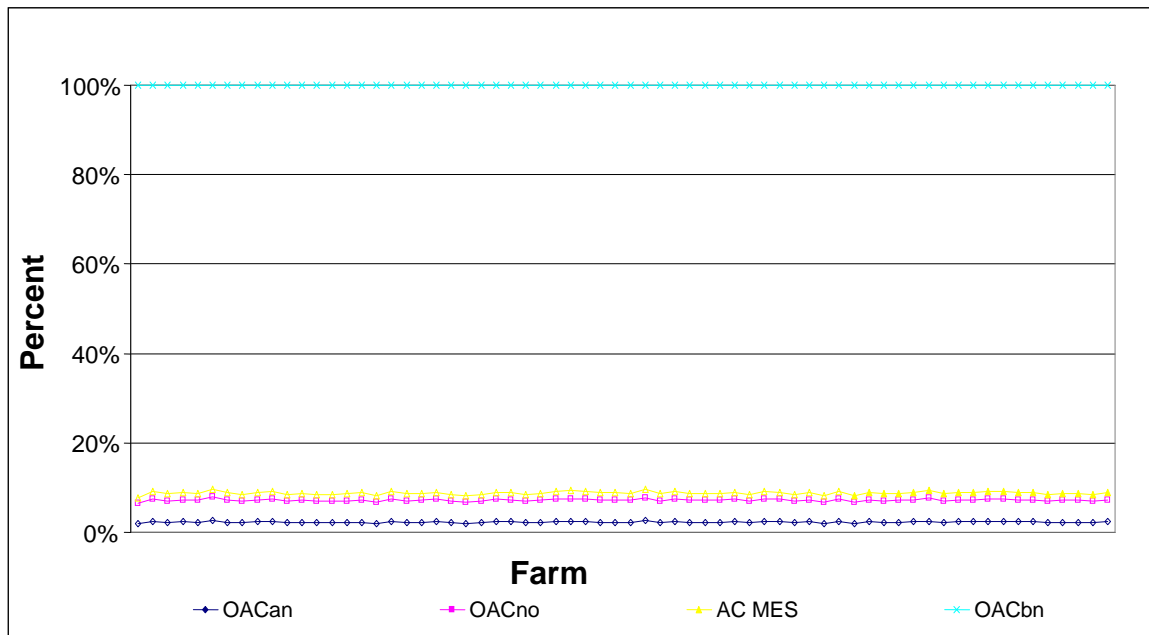


Source: Fieldwork (2008)

The analysis shows a total reduction of average costs of different farming scales under the BNOR scenario. Appendix 4.4 summarises the analysis leading to the determination of the farming limit costs and limit water demand under the rainfall regimes examined above.

Finally, the analysis climaxed with the determination of the “Minimum Efficient Scale” (MES) of three among the 69% of farms having incurred losses over the study period. A total of 95% key informants interviewed believed that farming activities are totally deficient at Muooni dam site, and that farmers needed to limit their losses to the minimum for efficiency. This meant that they should actually use efficiently watershed resources and appropriate new technologies for them improving agricultural production. Tables 4.16 and 4.17, and Figures 4.26 and 4.27 summarize the computation of the farming production Minimum Efficient Scale (MES) under the BNOR scenario shown in Appendix 4.5.

Figure 4.26: Operational average costs variation under the MES hypothesis



Source: Fieldwork (2008)

Table 4.16: Expected operational average costs under the minimum efficient scale

No	Farm Size	AC MES Values	ANOR		NOR		BNOR	
			OAC	Variation (%)	OAC	Variation (%)	OAC	Variation (%)
1.1	LSF	1,928.23	2,731.03	- 29.40 %	6,150.97	- 68.65 %	115,110.22	- 98.33 %
1.2	MSF	1,530.44	2,170.35	- 29.49 %	4,796.41	- 68.09 %	89,001.84	- 98.28 %
1.3	SSF	352.94	478.23	- 26.20 %	1,082.41	-67.39 %	20,300.39	- .98.26 %

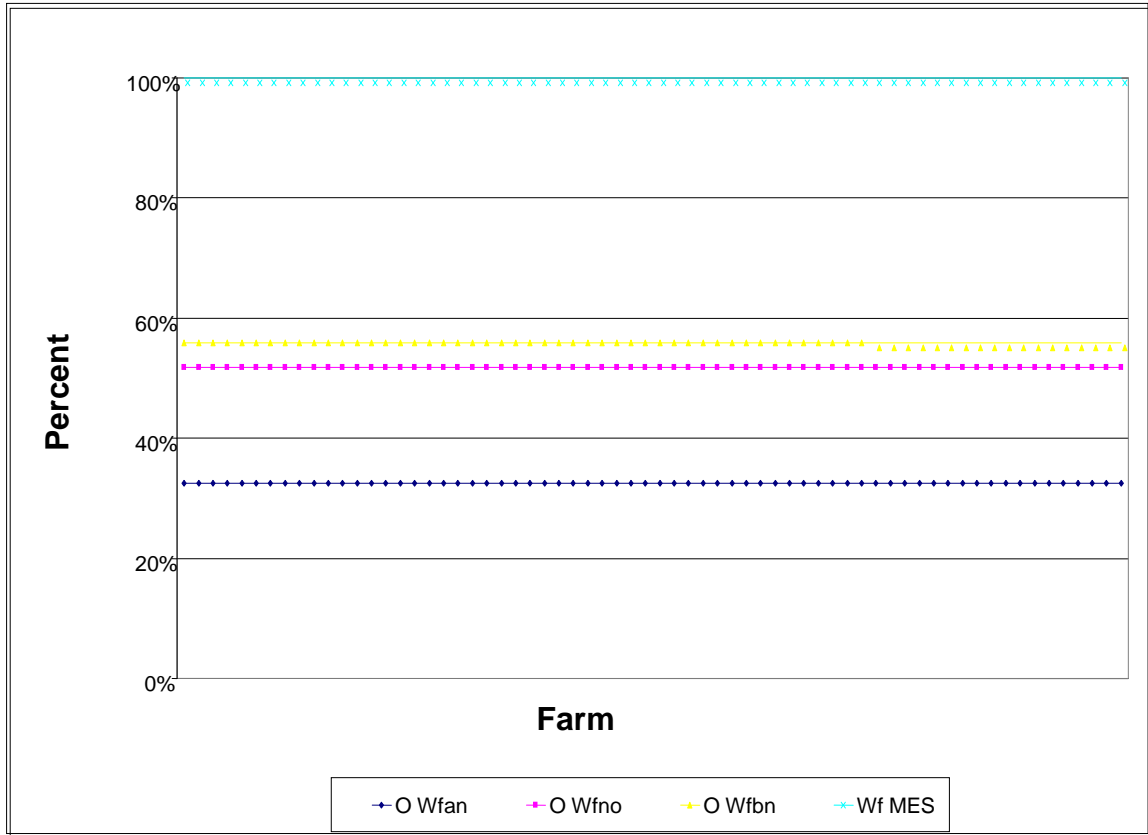
Source: Fieldwork (2008)

Table 4.17: Expected farmers' water demand under the minimum efficient scale

No	Farm Size	W _f MES Values	ANOR		NOR		BNOR	
			Original W _f	Variation (%)	Original W _f	Variation (%)	Original W _f	Variation (%)
1.1	LSF	19.61	14.47	35.56%	8.55	129.30%	1.83	972.45%
1.2	MSF	16.36	12.07	35.49%	7.14	129.19%	1.53	971.93%
1.3	SSF	4.25	3.13	35.62%	1.85	129.41%	0.40	972.97%

Source: Fieldwork (2008)

Figure 4.27: Operational farmer's water demand variation under the MES hypothesis



