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Toward a Hydro-Economic Approach for Risk Assessment and Mitigation Planning of Water Disasters in Semi-Arid Kenya

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1. Introduction

Mikhail Gorbachev, President of Green Cross International, once declared: "Water is one of the most important ingredients for development and stability. Without access to basic water supplies, disease and ill-health, poverty, environmental degradation and even conflict may be the result – all of which lead, in turn, to greater water stress. Water-related conflict does not have to take on the attributes of war in order to be debilitating – it can fester between groups, ignite between neighbouring farmers or industrialists, and can cause loss of trust between people and their governments. When water conflict erupts between sovereign states, the victims may not perish on any clearly discernible battlefield, but the people and the watercourse itself will suffer the consequences of the absence of either co-operation or communication between those sharing a basin." (Hartnady & Hay, 2004). This statement shows the whole importance of the science of management of water and related issues.

In fact, scientists long ago sought to understand the process of water cycle. This understanding helped them monitor the changes in the quantity and the quality of water occurring through the fluxes of water from the atmosphere to the surface of the earth and underground, fluxes of solutes and sediments and the effects of gravity and radiation. Science based knowledge of these hydrological processes assisted in explaining and predicting water-related hazards, notably droughts, floods, tornadoes, cyclones, landslides, mudslides, etc. Yet, due to the high risk associated to environmental changes, traditional scientific postulates and models have become inadequate to controlling water disasters, particularly in the "Arid and semi-arid lands" (ASALs) (Brasington et al., 1998). Under the effect of population pressure on natural resources, water disasters tend to cause agricultural inefficiency resulting in food insecurity and poverty outreach in most ASALs (FAO, 1995; Shisanya, 1996; UNDP, 2007; World Bank, 2007). There is thus need for reviewing traditional premises, hypotheses and theorems of water disaster management to adapt them to environmental changes. Hydro-economic risk assessment offers a novel framework towards sustainable management of agricultural water disaster in ASALs. This study evaluates hydro-geomorphologic risks, and their social and economic impacts associated with farming water use in dry and marginal lands of Kenya.

The risk assessment conducted in Muooni Dam Catchment of Kenya utilized an "hydro-economic" procedure to assess the risks related to farming water and land use, and served as a basis for mitigation planning, implementation, monitoring and evaluation of water disasters in agriculture in that catchment area. This novel approach called "hydro-economic risk assessment and management" (HERAM) assessed farming activities' effects on water and land, social welfare and economic efficiency under three scenarios: that of "Above normal" (ANOR), "Normal" (NOR) and "Below normal" (BNOR) rainfall regimes. Specifically, it sought to highlight hydro-geomorphologic, social and economic risks related to irrational use of farming water and land. The valuation of these externalities coming from the changing environment in Muooni Dam Catchment was done using inventory models. Finally, a risk management approach was suggested for efficient water use in farming in ASALs.

2. Justification of the approach

The global warming, El Niño rainfall and wind pressure are critical challenges to water management models built on traditional premises, hypotheses and theorems. Water and soil conservation measures based on these models are vulnerable to important water evaporation and seepage, increased salinity, and obsolescence leading to excessive costs of maintenance (Shakya, 2001; Uitto & Schneider, 1997). Ecological changes observed in many catchment areas hinder the productivity of natural resources, resulting in increased unit costs per water drop for producing the same quantity of crop or meat (Lal, 1993). An integral assessment of climate and land-use changes related risks on efficient use of natural resources is therefore vital to sustain agriculture efficiency in the course of climate change. It needs a new framework, strategic approach, elaborate hypotheses and comprehensive models to ensure sustainability in the management of both water resources and related disasters (Burdge, 2008; Shisanya & Khayesi, 2007 ; Vishnudas, 2006).

Brown (2001) stated that "If an economy is to sustain progress, it must satisfy the basic principles of ecology. If it does not it will decline and eventually collapse. There is no middle ground. An economy is either sustainable or it is not." This statement conveys an integration of market based variables of farming water demand within the framework of agro-ecology. Agro-ecological variables are determinants of the farming production optimum. These are bio-physical based variables of plant water leading to evapo-transpiration. Yet, when subjected to the market game, to farmers' ignorance, apprehension and false expectations, good bio-physical conditions can easily result in farming inefficiency. Thus, farmers' decision-making, economic power and social dynamics shall be taken into account when assessing water related hazards in farming.

Hydro-economic risk assessment and management (HERAM) is a step of "Integrated watershed management" (IWM). It is a major goal towards sustainable management of water resources, especially designed to improve irrigation planning in the course of climate change within various agro-ecological zones. In effect, HERAM is based on a postulate stating that water efficiency in agriculture can be effectively assessed, planned and evaluated under uncertain conditions of water availability by integrating both agro-ecological and socio-economic variables (Luwesi, 2009). If that link between the physical and market processes is mended, farmers would naturally balance the fluctuations of water to foster their farming efficiency in a changing environment. Finally, HERAM is in line with the principles adopted during the "IWRM inception conference" in Dublin (1992) and the "Yokohama strategy and plan of action for a safer world" endorsed during the "World conference on natural disaster reduction" (May 1994, Yokohama). The two forums recommended the integration of water resource development within the framework of planning and risk assessment as well as the valuation and recognition of the role of natural resources in sustaining life. They recommended the empowerment of local stakeholders to provide alternative and decentralized approaches towards water supply and relief options under conditions of drought or any other disaster.

