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Hydro-economic inventory for sustainable livelihood in Kenyan ASALs: The case of Muooni Catchment

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A B S T R A C T

South-East Kenya is vulnerable to increased siltation and pollution of drainage channels and dams as well as to high risk of crop failure under fluctuation of rainfall regimes. This increases the cost of water for the production of food and energy supply. A study conducted in Muooni Dam Catchment shows that both anthropogenic factors and environmental externalities perturb efficient use of water by farmers in the dam site. Land-use activities going on in Muooni Dam Catchment along with El Niño floods and droughts have an impact on the active water storage capacity of Muooni Dam. Under the effects of farmland degradation and the trade effects of the global climate change, they have resulted in relentless changes of the catchment microclimate. This study reveals that these factors have affected water availability in Muooni Dam at a decreasing rate of 6.2% per year. The latter thwarts any prospect of high yields and good incomes among smallholder farms, and hampers sustainable supply of bio-energy and hydro-electricity. Due to increased farming water costs and high crop water requirements, farmers use excessive multiple cropping to cope with water stress and poor incomes. They often substitute staple crops by eucalyptus and other alien trees to avoid high risk of crop failure. For efficiency, farmers were urged to adopt an "Economic order quantity (EOQ) or a "Limit average cost" (LAC) or at least a “Minimum efficient scale” (MES) of their water demand under the above normal (NOR), normal (NOR) and below normal (BNOR) rainfall regimes, respectively, using efficient farming technologies and hydro-political strategies. “Hydro-economic inventory” is thus a prerequisite for implementation of an «Integrated watershed management» to ensure sustainable food production and energy supply.

Keywords: *Climate change, Economic inventory, Hydro-geomorphologic impact assessment, Land degradation, Social impact assessment, Water use efficiency.*

INTRODUCTION

Human life is in jeopardy as the global climate change threatens all biological lives and their ecological systems under the impetus of population pressure on water and other natural resources. The subsequent land-use changes affect water availability and soil fertility in various catchment areas. Sub-Saharan Africa is vulnerable to food insecurity and poverty outreach due to these socio-environmental changes (Shisanya and Khayesi, 2007). The Republic of Kenya in general and South-East Kenya in particular are prone to deforestation, soil erosion, the siltation and pollution of drainage channels and water storages, among key factors affecting water availability and soil fertility for sustainable production of food, and supply of bio-energy and hydro-electricity (Gleditsch et al., 2004; Porras et al., 2007). Dry and marginal agricultural lands as well as other pressures that contribute to increased water stress and environmental degradation are corollaries of appropriation of surface and ground water by human beings in South-East Kenya (Huggins, 2002; Jaetzold et al., 2007). Water Vision 2000 declared that water crises were not “about too little water but about managing water badly such that billions of people and the environment suffer badly” (Mati, 2006). To curve the trend of water stress and scarcity, John Howard, former Australian prime minister, suggested a “complete overhaul of how water is managed” to restore rivers to health after many years of over-exploitation of water and droughts (Ngurari, 2009). One way to achieve such a goal is by conducting a "Hydro-economic inventory" (HEI) of water and land use for food production and energy supply.

This paper discusses hydro-economic issues related to crop failure and energy disruption in Kenyan "Arid and semi-arid tropics" (ASATs). It introduces the concept of HEI and deepens it with findings from the Hydro-geomorphologic impact assessment, the social impact assessment and the economic inventory conducted in Muooni Dam Catchment. Finally, it summarizes the main findings and concludes with some recommendations.

Concept of Hydro-Economic Inventory

Water stress and land degradation constitute major causes of losses of yields and incomes in the agriculture and energy sectors, particularly of African ASATs. Most homesteads in these areas often rely on agriculture, water and firewood supply, sand harvesting and quarrying as their main sources of livelihood. Due to the degradation of most catchment areas, many governments have embarked in the process of reforming the management of their natural resources with the aim of managing sustainably their water resource. The water sector reforms usually culminate with the enactment of comprehensive water legislations, policies, and strategies. As usual, most governments in developing countries rely on the funding and technical assistance from their bilateral and multilateral partners to implement their national agendas. Yet, a discreet observer would ask: (I) what significant changes have been recorded in different catchments since the implementation of these reforms? (ii) How have these interventions improved the life and behaviour of different categories of water users in the catchments? (iii) To what extent have they contributed to the economic efficiency of water and land uses?