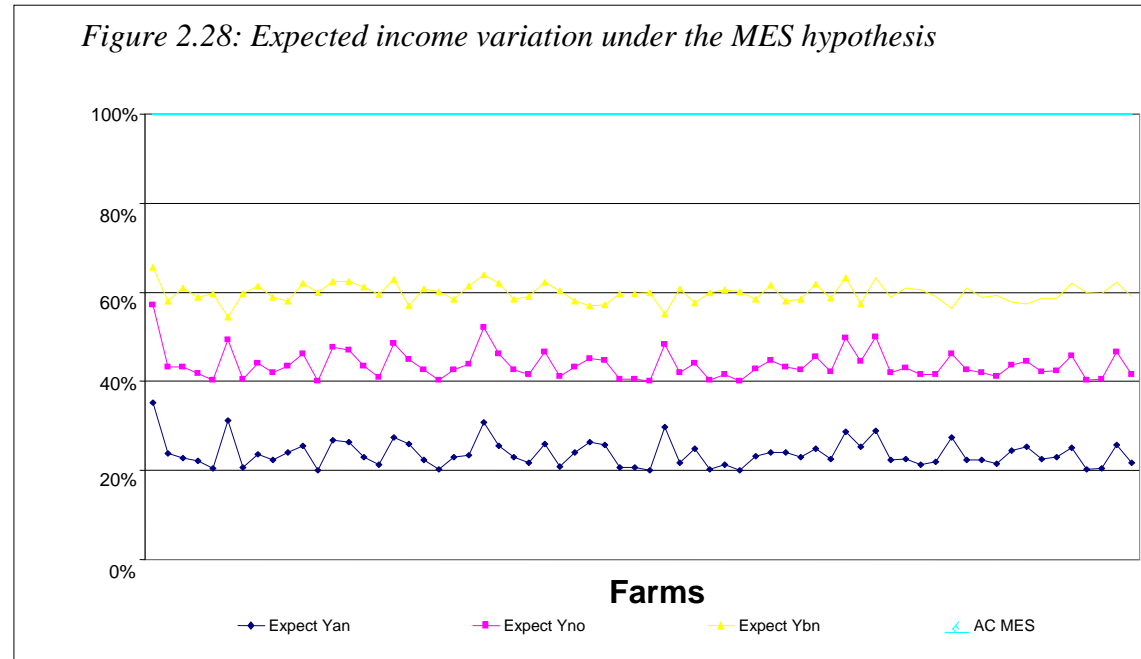
Source: Fieldwork (2008)

The simulation of operational costs variation under the hypothesis of a production MES reveals that higher costs reductions are observed under the BNOR and the NOR scenarios, ranging from 68% to 98%. Lower costs reduction is expected under the ANOR scenario (see Table 4.16 and Figure 4.26). Table 4.17 computes the variation of farmers' operational water demand under constraint of a minimum efficient scale of the farming production (see also Figure 4.27). It reveals that farmers' water orders will increase as soil moisture decreases with rainfall regime wetness depletion. For efficiency, farmers will limit their orders variation to 36%, 129% and 972% of their original W_f under respectively the ANOR, NOR and BNOR scenarios.

Table 4.18: Expected farmers' income variation under the MES hypothesis

No	Farm Size	AC MES Values	ANOR		NOR		BNOR	
			Actual E+[]	Variation (%)	Actual E	Variation (%)	Actual E-[]	Variation (%)
1.1	LSF	1,928.23	1,098.34	75.56%	999.17	92.98%	900.00	114.25%
1.2	MSF	1,530.44	776.12	97.19%	768.06	99.26%	760.00	101.37%
1.3	SSF	352.94	197.94	78.31%	176.47	100.00%	155.00	127.71%

Source: Fieldwork (2008)



Source: Fieldwork (2008)

These ratios suggest that smallholder farms should maintain their respective actual crops water requirements in order to alleviate the risks due to drastic increase of shortage costs. By so doing, they may improve their farming income and profit along with their efficiency and efficacy. Table 4.18 predicts farmers' income variation under the MES hypothesis. Assumptions of profit and loss were made under the ANOR and BNOR scenarios respectively. The comparison between the MES average costs and the expected farming income establishes the fact that these farming activities are not effective. For their efficacy, farmers need to increase their actual production at least by 76 % under any rainfall regime, through subsequent increase of their water productivity (see Figure 4.28). The expected farming income will vary according to the farm size (SSF, MSF and LSF) and rainfall regime (Above normal, normal and below normal). SSF and LSF farms incomes are expected to grow rapidly under the BNOR and NOR scenarios rather than under the ANOR one. MSF farms income variation is satisfactorily balanced around 100% under any rainfall regime. However, this variation is subject to the size of income, SSF farms having the highest rates and LSF the lowest ones, except under the ANOR scenario whereby MSF farms take the lead.

4.5.2 Discussion on Farmers' EOQ, LAC and MES Simulation

The analysis of farmers' water "Economic Order Quantity" (EOQ) gave evidence that farmers at Muooni dam site needed sufficient water from the dam at anytime for meeting the natural water requirements of their plants. Otherwise, they might experience crop failures, which in turn would amplify their shortage costs and increase their total costs, especially under the BNOR scenario. Increasing actual farming water demand will help

farmers avoid hazardous rainfed agriculture under that rainfall regime. This result also substantiates the fact that most farms incur losses at Muooni dam site because they rely on improbable rainfall, being unable to afford the cost of water for agriculture during periods of shortages. During the rainfall, lag time, they lean upon multiple crop yields of perennial species so that they may forget the discomforts caused by seasonal crops failure. Eucalyptus trees and some other alien species feature among the primary perennial species grown at Muooni dam site. These are known to be the main water resource over-abstractors. Consequently, farmers need to balance their water demand in order to avoid excessive costs of water saving during the ANOR scenario, and excessive water consumption during normal and below rainfall regimes.

Farmers have to increase their actual farming water demand either through direct orders from the dam or by rational crops selection and specialisation (to only 1-3 crops, namely Marama beans, buffalo gourds and sorghum or millets). Water storage facilities acquisition, green water credits acquirement and virtual water import may also supplement water deficit. They should make sure that their demand meets crops water requirements under any rainfall regime in order to avoid heavy external costs (costs of water savings and shortage costs). By doing so, they will maintain their actual crops water requirements and reduce significantly their total farming operational costs.

To regulate water demand at Muooni catchment, there is a need for fostering the creation of a “Water Resource Users Association” (WRUA) in that catchment. The latter will not only create awareness on water scarcity and solve water conflicts among stakeholders, but also make strategic plans for water allocation. During the DAAD Summer School

2008 held in Meru (Imenti North District, Kenya), the participants discussed on the mechanisms of introduction of water fees and charges in a catchment by the “Water Resource Management Authority” (WRMA) (Förch *et al.*, 2008). The mechanisms suggested to that end included water consumption metering, coordinated use of efficient irrigation schemes, and awareness created on acceptance of rules and regulations of water consumption metering, and charges and fees. Förch *et al.* (2008: 38) declare:

Charges constitute the cost factor in profit margin calculations that influences the choice of crop type, production method, increased efficiency, in order to have a higher profit through ‘more crops per drop’. The understanding should be that fees are used in order to manage the water up to the end tap. This means that it will be managed rationally for the benefit of all users.

These mechanisms are thence expected to create an environment that is conducive to equitable water distribution, which in turn, enhances rational water use by local stakeholders in farming production and narrows the gap between up-stream and down-stream users, present and future generations. Water metering will thus help farmers use watershed resources efficiently by managing their demand under the limitation of their operational average costs or of the minimum efficient scale of their farming production. This will finally hinder water conflicts through fair share of the resources in case of scarcity (UNEP, 1997).

The efficiency of agricultural watershed resources use required farmers to limit their costs to a certain level considered as normal at any rainfall regime. All smallholder farms were said to be vulnerable to inefficiency because of their high operational average costs. They needed to enhance the chances of yield and decrease the risks of loss of their farming production. They were accordingly recommended to limit to the best their

operational costs within the required normal limits. One of the main reasons evoked by scholars is that farmlands sub-division (for human population settlements) in south-eastern Kenya threatens the economic viability of smallholder farms (Jaetzold *et al.*, 2007; Waswa, 2006; Mutisya, 1997; Shisanya, 1996).

Inherently low fertile soils and unfavourable climate make smallholder agriculture a rather risky enterprise in much of Machakos and Makueni districts. It is no wonder that crop yields, particularly of the staple maize crop, are extremely low in the two districts. There is an urgent need for farmers to address the problem of soil infertility if there is any hope of improving the crop yields in the near future. The reason behind this alarming decline is that the soils are deficient of important micronutrients and the farmers are not using inputs to enhance crop yield. While appreciating that fertilizer inputs are expensive for a majority of the farmers in this area, crop yields can only be improved by giving back to the soil what has been removed! Increased biomass production of 'composting plants' like *Tithonia*, increased use of fertilizers and manure in order to maintain soil fertility, and increased food output per unit area, is of immediate concern for the intensively cultivated smallholderings of AEZs UM and LM 3 & 4. (Jaetzold *et al.*, 2007:419).

To be efficient, smallholder farms can therefore corporate into larger farm sizes under the supervision of a steering committee. The latter could be checking the management of each smallholder on the basis of normal limit average costs to ensure efficiency. Only operations within that limit could be allowed to farmers. There is no wonder that farmers would not lose their resources through such kind of mutualism. Ellis (1998) explains:

Tradeoffs between alternative household goals (e.g. family versus hired labour; own consumption versus sale of a food crop) affect the distribution of full income, but they do not affect its size at given market prices. Nor do they affect optimum resource use in farm production which follows standard profit maximising criteria.

Such kind of agricultural cooperatives would help farmers on the contrary establish a rural small credit fund for ensuring true farming business at efficient costs, and alleviate the risks of loss under extreme water stress.

