Journal of Agri-Food and Applied Sciences
Available online at jaas.blue-ap.org
©2013 JAAS Journal. Vol. 1(2), pp. 37-45, 10 December, 2013

Applied Inventory Models for Evaluating Water and Food Security: Approaches and Lessons from Smallholder Farms of Muooni Catchment, Machakos District, Kenya

Cush NGONZO LUWESI*, Chris Allan SHISANYA and Joy Apiyo OBANDO

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

Received: 22 November, 2013 Accepted: 30 November, 2013 Published: 10 December, 2013

ABSTRACT

This study attempts to explain food shortage in a water scarce Muooni catchment using operational research inventory models. It seeks specifically to evaluate farmers' water economic order quantity (EOQ), limit average cost (LAC) and minimum efficient scale (MES) of water use in farming, for rationalization and optimization of crops water requirement and crops yields under rainfall fluctuation. Such an approach helps integrating spatially distributed and descriptive mathematical variables of water storage with economic performance and environmental sustainability. Results show that Muooni dam siltation and subsequent water stress threatens the economic viability of smallholder farms in the catchment. Both endogenous on-farm management factors and exogenous environmental agents hamper the rate of fertile soil loss and water stress under rainfall fluctuation. They increase significantly the costs of costs water saving and shortage costs in farming, threatening agriculture economic viability and food security. For efficiency, farmers need to define a water demand EOQ under ANOR, or a quantity well-matched with the LAC under NOR, or a MES quantity under BNOR in order to optimize their crops water requirement. This means that they need to implement rational methods of water use in farming and appropriate farming technologies to foster allocative and technological efficiencies within the production possibility frontier. Also, the government should implement a catchment management strategy (CMS) in Athi catchment in general, and Muooni in particular, to mitigate the risk of food shortage and water conflicts under unexpected drought.

Keywords: *Applied Inventory, Evaluating, Food Security.*

INTRODUCTION

Euler, the famous German Mathematician of the 18th century, opened the way of looking for optimal allocation of watershed resources in Pregolya basin of ancient Königsberg city (current Kaliningrad city) of Russia (Swarp et al., 2007). Nowadays, scientists recognize the need to use water rationally to alleviate food insecurity and poverty facing semi-arid and arid lands (Clarke and King, 2004; Rockström, 2003; Earle, 2001; Shisanya, 1996). They advise the use of efficient methods and empirical techniques of water rationalization in agriculture (Kemper, 2003; Subramanian, 2001). Operational research inventory models are suggested to be major tools for assessing efficiency and allocating effectively resources, even under uncertainty (Oduol et al., 2006; Chavas et al., 2005; Luwesi, 1999; Charnes et al., 1978). They help integrating spatially distributed and descriptive mathematical variables of water storage and discharge, with economic performance and environmental sustainability (Luwesi, 2009; Kasambala et al., 2006; Brasington et al., 1998). This study attempts to explain food shortage in a water scarce Muooni catchment using operational research inventory models. It seeks specifically to evaluate farmers' water demand economic order quantity (EOQ), limit average cost (LAC) and minimum efficient scale (MES) for rationalization and optimization of crops water requirement and crops yield under above normal (ANOR), normal (NOR) and below normal (BNOR) rainfall regimes (Luwesi, 2010; Luwesi et al., 2011; Ngonzo et al., 2010).

Following this brief introduction, section two presents the research methodology and modelling approaches applied in watershed evaluation; section three expound fieldwork results and their discussion; and section 4 provides a summary of main findings and some conclusions

MATERIALS AND METHODS

Data Collection and Analysis

Data used in this study were collected on 66 farms randomly selected in Muooni dam site (through questionnaires), and 60 civil servants and professionals working at Muooni catchment (through Institutional in-depth interviews). Muooni catchment is a small catchment of 25 km^2 situated in Mitaboni location of Kathiani Division in Machakos District (Eastern Province of Kenya). It is situated in the upper midland agro-ecological zone 4 (sunflower and maize zone), whereby climatic conditions range from humid to arid. The study used a stratified random sampling of farms located in the dam site. Three different categories of smallholder farms were considered, namely: large scale farms (LSF), medium scale farms (MSF) and small scale farms (SSF). LSFs had more than 2.5 acres of land each, with a minimum of KES 288,000 annual income. MSF farmlands were 1 to 2.5 acres, yielding about KES 72,000 to 288,000 each year. SSFs had less than 1 acre of land, and a maximum of KES 72,000 annual income. To assess water stress related food shortage facing farmers, the study applied operational research inventory models to simulate farmers' water demand under rainfall fluctuation.