The answer to the first question requires an "Hydro-geomorphologic impact assessment", while the second implies a "social impact assessment", and the third one relies on an "Economic inventory" of the efficiency of water and land use to shed a light on the final outcome of the water sector reforms. These three techniques summed up make "Hydro-Economic Inventory" (HEI). The latter can be defined as "an assessment of the impact of water use on the hydrology and the geomorphology of a catchment area, the social welfare of local stakeholders, and the economic efficiency of water and land use in a changing environment" (Luwesi, 2010).

Hydro-geomorphologic impact assessment uses the technique of "Environmental impact assessment" (EIA). In their 1999 report, DETR and the National Assembly for Wales gave the following standard definition of EIA : "An important procedure for ensuring that the likely effects of new development on the environment are fully understood and taken into account before the development is allowed to go ahead" (Hacking and Guthrie, 2006). EIA is thus "the process of identifying, predicting, evaluating and mitigating the bio-physical, social, and other relevant effects of development proposals prior to major decisions being taken and commitments made" (Wikipedia, 2008). Figure 1 provides the sequence of repeatable steps followed when those conducting hydro-geomorphologic impact assessments.

The Social impact assessment (SIA) entails a similar process as EIA but overlaps both planning and Monitoring and Evaluation (M&E). SIA focuses on the effects of a project or public policies on stakeholders' cultural heritage and archaeological sites, food security (production, preservation and distribution), health and education, environmental health (protection and conservation of the natural resources), and disaster adaptation and mitigation (the impact of environmental changes on economic activities) (Burdge, 2008). Just like EIA, SIA is carried out prior a project approval by local authorities and consent by the public. This helps a better design of the planning goals and eventually much more efficient implementation of local development projects. Unlike EIA but like M&E, SIA can be carried out after a project has gone ahead in order to assess the achievement of its goals and its impacts on the beneficiaries. Yet, it substantially overlaps with M&E in the process of project management (Burdge, 2004).

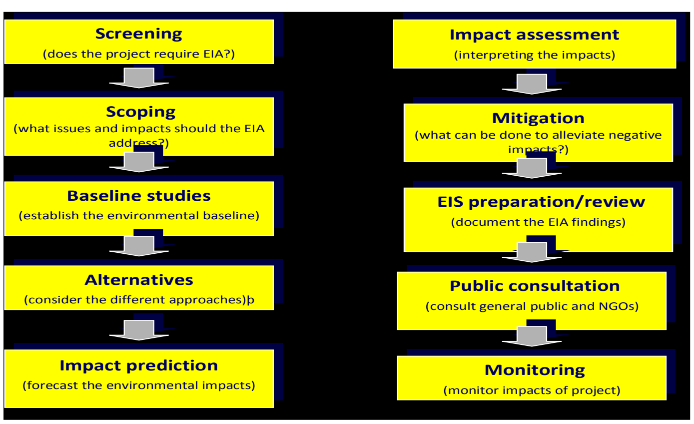

Figure 1. Environmental Impact Assessment Framework (Hacking & Guthrie, 2006)

"Economic inventory" assesses the effects of an economic environment on the productivity of financial and physical resources. It uses hybrid inventory models shaped after Wilson deterministic stock inventory, Baumol deterministic monetary inventory and Beranek dynamic cash inventory under above normal (ANOR), normal (NOR), and below normal (BNOR) economic conjunctures (Luwesi, 1999). These models combine both internal and external costs incurred in the management of inventories in order to simulate efficient levels of money and physical assets use in production under fluctuating economic conjunctures. Internal costs encompass both the cost of transaction and opportunity cost, while external costs include the cost of saving under ANOR, and the shortage cost under BNOR. Three key efficiency indicators come up from this analysis, namely the "Economic order quantity" (EOQ) computed under the ANOR, the "Limit average cost" (LAC) determined under NOR, and the "Minimum efficient scale" (MES) calculated under the BNOR, respectively (Luwesi, 2009). Finally, the analytical process assesses the variations of incomes vis-à-vis costs under different hypotheses of the management efficiency (EOQ, LAC and MES) to design strategic guidelines. Table 1 summarizes key outputs of an "Economic inventory."