The computation of the "Minimum Efficient Scale" (MES) of the farming production demonstrated that all smallholder farms could be efficient granted that the farmers limit

their losses to a minimum efficient scale. A comparison between the operational costs and the minimum efficient farming costs revealed that farmers operating at Muooni dam site need to reduce significant their original costs according to the wetness depletion of the rainfall regime. To that effect, they were recommended to limit their orders variation to 36%, 129% and 972% of their original water demand orders, respectively under the ANOR, NOR and BNOR scenarios. Increase water demand for meeting crops water requirements was expected to result in increased income through high yields under any rainfall regime. That meant adopting farming production methods that improve their water use in cropping while diminishing their operational costs. Efficient methods of agricultural production involve appropriate alternative technologies that value agricultural watershed resources (for allocative efficiency) and foster farming production (for technological efficiency) within the Production Possibility Frontier (PPF).

The simultaneous achievement of both efficiencies provides the sufficient condition to ensure economic efficiency (Ellis, 1998:68).

Smallholder farms are particularly urged to avoid inefficiencies resulting from the adoption of both expensive and superior production technologies, and cheap and good-for-nothing production technologies.

Jaetzold *et al.* (2007: 441) stressed exactly the situation of farming activities in Machakos and Makueni in these terms:

During the Small Farm Survey conducted in February 2004, the farmers listed their critical problems as follows: 1. Small land size: Due to the increasing human population, the land is increasingly becoming subdivided to units that are no longer economically viable. 2. Low income: There is no viable income-generating enterprise available within their locality. 3. High cost of inputs: The available farm inputs like fertilisers, pesticides and fungicides are expensive and hence out of reach to the majority of the farmers. This explains why the majority of them apply very little or no inputs at all to their farming enterprises. 4. Poor coffee prices: For a long time now, the market price of coffee has

discouraged farmers from caring the crop. The majority of the farmers have pruned back the crop and largely plant maize and legumes in what was once a purely sole cropped coffee plantation. Current attempts to revamp the coffee industry are yet to convince farmers to revert back to its production. 5. Inadequate off-farm income: Majority of the farmers lack any other income off their farms. In the absence of income-generating enterprises in the area, income levels are very low and poverty is real. The consequences of such conditions are detrimental to any sought development of the area.

These problems assessed in 2004 remain the same in 2008 at Muooni dam site. Yet, their resolution is being amplified over the years.

Notice that farmers' economic decisions are to be made on the basis of comparative advantages of alternative choices. That means if the opportunity costs of water and land resources use in farming are higher than in any other field, farmers need to adopt off-farm activities instead of running a deficient farming enterprise (Lal, 1993). Otherwise, farmers have to make some tradeoffs in terms of crops selection and specialisation (by no more than 3 crops), farming inputs (fertilisers, pesticides, rodenticides and fungicides), and on-farm technologies and environmental management in addition to rainwater harvesting and hydropolicies (e.g. green water credits and importing virtual water).

Research has shown that a combination of runoff-harvesting and farmyard manure significantly increases grain yields in these semi-arid areas. Farmers should therefore be encouraged to embrace these technologies if crop yields, particularly of cereal grains and legumes, are to improve (Jaetzold *et al.*, 2007:441).

For instance, increased biomass production of composting plants, zero grazing, mechanisation of field activities using oxen or cows as a source of draught power, and planting of perennial forages and cash crops that are drought resistant could be the best solution for intensively cultivated lands like Muooni dam site. This could help farmers minimizing their shortage costs while maximizing their crop yields within the normal limits of water demand, and of farming production costs (costs of transaction and

opportunity costs). However, the majority of poor farmers do not attempt applying farming inputs and adopting modern technologies.

Harvesting rainwater is another established lifeline for Kenya Arid and Semi-Arid Lands (ASALs). UNEP's water division programme officer explains:

Our problem is that we've just focused on all the below water, like the water in the streams without considering and exploiting the full potential of rainwater. We need to shift the paradigm. What is more, with some climate change models predicting an increase in extreme droughts across the continent, UNEP believes rainwater harvesting could be a cheap and effective way to 'climate-proof' some communities and go some way to achieving its millennium development goal to provide water for half of those people who don't have access to water today" (*b. spirit!*, 2008: 20).

According to hydrologists, rainfall in Kenya can supply six to seven times its population (GoK, 2008b; Hoff *et al.*, 2007; Ngigi *et al.*, 2005; Terer, 2004). So the first advantage of harvesting rainwater is that it can last as long as the farmer is able to store it using tanks, thus contributing significantly to the total farmer's water demand. Second, it does not cost much, just some costs of transaction. It also helps in developing farmers' management skills in water allocation and saving under different rainfall regimes. Last but not least, by storing and using rationally rainwater in agriculture, farmers could allow enough infiltration of surface water in the ground. This can improve the total runoff of the country over the time, and reduce significantly water costs in farming in ASALs (Ngigi *et al.*, 2005; Terer, 2004).

Alternatively, farmers could resort for other hydropolitical strategies such as green water credits and virtual water trade. By opting for green water credits mechanism, some farmers will accept to pay other stakeholders to perform some specified land and water management activities that determine all fresh water resources at source (Hoff *et al.*,

2007). These activities may include clearing eucalyptus trees and other alien tree species near wetlands, controlling soil erosion and mass movements in the wetlands, etc. Another strategy will be to assess the links between farmers upstream and downstream, so that those upstream could acknowledge saving some of the streamflow to the benefits of those downstream. Or else, farmers could decide to import virtual water stored in food and other materials for reducing their agricultural water cost.

The adoption of one strategy will be based on the variation of the farming production, which depends on water supply variations that determine water sufficiency in farming and its un-met demand. Stressing on virtual water storage in food, Renault (2002: 4) states:

The issue of optimal production is not only a problem of location of agricultural production sites but it is also time limited, as it has to do with performance of agricultural seasons. Except for irrigated agriculture, agricultural performance is highly dependent on variable climatic conditions. Thus in many rainfed farming areas we have the 'good years' and the 'bad years'. Food storage is then used to smooth the variation of the production: storing during the good year and supply during the bad ones. This constitutes a carry over of food and virtual water from the wet years to the dry ones.

Yet, the decision of importing virtual water should be based on comparative advantages of producing a certain quantity of food at a certain cost and buying the same food at the market price. Farmers will have to decide on the types of crops to yield based on the quantity of water to be mobilized for producing the said crop. They should include all operational costs pertaining to the period of decision (in terms of rainfall regimes). The marginal water productivity of the location could be an additional performance indicator for deciding on virtual water import as well.

Unless the Government of Kenya takes the decision of increasing farmers capital and mitigating environmental impacts assessed at Muooni dam site, off-farm income generating activities may be a good alternative. Otherwise, using watershed resources for performing agriculture efficiency at Muooni dam site will remain a useless howl. That can be evidenced by the important farming water demand to be increased over a 11,400% (by the year 2020) if crops water requirements, the farm size and socio-economic variables remain as usual, while rainfall trends are likely to worsen in the coming days, with direct impact on Muooni dam' water storage capacity.

CHAPTER FIVE

SUMMARY OF FINDINGS, CONCLUSIONS AND RECOMMENDATIONS

5.1. Summary of the Study Findings

5.1.1 Study Objectives and Methodology

This study dealt with evaluating the efficiency of watershed resources use in agriculture under fluctuating rainfall regimes at Muooni dam site. It set the prior objective of providing socio-economic and environmental cost-effective indicators of efficient use of watershed resources in farming activities. For that purpose, it focused on:

- (i) assessing socio-economic and environmental externalities affecting efficient use of water and land resources in farming activities at Muooni dam site;
- (ii) determining the extent to which land use activities affect the active water storage capacity of Muooni dam;
- (iii) simulating the variations of farmers' water demand and related operational costs resulting from rainfall fluctuation in Muooni catchment; and
- (iv) estimating the farmers' water economic order quantity and limit average cost related to subsequent their production efficiency under fluctuating rainfall regimes.

Empirical tools (namely on-farm survey and in-depth interview) and numerical tools (especially descriptive statistics, non-parametric tests, time series analysis and operational research simulation) of scientific research have been used to that end, along with a qualitative triangulation of results for better interpretation. This helped responding to the following research questions:

- (i) What socio-economic and environmental externalities affect farming activities efficient use of water and land resources at Muooni dam site?
- (ii) To what extent are land use activities affecting the active water storage capacity of Muooni dam?
- (iii) What variations of farmers' water demand and related operational costs are expected as a result of rainfall fluctuation in Muooni catchment?
- (iv) What are the farmers' water economic demand and limit costs related to their production efficiency under different rainfall scenarios?