Inventory Modelling Approaches Applied in Muooni Watershed Evaluation

Modelling Hypotheses

This study used hybrid operational inventory models to achieve its objectives. These models were adapted after Wilson inventory model, Baumol monetary model and Beranek treasury model (Swarp et al., 2007; Luwesi, 1999; 2009). They helped computing farming water EOQ, LAC and MES quantities. The analysis assumed that soil and water losses reduce agricultural efficiency through increased costs of production. If the total farming water cost under NOR rainfall regime is a combination of respective costs of transaction (C_t) and opportunity costs (C_o), it is loaded by the costs of water saving (C_s) under above normal (ANOR), and by water shortage costs (C_s^*) under below normal (BNOR) rainfall regime.

The study also used the concept of the flood hydrograph to assimilate rainfall fluctuation to Muooni river regime changes reflected by the fluctuations of the active water storage capacity of its dam reservoir (Musy, 2001). Therefore, the NOR scenario refers to an active water storage capacity relatively equal to the designed median capacity. The ANOR and BNOR scenarios are associated to an active water storage capacity that is respectively above the median, and below the median and/or the threshold. Under the NOR scenario, it was assumed that the farming activity was neither profitable nor unprofitable. Farmers were only to bear normal costs of transaction and opportunity costs. However, under ANOR and BNOR scenarios, the farming activity was to result in significant profits or losses, as farming water costs were overloaded or not by important costs of water saving or shortage costs. Notice that the total, average and marginal costs were computed on data collected from three minimum efficient farms selected (LSF, MSF and SSF) among the 66. The incremental analysis was done for each farming scale under the three scenarios retained (ANOR, NOR and BNOR).

Modelling Measurements

Crops water requirement (W_C) was derived from "Virtual water values" (VWV) as:

$$W_c = \sum ETP_c \qquad \text{(Formula 1)}$$

Where,

ETP_c is the total crop evapotranspiration (in m^3) during crop growth computed from FAO (2008) reference crop evapotranspiration (ET_m, in Kg/m^3) as:

$$ETP_c = \frac{1}{ET_m} \, x \, Y_c \qquad \text{(Formula 2)}$$

Where,

Y_c is the total crop yield (in Kg)

Operational farmers' water demand was derived from crops water requirement as follows:

$$W_f = 2W_c/n = \quad r.\, W_c \qquad \text{(Formula 3)}$$

Where,

W_c/n was the average crops water requirement (for two daily withdrawals by the farmer)

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

r was the water demand turnover, which is theoretically equal to $2/n$ or to the ratio of the active water storage capacity of the dam by its designed median under any rainfall regime ($\hat{S}_t / S_{mé}$)
All the farmers' income (*Y*) and expenditures (*E*) were standardized as follows:

$$Y = P.W_c/n.Q \quad \text{(Formula 4)}$$

$$E= P.W_c/n.q \quad \text{(Formula 5)}$$

Where,
Q was the standardized farming activity output
q was the standardized farming activity input
P was the standard water price per m^3
The total farming water cost function was computed under the NOR scenario as:

$$TC_{no} = C_t\,(=n.E) + C_o\,(= r.Y) \;\; = Y\, r+2E/\, r \quad \text{(Formula 6)}$$

The total farming water cost function under the ANOR scenario was the following:

$$TC_{an} = C_t\,(=n.E) + C_s\,(= r.Y+l\prod) = (Y+\prod)r-\prod + 2E/\, r \quad \text{(Formula 7)}$$

Where,
$\prod$ 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)
The total farming water cost function computed under the BNOR scenario was:

$$TC_{bn} = C_t\,(=n.E) + C^*_s\,(= r.Y + l^*\prod) \qquad = (Y-\prod)\, r+\prod+ 2E/\, r \quad \text{(Formula 8)}$$