Table 1. Economic inventory Outputs (Luwesi, 2010)

Economic conjuncture	Total Cost of inventory				Optimum (First Order Conditions)
	Internal Costs		External Costs		
					Limit Average Cost (LAC)
Normal (NOR)	Cost of Transaction	Opportunity Cost			$\bar{r}_{no} = \sqrt{2qQ}$
					Economic Order Quantity (EOQ)
Above Normal (ANOR)	Cost of Transaction	Opportunity Cost	Saving Cost		$\vec{r}_{no} = \sqrt{2q/(2Q-q)}$
					Minimum Efficient Scale (MES)
Below Normal (BNOR)	Cost of Transaction	Opportunity Cost		Shortage Cost	$\bar{r}_{bn} = \sqrt{2}$

Source: Luwesi (2010)

The HEI conducted in Muooni Dam Catchment sought to evaluate the efficiency of water use in agriculture under hypothesized fluctuations of rainfall in South-East Kenya. It responded to the following research questions: (i) What kind of anthropogenic and environmental factors affect efficient use of Muooni Dam water in farming? (ii) To what extent do land-use activities and environmental externalities influence the active water storage capacity of Muooni Dam? (iii) What variations of farmers' actual water demand and related costs are expected as a result of rainfall fluctuation in South-East Kenya? (iv) What are the efficient levels of farmers' water demand and related costs under fluctuating rainfall regimes?

(Zeiller ,2000) stratified random sampling was used to select some 66 farms at Muooni Dam site and 60 key informants outside the dam site. The method involved equal chances of selection for all the respondents, both the most accessible ones and those far away from Muooni Dam site. The hydro-geomorphologic impact assessment was based on (Gonzalez et al., 1995) impact assessment sampling technique. The latter aimed to record significant land-use activities and impacts randomly occurring on farmlands. Descriptive statistics, non-parametric tests, and time series analysis assisted in the valuation of impacts assessed, the establishment of their relationship with land-use activities observed, and the prediction of Muooni Dam's active water storage capacity. Spatial data processing used ArcView GIS to map land-use activities and impacts assessed. Then the analysis proceeded to assess social impacts using mainly descriptive statistics, trend analysis, and a triangulation of both quantitative and qualitative methods. This led to the economic inventory, which totally relied on hybrid inventory models for the computation of farmers' water demand and related costs. It also helped to simulate the optimum levels (EOQ, LAC and MES) of farming water demand and cost under three respective scenarios of rainfall fluctuation (ANOR, NOR and BNOR). These efficiency indicators were computed for three different categories of farmers, notably "Large-scale farmers" (LSF), "Medium-scale farmers" (MSF) and "Small-scale farmers" (SSF). The following sections present these analytical components in rapport with the HEI conducted in Muooni Dam Catchment.

Results of the Hydro-Geomorphologic Impact Assessment

(Gonzalez et al., 1995) hydro-geomorphologic sampling was based on the significance of the impact of farming activities on the dam and its catchment area, in terms of soil erosion problems, sedimentation of Muooni Dam and water over-abstraction in the catchment. After screening and scoping these issues, the analysis came up with six hydro-geomorphologic indicators of water and land use and their impact on Muooni Dam Catchment (Table 2).

Table 2. Land-use activities and impacts assessed at Muooni Dam (Luwesi, 2009)

Weight	Land-use activities	Weight	Environmental Impacts
1	Tree planting	1	Sheet/ rill erosion in the farm area
2	Intensive cultivation using water pumps/ tanks	2	Encroachment on wetland
3	Subsistence cultivation with limited irrigation	3	Sand harvesting/ quarrying impacts on farms
4	Subsistence cultivation without irrigation	4	Gully erosion on farmland
5	Livestock keeping with some cultivation	5	Landslide on farmland
6	Livestock keeping without cultivation	6	Eucalyptus water over-abstraction

This table indicates that land-use activities assessed and their likely hydro-geomorphologic impacts were assigned a meaningful figure (1, 2, 3, 4, 5 and 6). These numbers were given according to the significance of their contribution to the degradation of Muooni Dam environment. This environmental degradation referred to the soil erosion problems leading to soil loss on farmlands, the sedimentation of Muooni Dam, and to excess water loss from its reservoir and the whole catchment. Based on their spatial coordinates and significance, the analysis generated the following maps for land-use activities (Figure 2) and their likely environmental impact (Figure 3).

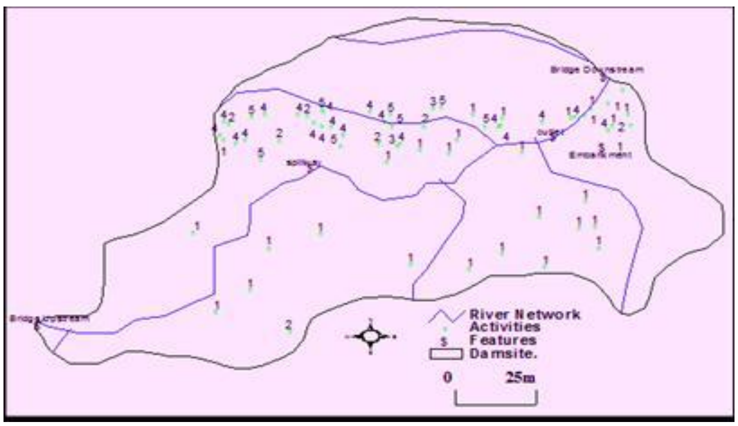

Figure 2. Spatial distribution of land-use activities in Muooni Dam Catchment (Luwesi, 2010)