5.1.2 Synoptic Review of the Study Findings

Results presented in this study reinforce findings by Jaetzold *et al.* (2007), Waswa (2006 and 2000), Shisanya (2005 and 1996), Morgan (1995), Tiffen *et al.* (1994), and Lal (1993). They show that land management is highly correlated with the level of education and poverty in the dam site. The intrusion of non-farmers in farming areas has an impact on land good husbandry, as the majority of them are “ignorant and agents of degradation” in pursuit of survival. Muooni catchment is no more a viable farming area. First, a majority of farmers were working in off-farm sectors, while only 33% are still working full-time. Second, full-time farmers are very poor and of very modest education, while intruders are acknowledged to have high levels of formal education and income. The latter are employing caretakers of low education level to conserve their soil and supplement their livelihood through some farming practices. Their lack of knowledge is apparent through failure to link gully erosion and mass movement to their main precursors, which are rills and inter-rills, and the destruction of ground cover. Agro-forestry and subsistence cultivation without irrigation are the most significant land-use

practices at Muooni dam site. Yet, they are threatened by soil erosion, landslides and water over-abstraction by ecosystems (namely, eucalyptus). The latter were propounded to be the most significant factors affecting water availability.

When assessing the relationship between land-use activities and the impacts observed on farmlands, Mann-Whitney U-test Z value proved with 99.8% confidence degree that land-use activities assessed and their presumed impacts were randomly drawn from independent populations' samples. They might have originated within and outside Muooni dam site. Spearman's rank correlation confirmed again that result at 99.8% confidence degree. It showed that the two random samples were behaving independently one from another. There was thus no strong relationship between land-use activities assessed and the impacts recorded on the farms. Those impacts may have come from Muooni dam Immediate Silting Zone (ISZ) through on-farm soil erosion, as well as from its Gradual Silting Zone (GSZ) by the effect of off-farm soil erosion.

Though not directly related to land-use activities assessed, environmental impacts observed were actually threatening Muooni dam's water storage capacity. The dam reservoir was overloaded by important sediments from farms (or the ISZ) and other environmental agents (from the GSZ) such as off-farm effects of slopes and winds, and El Niño floods and droughts. Responding to the question "to what extent are land use activities affecting the active water storage capacity of Muooni dam?" the study reveals that they may explain about 61.1% of the total variation of Muooni dam active storage capacity (with a decreasing trend). However, the Rho test proved at 99.5% degree of confidence and 34 degree of freedom that 62.4% of the dam storage capacity variation

was reflected in the variation of the time, and that 38.9% of its total variation was due to the dam reservoir infrastructures lack of resistance as years passed. The decreasing evolution of the storage capacity may therefore be explained by both the obsolescence of the dam infrastructures and external environmental impacts loading important sediments into its reservoir. Muooni dam's active water storage capacity trend line shows an annual decreasing rate of 6.22%. The reservoir maximum capacity that was fixed at 1,559,400 m³ in 1987, is nowadays estimated to 236,449.7 m³ (in 2008). If these trends continue, the dam storage capacity will be under its threshold in the year 2020, storing only about 112,093.8 m³ of the total flow of Muooni stream. This is a justification of water stress facing farmers and of the incoming scarcity if the decrescendo continues without let-up.

There was a large gap between farmers' water demand and their crops actual water requirements. In fact, LSF farmers were ordering approximately 28.9% of their actual crops water demand, while MSF and SSF ones were buying respectively 12.2% and 4.4% of their actual crops water requirement. However, the total, average and marginal costs functions were highly variable under the influence of external agents, especially rainfall fluctuation due notably to El Niño droughts and floods. Some internal factors like excessive multiple cropping and inadequate on-farm inputs management were also impacting on high water prices and operational costs high variation. The analysis revealed an increase of about 175%, 518% and 11,437% of actual costs values observed respectively under the ANOR, NOR and BNOR scenarios in terms of operational average costs. These values were simulated under the hypothesis of a theoretic water demand turnover value being equal to the ratio of the dam's active water storage capacity and the

median capacity fixed by the engineers. For efficiency, farmers needed to limit their water demand, farming costs and losses using their best management skills associated with innovative measures and technologies. The introduction of efficient methods of crops treatment, selection and specialisation, soil conservation and water saving strategies were among some avenues suggested by the study.

After optimization of the water demand turnover for each farming scale and rainfall regime scenario, the analysis revealed that farmers' water orders were insufficient for meeting their crops natural water requirements. LSF, MSF and SSF farmers had to increase their respective actual water demand by an average of 147.9%, 142.2% and 152.2% to meet their water Economic Order Quantities (EOQs). Thus, they could avoid more shortage costs and losses due to crops failure. Also, it was expected a fall of their operational costs up to 40%, 70% and 98% under respectively ANOR, NOR and BNOR.

However, there was a certain Limit Average Cost (LAC) beyond which the farmers could not go. The analysis demonstrated that they had to maintain their normal EOQ under any rainfall regime, if losses were to be avoided. That meant for them keeping their current average costs increasing up to 100 % under any rainfall regime. To improve the economic viability of their farming activities, they needed also to increase their actual water demand by 50% (for SSF and LSF) or at least by 40% (for MSF) to meet the natural water requirements of their crops. Otherwise, they would have to experience crops failure, especially under the BNOR scenario.

Finally, as 69% of farms surveyed were incurring losses. The study suggested that they limit their production to a Minimum Efficient Scale (MES). By keeping their farming production under the MES, the analysis revealed that higher costs reductions were expected under the BNOR and NOR scenarios, ranging from 68% to 98%. Lower costs reductions were expected under the ANOR scenario. Moreover, farmers were to increase their water orders as soil moisture decreased with rainfall regime wetness. For efficiency, they had to limit their operational water demand variation to 36%, 129% and 972% (instead of 175%, 518% and 11,437%) under the ANOR, NOR and BNOR scenarios, respectively. The differential water demand was to be compensated by rainfall input, efficient on-farm management and technological innovation.

Due to increased water productivity, the latter could help increase the farming income at least by 76 % (under the ABNOR and NOR scenarios) and beyond 120% (under the BNOR scenario). However, the efficiency rate highly depended on the farm size and rational management of watershed resources. This result confirmed the assertion that farming areas sub-division for human population settlements threatened the economic viability of smallholder farms. Farmers needed to use efficient methods of water saving in agricultural production in order to keep their production in the optimum limits of the production possibility frontier. These involved water consumption metering, rainwater harvesting and hydroplacies (green water credits and virtual water import), rational crops treatment, selection and specialisation (with no more than 3 crop species), farming inputs application (fertilisers, pesticides, fungicides, rodenticides, etc) and other on-farm technologies and management strategies. A majority of farmers being poor, they were not

attempting to apply farming inputs and modern technologies. They were suggested to make some tradeoffs between on-farm and off-farm income-generating activities for the sustainability of their livelihood.

5.2. Conclusions

The on-farm survey conducted at Muooni dam site was very rich in information. It revealed that farms would no longer be efficient economic units since both on-farm and off-farm socio-economic and environmental impacts were affecting their economic viability. For instance, the survey showed that genuine farmers were vanishing from the dam site because of poor farming yields and income. The latter was tributary to low productivity of land resources and was directly related to the poor education of many farmers. Farmers were using excessive multiple cropping on small farming areas with the risk of threatening the soil under the impulsion of external agents (such as El Niño, floods and droughts, wind pressure and adverse effects of deforestation). The direct consequences of these agents' action were soil erosions, landslides and water excess loss. These processes were likely to enhance sediment loads into the dam reservoir as well as the over-abstraction of its water resources. These, in turn, affected rational farmland management and the active storage capacity of Muooni dam. Consequently, water stress and land scarcity along with other socio-economic and environmental issues (such as enhanced poverty and illiteracy, and farming areas depletion) were observed among other corollaries. These were finally expected to impel farming operational costs to the high, especially under rainfall regimes fluctuation. Such costs variation prohibited farmers' water demand meeting crops water requirement. So, farmers were impotently assisting to

their crops failure, especially under the BNOR scenario.

To improve agricultural efficiency at Muooni dam site, farmers need to monitor and evaluate their activities on a regular basis. Effective management of watershed resources use in agriculture will help them limit rationally their crops water requirement, and subsequent farming operational costs and losses. Farmers need also to assess and adopt alternative farming strategies and technologies for avoiding increasing costs of transaction, opportunity costs, costs of water saving and shortage costs. They may improve their actual farming water demand either through direct metering of their water orders from the dam or by rational crops treatment, selection and specialisation, green water credits acquirement and virtual water import. They are to make sure that their demand meets crops water requirement under any rainfall regime, if any farming income and profit are to be expected. By so doing, they will be able to ensure both efficiency and sustainability of their farming activities at Muooni dam site.

