Journal of Agri-Food and Applied Sciences

Journal of Agri-Food and Applied Sciences
Available online at jaas.blue-ap.org
©2013 JAAS Journal. Vol. 1(1), pp. 16-23, 5 December, 2013

Hydro-Geomorphologic Impact Assessment and Economic Viability of Smallholders Farms in Muooni Catchment, Machakos District

Cush L. NGONZO[*], Chris A. SHISANYA and Joy A. OBANDO

Integrated Watershed Management Department of Geography Kenyatta University Nairobi, Kenya
Corresponding Author: Cush L. NGONZO

Received: 22 November, 2013 *Accepted: 30 November, 2013* *Published: 5 December, 2013*

A B S T R A C T

Water depletion, sheets, rills, inter-rills and big gullies have an impact on water and land productivity in a catchment area, endangering thus substantial wealth creation in agriculture. An assessment of 66 farms selected randomly at Muooni dam site reveals that they are no longer viable due to soil erosion problems and water over-abstraction by natural ecosystems, eucalyptus particularly. Though farmers are striving to consolidate soil protection using terracing, contouring and runoff cut-outs, soil degradation and water stress are still major challenges they have to face to. Results show that farmers' poor education and economic poverty, adverse effects of deforestation and off-site effects of external agents such as El Niño floods and droughts, wind pressure are hampering the rate of soil erosion, mass movements and water stress in the catchment. These processes are likely to enhance sediment loads into the dam reservoir as its water storage capacity decreases by 6.22% each year. They may have increased farming water shortage costs and the cost of fertile soil excess loss, threatening chances of high yields and income in farming. Consequently, they undermine the economic viability of smallholder farms and Muooni dam. To improve their livelihood, farmers need to apply appropriate methods of crops selection and specialization, water saving and farming technologies. The ongoing implementation of climate change adaptation and mitigation programmes is to be reinforced in Muooni catchment through policy instruments and direct investments.

Keywords: *Hydro-Geomorphologic, Smallholders Farms, Machakos*

INTRODUCTION

Climate and other environmental patterns changes are propounded to be major causes of land degradation and water scarcity, as well as food insecurity and poverty outreach in most marginal and dry lands (Ngonzo, 2009; Lexén, 2008; UNEP, 2002 and 2000; IPCC, 2001; Eriksen, 1998). The agricultural sector in Machakos District in general and Muooni catchment in particular relies on marginally degraded lands, and faces critical environmental challenges in addition to coping with high population pressure and over-reliance on water and land for livelihood (Jaetzold et al., 2007; Jansky et al., 2005). Though farmers are striving to consolidate soil protection using terracing, contouring and runoff cut-outs, soil erosion problems and water over-abstraction by eucalyptus trees hasten soil degradation and water stress in most farmlands. The aim of this study is firstly, to examine environmental issues affecting efficient use of water and land in agriculture in Muooni catchment; secondly, to determine the extent to which they impact on the active water storage capacity of Muooni dam; finally, to analyse their outcome on the farming community livelihood. Results are expected to shed light on the kind of farming strategies to be put in place to alleviate water and land scarcity.

After this introduction, the remaining parts of this paper will present the study area and methodology, results and their discussion, and a summary of the main findings and conclusion.