Where,
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:

$$AC = \frac{TC}{r} \quad \text{(Formula 9)}$$

$$MC = \frac{dTC}{dr} \quad \text{(Formula 10)}$$

From formulas 5, 6, 7, 8 and 9, the average and marginal costs functions derived under each rainfall scenario were the following ones:

Under the NOR scenario:

$$AC_{no} = \frac{TC_{no}}{r_{no}} = Y^2+2E/\, r^2 \quad \text{(Formula 11)}$$

$$MC_{no} = \frac{dTC_{no}}{dr_{no}} = Y -2E/\, r^2 \quad \text{(Formula 12)}$$

Under the ANOR scenario:

$$AC_{an} = \frac{TC_{an}}{r_{an}} = Y+\prod-\prod/\, r+ 2E/\, r^2 \quad \text{(Formula 13)}$$

$$MC_{an} = \frac{dTC_{an}}{dr_{an}} = Y+\prod-2E/\, r^2 \quad \text{(Formula 14)}$$

Under the BNOR scenario:

$$AC_{bn} = \frac{TC_{bn}}{r_{bn}} = Y-\prod+\prod/\, r+ 2E/\, r^2 \quad \text{(Formula 15)}$$

$$MC_{bn} = \frac{dTC_{bn}}{dr_{bn}} = Y-\prod-2E/\, r^2 \quad \text{(Formula 16)}$$

Using the theoretic water demand turnover derived from the variations of the dam's active water storage capacity, the analysis computed expected costs and water demand values. After optimization of the said water demand turnover, minimum farming water costs and demand were obtained under the EOQ, LAC and MES scenarios, for each farming scale and rainfall regime scenario. The optimized water demand turnover ($\bar{r}$) values derived from each marginal cost function were as follows:

Under the NOR scenario:

$$\bar{r}_{no} = \sqrt{2q/Q} \quad \text{(Formula 17)}$$

Under ANOR scenario:

$$\bar{r}_{an} = \sqrt{2q/(2Q-q)} \quad \text{(Formula 18)}$$

Under BNOR scenario:

$$\bar{r}_{bn} = \sqrt{2} \quad \text{(Formula 19)}$$

Using each optimized *r* values, farmers' EOQ ($\bar{W}_f$), LAC and MES were computed under hypotheses of significant profit (ANOR), no significant profit or loss (NOR) and significant loss (NBOR) as optimized farmer water demand ($\bar{W}_{f\ f}$) values:

$$\bar{W}_f = \bar{r}\ W_c \quad \text{(Formula 20)}$$

To assess farming costs, incomes and water demand variations for crops water optimization, the following formulae were used under EOQ, LAC and MES hypotheses:

$$\text{Expected Costs Variation} = \frac{MAC - OAC}{OAC} \quad \text{(Formula 21)}$$

$$\text{Expected Income Variation} = \frac{MAC - Y}{Y} \quad \text{(Formula 22)}$$

$$\text{Expected Water Demand Variation} = \frac{\min W_f - W_f}{W_f} \quad \text{(Formula 23)}$$

RESULTS AND DISCUSSION

Ex Post Socio-Economic and Environmental Impact Assessment

Muooni catchment is facing severe environmental issues in addition to coping with high population pressure and over-reliance on water for livelihood, especially for irrigation (Jaetzold, 2007; Benson and Clay, 1998). Erosional processes, erratic rainfalls, river flows and forests cover depletion, silting drainage systems and asset investments degradation are making farming activities inefficient (Table 1).

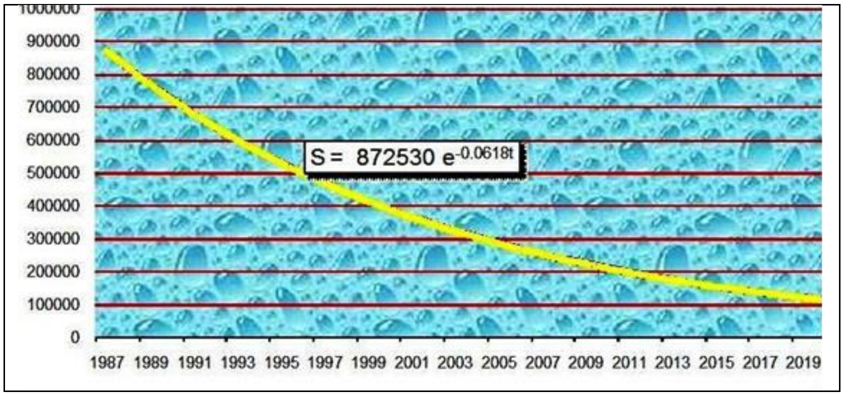
Table 1. Environmental impacts assessed in Muooni dam site farms