3. Hydro-economic risk assessment: Methods and techniques

Hydro-economic risk assessment and management (HERAM) basically features in the framework of "Environmental risk analysis" (ERA) in a catchment area. Ganoulis & Simpson (2006) define ERA as "the evaluation of uncertainties in order to ensure reliability in a broad range of environmental issues, including utilization of natural resources (both in terms of quantity and quality), ecological preservation and public health considerations". They provide the following framework for assessing and managing the risk: problem formulation, load-resistance (or exposure-response) characterization, risk quantification, evaluation of incremental benefits against different degrees of risk, and decision-making for risk management. The Risk analysis consists of two procedures: Risk assessment (RA) and Risk management" (RM). Risk assessment deals with the identification of the hazard, the determination of its value (both quantitative and qualitative) and the observable effects it is likely to yield on the people, their environment and economy. Risk management entails the design and implementation of mitigation plans, and their monitoring and evaluation for sustainability. Like ERA, "Hydro-economic risk assessment and management (HERAM) involves a Risk assessment (RA) and a Risk management" (RM). The RA encompasses three other procedures: a "hydro-geomorphologic risk assessment" (HRA), a "social impact assessment" (SIA), and an "Economic inventory" (EI). These three procedures are embedded in the Risk management" (RM). Figure 1 provides the sequence of repeatable steps involved in the conduction of a HERAM.

Fig. 1. Hydro-economic risk assessment and management framework

It shall be noted that "Economic inventory" (EI), which in fact is an incremental analysis of farming water efficiency, makes the particularity of the HERAM. It assesses the effects of water management on its productivity and efficiency in agriculture. It uses hybrid inventory models shaped after Wilson deterministic stock inventory, Baumol deterministic monetary inventory and Beranek dynamic cash inventory, both under above normal (ANOR), normal (NOR), and below normal (BNOR) rainfall regimes (Luwesi, 2010). These models combine internal and external costs incurred in the management of water inventories in order to simulate efficient levels of water use in farming under fluctuating rainfall regimes. Internal costs encompass both the cost of transaction and opportunity cost of water management, while external costs include the cost of water saving under ANOR, and water shortage cost under BNOR. The incremental analysis of the total cost leads to three key indicators of farming water efficiency, 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. 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" during a HERAM.

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

Table 1. Economic inventory outputs

Note: r_{no}, r_{an} and r_{bn} refer to the water demand turnover under NOR, ANOR and BNOR, while Q and q stand for the farming activity output and input, respectively standardized as follows:

$$Q = \frac{n * Y}{W_f * P} \tag{1}$$

$$q = \frac{n * E}{W_f * P} \tag{2}$$

Where, Y is the farming income, E is the farming expense, P is water price in the market (per m^3), W_f is the farmer water demand, and n the number of water withdrawals by the farmer.

The HERAM 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? (v) How can farmers improve their water efficiency in the course of climate change?

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 impacts sampling was based on Gonzalez et al. (1995) impact assessment 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 were processed using ArcView GIS mapping for both 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 each of the three categories of farmers, notably "Large-scale farmers" (LSF), "Medium-scale farmers" (MSF) and "Small-scale farmers" (SSF). Different techniques of "Integrated watershed management" (IWM) were suggested to improve the efficiency of farming water use in Muooni Dam Catchment. The following sections present the sequential analytical steps of the HERAM conducted in Muooni Dam Catchment.

4. Hydro-economic risk assessment conducted in Kenya

This section presents the main findings from the HERAM conducted in Muooni Dam Catchment of Kenya. It consecutively outlines the problem formulation, the screening and scoping strategy, the exposure–response characterization, the risk quantification, the incremental analysis, and the strategy for mitigation of water disasters in farming.

4.1 Problem formulation

Muooni Dam Catchment is subject to demographic expansion, climate variability, and land-use changes occurring at a large scale. These socio-environmental changes are among key factors leading to soil erosion, the siltation and pollution of drainage channels and water storages, thus affecting water availability and soil fertility in various catchment areas. Pressures on water and soil contribute to the catchment degradation and increased cost of water and land in agriculture in most arid and semi-arid lands of Kenya. Food insecurity, energy disruption and poverty are corollaries of such increased stress of water and land in Muooni Dam Catchment. Therefore, what kind of anthropogenic and environmental factors affect efficient use of water and land by farmers in this catchment area? Is there a way to improve the efficiency of farming water use under fluctuating rainfall regimes?

4.2 Screening and scoping strategy

This study was based on risks associated to land-use activities going on in Muooni Dam Catchment. The key criterion for screening was the intensity of the hydro-geomorphologic risks assessed on farmlands and Muooni Dam. A scope of most significant risks was determined from their contribution to the degradation of Muooni Dam catchment. As presented in Table 2, the most significant land-use activities and their likely hydro-geomorphologic risks ranged from 1 to 6.