MATERIALS AND METHODS

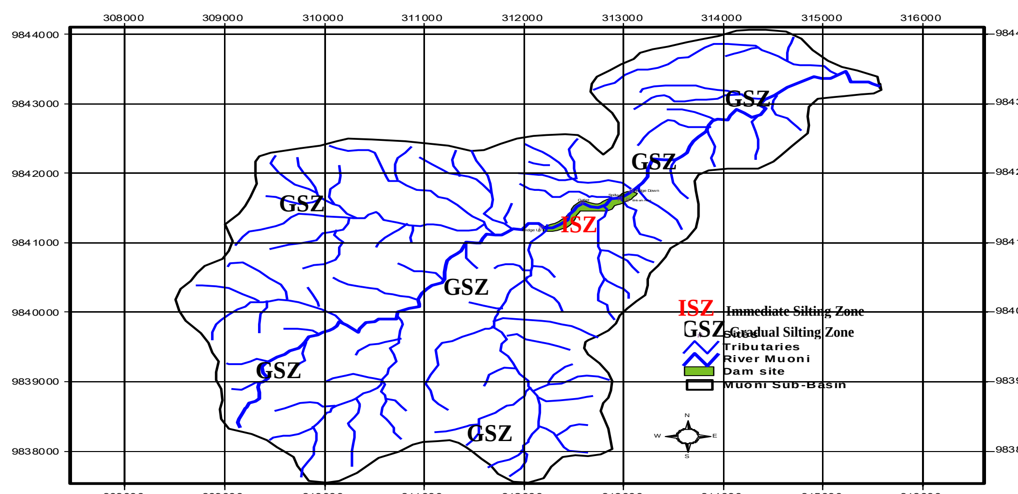
Study Area

This study was conducted at Muooni catchment, a catchment of 25 km^2 located in Mitamboni location of Kathiani Division, in Machako District of Eastern Province of Kenya. Geographically, it is bounded by latitudes 37° 16’ 30” E and 37° 20’ 30” E, and longitudes 1° 24’ 30” S and 1° 28’ 15” S. It is mainly a Sunflower-Maize Upper Midland agricultural zone lying on dry and hilly lands with small plateaus rising between 1434 m and 2005 m (Jaetzold, 2007). Agriculture is mainly relies on rainfall, and Muooni River and its dam, which was built in 1987 by the Ministry of water.

Methods and Techniques

Empirical tools of data collection included an on-farm survey and off-farm in-depth interviews involving respectively 66 farmers and 60 key informants. According to its altimetry, the catchment was stratified into two zones: the “Immediate Silting Zone” or ISZ, and the “Gradual Silting Zone” or GSZ (Figure 1). The ISZ was demarcated as the on-farm survey area and the GSZ as the in-depth interviews Zone. The study used a stratified random sampling of farming activities as well as the hydro-geomorphologic sampling technique proposed by (Gonzalez et al., 1995). This allowed figuring out 6 significant farming activities and 6 presumed impacts randomly occurring on farmlands, according to their weight (represented a number 1, 2, 3, 4, 5 or 6) on the siltation of the dam and on the dam site water over-abstraction. To collect computational data, technological means availed included a digital camera, Global Positioning System (GPS), Arc View 3.3 version of Geographic Information System (GIS) and computer machines. Data collected were analyzed using descriptive statistics, time series analysis and non-parametric tests such as Mann-Whitney U-test, Spearman’s Rank Correlation and Spearman’s Rho test. The study used SPSS-PC and MS EXCEL-PC computer packages to generate some 1,452 cross-sectional survey data (for a total number of 22 variables), and 840 in-depth interviews data (for 14 variables). Secondary data found in literature assisted in the interpretation of analytical results of primary and computational data, through a realistic triangulation.

Figure 1: Stratification from the Study Area



Source: Fieldwork (2008)

RESULTS AND DISCUSSION

This section presents and discusses empirical findings on the distribution of land-use activities assessed on farmlands, the distribution of impacts recorded, and the relationship between land-use activities and the impacts assessed, as well as the impact of the catchment degradation on Muooni dam’s active water storage capacity and farmers’ livelihood economic viability.

Land-Use Activities Assessed on Farmlands

The most significant activities noticed on farms were related to agro-forestry and subsistence cultivation without irrigation, representing respectively 45.5% and 28.8% of farms (Table 1). Other farming activities included livestock keeping with some cultivation (12.1%), intensive cultivation using water pumps and storing devices (10.6%), and subsistence cultivation with limited irrigation (3%). Figure 2 presents the spatial distribution of these land-use activities assessed on farmlands.