5.3. Recommendations

5.3.1. Agricultural Watershed Resources Management: Policy Guidelines

From the study findings, the following recommendations will help fostering efficient watershed resources use in farming activities at Muooni dam site. The Government of Kenya is thus urged to:

- (i) Rehabilitate the dam infrastructures and keep maintaining them to enhance its water productivity and recover its capital investment.
- (ii) Set consumption metering as a requirement for any use of water resource from the dam, and issue water users with permits according to the legal prescriptions.

- (iii) Identify illegal abstractors and impeach them to use water from the dam without permits.
- (iv) Promote roof catchments for harvesting rainwater and other techniques of rainwater saving.
- (v) Promote and create off-farm employments in the catchment for tackling the issues of poverty, soil erosion and water over-abstraction by alien trees (such as eucalyptus, grevillia, etc).
- (vi) Fund “green water credits” projects, with the aim of replacing eucalyptus trees by indigenous ones.
- (vii) Keep enforcing the 1999 EMCA in Muooni catchment for the preservation of wetlands natural ecosystems.
- (viii) Reinforce farmers’ capabilities in soil conservation, and build Muooni catchment public officers’ capacity in sustainable management of dams.
- (ix) Encourage participatory watershed rehabilitation activities to enhance cooperation among direct stakeholders in the watershed through the development of the Athi Catchment Management Strategy and Muooni Sub-Catchment Management Plan.
- (x) Encourage public-private sectors partnership through institutional linkages between the “Water Resource Management Authority” (WRMA), the “Water Services Providers” (WSP), the “Water Resource Users Association” (WRUA) and all other associations of farmers (Cooperatives, NGOs, CBOs, etc).
- (xi) Take urgent actions to curb the faster settlement and rapid population growth, and enhance agricultural efficiency at Muooni catchment to avoid food crises.

5.3.2 On-farm Watershed Resources Strategic Management

With regard to the farming production efficiency, it recommended that farmers decrease their operational costs and increase their actual water productivity through:

- (i) Use of crops selection of and specialisation (by one to three species per hectare) along with science-based intensive agriculture, where applicable
- (ii) Application of alternative technologies valuing watershed resources and fostering farming production within the production possibility frontier.
- (iii) Increase of soil micronutrients by producing biomass of ‘composting plants’ (like Tithonia) and using fertilizers and manure.
- (iv) Rational use of multiple cropping along with other soil conservation measures.
- (v) Corporation of smallholder farms into large farming enterprises (i.e. agricultural cooperatives) under the supervision of a steering committee.
- (vi) Employment of semi-qualified and qualified labour for livestock keeping and land care (instead of unqualified relatives).
- (vii) Incorporation of factors like soil types, land form and terrain characteristics, rainfall regime and hydrology, farming systems and socio-economic factors for erosion prevention in the soil erosion control strategy.
- (viii) Control of animals stock and grazing, particularly around watering points, to prevent wetlands grass cover destruction.
- (ix) Avoidance of illegal water abstraction from the dam by using pumping and storing devices, cropping eucalyptus trees and any other water unfriendly crops in the wetlands or using inadequate irrigation methods such as furrow irrigation.
- (x) Limitation of hazardous rainfed agriculture by using weather information.

- (xi) Taking advantage of reduced water shortage costs and increased yields during the ANOR and NOR to meet perennial and seasonal economic benefits.
- (xii) Use of water saving methods (e.g. rainwater harvesting, virtual water import, green water credits, etc) to meet crops water requirement.
- (xiii) Limitation of average costs and determination of efficient production scale by planning all operational costs, crops water requirement and farming water orders.
- (xiv) Tradeoffs made between farming activities and alternative livelihood sources.
- (xv) Maintenance of living standards and settlement by limitation of household size (e.g. through contraceptive methods).

5.3.3 Prospective Strategic Researches

In the future, it will be commendable that particular attention be given to the following research topics in Muooni catchment in general and Muooni dam site in particular:

- (i) To study methods of control of human-induced activities exacerbating effects on human welfare, community development and environment conservation.
- (ii) To assess climate change impact on farmers' water demand, and design adequate measures for adaptation.
- (iii) To suggest appropriate land-use practices for degraded catchment areas (like Muooni) for the sustainability of local initiatives.
- (iv) To propound alternative drought resistant hybrid crops suitable to Muooni catchment agro-ecological zone.
- (v) To monitor Muooni river daily flow and its dam's water active storage capacity.
- (vi) To integrate farming issues in the Catchment Management Strategy (CMS).

- (vii) To develop a participatory watershed resources demand plan, and its monitoring and evaluation process.
- (viii) To study interdisciplinary methods of ex post environmental impacts assessment with a participatory approach in view.

5.3.4 Further Scientific Research Strategy

This scientific research was mainly based on an operational research simulation of farming costs variability at Muooni dam site. For the sake of comparability and attribution analysis, it will be commendable to duplicate it in a similar environment (i.e. a dam site of a semi-arid catchment and within an upper mid-land agro-ecological zone) as well as replicating it in other environments (e.g. catchment without a dam, within a tropical humid climatic zone and/or a lower mid-land agro-ecological zone). Successful results obtained could be disseminated in the whole country to monitor and enhance farming activities efficient use of watershed resources. Finally, for further monitoring and evaluation of Muooni dam's active water storage capacity, it will be commendable that Soil and Water Analytical Tools (SWAT) be used to measure accurately soil loss and water balance at Muooni catchment in general and Muooni dam site in particular.

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APPENDICES

Appendix 4.1

Crops Water Requirement and Farmers' Water Demand Computation

N ^o	Crop Type	ETM (Kg/m ³)	VWV (m ³ /Kg)	LSF	
				Qty (Kg)	W _c (m ³)
1	Avocado	3.5	0.2857	288	82.25
2	Banana	4	0.25	514	128.57
3	Blue Gum	2.16	0.463	0	0
4	Cabbage	16	0.0625	2400	150
5	Cassava	5.5	0.1818	0	0
6	Coffee	3.5	0.2857	720	205.7143
7	Cow peas	0.3875	2.5806	300	774.1935
8	Cypres	2.16	0.463	120	55.55556
9	Eucalyptus	2.16	0.463	0	0
10	Finger millets	1.2	0.8333	0	0
11	French Beans	1.1	0.9091	450	409.09
12	Green Pepper	2.25	0.4444	0	0
13	Grevilia	2.16	0.463	240	111.11
14	Groundnuts	0.7	1.4286	0	0
15	Guava	3.5	0.2857	0	0
16	Irish Potatoes	5.5	0.1818	1,1000	200
17	Maize	1.2	0.8333	2160	1800
18	Mango	3.5	0.2857	720	271.43
19	Marrow	3.55	0.2817	118	33.24
20	Onions	9	0.1111	270	30
21	Sweet Pepper	2.25	0.4444	225	100
22	Pumpkins	6.5	0.1538	0	0
23	Sorghum	0.8	1.25	0	0
24	Sukuma	16	0.0625	0	0
25	Sugar cane	3.65	0.274	1080	295.89
26	Sweet Apple	10	0.1	0	0
27	Sweet Potatoes	5.5	0.1818	1440	261.8182
28	Tomatoes	11	0.09091	900	81.8182
	Total Annual W_c				4,990.68
	Total Daily W_c				13.863
	Total Annual W_f				1,440
	Total Daily W_f				4.0
	Daily W_c Gap (m³)				9.863
	Daily W_c Gap (%)				71.15

Appendix 4.1, Continued

N ^o	Crop Type	MSF		SSF	
		Qty (Kg)	W_c (m ³)	Qty (Kg)	W_c (m ³)
1	Avocado	480	137.1429	0	0
2	Banana	514.2857	128.5714	51.42857	12.85714
3	Blue Gum	0	0	0	0
4	Cabbage	0	0	1200	75
5	Cassava	180	32.72727	0	0
6	Coffee	720	205.7143	108	30.85714
7	Cow peas	480	1238.71	300	774.1935
8	Cypres	0	0	0	0
9	Eucalyptus	0	0	0	0
10	Finger millets	0	0	0	0
11	French Beans	0	0	0	0
12	Green Pepper	0	0	0	0
13	Grevilia	0	0	0	0
14	Groundnuts	0	0	0	0
15	Guava	0	0	0	0
16	Irish Potatoes	900	163.6364	45	8.181818
17	Maize	2160	1800	216	180
18	Mango	0	0	0	0
19	Marrow	0	0	0	0
20	Onions	0	0	0	0
21	Sweet Pepper	0	0	0	0
22	Pumpkins	0	0	0	0
23	Sorghum	0	0	0	0
24	Sukuma	0	0	0	0
25	Sugar cane	720	197.2603	0	0
26	Sweet Apple	0	0	0	0
27	Sweet Potatoes	1440	261.8182	0	0
28	Tomatoes	0	0	0	0
	Total Annual W_c		4,165.58		1,081.0897
	Total Daily W_c		11.571		3.003
	Total Annual W_f		540		48
	Total Daily W_f		1.5		0.1333
	Daily W_c Gap (m³)		10.071		2.87
	Daily W_c Gap (%)		87.80%		95.57