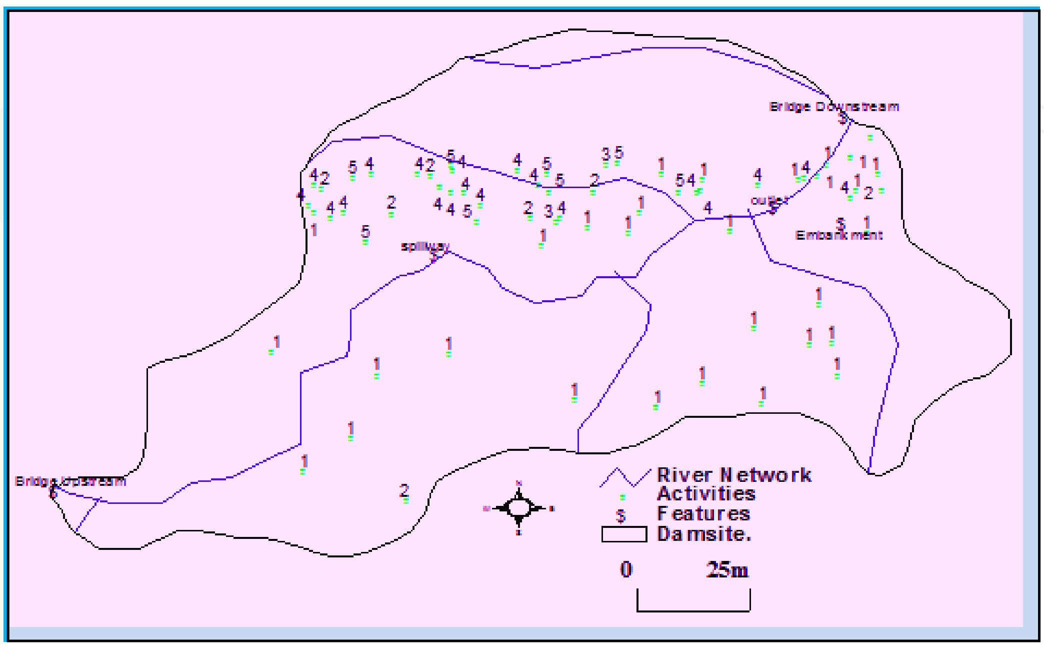
Weight	Land-use activity	Weight	Hydro-geomorphologic risk
1	Tree planting	1	Sheet/ rill erosion on farmland
2	Intensive cultivation using water pumps/ tanks	2	Encroachment on wetland
3	Subsistence cultivation with limited irrigation	3	Sand harvesting/ quarrying impacts on farmland
4	Subsistence cultivation 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

Table 2. Land-use and associated risks in Muooni Dam Catchment

This table points out that the catchment degradation was basically defined in terms of soil erosion problems leading to the sedimentation of the dam, and to excess water loss from the dam reservoir. Gonzalez et al. (1995) mapping technique was applied along with GIS spatial modelling to plot each land-use activity and its likely environmental risk. Figure 2 illustrates the distribution of land-use activities assessed on farmlands, while Figure 3 suggests a display of their associated risks. These figures emphasize the fact that agro-forestry and subsistence cultivation and their associated risks (sheets and rills as well as eucalyptus water over-abstraction) had very high significance in their occurrence in the catchment.

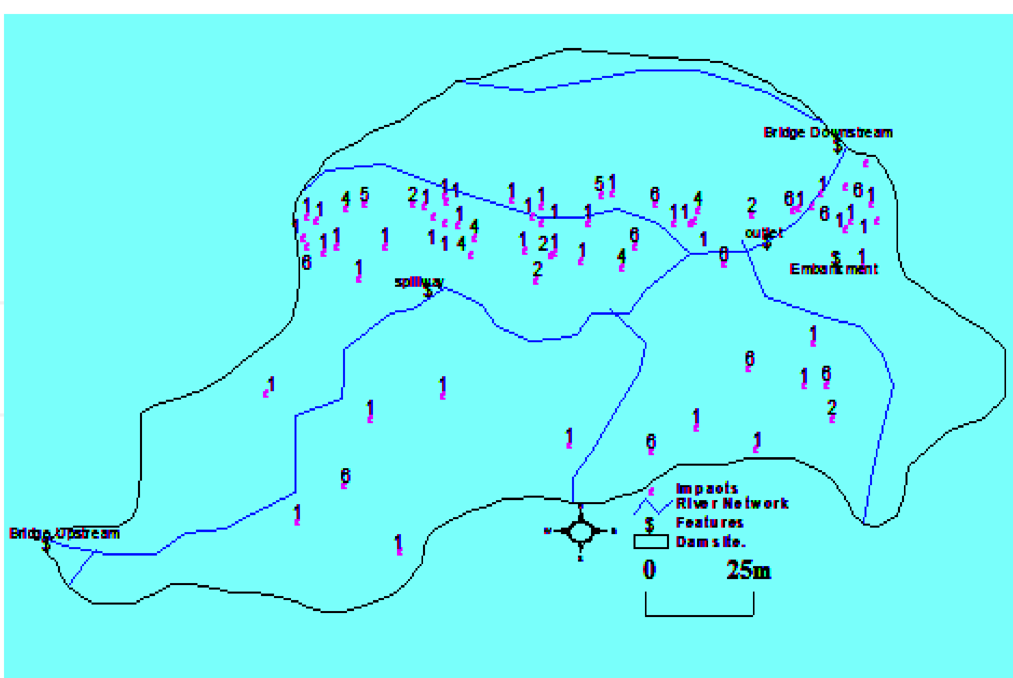
Following the depletion of the forest cover, they were propounded to be the key factors hindering water availability in drainage systems and the dam reservoir in Muooni Dam Catchment. These land-use activities and associated risks represented more than three fourths of the total farming area surveyed. Other land-use practices, though not significant, 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%). Their related hydro-geomorphologic risks were mainly gully erosion, landslides and encroachment of farms on wetlands, which accounted for 8%, 3%, and 8% of farms surveyed, respectively.

This assessment of hydro-geomorphologic risks also looked at environmental externalities affecting water availability and land fertility in Muooni Dam Catchment. Off-site effects of environmental changes on the catchment were highly significant in terms of soil erosion problems and water stress in the catchment. The significance of these environmental externalities was elucidated by the effects of El Niño rainfall and heavy wind pressure associated to the siltation of the dam and drainage channels, deforestation, floods, gully erosion, and landslides in the catchment. Table 3 summarizes these externalities and their associated risks.



Note: Numbers 1 to 6 refer to the weight of land-use activities found in Table 2.