Table 1. Types of farming activities assessed at Muooni dam site

Weight	Farming Land-Use Activities Assessed	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)

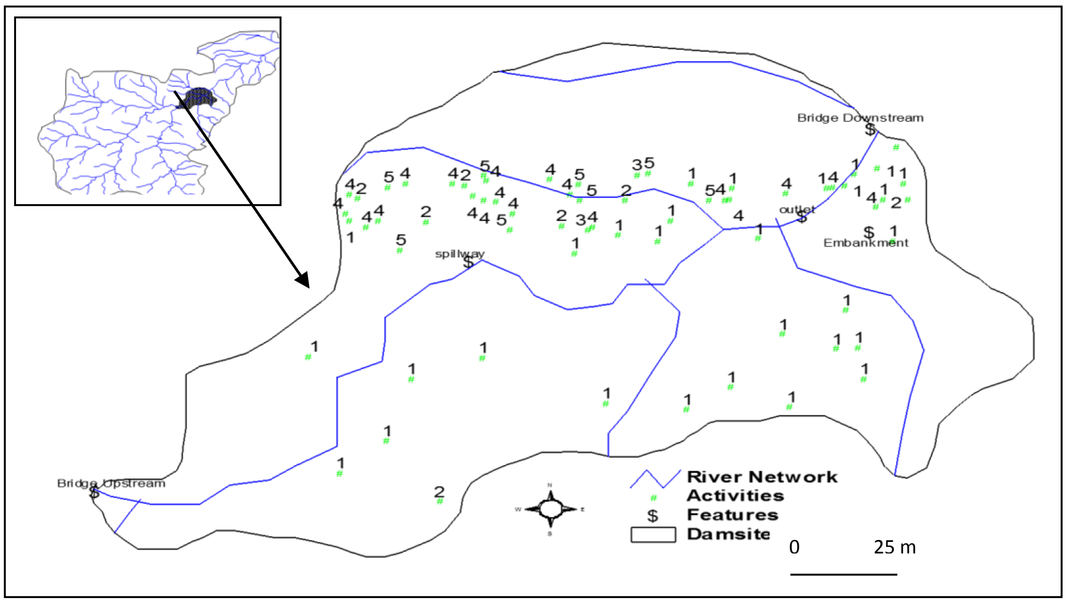


Figure 2. Spatial distribution of farming activities in the dam site

Source: Fieldwork (2008)
Notice: Figures 1, 2, 3, 4, 5 and 6 indicates the weight of activities found in Table 1

It was observed that farmers were enhancing soil protection with terracing, contouring, cut-off drains, polyculture and agro-forestry. None of them was keeping livestock without any other form of cultivation. Farming systems and soil conservation measures applied were a clear indication of their awareness on environmental issues and catchment degradation (Jaetzold, 2007; Tiffen et al., 1994). The latter were propounded to be major causes of soil erosion, landslides and the adverse effects of eucalyptus trees on water availability in the catchment in general, and the dam in particular.

Land-Use Activities Impact on Farmlands

Rills and sheet erosion represented more than half of the impacts observed on farmlands; adverse effects of eucalyptus trees planted within the dam site accounted for 18.2% of the total number of impacts recorded (Table 2). Other significant impacts included: agricultural impacts on wetlands, gully erosion and landslides. Though widespread in the catchment, no impact of sand harvesting and quarrying was recorded on farmlands. Figure 3 presents the distribution of land-use activities' impacts.

Table 2. Environmental impacts assessed in Muooni dam site farms

Weight	Hydro-geomorphologic Impacts Recorded	Frequency	Percentage
1	Sheet/ rill erosion in the farm area	42	63.6
2	Agriculture impacts on wetland	5	07.6
3	Sand harvesting/ quarrying impacts on farms	0	00.0
4	Gully erosion in the farm area	5	07.6
5	Landslide in the farm area	2	03.0
6	Eucalyptus water over-abstraction	12	18.2

Source: Fieldwork (2008)