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	0.0
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: Luwesi (2010)

Muooni catchment degradation is a corollary of the catchment microclimate modification resulting in a bare, loose and rocky soil (Thompson and Scoging, 1995). Deforestation and bad land husbandry are primary causes of Muooni catchment degradation. They promote on-site effects of soil erosion, eucalyptus and other alien trees water over-abstraction, and have adverse effects on farmlands subdivision in the catchment (Luwesi, 2009; Jaetzold et al., 2007). These endogenous on-farm management factors are highly correlated to farmers' education and poverty (Waswa, 2006). Besides, there are other factors related to rainfall fluctuation that impact on the catchment degradation; these are El Niño floods and droughts, high wind pressure and other changing climatic patterns. They hamper the risk of fertile soil loss and water stress through off-site effects.

Figure 1 show that Muooni dam's water storage capacity is decreasing at an annual rate of 16.2 %, likely because of sediment loads into the dam reservoir and its water resource over-abstraction. It is expected to be under its threshold by the year 2019, storing about 119,287.4 m^3 of Muooni streamflow. This decrescendo really justifies water stress facing farmers in Muooni catchment. If no urgent action is taken, water scarcity will result in significant water costs of transaction, opportunity costs and shortage costs as well as socio-economic externalities threatening food security, agriculture viability and community livelihood in the catchment.



Source: Luwesi (2010)

Figure 1. Muooni dam active storage capacity trendline

Assessment of Farmers' Water Demand and their Crops Water Requirement

Table 2 gives an idea of farmers' physical income and costs (in Kenya Shillings, or KES) for each farming scale. It shows that all farmers' categories (LSF, MSF and SSF) are incurring losses. Thus, it suggests that farmers mainly optimize their faming water costs to ensure high yields and income. To determine the optimum farmers' water demand, the analysis first computed the actual crops water requirement (Table 3). Then, it simulated farmers' water demand from their operational costs and a theoretic water demand turnover. Water demand turnover under ANOR (r_{an}=1.0435), NOR (r_{no}=0.6169) and BNOR (r_{bn}=0.1319) scenarios represented the ratio of Muooni dam's active water storage capacity estimated for the years 1988, 1998 and 2020, by the designed median storage capacity ($S_{mé}$= 836,000 m^3). Farming water cost functions were computed from daily observed operational costs of three minimum efficient farms selected among each farming category (LSF, MSF and SSF).

Table 2: Farmers' annual income by farming scale

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: Luwesi (2010). Note: [1] KES: Kenya Shilling Currency

Table 3. Crops water requirement computation from a SSF data sheet

Nº	Crop Type	ETm (Kg/m³)	VWV (m³/Kg)	Qty (Kg)	*Wc* (m³)
1	Banana	4	0.25	51.42857	12.86
2	Cabbage	16	0.0625	1200	75
3	Coffee	3.5	0.2857	108	30.86
4	Cow peas	0.3875	2.5806	300	774.19
5	Irish Potatoes	5.5	0.1818	45	8.18
6	Maize	1.2	0.8333	216	180
	Total Annual W_c				**1,081.09**

Source: Luwesi (2010)

The total cost functions below were obtained under each rainfall regime scenario:

Under ANOR scenario:

LSF TC_{an} = 800.83 r+99.17+1,998.34/r (Formula 24)
MSF TC_{an} = 751.94 r+8.06 +1,536.12/r (Formula 25)
SSF TC_{an}=133,53 r +21,47 +352.94 /r (Formula 26)