Fig. 2. Spatial distribution of land-use activities in Muooni Dam Catchment



Note: Numbers 1 to 6 refer to the weight of hydro-geomorphologic risks found in Table 2.

Fig. 3. Spatial distribution of hydro-geomorphologic risks in Muooni Dam Catchment

Weight	externality	Weight	Hydro-geomorphologic risk
7	Heavy wind pressure	7	Siltation of dams & drainage systems
8	Heavy wind pressure	8	Deforestation
9	El Niño rainfall	9	Flooding
10	El Niño rainfall	10	Gully erosion in the catchment
11	El Niño rainfall	11	Landslides in the catchment
12	El Niño rainfall	12	Drought

Table 3. Environmental externalities and associated risks in Muooni Dam Catchment

It shall be noted that the rainfall regime in South-East Kenya is mainly dominated by two dry "monsoon" seasons and two rainy seasons associated with the movement of the ITCZ. The annual average rainfall fluctuates between 500 and 1,300 mm, with 66% of reliability, part of it coming from the trade effects of south-eastern winds blowing on slopes (Jaetzold et al., 2007). In such kind of environment, droughts and floods are likely to be recurrent due to the effects of "El Niño southern oscillation" (ENSO) (Shisanya, 1996).

4.3 Exposure–response characterization

The hydro-geomorphologic risk assessment conducted in Muooni Dam Catchment revealed a correlation between on-farm management, farmers' level of income and education, and environmental degradation. Most farmers seemed not to be aware of processes going on but complained about soil erosion problems, wetland degradation and farmland infertility. A majority among them got used to enhance their soil protection with terraces, contours, cut-off drains, polyculture and agro-forestry (Tiffen et al., 1994). Yet, eucalyptus and other fast growing alien trees remained the most dominant plant species in the catchment. Accelerated land degradation and acute water stress drove governmental agencies to implement some soil and water conservation measures in this area, especially during the dry season.

In effect, Muooni Dam Catchment area was formerly surrounded by Iveti forest. Demographic pressure, the expansion of farming areas and other economic activities contributed to the encroachment of the forest and to the destruction of more than 25% of its estimated coverage in 1987 (WRMA, 2008). Thence soil erosion, landslides and water over-abstraction by ecosystems, especially by eucalyptus trees planted in the wetlands, thwarted farmers' livelihood and the economic viability of their farming activities. Besides being intensively cultivated, farmlands had poor soils and soil moisture (Lal, 1993; Waswa, 2006). Due to the shortness of the rainy seasons, the fluctuations of rainfall affect efficient use of water and land in agriculture, especially in terms of crop water requirements and crop treatments. In such circumstances, farming incomes are likely to be insignificant, unless supplemented by off-farm incomes. The introduction of "marginal" crops with lower diurnal potential evapo-transpiration (mainly bean and maize species) has proved to be a salvation for farmers under extreme water stress conditions (Jaetzold et al., 2007). Unfortunately, chances for high yields and good incomes are ever reduced as soil moisture declines so quickly due to the smallness of farmlands and to prolonged droughts.

Consequently, farmers are constrained to adopt unsustainable farming strategies to cope with these poor yields and incomes during unpredictable droughts. Such strategic farming methods included excessive intercropping and multiple cropping of perennial indigenous and alien crop species on small farmlands. Yet, this could not hold their operational costs and losses significantly back. Water over-abstraction by eucalyptus and other alien trees along with off-site effects of El Niño flooding and drought accelerated the risk of soil erosion and water excess loss. Eucalyptus tree planting and subsistence cultivation with irrigation in Muooni Dam Catchment were limited to overland flow and encroached on wetlands. The natural vegetation in those wetlands has been substituted by exotic trees, crops and weeds. These interlopers generally exacerbate the vital functions of the whole ecosystem, owing to the fact that they are not water friendly (Jansky et al., 2005; Kitissou, 2004). Moreover, the practice of overland flow irrigation increases the rate of streamflow evaporation beyond 30% of the total water resource available (Shakya, 2001). Therefore, soils in farmlands are deprived of most of their resilience, fertility and moisture (Lal, 1993).

Potential rich soils are rare in most Kenyan ASALs, especially where shallow topsoil overlies a light soil. The impact of a raindrop, whether by through-fall or drip from raindrops intercepted by tree canopy, is a necessary and sufficient condition for soil erosion to occur in these areas. Thus, sheets and rills in Muooni Dam Catchment appeared in more than half of the fields surveyed. High rates were recorded in lands managed by full-time farmers and farmers employed in the private sector. The increase of runoff on the surface and the decrease of water infiltration in the soil were likely to cause an "overland flow" and generally resulted in pronounced channels known as "rills" and "inter-rills" (Soilerosion.net, 2007; Thompson & Scorging, 1995). Inter-rills were to become "gullies", when overflowing massive surface materials (cobbles, stones and grasses) were detached on hillsides during rainstorms and the infiltration capacity of the soil was exceeded. Mass movements were expected in some parts of the catchment, "when obliterated by weathering and ploughing" (Morgan, 1995). No doubt that any farmer, who had not been keen to clear sheets or rills, immediately after their occurrence, had to face acute soil erosion problems. That is why a majority among farmers wanted to cultivate near the riverbanks and other wetlands.

The combined effects of all these factors justify the changes observed in the microclimate of Muooni Dam Catchment through the variation of its temperatures and rainfall regimes. They might also explain the recurrence of droughts and the phenomenon of seasonal water courses in this catchment area. The latter nurtured colossal soil loss and sediment load in the drainage systems of Muooni River and its dam reservoir. This might have led to the decrease of Muooni Dam active water storage capacity. The following section analyzes the relation between land-use activities assessed and their associated risks, and between the risks and Muooni Dam active water storage capacity to establish that assertion.