Some may believe that soil erosion is inevitable in such kind of environment due to its topography. However, Waswa (2006) stresses the fact that land management in Kenya is highly correlated with education and poverty levels, most land-users being "'ignorant and agents of degradation" in pursuit of survival. Sheets, rills and inter-rills tend to pass unnoticed, until big gullies, difficult to jump over, appear on the farmlands. Then farmers come to realize that their activity has threatened the ecosystems functions. Further interventions can no more compensate for the damage that has already been caused to the ecosystems. Due to continuous bad harvesting, farmlands are transformed into settlements, a majority of farmers working in off-farm sectors, while only 33% are still working as full-time ones. Jaetzold et al. (2007:391) report that 'a high population growth due to preference for a large family size, high rate of urbanization, increased settlement in areas that are of marginal agricultural potential, sub-division of ranches for sedentary small-scale farming practices, and further sub-division of land for settlement' are some of the characteristics of Machakos District. In addition, full-time farmers are very poor and of very modest education, while part-time ones are acknowledged to have high levels of formal education and income. The latter employ caretakers of low formal 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 (Thompson and Scoging, 1995; Douglas, 1994).

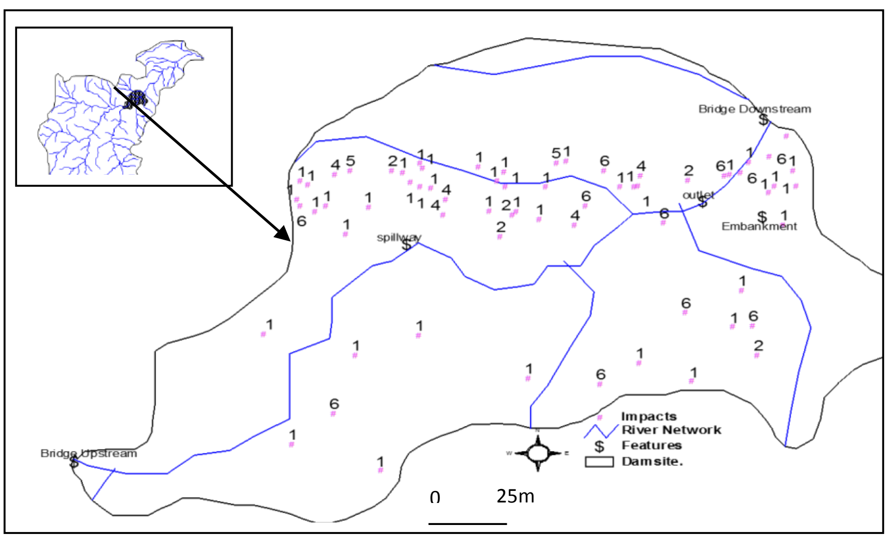


Figure 3. Spatial distribution of farming environmental impacts in the dam site

Source: Fieldwork (2008)
Notice: Table 2 indicates the legend of impacts and their weight (1, 2, 3, 4, 5 and 6)

Relationship between Land-Use Activities and the Impacts Observed

The analysis tested the assumption that land-use activities going on around Muooni dam site were causing soil erosion and water over-abstraction. 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 (Table 3). Spearman's rank correlation confirmed the result that soil erosion and water over-abstraction assessed might have originated from diverse sources, within and outside Muooni dam site. It accepted with 99.8% confidence degree the null hypothesis stating that there was no significant relationship between the populations of land-use activities and impacts assessed (Table 4). The two random samples were thus 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 from Muooni dam's ISZ through on-site soil erosion, and others from the GSZ by the effect of off-site soil erosion due to El Niño floods and droughts, heavy winds pressure, footpaths and roadside erosion, sand harvesting and deforestation, etc.