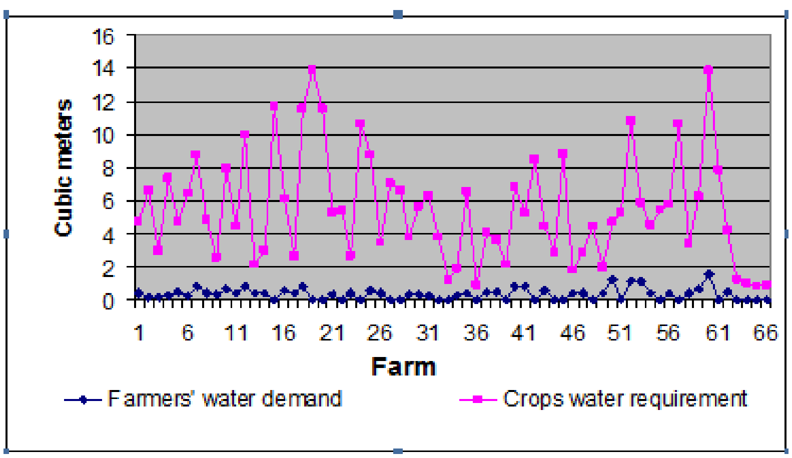
Under NOR scenario:

LSF TC_{no} = 900 r +1,998.34/r (Formula 27)
MSF TC_{no} = 760 r + 1,536.12/r (Formula 28)
SSF TC_{no} = 155 r + 352.94 /r (Formula 29)

Under BNOR scenario:

LSF TC_{bn} = 999.17r -99.17+ 1,998.34/r (Formula 30)
MSF TC_{bn} = 768.06 r – 8.06 +1,536.12/r (Formula 31)
SSF TC_{bn} = 176.47 r – 21.47 + 352.94 /r (Formula 32)

Results show that rainfall fluctuation really threatens the economic viability of farming activities at Muooni catchment. Farmers' water demand is generally not enough to meet their crops water requirement (Figure 2). Water stress is therefore the principal factor limiting the agricultural efficiency and fostering food shortage in Muooni catchment. Table 4 reveals that there is a gap of 71.15%, 87.8% and 95.57% between water demand and crops water requirement of respectively LSF, MSF and SSF. The small share of water demand by farmers is explained by increased costs of rainwater saving and water shortage costs under ANOR and BNOR, respectively. Under ANOR, farmers' water demand decrease is explained by high soil moisture and fields destruction by soil erosion and water flooding. Likewise, significant fertile soil losses and water stress due to drought result in crops failure and yields loss under BNOR. Yet, even under normal conditions, farmers do not order sufficient water for their crops, the differential being filled up by soil moisture and/or illegal water abstraction from the dam. Yet, Table 5 suggests that farmers' water demand decreases more significantly under BNOR due to excessive dam's water shortage costs boosting the cubic meter to more than 11,400% of its actual price.



Source: Luwesi (2010)

Figure 2. Difference between farmers' water demand and their crops water requirement

Table 4. Farmers' water demand and their crops water requirement gaps

No	Farm Size	Crops W_c (m^3)		Farmers W_f (m^3)		W_c Gap
		Daily	Yearly	Daily	Yearly	(%)
1	LSF	13.863	4,991.7	4	1,440	71.15
2	MSF	11.571	4,165.6	1.5	540	87.8
3	SSF	3.003	1,081.1	0.133	48	95.57

Source: Luwesi (2010)

For facing poor yields and incomes, especially during unpredictable droughts, farmers have adopted a strategic farming method. It consists of using excessive intercropping and multiple cropping of perennial indigenous and alien crop species on small farmlands. Yet, this cannot limit significantly their operational costs and losses. Eucalyptus and other alien trees water over-abstraction along with off-site effects of El Niño flooding and drought hamper the risk of soil erosion and water excess loss. With a declining farming area rate of 40% in about 10 years, excessive intercropping and multiple cropping become a kind of "land harassment", in such circumstances. This strategy later rebound on the dam's active water storage capacity by spoiling its water reserves and loading important sediments in the reservoir (after tree harvesting). This negative evolution of the dam's active water storage capacity affects considerably the quantity and price of water in the catchment, resulting in high costs of agricultural production. (Jaetzold et al., 2007) conclude: 'it is this mismatch of crops against the suitability of the agro-ecological zone that contributes to persistent crop failures in these areas'.