4.4 Risk quantification

The estimate of the risk magnitude was done in three steps. First, the study sought to establish a cause-and-effect relationship between land-use activities assessed and their associated risks. Second, an estimate of the variations of Muooni Dam's active water storage capacity under the effects of risks identified was done to predict its trend. Lastly, the analysis estimated the magnitude of socio-economic impacts.

4.4.1 Land-use and associated impacts/ risks

The hydro-geomorphologic risk assessment 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 their likely impacts on farmlands were randomly drawn from independent populations (Table 4). These findings were reinforced by Spearman's rank correlation (Table 5).

No	*Decision Parameters*		*Decision*
1	U_1= 2,178	n_1= n_2=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 Ho (μ_1=μ_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	

Table 4. Results of Mann-Whitney U-Test

As displayed on Table 5, Spearman's rank correlation confirmed with 99.8% confidence level that there was no strong relationship between the two random samples analyzed. Land-use activities assessed in Muooni Dam Catchment and their likely impacts may have originated from diverse sources, within and outside the catchment. These two samples were behaving independently one from another. These hydro-geomorphologic impacts might have been the results of various risks hastening the degradation of the catchment area.

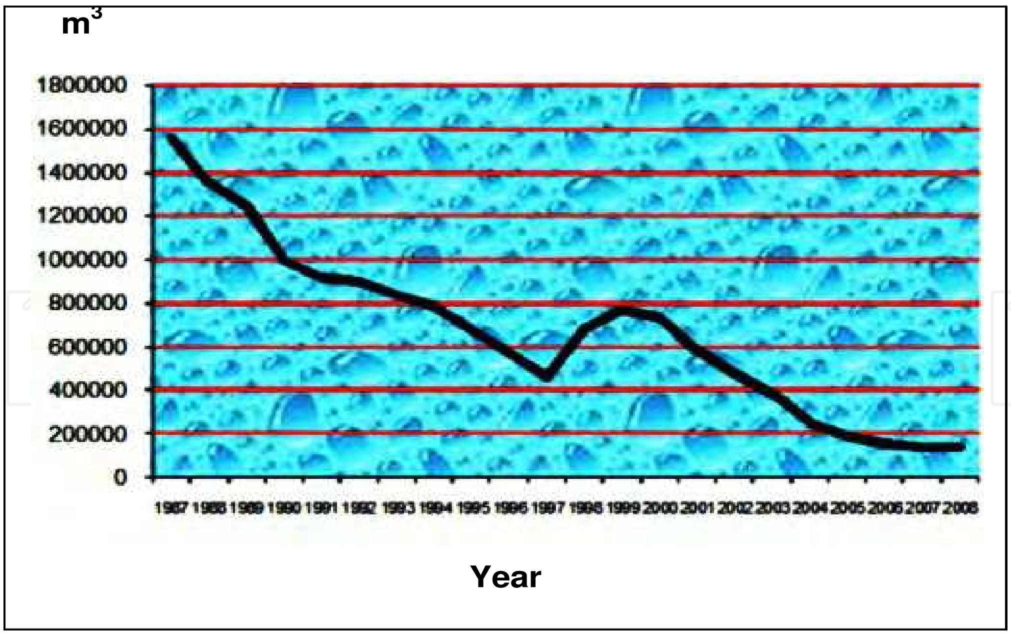
No	*Decision Parameters*		*Decision*
1	Σdi_2= 52,081.5	n= 66	There is a weak correlation between land-use activities and impacts assessed.
2	r_s = -0.08718	n= 66	
3	Z_u= -0.01081	n-1=65	Acceptance of Ho (ρ_s=0) stating that there is no significant relationship between the populations from which the two samples were drawn.
4	Z_ρ = -3.99	α =0.002	

Table 5. Results of the Spearman's rank correlation

The on-site effects of soil erosion and eucalyptus water over-abstraction may be explained by inadequate soil conservation measures used by farmers (Mutisya, 1997). Off-site effects of soil erosion and high water evaporation from the dam reservoir may be elucidated by the effects of global warming, El Niño floods and droughts, heavy wind pressures, footpaths and roadsides, sand harvesting , deforestation and others forces from outside farming activities. Both on-site and off-site risks were hindering water availability in drainage systems and the dam reservoir in Muooni Dam Catchment (Luwesi, 2009).

4.4.2 Prediction of Muooni Dam's active water storage capacity

After identifying the actual risks, the analysis proceeded to estimate the variations of Muooni dammed water and predict its trend. It revealed a decrease of the dam active water storage capacity, since its construction was completed in 1987 (Figure 4).



Note: Estimates from various data sources provided by key informants and WRMA (2008)

Fig. 4. Variability of Muooni Dam's active water storage capacity

It was believed by 97% of public officers and key informants interviewed that soil erosion and landslides were outwitting the Muooni Dam's active water storage capacity under the effects of El Niño floods and wind erosion. The decreasing water storage capacity of the dam was a fact of its siltation by farming activities going on around the dam site. An uplift has been observed in the years 1997-1998 due to the El Niño rainfall, which effects were prolonged until a new descent started in the year 2000. Statistical predictions from Table 6 and Figure 5 emphasize a continuous decreasing trend of the dam's water storage capacity in the near future.