Table 3. Summary of the Mann-Whitney U-test results

Nº	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_o ($\mu_1 = \mu_2$) Rejection: There is no significant relationship between the two populations.
4	$Z_{\rho;} = 3.99$	$\alpha = 0.002$	

Source: Fieldwork (2008)

Table 4. 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_o ($\rho_s = 0$) Acceptance: There is no significant relationship between the two populations.
4	$Z_{\rho;} = -3.99$	$\alpha = 0.002$	

Source: Fieldwork (2008)

Catchment Degradation and Muooni Dam's Active Water Storage Capacity

Agro-forestry and subsistence cultivation without irrigation were the most significant land-use practices observed at Muooni dam site. Yet, they were threatened by soil erosion, landslides and water over-abstraction by ecosystems, namely by eucalyptus trees. Though not directly related to land-use activities assessed, they were propounded to be the most significant factors affecting water availability in drainage systems and the dam reservoir (Benson and Clay, 1998). Environmental impacts observed were actually threatening Muooni dam's water storage capacity. Available records from the dam management (provided by Athi WRMA, 2008) and estimates recorded from the institutional in-depth interviews suggest that the dam reservoir was overloaded by important sediments from eroded farms, and from El Niño floods and droughts and winds pressure (Table 5). Muooni dam's active water storage capacity has been decreasing annually at the rate of 6.22%. This trend of the dam's active water storage capacity is clearly depicted in Figure 4.

Table 5. Muooni dam's active water storage capacity averaged values per year

Year	1987	1990	1993	1996	1999	2002	2005	2008
storage Capacity[1]	1,559	1,250	525	340	836	440	210	200

Sources: Athi WRMA (2008) and Fieldwork (2008)
Note: [1] Values in thousands of m^3

The dam's reservoir maximum capacity that was fixed at 1,559,400 m^3 in 1987 is nowadays estimated to 222,190 m^3 (in 2009). It will be under its threshold in the year 2019, storing only about 119,287.4 m^3 of Muooni stream total flow, if this decrescendo continues without let-up. This may be a good justification of water stress facing farmers and of the predicted water scarcity. But to what extent are farming activities affecting the active water storage capacity of Muooni dam? The correlation coefficient showed that 62.4% of the storage capacity variations were reflected over the years. Otherwise, the dam's active water storage capacity variation had the same bearing as its reservoir infrastructures depreciation. The coefficient of determination confirmed this result by attributing 38.9% of the total variation of the dam's active storage capacity to its logistics depreciation over the years.

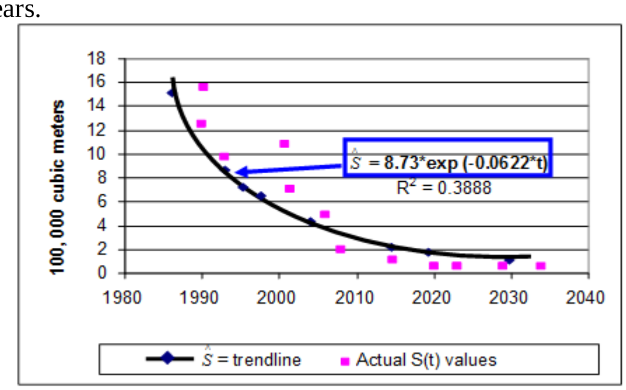


Figure 4. Muooni dam active storage capacity trendline

Source: Fieldwork (2008)

That is to say that other factors, especially sediment load and water over-abstraction from the dam's reservoir, may explain about 61.1% of the total variation of Muooni dam active storage capacity. Results of Spearman Rho test certified the null hypothesis stating that there was a strong correlation between the dam storage capacity and its logistics old-age (Table 6). It proved at 99.5% confidence degree and 34 degree of freedom that the dam storage capacity variation was correlated to time. Consequently, the decreasing active water storage capacity of the dam may be explained by both its infrastructures obsolescence, and important sediments loads in and/or water reserves over-abstraction from the reservoir by external environmental impacts assessed. The declining reservoir infrastructures resistance is likely due to its poor maintenance. This may have resulted in a lot of evaporation and/or seepage 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 (Wikipedia, 2008). The latter can have an impact on the variation of temperatures of stored water, contributing thus to the catchment's warming, as well as to that of the whole country's and the global environments (GEF et al., 2008; Brown, 2001; IPCC, 2001).