Table 5. Farmers' observed average costs variability under abnormal rainfall regimes

No	Farm Size	Daily AC[1] (KES)	ANOR		NOR		BNOR	
			OAC[2] (KES)	Variation (%)	OAC [2] (KES)	Variation (%)	OAC[2] (KES)	Variation (%)
1	LSF	999	2,731	173	6,151	516	115,110	11,421
2	MSF	768	2,170	183	4,796	525	89,002	11,488
3	SSF	177	478	171	1,082	513	20,300	11,404

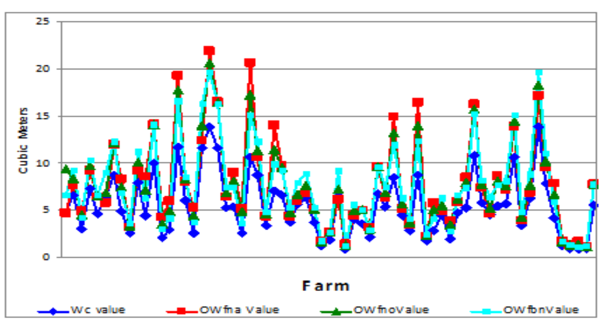
Source: Luwesi (2010)

Note: [1] AC: Actual Average Cost

[2] OAC: Operational Average Cost

Optimization of Crops Water Requirement under Fluctuating Rainfall Regimes

It is imperative that farmers optimize their crops water requirement under the limits of affordable costs and efficient production. To optimize operational farming water costs, the study conducted an incremental analysis. Optimum water demand turnover values were computed from marginal operational cost functions, under ANOR, NOR and BNOR rainfall scenarios (Figure 3). These results reveal that farmers' water orders shall be well-matched with their "economic order quantity" (EOQ) under ANOR, "limit average cost" (LAC) quantity under NOR and "minimum efficient scale" (MES) quantity under BNOR, if their actual crops water requirement are to meet. The required farming water should be slightly above their current crops water requirement to avoid any shortage under unexpected drought. Efficient LSF, MSF and SSF selected, had respectively 13.86 m^3, 11.57 m^3 and 3 m^3 of daily crops water demand. They rationally needed to order 21.9 m^3, 16.54 m^3 and 4.88 m^3 under ANOR; 20.66 m^3, 16.45 m^3 and 4.53 m^3 under NOR; and 19.61 m^3, 16.36 m^3 and 4.25 m^3 under BNOR. The decision of ordering an EOQ, LAC or MES water demand should not only be based on the physical rainfall regime, but more likely on the farming activity economic profitability.



Source: Luwesi (2010)

Figure 3. Crops water requirement and farmers' water demand EOQs

These results divulge that farming profitability under ANOR was the most important economic incentive that led to farmlands subdivision (evidently from 1987 to 2003), due to high water productivity in the catchment. Yet, new farmers entering the agricultural industry had less absolute cost advantages than existing farmers. Their average costs being significantly higher than the latter, they had to adopt a certain limit average cost (LAC), if any loss was to avoid in the short term. Existing farmers' cost advantages might also have included technological advantages, farming skills and knowledge of the environment as well as other factors helping them minimize the costs of 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 (Nicholson, 1992). To improve their cost advantages, new entrants needed a lot of time to develop specific on-farm management skills and credentials. Though they had less absolute cost advantages than their competitors, they were hoping to reap all the economies of scale in the medium or long term. However, things turned around with high degradation of the catchment and increased 'low fertile soils and unfavourable climate' (Jaetzold et al., 2007). To improve their poor yields and incomes, some attempted to practice economies of large-scale production by ordering the above EOQ or LAC water levels. This may have obliged them to sacrifice their short-term benefits by adopting a MES or simply abandon farming.

A comparison between the MES average costs and the expected farming income establishes the fact that farming activities are not effective in Muooni catchment (Table 6). Efficacy necessitates that farmers enhance their actual production at least by 76 % under any rainfall regime, through subsequent increase of their water productivity. By increasing their water demand at a level convenient to their crops water requirement, smallholder farms would be able to limit their losses to a minimum efficient scale and expect further increased income through high yields under any rainfall regime.