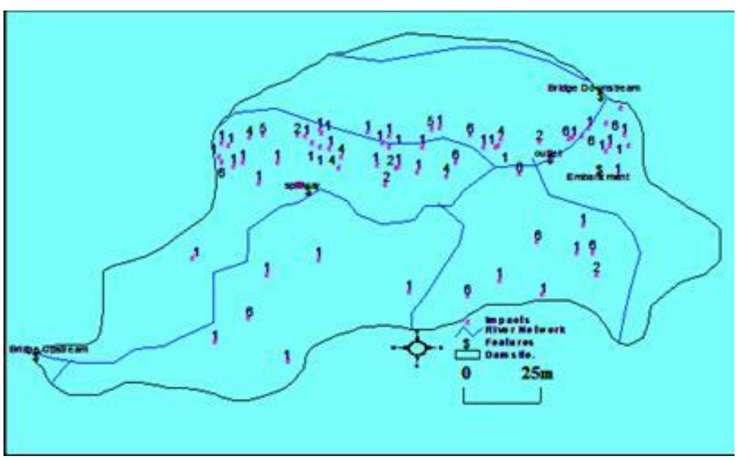

Figure 3. Spatial distribution of hydro-geomorphologic impacts in Muooni Dam (Luwesi, 2010)

Figure 2 shows a predominance of land-use activities related to food cropping and sylviculture. Agro-forestry and subsistence cultivation without irrigation represent both two thirds of the total farming area estimated to 31.2 acres. They were propounded to be the most practised land-use activities, with proportions of farmers averaging 46% and 29%, respectively. Other land-use practices were not significant. They 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%). None among farmers surveyed was practising livestock keeping without cultivating. Figure 3 reveals that sheet and rill erosions along with Eucalyptus water over-abstraction were the most significant environmental impacts observed in the catchment. Following the depletion of the forest cover, eucalyptus trees were planted everywhere in the catchment, including 18% of farms located in the wetlands. Under these wooden areas, sheets and rills occurred in more than 63% of farms assessed, while gully erosion, landslides and encroachment of agricultural fields on wetlands accounted for 8%, 3%, and 8% of farms surveyed.

Though widespread on farmlands, the analysis did not establish a direct relationship between land-use activities assessed and their likely hydro-geomorphologic impacts. Mann-Whitney U-Test proved with 99.8% confidence level that land-use activities assessed and the impacts observed on farmlands were randomly drawn from independent populations (Table 3).

Table 3. Results of Mann-Whitney U-Test (Luwesi, 2010)

No	Decision Parameters		Decision
1	$U_{1=}$ 2,178	n_1= n2=66	The deviations around the means of the two samples are far significant; so are their differences.
2	μ_1=1,089	σ_1 =219.725	
3	Z_u= 4.9562	n= 66	**Rejection** of H_o ($\mu_1=\mu_2$) stating that there are significant differences between the populations from which the two samples were drawn.
4	Z_ρ = 3.99	α = 0.002	

Spearman's rank correlation confirmed at 99.8% confidence level that land-use activities assessed in Muooni Dam Catchment and their likely impacts may have originated from diverse sources, within and outside Muooni Dam Catchment. Table 4 shows there was no strong relationship between the two random samples analyzed. The latter were behaving independently one from another. These impacts might have been the results of various forces hastening the degradation of the catchment area. Though farmers are used to enhancing their soil protection through terracing, contouring, cut-off drains, polyculture and agro-forestry, the on-site effects of soil erosion and eucalyptus water over-abstraction may be explained by inadequate soil conservation measures (Tiffen et al., 1994). Off-site effects of soil erosion and high water evaporation from the dam reservoir may be elucidated by the effects of environmental changes, notably by El Niño floods and droughts, heavy wind pressures, footpaths and roadsides, sand harvesting and deforestation and others forces from outside Muooni Dam Catchment area. Both on-site and off-site sources of impacts observed were hindering water availability in drainage systems and the dam reservoir in Muooni Dam Catchment (Luwesi, 2009).