Table 6. Results of the Spearman's Rho Test

Nº	Decision Parameters		Decision
01	$r = 0.6236$	$\alpha = 0.005$	There is a strong correlation between *S* and *t*
02	$S_r = 0.134073$	$n\text{-}2 = 64$	The correlation coefficient has good quality
03	$t_{\rho;n-2} = 4.650941$	$t_{\alpha;n-2} = 2.576$	Rejection of Ho (ρ=0);So, *S* is explained by *t*.

Source: Fieldwork (2008)

The World Commission on Dams explains such climatic patterns change by the decay of plant materials in an anaerobic environment of flooded areas, and questions therefore the quality and safety of such dams' water and the sustainability of their energy supply (UNEP, 2002).

The obsolescence of reservoir logistics was just one among other factors limiting Muooni dam's active water storage capacity. 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. The global climate change has therefore a big impact on the decreasing trend of Muooni dam's active water storage capacity. Traditional soil conservation methods have become rudimentary to control climate change disasters. So, the dam is susceptible to important water evaporation, frequent damage by floods and constant maintenance (Dixon, 2005; Flintan and Tamrat, 2003). 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. (Jaetzold et al., 2007) conclude 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). El Niño phenomenon known as Anti-ENSO sometimes results in extreme water stress, leading to plants desiccation (Lal, 1993). When followed by an Into-ENSO, characterised by extreme intense rainfalls, gullies and landslides are likely to occur in the farmlands and elsewhere in the catchment (Wambongo, 2007; Shisanya, 1996). Off-site problems of soil erosion appear then as a result of downstream and downwind sedimentation of rivers and drainage ditches (Uitto and Schneider, 1997; Obando, 2005). They enhance the risk of flooding, block irrigation canals and shorten the designed lifespan of dams (Morgan, 1995). This self-explanatory water stress at Muooni dam site is a prelude to the economic failure of most faming activities going on in the Catchment, and to escalation of poverty among the farming community.

Catchment Degradation Impact on the Farming Community Livelihood

Erosional processes going on in Muooni catchment affect not only Muooni dam's active water storage capacity, but also the economic viability of the catchment's smallholder farms. Results show that they have increased farming water shortage costs and the cost of fertile soil excess loss, thus threatening chances for high yields and good incomes in farming. Poor farming incomes are depicted by the average farmer income of less than US$ 1, the annual average income being KES 166,526, the equivalent of US$ 231 per year (that is about 65 cents per day). Table 7 shows that, all scale confused, a majority of farmers are incurring losses. Their average farming water costs are significantly higher than their average income per water m^3 input. This endangers the economic viability of the livelihood of particularly small scale farms (SSF) and medium scale ones (MSF), which earn less than US$ 2 a day and represent more than 80% of farms existing in the catchment. In fact, (Waswa ,2006) declares that this situation is general to most smallholder farms in Kenya. Their incomes levels are reflected in the level of their education, a majority having no formal education at all. He 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. They just look at visible indicators of yield and direct effects on their subsistence without much concern on innovative approaches of farming.

Table 7. Large, medium and small scale farmers' annual incomes and physical costs

N°	Operations	LSF (KES)[1]	MSF (KES)[1]	SSF (KES)[1]
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	85.8	65.7	51.6
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	114.9	66.4	58.8
3.0	Farming Profit	-140,600	-2,900	-7,730
3.1	Total Profit	-140,600	-2,900	-7,730
3.2	Average Profit/m^3	-28.2	-0.7	-7.2