Appendix 4.2

Farmer's Operations costs Simulation under different Rainfall Regimes

No	Function/ Value	ANOR	NOR
1.1	Total Cost (TC)	$TC_{an}=(Y+\Pi) r-\Pi+2E/r$	$TC_{no}=Y r+2E/r$
1.2	LSF TC Function	$800.83 r+99.17+1,998.34/r$	$900 r+1, 998.34/r$
1.3	MSF TC Function	$751.389 r+8.06+1,536.12/r$	$760 r+1,536.12/r$
1.4	SSF TC Function	$133.53 r+21.47+352.94/r$	$155 r+352.94/r$
2.1	Average Cost (MAC)	$AC_{an}=Y+\Pi-\Pi/r+2E/r^2$	$AC_{no}=Y+2E/r^2$
2.2	LSF AC Function	$800.83 +99.17/ r +1,998.34/r^2$	$900 +1,998.34/r^2$
2.3	MSF AC Function	$751.94+8.06/r +1,536.12/r^2$	$760 +1,536.12/r^2$
2.4	SSF AC Function	$133.53+21.47/r +352.94/ r^2$	$155 + 352.94/r^2$
3.1	Marginal Cost (MMC)	$MC_{an}=Y+\Pi-2E/r^2$	$MC_{no}=Y-2E/r^2$
3.2	LSF MC Function	$800.83 - 1,998.34/r^2$	$900. -1,998.34/r^2$
3.3	MSF MC Function	$751.94 - 1,536.12/r^2$	$760 - 1,536.12/r^2$
3.4	SSF MC Function	$133.53 - 352.94/ r^2$	$155 - 352.94/r^2$
4.1	1988 turnover (r_{an})	$r_{an}=1.04351$	-
4.2	1998 turnover (r_{no})	-	$r_{no}=0.6169$
4.3	2020 turnover (r_{bn})	-	-
5.1	LSF TC Value	$LSF TC_{an}=2,849.86$	$LSF TC_{no}=3,794.54$
5.2	MSF TC Value	$MSF TC_{an}= 2,264.79$	$MSF TC_{no}=2,958.91$
5.3	SSF TC Value	$SSF TC_{an}= 499.03$	$SSF TC_{no}= 667.74$
6.1	LSF AC Value	$LSF AC_{an}=2,731.03$	$LSF AC_{no}=6,150.97$
6.2	MSF AC Value	$MSF AC_{an}= 2,170.35$	$MSF AC_{no}= 4,796.41$
6.3	SSF AC Value	$SSF AC_{an}=478.23$	$SSF AC_{no}=1,082.41$
7.1	LSF MC Value	$LSF MC_{an}= -1,034.34$	$LSF MC_{no}= -4,350.97$
7.2	MSF MC Value	$MSF MC_{an}= -658.75$	$MSF MC_{no}= -3,276.41$
7.3	SSF MC Value	$SSF MC_{an}= -190.59$	$SSF MC_{no}= -772.41$
8.1	LSF W_c Value	$LSF W_{can}=13.863$	$LSF W_{cno}=13.863$
8.2	MSF W_c Value	$MSF W_{can}=11.571$	$MSF W_{cno}=11.571$
8.3	SSF W_c Value	$SSF W_{can}=3.003$	$SSF W_{cno}=3.003$
9.1	Water Demand (W_f)	$Wf_{an}=rWc_{an}$	$Wf_{no}=rWc_{no}$
9.2	LSF W_f Value	$LSF Wf_{an}=14.47$	$LSF Wf_{no}= 8.55$
9.3	MSF W_f Value	$MSF Wf_{an}=12.07$	$MSF Wf_{no}= 7.14$
9.4	SSF W_f Value	$SSF Wf_{an}=3.13$	$SSF Wf_{no}= 1.85$

Appendix 4.2, Continued

No	Function/ Value	BNOR	Comments
1.1	Total Cost (TC)	$TC_{bn}=(Y-\Pi)r + \Pi+2E/r$	Formula 3.16-3.17-3.18
1.2	LSF TC Function	$999.17r-99.17+1,998.34/r$	
1.3	MSF TC Function	$768.06r - 8.06 + 1,536.12/r$	
1.4	SSF TC Function	$176.47r-21.47+352.94/r$	
2.1	Average Cost (MAC)	$AC_{bn}=E+\Pi/r + 2E/r^2$	Formula 3.21-3.23 -3.25
2.2	LSF AC Function	$999.17-99.17/r+ 1,998.34/r^2$	
2.3	MSF AC Function	$768.06 - 8.06/r + 1,536.12/r^2$	
2.4	SSF AC Function	$176.47 - 21.47+352.94/r^2$	
3.1	Marginal Cost (MMC)	$MC_{bn}=E-2E/r^2$	Formula 3.22-3.24-3.26
3.2	LSF MC Function	$999.17 - 1,998.34/r^2$	
3.3	MSF MC Function	$768.06 - 1,536.12/r^2$	
3.4	SSF MC Function	$176.47 - 352.94/r^2$	
4.1	1988 turnover (r_{an})	-	$r = S_{1988}/ S_{median}$
4.2	1998 turnover (r_{no})	-	$r = S_{1998}/ S_{median}$
4.3	2020 turnover (r_{bn})	$r_{bn} = 0.1319$	$r = S_{2020}/ S_{median}$
5.1	LSF TC Value	$LSF TC_{bn}=15,183.04$	
5.2	MSF TC Value	$MSF TC_{bn}=11,739.34$	
5.3	SSF TC Value	$SSF TC_{bn}= 2,677.62$	
6.1	LSF AC Value	$LSF AC_{bn}=115,110.22$	
6.2	MSF AC Value	$MSF AC_{bn}= 89,001.84$	
6.3	SSF AC Value	$SSF AC_{bn}=20,300.39$	
7.1	LSF MC Value	$LSF MC_{bn}= -113,863.73$	
7.2	MSF MC Value	$MSF MC_{bn}= -87,526.83$	
7.3	SSF MC Value	$SSF MC_{bn}=-20,110.22$	
8.1	LSF W_c Value	$LSF W_{c_{bn}}=13.863$	
8.2	MSF W_c Value	$MSF W_{c_{bn}}=11.571$	
8.3	SSF W_c Value	$SSF W_{c_{bn}}=3.003$	
9.1	Water Demand (W_f)	$W_f W_{f_{bn}} = rW_{c_{bn}}$	Formula 3.30
9.2	LSF W_f Value	$LSF W_{f_{bn}} = 1.83$	
9.3	MSF W_f Value	$MSF W_{f_{bn}} = 1.53$	
9.4	SSF W_f Value	$SSF W_{f_{bn}} = 0.40$	

Appendix 4.3

Farmers' water Economic Order Quantity (EOQ) under Rainfall Fluctuation

No	Function/ Value	ANOR	NOR
1.1	LSF TC Function	$800.83 r + 99.17 + 1,998.34/r$	$900 r + 1, 998.34/r$
1.2	MSF TC Function	$751.389 r + 8.06 + 1,536.12/r$	$760 r + 1,536.12/r$
1.3	SSF TC Function	$133.53 r + 21.47 + 352.94/r$	$155 r + 352.94/r$
2.1	LSF AC Function	$800.83 + 99.17/r + 1,998.34/r^2$	$900 + 1,998.34/r^2$
2.2	MSF AC Function	$751.94 + 8.06/r + 1,536.12/r^2$	$760 + 1,536.12/r^2$
2.3	SSF AC Function	$133.53 + 21.47/r + 352.94/r^2$	$155 + 352.94/r^2$
3.1	LSF MC Function	$800.83 - 1,998.34/r^2$	$900. -1,998.34/r^2$
3.2	MSF MC Function	$751.94 - 1,536.12/r^2$	$760 - 1,536.12/r^2$
3.3	SSF MC Function	$133.53 - 352.94/r^2$	$155 - 352.94/r^2$
4.1	LSF optimum r	$LSF r_{an} = 1.5797$	$LSF r_{no} = 1.4901$
4.2	MSF optimum r	$MSF r_{an} = 1.4293$	$MSF r_{no} = 1.4217$
4.3	SSF optimum r	$SSF r_{an} = 1.6258$	$SSF r_{no} = 1.509$
5.1	LSF MTC Value	$LSF MTC_{an} = 2,629.25$	$LSF MTC_{no} = 2,682.17$
5.2	MSF MTC Value	$MSF MTC_{an} = 2,157.54$	$MSF MTC_{no} = 2,160.97$
5.3	SSF MTC Value	$SSF MTC_{an} = 455.65$	$SSF MTC_{no} = 467.78$
6.1	LSF MAC Value	$LSF MAC_{an} = 1,664.40$	$LSF MAC_{no} = 1,799.99$
6.2	MSF MAC Value	$MSF MAC_{an} = 1,509.51$	$MSF MAC_{no} = 1,519.99$
6.3	SSF MAC Value	$SSF MAC_{an} = 280.26$	$SSF MAC_{no} = 310.00$
7.1	LSF MMC Value	$LSF MMC_{an} = -0.04$	$LSF MMC_{no} = 0.01$
7.2	MSF MMC Value	$MSF MMC_{an} = -0.01$	$MSF MMC_{no} = 0.01$
7.3	SSF MMC Value	$SSF MC_{an} = 0.00$	$SSF MMC_{no} = 0.00$
8.1	LSF Observed W_c Value	$LSF W_{can} = 13.863$	$LSF W_{cno} = 13.863$
8.2	MSF Observed W_c Value	$MSF W_{can} = 11.571$	$MSF W_{cno} = 11.571$
8.3	SSF Observed W_c Value	$SSF W_{can} = 3.003$	$SSF W_{cno} = 3.003$
9.1	EOQ (\bar{W}_f)	$\bar{W}_{f an} = \bar{r}_{an} \cdot W_{can}$	$\bar{W}_{f no} = \bar{r}_{no} W_{cno}$
9.2	LSF EOQ Value	$LSF \bar{W}_{f an} = 21.90$	$LSF \bar{W}_{f no} = 20.66$
9.3	MSF EOQ Value	$MSF \bar{W}_{f an} = 16.54$	$MSF \bar{W}_{f no} = 16.45$
9.4	SSF EOQ Value	$SSF \bar{W}_{f an} = 4.88$	$SSF \bar{W}_{f no} = 4.53$