Table 4. Results of the Spearman's rank correlation (Luwesi, 2010)

No	Decision Parameters		Decision
1	Σdi^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	**Acceptance** of H_o (ρ_s=0) stating that there is no significant relationship between the populations from which the two samples were drawn.
4	Z_ρ = -3.99	α =0.002	

The environmental impact assessment conducted in Muooni Dam Catchment revealed that soil erosion and landslides were outwitting the active water storage capacity of the Dam. Time series analysis predicts a decreasing active water storage capacity of 6.2% per annum (Figure 4).

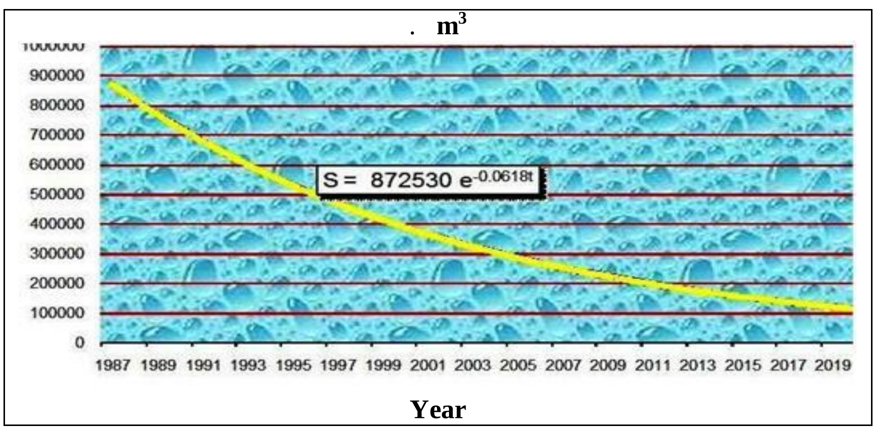

Figure 4. Trendline of Muooni Dam's active water storage capacity (Luwesi, 2010)

An analysis of the records of the dam management suggests an important siltation of the dam reservoir since its creation in 1987. The dam reservoir was actually overloaded by important sediments eroded from farms, and from El Niño floods and winds. If no immediate action is taken, the study shows that the maximum capacity of the dam reservoir established at 1,559,400 m^3 in 1987 will reach out its threshold by the year 2019, with an estimated storage capacity of about 119,287 m^3 of the total flow of Muooni River. The prediction model used was propounded to be sufficiently strong. Table 5 indicates that

81% of the variations of the dam's active water storage capacity were reflected in the changes of its infrastructure old-age, and 65.7% of its total variation was actually explained by the resistance of the dam logistics in time.

Table 5. Significance of Muooni Dam's storage capacity trendline (Luwesi, 2010)

Model (S_t)	Coefficients		t-statistic	Sig.
	B	Std. Error		
1. (Constant)	872,530	316,576	2.756	0.013
2. t	-0.0618	0.017	-3.564	0.005
Note: r = 0.81; R^2 = 0.6565; Mean = 671,874 m^3; ET = 173,400 m^3.				

The Rho Test ascertained with 99.5% confidence level and 20 degrees of freedom that the decreasing trend of Muooni Dam's active water storage capacity was due to its logistics old age (Table 6). This may have been a consequence of its reservoir logistics depreciation either by destruction or by lack of maintenance. Therefore, the study needed to explain the remaining 34.3% of the total variation of the dam's active storage capacity not attributed to logistics obsolescence, which might be due to the degradation of the dam's catchment area.

Table 6. Results of the Spearman's Rho test (Luwesi, 2010)

Statistical Parameters		*Decision*
1. $r = 0.81$	$\alpha = 0.005$	There is a strong correlation between *S* and *t*
2. $S_r = 0.134$	$n\text{-}2 = 20$	The correlation coefficient is good
3. $t_{\rho;n-2} = 4.651$	$t_{\alpha;n-2} = 2.84$	**Rejection** of H_0 (ρ=0) stating that there was no relationship between the decreasing storage capacity of the dam and its logistics old age.