Source: Fieldwork (2008)
Note: [1] KES: Kenya Shilling Currency

That is why most farmers are attracted by eucalyptus trees' quick economic returns, ignoring the fact that they have harmful effects on the environment. Using their indigenous knowledge, they are unable to make a linkage between environmental degradation, water stress and the economic viability of their farming activities (Cheserek, 2005). Water depletion, sheets, rills and inter-rills in the catchment tend to pass unnoticed, until big gullies, difficult to jump over, appear on farmlands. These have an impact on water and land productivity, endangering thus substantial wealth creation in agriculture (Kitissou, 2004; Terer, 2004). To improve their livelihood, farmers need to monitor and evaluate regularly their activities in order to apply appropriate methods of crops selection and specialization, water saving and farming technologies. Efficient crops selection and specialization (to 2 or 3 crops), and appropriate alternative technologies are suggested to value agricultural water resources allocative efficiency and foster the farming production technological efficiency within the production possibility frontier in Muooni catchment (GoK, 2007; Ellis, 1993). Beside, farmers need to regularly monitor and evaluate their crops water requirement to allow purchase of green water credits, import of virtual water and implementation of other efficient on-farm management practices. This can enhance chance of good crop yields, thus boosting the differential water productivity above the limit average costs.

The Government of Kenya needs to promote the ongoing programmes of climate change adaptation and mitigation in Muooni catchment through direct policy instruments and investments. Policy instruments such as Dams' dredging "Strategic Action Plans", and ENSO "Early Warning Systems" and "Early Actions" can improve on-farm water management for better livelihood and wealth creation. The Athi Water Resource Management Authority (Athi WRMA) is urged to plan water allocation and consumption with the participation of all stakeholders. Water charges and consumption metering are put forward to be the cost factor that increases efficiency through 'more crops per drop' and managing the water up to the end tap (Förch et al., 2008). They may help farmers calculate in advance their margin profit and select appropriate crop type and production method to generate higher profits.

CONCULSION

The on-site survey and off-site in-depth interviews conducted at Muooni catchment were very rich in information. They revealed that farming activities are no longer viable due to soil erosion problems and water over-abstraction by natural ecosystems, especially by eucalyptus trees. The latter were attributed to poor land husbandry, which is directly related to the poor education and economic poverty of many farmers. It was also credited to the off-site effects of external agents such as El Niño, floods and droughts, wind pressure and adverse effects of deforestation, etc. These processes are likely to enhance sediment loads into the dam reservoir as well as its water resource over-abstraction, thus affecting the active water storage capacity of Muooni dam. Consequently, water scarcity is expected in the near future in Muooni catchment, if no urgent action is taken. To improve agricultural efficiency at Muooni dam site, farmers need to monitor and evaluate regularly their activities' impact on water and land resources. The Government of Kenya needs to promote sustainable management of Muooni catchment through support of the ongoing programmes on climate change mitigation and adaptation.

REFERENCES

Athi Catchment Water Resource Management Authority, Athi WRMA. 2008. Report on the Muooni Catchment (Unpublished). Machakos, Kenya.

Benson C and Clay E. 1998. The impact of drought on Sub-Saharan African economies: a preliminary examination. World Bank Technical Paper No 1. Washington, DC, USA, The World Bank.

Brown LR. 2001. Eco-economy: Building an economy for the Earth. New York, USA, W.W. Norton and Company Ltd.

Cheserek G. 2005. Indigenous Knowledge in Water and Watershed Management: 'Marakwet' Conservation Strategies and Techniques. In FWU Water Resources Publications, Vol. 3, 25-33.

Dixon AB. 2005. Sustainable Management of Headwater Wetlands: the Role of Indigenous Knowledge in South-East Ethiopia. In Jansky L., Haigh M. and Prasad H. (Eds), Sustainable Management of Headwater Resources: Researches from Africa and India. Tokyo, Japan, United Nations University Press: 60-86.

Douglas M. 1994. Sustainable use of agricultural soils: a review of the prerequisites for success or failure. Berne, Switzerland, University of Berne, Institute of Geography.

Ericksen SH. 1998. Shared river and lake basins in Africa: Challenges for cooperation. Ecopolicy, 10. Nairobi, Kenya, ACTS English Press Ltd.

Flintan F and Tamrat I. 2003. Spilling blood over Water? The case of Ethiopia. In Lind and Sturman.(Eds.), Scarcity and surfeit: The ecology of Africa's conflicts. California, USA, Campbell: 319-387.

General Environment Facility, GEF, International Development Research Institute, IDRC and Bibliotheca Alexandrina, BIBALEX. (Eds). 2008. International conference on evaluating climate change and development. Conference booklet. Alexandria, Egypt, 10-13 May 2008.