Year	*Dam storage capacity (m^3)*
2009	222,190
2010	208,791
2011	196,200
2012	184,368
2013	173,250
2014	162,802
2015	152,984
2016	143,759
2017	135,089
2018	126,943
2019	119,287

Table 6. Prediction of Muooni Dam's active water storage capacity

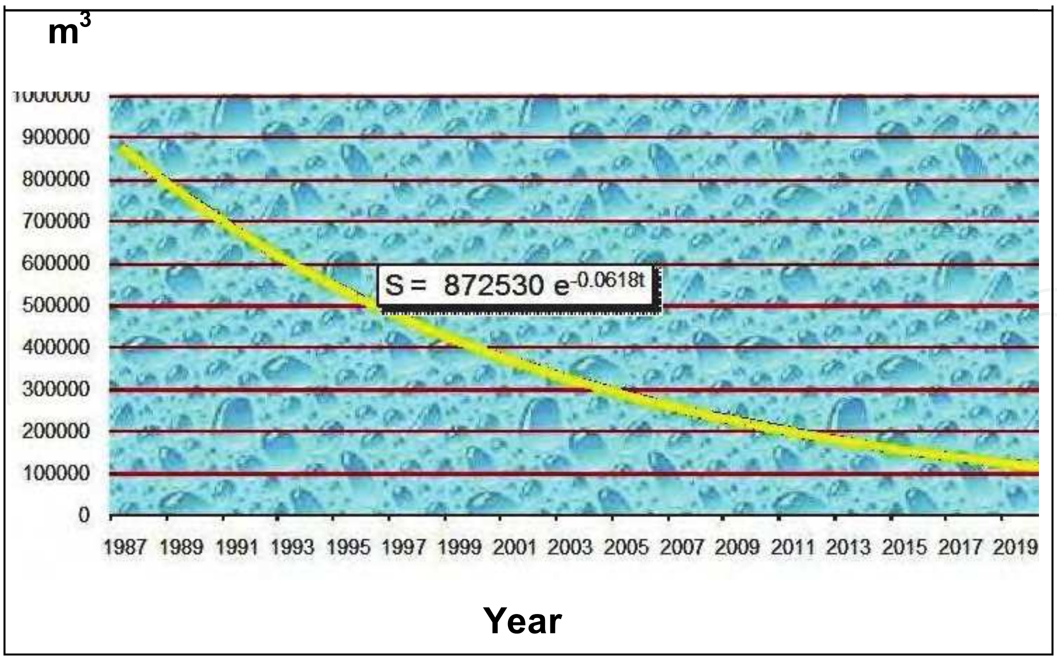


Fig. 5. Trendline of Muooni Dam's active water storage capacity

The maximum capacity of Muooni Dam reservoir that was established to 1,559,400 m^3 in 1987 has decreased to an estimate of 196,200 m^3 in the year 2011. It will go under its threshold by the year 2019, storing less than 119,400 m^3. The analysis also established an annual decreasing rate of 6.2% of the dam's active water storage capacity (Table 7).

Model (St)	*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				

Table 7. Significance of Muooni Dam's storage capacity trendline

This table shows that the annual mean water storage capacity was 671,874 m^3 with a standard error (*SE*) of 316,576 m^3 and an error term (*ET*) of 173,400 m^3. The fact that the deviations around the mean (*SE* and *ET*) are far less significant than the sample mean attests that the model is viable for further predictions. The correlation coefficient (r) and the coefficient of determination (R^2) also testify that the regression model is sufficiently strong to explain the variations of the dam's active water storage capacity (S_t) by the time (t). In fact, the correlation coefficient shows that 81% of the variations of the active water storage capacity of Muooni Dam reflect its old age. The fluctuations of the dam's active water storage capacity have thence the same bearing as the depreciation of its reservoir infrastructure. The coefficient of determination confirms this result by attributing 65.7% of the total variation of the dam's active storage capacity to its logistics obsolescence. Spearman's Rho test certifies these assertions (Table 8).

Statistical Parameters		*Decision*
1. r = 0.81	α = 0.005	There is a strong correlation between S and t
2. S_r = 0.134	n-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): S is explained by t. So, the decreasing trend of the dam's storage capacity is related to its logistics old age.

Table 8. Results of the Spearman's Rho test

This table highlights the fact that the prediction model was sufficiently strong to explain the decreasing trend of Muooni Dam's active water storage capacity by its logistics old age. It reveals with 99.5% confidence level and 20 degrees of freedom that 81% of the variations of the dam's active water storage capacity were reflected in the changes of its infrastructure resistance over years. However, only 65.7% of its total variation could be explained by the dam's logistics old-age. The decreasing active water storage capacity of Muooni Dam might 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 its logistics obsolescence. This proportion of the total variation of Muooni dam's active storage capacity might be due to the hydro-geomorphologic risks identified earlier, and which were degrading the dam's catchment area. Both the dam's logistics obsolescence and hydro-geomorphologic risks associated to land-use activities and environmental externalities were threatening the social welfare and economic stability of farmers, as demonstrated in the following subsection.

4.4.3 Magnitude of social and economic impacts

The decrescendo of Muooni dam's active storage capacity may have severed smallholder farming water security, and farmers' yields and incomes. Due to excess water costs, it could therefore not be surprising to see farmers using water inefficiently. These inefficient practices thwarted the economic viability of farmers'activities and led to poverty. Farmers' poverty in this area was likely due to an accumulation of losses over years, and as a result of water stress and lack of potential agricultural lands (Table 9).

This table 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. The Social impact assessment (SIA) confirmed that poverty was a reality in the study area. The distribution of farmers by level of income 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. Hence, the study needed to assess the variations of actual farmers' water costs in Muooni Dam Catchment vis-à-vis the optimum levels of farming water (EOQ, LAC and MES) to establish their efficiency under fluctuating rainfall regimes.