Appendix 4.3, Continued

No	Function/ Value	BNOR	Comments
1.1	LSF TC Function	$999.17r - 99.17 + 1,998.34/r$	Formula 3.16-3.17-3.18
1.2	MSF TC Function	$768.06r - 8.06 + 1,536.12/r$	
1.3	SSF TC Function	$176.47r - 21.47 + 352.94/r$	
2.1	LSF AC Function	$999.17 - 99.17/r + 1,998.34/r^2$	Formula 3.21-3.23 -3.25
2.2	MSF AC Function	$768.06 - 8.06/r + 1,536.12/r^2$	
2.3	SSF AC Function	$176.47 - 21.47 + 352.94/r^2$	
3.1	LSF MC Function	$999.17 - 1,998.34/r^2$	Formula 3.22-3.24-3.26
3.2	MSF MC Function	$768.06 - 1,536.12/r^2$	
3.3	SSF MC Function	$176.47 - 352.94/r^2$	
4.1	LSF optimum \bar{r}	$LSF \bar{r}_{bn} = 1.4142$	Formula 3.27-3.28-3.29
4.2	MSF optimum \bar{r}	$MSF \bar{r}_{bn} = 1.4142$	
4.3	SSF optimum \bar{r}	$SSF \bar{r}_{bn} = 1.4142$	
5.1	LSF MTC Value	$LSF MTC_{bn} = 2,726.91$	
5.2	MSF MTC Value	$MSF MTC_{bn} = 2,164.34$	
5.3	SSF MTC Value	$SSF MTC_{bn} = 499.13$	
6.1	LSF MAC Value	$LSF MAC_{bn} = 1,928.23$	
6.2	MSF MAC Value	$MSF MAC_{bn} = 1,530.44$	
6.3	SSF MAC Value	$SSF MAC_{bn} = 352.94$	
7.1	LSF MMC Value	$LSF MMC_{bn} = -0.02$	
7.2	MSF MMC Value	$MSF MMC_{bn} = -0.01$	
7.3	SSF MMC Value	$SSF MMC_{bn} = 0.00$	
8.1	LSF W_c Value	$LSF W_{cbn} = 13.863$	
8.2	MSF W_c Value	$MSF W_{cbn} = 11.571$	
8.3	SSF W_c Value	$SSF W_{cbn} = 3.003$	
9.1	EOQ (\bar{W}_f)	$EOQ_{bn} = \bar{W}_f_{bn} = \bar{r}_{bn} \cdot W_{cbn}$	Formula 3.30
9.2	LSF EOQ Value	$LSF \bar{W}_f_{bn} = 19.61$	
9.3	MSF EOQ Value	$MSF \bar{W}_f_{bn} = 16.36$	
9.4	SSF EOQ Value	$SSF \bar{W}_f_{bn} = 4.25$	

Appendix 4.4

Farmers Limit Average Cost (LAC) and Water Demand Rational Limit

No	Function/ Value	Results	Comments
1.1	Limit Total Cost (LTC)	$LTC = Y r + 2E/r$	Formula 3.17
1.2	LSF LTC Function	$900 r + 1, 998.34/r$	
1.3	MSF LTC Function	$760 r + 1, 536.12/r$	
1.4	SSF LTC Function	$155 r + 352.94/r$	
2.1	Limit Average Cost (LAC)	$LAC = Y + 2E/r^2$	Formula 3.23
2.2	LSF LAC Function	$900 + 1, 998.34/r^2$	
2.3	MSF LAC Function	$760 + 1, 536.12/r^2$	
2.4	SSF LAC Function	$155 + 352.94/r^2$	
3.1	Limit Marginal Cost (LMC)	$LMC = Y - 2E/r^2$	Formula 3.24
3.2	LSF LMC Function	$900 - 1, 998.34/r^2$	
3.3	MSF LMC Function	$760 - 1, 536.12/r^2$	
3.4	SSF LMC Function	$155 - 352.94/r^2$	
4.1	LSF Limit turnover (r^*)	$LSF r^* = 1.4901$	Optimum turnover under normal rainfall regime
4.2	MSF Limit turnover (r^*)	$MSF r^* = 1.4217$	
4.3	SSF Limit turnover (r^*)	$SSF r^* = 1.509$	
5.1	LSF LTC Value	$LSF LTC_{no} = 2,682.17$	
5.2	MSF LTC Value	$MSF LTC_{no} = 2,160.97$	
5.3	SSF LTC Value	$SSF LTC_{no} = 467.78$	
6.1	LSF LAC Value	$LSF LAC_{no} = 1,799.99$	
6.2	MSF LAC Value	$MSF LAC_{no} = 1,519.99$	
6.3	SSF LAC Value	$SSF LAC_{no} = 310.00$	
7.1	LSF LMC Value	$LSF LMC_{no} = 0.01$	
7.2	MSF LMC Value	$MSF LMC_{no} = 0.01$	
7.3	SSF LMC Value	$SSF LMC_{no} = 0.00$	
8.1	W_c Observed LSF Value	$LSF W_c = 13.863$	
8.2	W_c Observed MSF Value	$MSF W_c = 11.571$	
8.3	W_c Observed SSF Value	$SSF W_c = 3.003$	
9.1	Limit Water Demand ($Lim W_f$)	$Lim W_f = r^* \cdot W_{can}$	Relation 3.30
9.2	LSF W_f Limit Value	$LSF Lim W_f = 20.66$	
9.3	MSF W_f Limit Value	$MSF Lim W_f = 16.45$	
9.4	SSF W_f Limit Value	$SSF Lim W_f = 4.53$	

Appendix 4.5

Farming Production Minimum Efficient Scale (MES) under Rainfall Fluctuation

No	Function /Value	LSF	MSF
1.1	MTC Function	$999.17 r - 99.17 + 1,998.34/r$	$768.06 r - 8.06 + 1,536.12 r$
1.2	MAC Function	$999.17 - 99.17/r + 1,998.34 /r^2$	$768.06 - 8.06/r + 1,536.12/r^2$
1.3	MMC Function	$999.17 - 1,998.34 /r^2$	$768.06 - 1,536.12/r^2$
2.1	Minimum Turnover (\bar{r})	$\bar{r}_{bn} = 1.4142$	$\bar{r}_{bn} = 1.4142$
3.1	MTC Value	$LSF MTC_{bn} = 2,726.91$	$MSF MTC_{bn} = 2,164.34$
3.2	MAC Value	$LSF MAC_{bn} = 1,928.23$	$MSF MAC_{bn} = 1,530.44$
3.3	MMC Value	$LSF MMC_{bn} = -0.02$	$MSF MMC_{bn} = -0.01$
4.1	Min W_c Value	$min W_{c_{bn}} = 13.863$	$min W_{c_{bn}} = 11.571$
5.1	Min W_f Function	$min W_{f_{bn}} = rW_{c_{bn}}$	$min W_{f_{bn}} = rW_{c_{bn}}$
5.2	Minimum W_f Value	$min W_{f_{no}} = 19.61$	$min W_{f_{bn}} = 16.36$

Appendix 4.5, Continued

No	Function /Value	SSF	Comments
1.1	MTC Function	$176.47 r - 21.47 + 352.94/r$	Formula 3.18
1.2	MAC Function	$176.47 - 21.47 + 352.94/r^2$	Formula 3.25
1.3	MMC Function	$176.47 - 352.94/r^2$	Formula 3.26
2.1	Minimum \bar{r}	$\bar{r}_{bn} = 1.4142$	
3.1	MTC Value	$SSF MTC_{bn} = 499.13$	
3.2	MAC Value	$SSF MAC_{bn} = 352.94$	
3.3	MMC Value	$MMC_{bn} = 0.00$	
4.1	Min W_c Value	$min W_{c_{bn}} = 3.003$	
5.1	Min W_f	$min W_{f_{bn}} = rW_{c_{bn}}$	Formula 3.30
5.2	Minimum W_f Value	$min W_{f_{bn}} = 4.25$	

13. Your main seasonal crops: None Maize Irish potatoe Sweet potatoes
Cassava Cowpeas Finger millets Sorghum Groundnuts French beans
 Others (*specify*).....
14. Your main livestock species: None Cattle Goats Sheep Pigs
 Chicken Others (*specify*).....