González A, Díaz de Terán JR, Francés E and Cendrero A. 1995. The incorporation of geomorphological factors into environmental impact assessment for master plans: a methodological proposal. In Duncan F. M. McGregor and Donald A. Thompson (Eds), Geomorphological and land management in a changing environment. Chichester, UK, John Wiley and Sons: 179-193.

Intergovernmental Panel on Climate Change, IPCC. 2001. Synthesis report: third assessment report. Geneva, Switzerland, IPCC Secretariat / W.M.O.

Jaetzold R, Schmidt H, Hornetz B and Shisanya C. 2007. Part C East Kenya, Subpart C1 Eastern Province. In Ministry of Agriculture and GTZ (Eds), Farm management handbooks of Kenya, Vol. II: Natural Conditions and Farm Management Information. Nairobi, Kenya.

Jansky L, Haigh M and Prasad H (Eds). 2005. Sustainable management of headwater resources: Researches from Africa and India. Tokyo, Japan, United Nations University Press.

Lal R. 1993. Agricultural sustainability and soil resilience. Desertification control bulletin, 23: 26-43.

Lexén K. 2008. Water: the key to climate change adaptation. Stockholm Water Front, 1: 10-11.

Morgan RPC. 1995. Soil erosion and conservation. Essex, UK, Longman Group.

Ngonzo LC. 2009. An evaluation of efficient use of agricultural watershed resources under fluctuating rainfall regimes at Muooni Dam site, Machakos District, Kenya. Masters Thesis. Nairobi, Kenya, Kenyatta University, School of Pure and Applied Sciences.

Ngonzo LC. 2008. An analysis of farming activities affecting Muooni Dam storage capacity, Machakos District, Kenya. Watershed evaluation seminar working paper. Nairobi, Kenya, Kenyatta University, Department of Geography.

Obando JA. 2005. A Catchment Model of Runoff and Sediment Yield for Semi-Arid Areas. In Libor Jansky., Martin Haigh and Haushila Prasad (eds), Sustainable Management of headwater resources-Research from Africa and India. Tokyo, United Nations University Press: 249-263.

Shisanya CA. 1996. Chances and risks of maize and bean growing in the semi-arid areas of Kenya during expected deficient, normal and above normal rainfall of the short rainy seasons. PhD Thesis. Trier, Germany, Universität Trier, Faculty of Geosciences.

Tiffen M, Morimore M and Gichuki F. 1994. More People, less erosion: environmental recovery in Kenya. Nairobi, Kenya, ACTS Press.

Thompson DA and Scoging HM. 1995. Agricultural terrace degradation in south-east Spain: modelling and management strategies. In McGregor, D.F.M. and Thompson D.A. (Eds), Geomorphological and land management in a changing environment. Chichester, UK, John Wiley and Sons: 153-175.

Uitto JI and Schneider J. 1997. Freshwater resources in arid lands. United Nations University Global Environmental Forum V. Tokyo, Japan, United Nations University Press.

United Nations Environment Programme, UNEP. (Ed). 2002. Global environmental outlook 3. London, UK, Earthscan Publications Ltd.

United Nations Environment Programme, UNEP. (Ed). 2000. Global environmental outlook: past, present and future perspectives. Available at: www.unep.org/GEO-2000/

Wambongo CS. 2007. Seasonal climate forecast, access and use in agricultural production: a case of semi-arid South-East Kenya. Masters thesis. Nairobi, Kenya, Kenyatta University, School of Social Sciences and Humanities.

Waswa PF. 2006. Opportunities and challenges for sustainable agricultural land management in Kenya. In Fuchaka P. Waswa, Samuel Otor and Daniel Mugendi (Eds), environment and sustainable development: a guide for higher education in Kenya, 1: 1-19.

Wikipedia Free Online Encyclopaedia, Wikipedia. 2008. Environmental impacts of dams. Available at: www.wikipedia.org/wiki/environmental_impacts_of_dams.