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/m³***	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 /m³	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/m³	-28.1725	-0.701	-7.1502

Note: KES stands for Kenya Shillings

Table 9. Farmers' annual income and expenses distribution

4.5 Incremental analysis

Results of the "Economic inventory" (EI) show that increased shortage costs of farming water and the cost of fertile soil excess loss constrained farmers to order less farming water (W_f) than required by their crops (W_c). 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 6). In such conditions, operational costs of farming water soared by 175%, 518% and 1,420% of the actual total costs under the ANOR, NOR and BNOR scenarios, respectively (Figure 7). This underscored a progressive accumulation of farming losses by a majority of farmers over years.

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 the ANOR rainfall regime. Their unit cost per m³ 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.

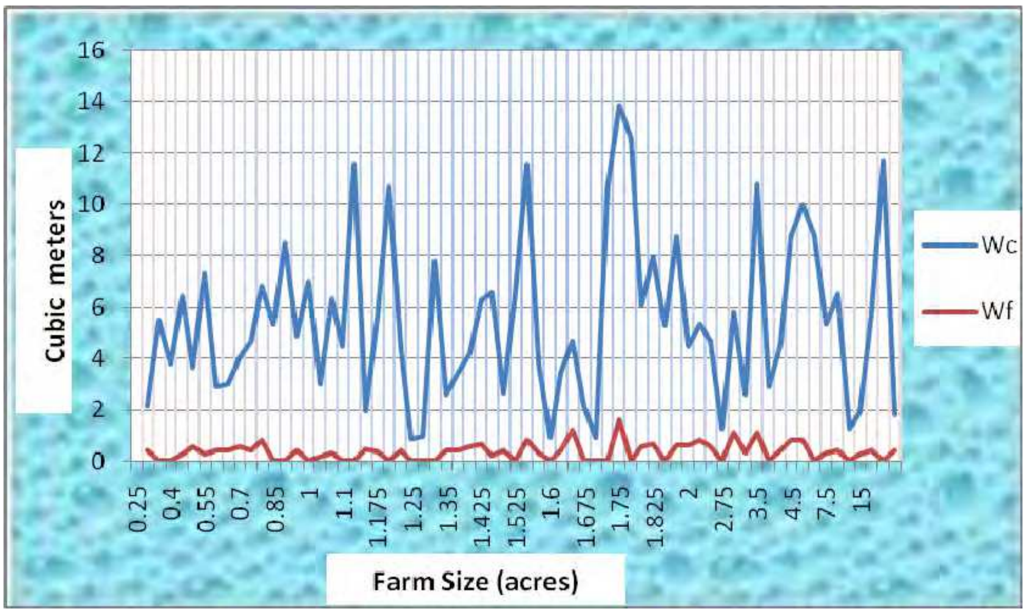


Fig. 6. Farmers' water demand and crop water requirements

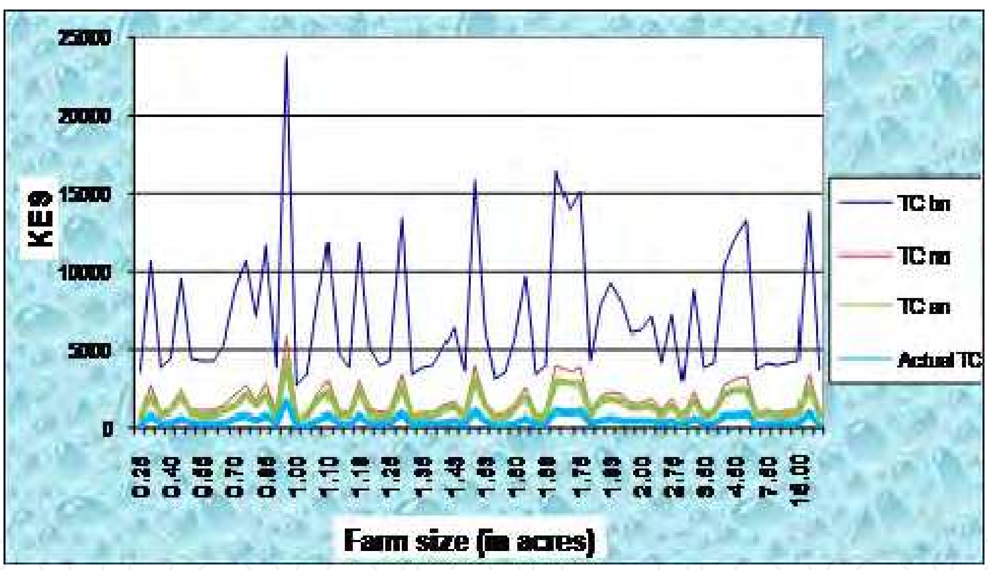


Fig. 7. Farming water costs under fluctuating rainfall regimes

From 2004 to date the loss of farming profitability under the NOR scenario is the most important economic incentive that leads farmers to subdivide their lands. Their average costs having become significantly high, older farmers have to limit their farming water costs to a "Limit average cost" (LAC) of KES 444, 415 and 361 for LSF, MSF and SSF, respectively. Many farmers have adopted inadequate practices such as eucalyptus tree planting , leasing or even sale of part of their farmlands to new comers in order to limit their farming water costs. Others have left their farmlands under fallow for several years.