Table 6. Expected farmers' income variation under the MES Scenario

No	Farm Size	AC MES Values	ANOR		NOR		BNOR	
			Expected Y	Variation (%)	Expected Y	Variation (%)	Expected Y	Variation (%)
1	LSF	1,928.2	1,098.3	75.6%	999.2	93%	900.00	114.3%
2	MSF	1,530.4	776.1	97.2%	768.1	99.3%	760.00	101.4%
3	SSF	352.9	197.9	78.3%	176.5	100%	155.00	127.7%

Source: Luwesi (2010)

Therefore, farmers need to implement rational water use methods in farming. This means they should adopt efficient crops selection and specialization (to 2 or 3 crops) as well as appropriate alternative technologies that value agricultural water resources allocative efficiency and foster farming technological efficiency within the production possibility frontier (GoK, 2007; Ellis, 1993). Beside, farmers need to monitor and evaluate regularly their crops water requirement to allow farming joint ventures, green water credits purchase and virtual water imports. They are also suggested to monitor water demand in the dam under the leadership of a "water resource users' association" (WRUA) and the management of the "water resource management authority" (WRMA). The latter is suggested to water consumption mechanisms instituting water use permits, metering, fees and charges (GoK, 2002). The introduction of water fees and charges at Muooni catchment may foster higher profits if farmers are able to calculate in advance their margin profit and choose adequate crop type and method of production (Förch et al., 2008). Thus, they may hinder water conflicts through equitable water distribution and fair share of the resource, especially under scarcity.

CONCULSION

Food shortage in Muooni catchment is a result of both endogenous on-farm management factors and exogenous environmental agents hampering the rate of fertile soil loss and of water stress. On-farm land management is highly correlated to farmers' education and economic poverty, while off-site El Niño floods and droughts are more related to rainfall fluctuation. All these factors increase significantly the total farming water cost through high water costs of transaction, opportunity costs, saving and shortage costs. For efficiency, farmers need to define their crops water requirements according to an economic order quantity (EOQ), a limit average cost (LAC) and a minimum efficient scale (MES), under above normal, normal and below normal rainfall regimes, respectively. They need thus to implement rational farming water use methods, notably crops selection and specialization (to 2 or 3 crops) and appropriate farming technologies that foster allocative and technological efficiency within the production possibility frontier. Finally, they also may opt for farming joint ventures, green water credits purchase and virtual water imports to enhance efficiency. WRMA should therefore speed up the implementation of water sector reform through consumption metering, fees and charges, and the development of a catchment management strategy (CMS) for the Athi catchment in general, and Muooni sub-catchment in particular. This may be a sustainable remedy to water stress and crops failure as well as to struggle against poverty facing farmers in the catchment.