The obsolescence of Muooni Dam might have resulted in a lot of evaporation and seepage at the same time from the bottom of the dam reservoir. The decomposing wooden logistics may have produced some methane and carbon dioxide gases in the dam reservoir, thus contributing to the emission of greenhouse gases. The latter must have an impact on the variation of the temperature of water stored in the dam, and on the change of the catchment microclimate and the country climate as well as on the global climate (GEF et al., 2008; Sylva-Monde et al., 2008). Reports by the World Commission on Dams highlight the fact that the decay of plant materials in anaerobic environments of flooded areas result in a change of climatic patterns of such environments (UNEP, 2002; Wikipedia, 2008). The quality and safety of water as well as the sustainability of energy provided by such dams is thus questionable worldwide. The combined effect of these factors justifies the changes observed in the catchment microclimate through the phenomena of drought recurrence and watercourses seasonality under relentless variations of rainfall regimes. The subsequent water stress may have threatened farmers' social welfare and the economic viability of their activities. It may have resulted in the prevalence of food shortages, energy rationing or disruption, water borne diseases and other disasters in these areas along with the variations of farming water costs under fluctuating rainfall regimes. The SIA and economic inventory presented in the following sections deal with such issues.

Results of the Social Impact Assessment

The study conducted in Muooni Dam Catchment revealed that land management was highly correlated with the farmers' level of education and poverty. Their formal educational credits and professional status reflected the type on-farm management observed on the ground. In fact, a majority of farmers attained some level of formal education, with some primary (33.3%) and secondary (30.3%) educational credits, professional credentials (12.1%) and university degrees (6.1%). Only some 18.2% of the farmers interviewed had no formal education. An analysis of their professional status divulged that most farmers were self-employed, either in full-time farming (33.3%) or in off-farm activities (21.2%). Some others worked with private enterprises (36.4%) or in the Public Service (9.1%). None of them was a schoolteacher or a university lecturer.

The distribution of farmers by level of income confirmed that poverty was a reality in the study area. Survey results disclosed that 30% of farmers in Muooni Dam Catchment had a daily average income of less than US $1, with an annual income averaging US$ 231 (for $1=KES 60). Accordingly, the distribution of farmers by class of income was dominated by small and Medium-scale farmers (SSF and MSF) earning a monthly income below KES 3,000, and between KES 3,000 and 5,999, respectively. Farmers' poverty in this area was likely due to lack of potential agricultural lands and population pressure. Population pressure on land was characterized by increased settlement in marginal lands, the sub-division of ranches for sedentary small-scale farming portrayed by excessive multiple cropping and intercropping, and further sub-division of land for settlement (Jaetzold et al., 2007). Farmland subdivision in Muooni Dam Catchment was a clear indication of their strategy to fight extreme poverty. Farmers were subdividing their lands to allow new settlers undertake off-farm activities and/ or work part-time in farming. The risk of soil loss and water over-abstraction was to worsen in Muooni Dam Catchment since farm caretakers lack sufficient knowledge on soil conservation and efficient farming methods (Douglas, 1994; Waswa, 2006). Moreover, poor yields and incomes led a majority among farmers to substitute eucalyptus tree planting with subsistence cultivation, and monoculture with excessive multiple cropping and intercropping (of 6 to 15 species). Thus, exotic trees, crops, and weeds substituted the natural vegetation in most wetlands. These interlopers generally exacerbate the vital functions of the whole ecosystem, owing to the fact that they are not water friendly (Kitissou, 2004; Jansky et al., 2005).

Farmers' recourse to excessive intercropping and multiple cropping of perennial indigenous and alien crop species on small farmlands could not hold them back from poverty. The multiple cropping of about 6 seasonal crops and 9 perennial crops within a small plot area of 1.5 acres in such a hostile environment could only enhance the inefficiency of their farming activities. With a declining rate of farming area of 40% in about 10 years, excessive intercropping and multiple cropping may have resulted in "land harassment". Moreover, water over-abstraction by eucalyptus and other alien trees along with off-site effects of El Niño floods and droughts accelerated the risk of soil erosion and water excess loss. Farmers' strategy later rebounded on the dam's active water storage capacity by spoiling its water reserves and loading important sediments in its reservoir, especially after tree harvesting. The negative trend of the active water storage capacity of the dam affected considerably the quantity and price of water in the catchment, resulting in a costly farming production. The following section develops an economic inventory to discuss issues related to the variations of the farming water demand and cost in Muooni Dam Catchment under fluctuating rainfall regimes.

Results of the Economic Inventory

The decreasing water levels in Muooni Dam thwarted smallholder farms' yields and incomes. Table 7 suggests that most farmers surveyed were at the brink of poverty since they were incurring losses over years due to the decreasing productivity of their farming water and land resources. Therefore, the study needed to assess the variations of actual farmers' water demand and related costs vis-à-vis the optimum levels of farming water demand (EOQ, LAC and MES) to establish their efficiency under fluctuating rainfall regimes in Muooni Dam Catchment.