Crops Production Cost-Benefit Analysis

15. What are the main inputs used in your farming activity?

(*Please, indicate also the quantity and costs per cycle to complete your answer*)

<i>N^o</i>	<i>Nature of Input</i>	<i>Quantity(Kg)</i>	<i>Unit cost/kg</i>	<i>Total Cost</i>	<i>Comment</i>
1	Crop seeds				
2					
3					
4					
5					
6					
7					
8	Fertilizers				
9					
10					
11					
12	Manure				
13	Insecticides				
14	Herbicides				
15	Fungicides				
16	Rodenticide				
17					

16. Do you pay your water for agriculture? YES NO

How much per month? Ksh..... / per m³

17. Give an estimate of some other costs incurred in your farming activity, if any.

<i>No</i>	<i>Nature of Cost</i>	<i>Monthly cost</i>	<i>Total Cost</i>	<i>Comment</i>
1	Wages (for....workers)			
2	Transport			
3	Fuel (for water Pumps)			
4	Taxes			
5				

18. Can you evaluate your mean annual production and sales (per crop)?

<i>No</i>	<i>Type of Crop</i>	<i>Average Monthly Sale</i>	<i>Average Annual Sale</i>	<i>Comment</i>
1	Cabbage			
2	Cowpeas			
3	French beans			
4	Groundnuts			
5	Sorghum			
6	Finger millets			
7	Maize			
8	Banana			
9	Irish potatoes			
10	Sweet potatoes			
11	Sugarcane			
12	Coffee			
13	Eucalyptus			
14	Mango			
15	Guava			
16				
17				
18				
19				

19. After this cost analysis of your agricultural activity, what can you say about farming activities *efficiency* at Muooni dam site? (*Plse. continue on separate sheet to complete your answer*).....

.....

20. Why do most people persist in farming activities even when they incur losses over the time?.....

.....

21. What would you suggest for efficient farming income generating at Muooni dam site?

.....

On-Farm Environmental Resources Management

22. What environmental problems are you facing?

- Frequent drought Frequent floods Limited land Grazing field depletion
 Water distance Grazing distance Animals/plants sicknesses Others

23. How would you explain the increasing drought in the catchment? Please, provide a detailed description of what you see (*Plse, continue on separate sheet*).....

.....

24. Farming activities and hydro-geomorphologic impacts (*To be filled by the Surveyor*)

Tick	Farming Activities	Tick	Hydro-geomorphologic Impacts
	Subsistence cultivation without irrigation		Presence of slides in the farm area
	Subsistence cultivation with limited irrigation		Agriculture in wetlands Impact
	Intensive cultivation with water pumps		Presence of sheets in the farm area
	Dairy & meat farming without cultivation		Quarrying / sand harvesting in the farmland
	Dairy & meat farming with some cultivation		Presence of gullies in the farm area
	Tree planting		Eucalyptus tree water abstraction

25. What are your traditional water conservation methods? None Roof catchment
 Buckets/calabashes storage Underground tank Seasonal wells Others.....

26. What are your traditional soil conservation methods? None Contouring
 Terraces Windbreaks Headwater fencing Agro-forestry Small dams
 Others

27. Your Traditional Animal watering Techniques None Human-cattle Mix

Watering Animals Watering basins/Wells Animals Time Allocation
 Others

28. Your Traditional water Hygienic Measures: None Water prohibitions /taboos

- Drinking/washing alternative sites Human/wildlife alternative sites
- Water purification Fencing headwaters Others.....

29. According to you, are traditional methods of water and soil conservation effective or efficient? Efficient/effective Fairly effective/efficient Inefficient

30. Please provide some details about what you think to be an effective or efficient method of water / soil conservation method (*Please continue on separate sheet to complete your answer*).....

.....

.....

31. If the Government asked you to relocate from the dam site, will you agree?

Yes Yes but... Not at all

32. What kind of compensation do you expect from the government?

.....

.....

.....

.....

33. Why do you expect compensation from the Government?

.....

.....

.....

.....

THANK YOU A LOT FOR YOUR CONTRIBUTION TO THIS STUDY.

Appendix 4.7

Institutional Interview Guide

Place of Interview/ Name of Institution:.....

Name of Interviewer:.....

Person Interviewed:.....

Date & time of Interview:.....

Preamble

Dear Sir / Madam. Hello. My name is Cush Ngonzo, Master’s student at Kenyatta University (Registration Number: I56/10078/07). I would appreciate your contribution to this study dealing with water and land resources efficient use in farming activities at Muooni Dam site. I expect you to provide me with some information on farming activities environmental challenges. Notice that it is not an exam; and any answer provided will be kept strictly confidential, according to research regulations of Kenyatta University. Thank you for your willingness.

Interview Questions

1. What are the main topographic, climatic and hydrological features of the Muooni catchment? *(Plse, continue on separate sheet to complete your answers)*

.....
.....
.....

2. What types of land-use are frequently practised in the catchment?

.....
.....
.....

3. What is the importance of Muooni dam for the agriculture sector in the catchment?.....

4. Give an estimate of the main costs incurred in the farming activity in the catchment.

<i>No</i>	<i>Nature of Cost</i>	<i>Monthly cost</i>	<i>Annual Cost</i>	<i>Comments</i>
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				

5. Can you evaluate the catchment's mean annual productions and sales (per crop)?

<i>No</i>	<i>Type of Crop</i>	<i>Mean Income (per hectare)</i>	<i>Annual Income</i>	<i>Comments</i>
1	Cabbage			
2	Cowpeas			
3	French beans			
4	Groundnuts			
5	Sorghum			
6	Finger millets			
7	Maize			
8	Banana			
9	Irish potatoes			
10	Sweet potatoes			
11	Sugarcane			
12	Coffee			
13	Eucalyptus			
14	Mango			
15				

6. Do farmers pay their water for agriculture? YES NO

How much per month (in average)? Ksh..... / per m³

7. Can you evaluate the dam storage capacity for every three years (from 1987 to 2013)?

Is it increasing or decreasing?.....

1987:	m ³	1990:	m ³
1993:	m ³	1996:	m ³
1999:	m ³	2002:	m ³
2005:	m ³	2008:	m ³
2011:	m ³	2013:	m ³

8. What problems of water and soil conservation due to agriculture have you observed?

.....
.....
.....

9. What may be the responsibility of farmers on physical processes taking place in the dam site and/or in all the catchment?.....

.....
.....

10. After your cost-benefit analysis of the catchment's agricultural sector, what can you say about farming activities *efficiency* at Muooni dam site?

.....
.....
.....
.....
.....

11. What suggestion would you give for improving farming activities' efficiency at Muooni dam site?.....

.....
.....
.....
.....

THANK YOU A LOT FOR YOUR CONTRIBUTION TO THIS STUDY

Appendix 4.8

Incremental Institutional Data Request Sheet

Date & time:

Name of Institution:.....

Name of Interviewer:.....

Person Interviewed:.....

Preamble

Dear Sir / Madam. Hello. My name is Cush Ngonzo, Master's student at Kenyatta University (Registration Number: I56/10078/07). I would appreciate your contribution to this study dealing with water and land resources efficient use in farming activities at Muooni Dam site. I expect you to provide me with quantitative data on your *water prices*. Notice that all the data you provide will be kept strictly confidential, according to research regulations of Kenyatta University. Thank you for your willingness.

Water Prices Table

Month	2005	2006	2007	2008
January				
February				
March				
April				
May				
June				
July				
August				
September				
October				
November				
December				

Final Comments:

THANK YOU A LOT FOR YOUR CONTRIBUTION TO THIS STUDY