REFERENCES

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

Benson C & 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.
Brasington J, El-Hames A & Richards K. 1998. Hydrological modelling in humid tropical catchments. In David Harper & Thomas Brown (Eds), The sustainable management of tropical catchments. Chichester, UK, Wiley and Sons Ltd: 313-336.
Charnes A, Cooper WW & Rhodes E. 1978. Measuring efficiency of decision making units. American Journal of Agricultural Economics, 87: 160-179.
Chavas JP, Ragan P & Michael R. 2005. Farm household efficiency: evidence from the Gambia. European Journal of Operational Research, 2: 449-458.
Clarke R & King J. 2004. The atlas of water. London, UK, Earthscan Publications Ltd.
Dixon AB. 2005. Sustainable Management of Headwater Wetlands: the Role of Indigenous Knowledge in South-East Ethiopia. In Libor Jansky, Michael Haigh and Haushila Prasad (Eds), Sustainable Management of Headwater Resources: Researches from Africa and India. Tokyo, Japan, United Nations University Press: 60-86.
Earle A. 2001. The role of virtual water in food security in southern Africa. University of London SOAS Occasional Paper, 33.
Ellis F. 1993. Peasant economics: farm households and agrarian development. Cambridge, UK, Cambridge University Press.
Food and Agriculture Organization, FAO. (Ed). 2008. Crop water requirement. Available at: www.fao.org/ag/AGL/aglw/cropwater/ .
Förch G, Winnegge R & Thiemann S. (Eds). 2008. Water demand in participatory watershed management: Ngaciuma-Kinyaritha Watershed, Kenya. DAAD Alumni Summer School 2008 final report. Meru, Kenya, Universität Siegen.
Global Development And Environment Institute, GDAE. 2008. Advancing theory. Available at: www.ase.tufts.edu/gdae/advancing_theory/theory_pubs.html.
González A, Díaz de Terán JR, Francés E & 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 & Sons: 179-193.
Jaetzold R, Schmidt H, Hornetz B & 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.
Kasambala S, Kamara AB and Nyange D. 2006. Water resources and food security: simulations for policy dialogue in Tanzania. In Perret, Farolfi & Hassan (Eds), Water governance for sustainable development: approaches and lessons from developing and transitional countries. London, Earthscan Publications Ltd: 189-204.
Kemper KE. 2003. Rethinking groundwater management. In Caroline M. Figueres, Cecilia Tortajada & Johan Rockström (Eds), Rethinking water management: innovative Approaches to Contemporary Issues. London, UK, Earthscan Publications Ltd: 120-143.
Luwesi CN, Shisanya CA & Obando JA. 2011. "Toward a hydro-economic approach for risk assessment and mitigation planning for farming water disasters in semi-arid Kenya". In: M. Savino (ed), Risk Management in Environment, Production and Economy, InTech, Rijeka, pp 27-46.
Luwesi CN. 2010. Hydro-economic Inventory in Changing Environment – An assessment of the efficiency of farming water demand under fluctuating rainfall regimes in semi-arid lands of South-East Kenya. Lambert Academic Publishing AG & CO.KG, Saarbrüken.
Luwesi CN. 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.
Ministry of Water MoW. 1987. Muooni Dam construction technical report (Unpublished). Machakos, Kenya.
Musy A. 2001. E-drologie. Lausanne, Switzerland, Ecole Polytechnique Fédérale.
Ngonzo CL, Shisanya CA and Obando JA. 2010. Land use and water demand under a Changing Climate: Experiences of Smallholder Farmers from Muooni. In: S.P. Saikia (eds.), Climate Change, International Book Distributors, Assam, pp. 117-140.
Nicholson W. 1992. Microeconomic theory. Orlando, USA, The Dryden Press.
Oduol JBA, Hotta K, Shinkai S & Tsuji M. 2006. "Farm Size and Productive Efficiency: Lessons from Smallholder Farms in Embu District, Kenya". Kyushu University Journal of the Faculty of Agriculture, 51 (2): 449-458.
Oduor AR. 2003. Hydrologic assessment of smallholder runoff catchment schemes: a case of harvesting rainwater in semi-arid Machakos, Kenya. Delft, Netherlands, UNESCO International Institute for Hydraulics and Environmental Engineering.
Phillip's-EAEP. (Ed). 2002. The atlas. Nairobi, Kenya, E.A.E.P. Publishers Ltd.
Republic of Kenya GoK. 2007. Kenya vision 2030. Available at: www.investmentkenya. com/Documents/Publications/vision_2030_BROCHURE_July_2007.pdf.
Republic of Kenya GoK. 2002. The Water Act, 2002. Kenya Gazette Supplement, 107 (9): 935-1053.
Rockström J. 2003. Managing rain for the future". In Caroline M. Figueres, Cecilia Tortajada. & Johan Rockström (Eds), Rethinking water management: innovative approaches to contemporary issues. London, UK, Earthscan Publications Ltd: 70-101.
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.
Swarp K, Gupta PK & Mohan M. 2007. Operations research. New Delhi, India, Sultan Chand & Sons.
Thompson DA. & Scoging, H.M. 1995. Agricultural terrace degradation in south-east Spain: modelling and management strategies. In Duncan F. M. McGregor & Donald A. Thompson (Eds), Geomorphological and land management in a changing environment. Chichester, UK, John Wiley & Sons: 153-175.
Waswa PF. 2006. Opportunities and challenges for sustainable agricultural land management in Kenya. In Fuchaka P. Waswa, Samuel Otor & Daniel Mugendi (Eds), environment and sustainable development: a guide for higher education in Kenya, 1: 1-19.