Table 7. Allocation of farmers' annual income (Luwesi, 2010)

N°	Operations	LSF (KES)	MSF (KES)	SSF (KES)
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
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
3	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

Results show that increased shortage costs of farming water and the cost of fertile soil excess loss constrained farmers to order less farming water (Wf) than required by their crops (Wc). Large-scale (LSF), Medium-scale (MSF) and Small-scale farms (SSF) could just afford ordering 28.9%, 12.2% and 4.4% of their actual crop water requirements, respectively (Figure 5). In such conditions operational costs soared by 175%, 518% and 1,420% of the actual total costs of farming water under the ANOR, NOR and BNOR scenarios, respectively (Figure 6). This underscored a progressive accumulation of farming losses by a majority of farmers over years.

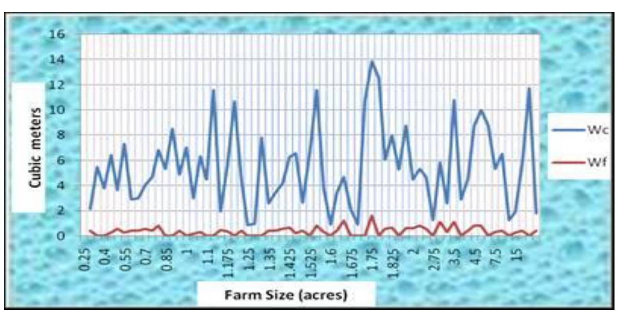

Figure 5. Farmers' water demand and crop water requirements (Luwesi, 2010)

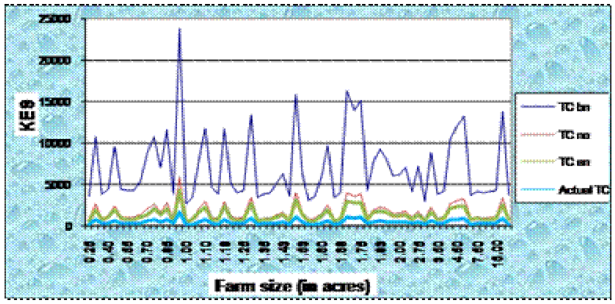

Figure 6. Farming water costs computed under fluctuating rainfall regimes (Luwesi, 2010)

An analysis of the optimum levels of farming water demand (EOQ, LAC and MES) revealed that farmers operating in Muooni Dam Catchment recorded high water productivities from 1987 to 2003, under ANOR rainfall regime. Their unit cost per m^3 averaged KES. 197, 188 and 159 for LSF, MSF and SSF, respectively. This water cost was assorted to an "Economic order quantity" (EOQ) of farming water demand in a very profitable economic conjuncture at Muooni Dam Catchment. From 2004 to date the loss of farming profitability under the NOR scenario was the most important economic incentive that led farmers to subdivide their lands. As their average costs became significantly high, older farmers had to limit their water farming costs to a "Limit average cost" (LAC) of KES. 444, 415 and 361 for LSF, MSF and SSF respectively. They did it by practicing sylviculture (mainly eucalyptus tree planting), and by leasing or even selling part of their farmlands to new comers. Some even left their farmlands under fallow. By the year 2019, when the storage capacity of Muooni Dam will have gone under its threshold, a majority would be obliged to abandon their farming activities and adopt off-farm activities. Some would even embrace small-scale businesses, or jobs in the private and public sectors. The "survivors" would have to sacrifice their short-term benefits by adjusting their farming water demands to a "Minimum efficient scale" (MES) of KES. 831, 769.3 and 676.7, for LSF, MSF and SSF, respectively. Using the minimum efficient farming water demand (MES), farmers would be able to secure more water than their present actual water demand (Actual Wf) and crop water requirements (Wc) (Figure 7). This would allow them mitigate the high risk of crop failures under fluctuating rainfall regimes, particularly under drought.

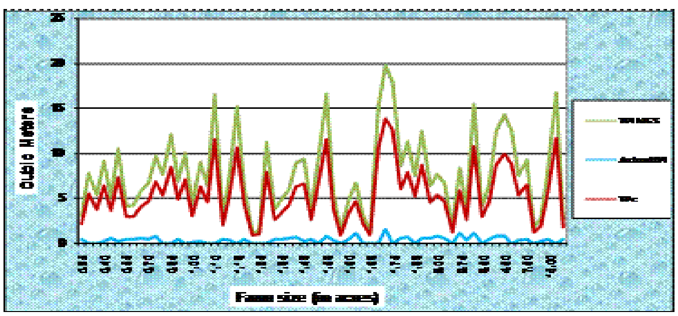

Figure 7. Minimum farming water demand under fluctuating rainfall regimes (Luwesi, 2010)