By the year 2019, when the active water storage capacity of Muooni Dam will have gone under its threshold, a majority will be obliged to abandon their farming activities and adopt off-farm activities. Some will even embrace small-scale businesses, or jobs in the private and public sectors. The "survivors" will 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 will be able to secure more water than their actual water demand (Actual W_f) and crop water requirements (W_c) (Figure 8). This will allow them mitigate the high risk of crop failures under fluctuating rainfall regimes, particularly under drought.
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 ANOR rainfall regime (EOQ), NOR rainfall regime (LAC) and BNOR rainfall regime (MES), respectively. By so doing, they would expect a fall of their farming water costs up to 36%, 78% and 232% under the three respective scenarios. Such optimization of their farming water demand would result in a decrease of their operational average costs by a range of 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.

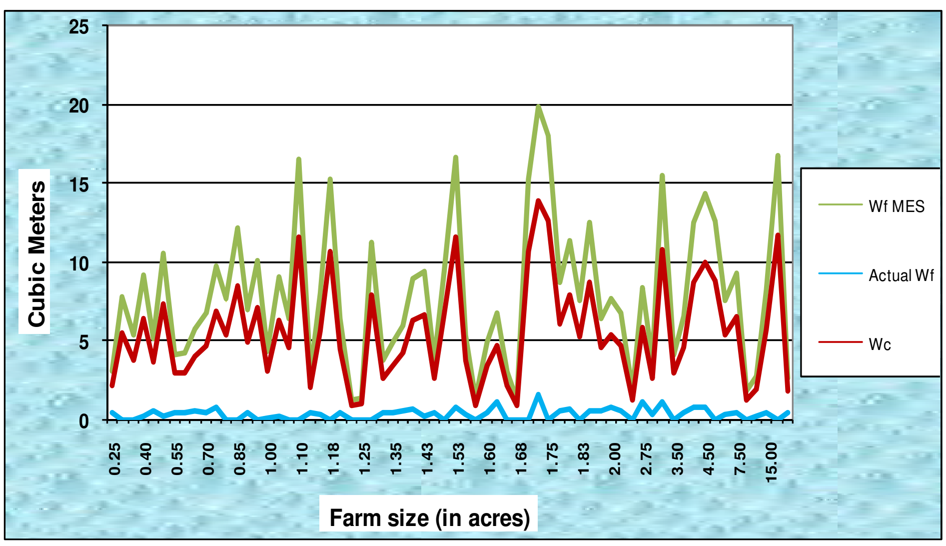


Fig. 8. Minimum farming water demand under rainfall fluctuations

There is not yet a 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 can 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. Therefore, how would farmers ensure the sustainability of their farming efficiency in view of such disasters? The following subsection presents the strategy that farmers need to apply in order to mitigate the high risk of crop failures due to water disasters in the course of climate change.

4.6 Strategy for water disasters mitigation in farming

"Water crises are not about too little water but about managing water badly such that billions of people and the environment suffer badly"(Water Vision, 2000, as cited in Mati, 2006). To curve the trend of water stress and scarcity, the Government of Kenya set a major goal of implementing an "Integrated Watershed Management" (IWM). The overall implementation of IWM includes the creation of "Water resource users' associations" (WRUAs) in all the catchments to ensure that the "Water resources management authority" (WRMA) implements the new water policy in consultation with the public (GWP, 2000; UNDP, 2007). Talking about such implementation of IWM in Kenya, Förch et al. (2008) suggest that the government speeds up the process by enforcing 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, Ellis (1993) firmly encouraged farmers to make some tradeoffs between on-farm and off-farm income-generating activities, if efficiency was to achieve. This meant that they could adopt off-farm activities if their farming water opportunity costs were higher than elsewhere. They would thus avoid running deficient farming enterprises.

Finally, the incremental analysis showed that farmers' efficiency was tied to the adjustment of their crop water requirements with the level of soil moisture. If they could specialize to less than three water friendly crop species for instance, they would improve their productivity (GoK, 2007). Yet, they have also to minimize their farming water costs by using other effective agronomic technologies and efficient on-farm management techniques such as rational crop treatments and selection, and application of improved farming inputs (fertilizers, pesticides, fungicides, and rodenticides). Finally, making good use of hydro-political strategies in the context of "Integrated Watershed Management" (IWM) will also help them. These include water consumption metering, evapo-transpiration quotas allocation, green water saving and rainwater harvesting, payment for watershed services, virtual water import and etc.

5. Conclusion

Traditional soil conservation methods having become rudimentary to control climate change related risks, the Kenyan government needs to support programmes dealing with disaster mitigation and adaptation to climate change. This involves making new adaptation policies and direct investments in water projects, including strategic action plans for dredging dams and irrigation schemes, and designing early warning systems for preparedness to ENSO, among others. But prior to implementation of such policies and schemes, the government needs to conduct a serious risk assessment that encompasses both environmental and socio-economic risks. This study offered a novel approach for achieving sustainability in a watershed and mitigating recurrent water shortages in farming. This hydro-economic risk assessment and management would assist the government to foster the implementation of "Integrated watershed management" (IWM) in different catchments of the country. This would curve the trend of food shortages and energy crises in ASALs. The government shall also encourage public-private partnerships through institutional linkages between the "Water resources management authority" (WRMA), the "Water services providers" (WSP), the "Water resource users' associations" (WRUA) and associations of farmers (Cooperatives, Mutuals, NGOs, CBOs, etc). Thence, the government's task will become easier, as farmers strive to improve their farming efficiency in the course of climate change using efficient hydro-political strategies, and innovative agronomic technologies.

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The term "risk" is very often associated with negative meanings. However, in most cases, many opportunities can present themselves to deal with the events and to develop new solutions which can convert a possible danger to an unforeseen, positive event. This book is a structured collection of papers dealing with the subject and stressing the importance of a relevant issue such as risk management. The aim is to present the problem in various fields of application of risk management theories, highlighting the approaches which can be found in literature.

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