For efficiency, farmers need to increase their respective actual water demand by at least 42% to meet their optimal farming water levels under the scenario of an EOQ (ANOR rainfall regime), a LAC (NOR rainfall regime) and a MES (BNOR rainfall regime), respectively. By so doing, they would expect a fall of their farming water costs up to 36%, 78% and 232% under the three respective rainfall regimes. Such optimization of the farming water demand would result in a decrease of their operational average costs ranging from 30% to about 100%. This fall of operational costs would be accompanied by an increase of water productivities due to high farming yields and good incomes under the ANOR rainfall regime, if the EOQ was to be respected. This would allow farmers to meet their crop water requirements and ensure the economic viability of their farming activities in time of water stress and scarcity.

For now on, there is no prospect of significant increase of farming yields and incomes under the NOR rainfall regime, and more less under the BNOR scenario, even where the LAC and the MES are to be applied with scrutiny. Farmers are particularly expecting a significant decrease of their farming profitability under the BNOR rainfall regime due to farmland subdivisions and poor soil moisture. This soil moisture decrease is particularly attributed to both the change of the catchment microclimate and the global climate change. Farmers need to adjust their crop water requirements with soil moisture depletion. Otherwise, they would have to specialize to less than three water friendly crop species (GoK, 2007). They have also to minimize their costs of farming water by using other effective agronomic technologies and efficient on-farm management techniques such as rational crop treatments and selection, application of improved farming inputs (fertilizers, pesticides, fungicides, and rodenticides). They would have also to make use of hydro-political strategies such as water consumption metering, evapo-transpiration quotas, green water credits, virtual water import and rainwater harvesting in the context of “Integrated Watershed Management” (IWM).

In line with “Integrated Watershed Management” in (Kenya Förch et al., 2008) suggest that the government speeds up the process of enforcement of key regulations of the water sector reforms. These include water quality control, water use allocation and metering, and irrigation schemes and dams coordination. Farmers need to comply with these rules by paying relevant water charges. Nevertheless, they shall factor these water charges in their marginal profit calculations by adopting the right crop type and production method, and by using efficient farming water saving techniques to achieve high profits through “more crops per drop”. The authors urge farmers to understand that fees are used to manage the water rationally, up to the end tap, for the benefit of all stakeholders. (However Lal ,1993) firmly encourage farmers to make some tradeoffs between on-farm and off-farm income-generating activities, if efficiency was to achieve. This would mean that they adopt off-farm activities if their farming water opportunity costs are higher than elsewhere to avoid running a deficient farming enterprise.

CONCULSION

Many people’s livelihood is often disrupted by both endogenous on-farm management side effects and exogenous externalities from the environment affecting food production and energy supply. These factors enhance the rate of deforestation, soil erosion, fertile soil loss from farmlands and water stress in many catchment areas. The Hydro-economic inventory conducted in Muooni Dam Catchment revealed the significance of hydro-geomorphologic impacts occurring on farmlands and their prevalence on the stress of water availability in the production of food and energy. Bad land management associated with low levels of education are propounded to be major causes of low agricultural yields and incomes, poverty and food insecurity. Put altogether, these factors affect at least 34% of the total variation of Muooni Dam’s active water storage capacity, reducing it by 6.2% every year. The subsequent water stress leads to the increase of farming water costs. The latter thwarts farmers’ social welfare and the economic viability of their farming activities, especially under drought. Though farmers use excessive multiple cropping and the substitution of staple crops by eucalyptus and other alien trees, as well as the subdivision of their farmlands to cope with poor yields and incomes, these practices cannot hold them back from poverty under water stress. For efficiency, farmers need to adjust their crop water requirements to an optimum water level that fits the soil moisture in the catchment. Therefore, an absolute economic order quantity (EOQ), or a limit average cost (LAC) or finally a minimum efficient scale (MES) must be observed under ANOR, NOR and BNOR rainfall regimes, respectively. Farmers need to implement rational farming methods and farming water saving strategies notably through crop selection and specialization (to 2 or 3 crops), appropriate farming technologies, and hydro-political strategies that foster farming water allocative and technological efficiency within the production possibility frontier. The “Water resources management authority” (WRMA) shall therefore speed up the implementation of the water sector reforms through development of a “Water resource users’ association” (WRUA) and of a Sub-catchment management plan (SCMP). This would be a sustainable remedy to energy disruption, water stress, farming inefficiency, poor yields and incomes, and farmers’ poverty in this catchment.

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