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Why Green Water Saving is not Fully Rewarded by Farmers in Mount Kenya Region

A research frontier of pure: applied sciences and engineering

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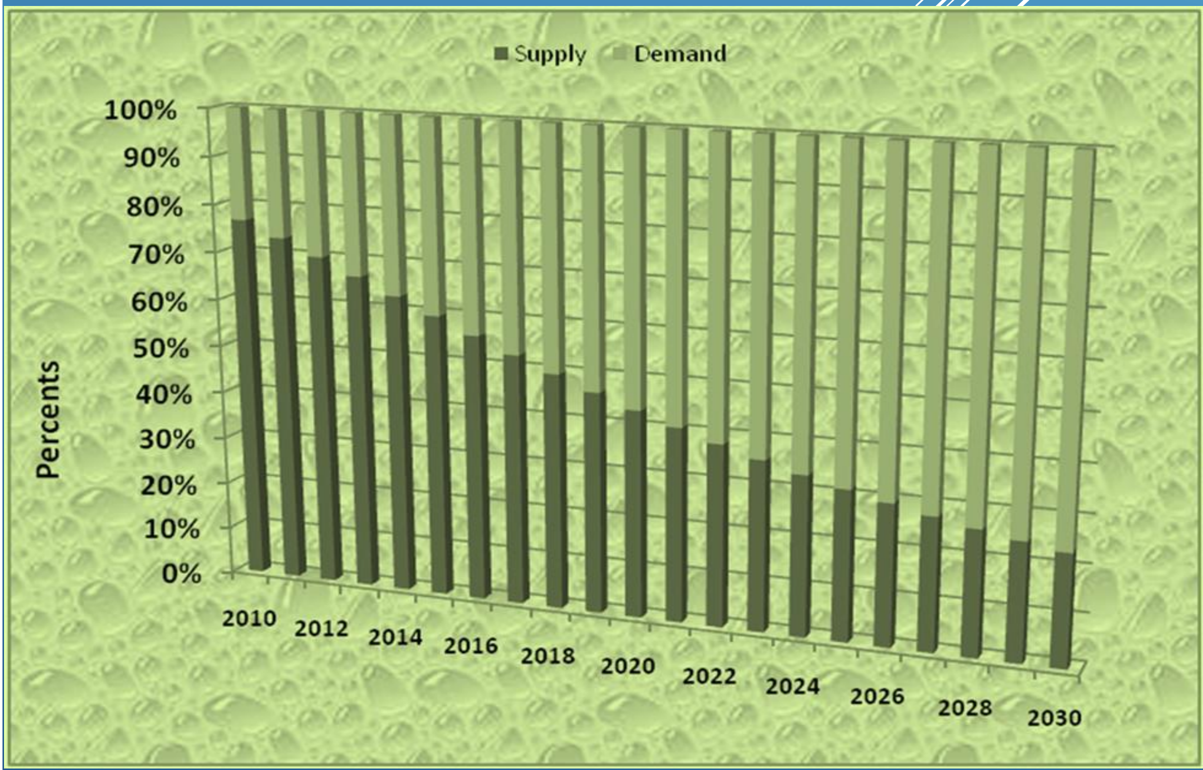

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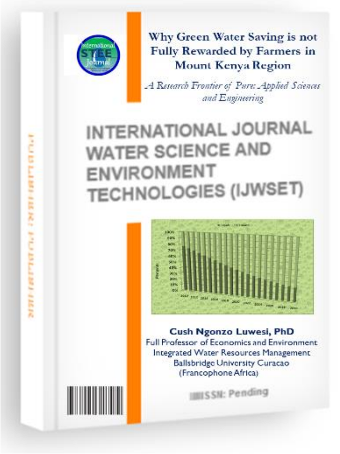

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Acronyms and Abbreviations

ANOR: Above Normal Rainfall Regime
ASALs: Arid and Semi-Arid Lands
ASAT: Arid and Semi-Arid Tropic
BNOR: Below Normal Rainfall Regime
BOL : Build Operate and Lend
BOS : Build Operate and Sell
BOT : Build Operate and Transfer
BWS: Blue Water Supply
CCDP: Climate Change for Development Professionals (See WBICC)
CDM: Clean Development Mechanism
CFA: Cooperative Framework Agreement (see NBI)
CIS: Climate Information System
EOQ: Economic Order Quantity
ETQ: Evapo-Transpiration Quotas
FGDs: Focus Group Discussions
GEF: General Environment Facility
GIS: Geographic Information System
GPS: Geographic Positioning System
GoK: Government of Kenya
GWC: Green Water Credits
GWS: Green Water Saving
IDRC: International Development Research Center
IFRC: International Federation of the Red Cross and Red Crescent
IPCC: Intergovernmental Panel on Climate Change
IWM: Integrated Watershed Management
IWMI: International Water Management Institute
KES: Kenya Shilling Currency
KMD: Kenya Meteorological Department
LAC: Limit Average Cost
MES: Minimum Efficient Scale
MWI: Ministry of Water and Irrigation
NBI: Nile Basin Initiative
NOR: Normal Rainfall Regime
PES: Payments for Environmental Services
PESTLE: Political, Economic, Social, Technical, Legal and Environmental Analysis
PWS: Payments for Watershed Services
REDD: Reducing Emissions from Deforestation and Degradation
SWC: Soil and Water Conservation
SWOT: Strengths, Weaknesses, Opportunities and Threats
UNDP: United Nations Development Program
UNEP: United Nations Environment Program
USAID: United States Agency for International Development
VCA: Vulnerability Capacity Assessment
VCA+: Vulnerability Capability Assessment
WBG: World Bank Group
WBICC: World Bank Institute Climate Change Unit
WRI: World Resource Institute
WRUA: Water Resource Users' Association
WRMA: Water Resources Management Authority

Operational Definition of Key Concepts

Green Water: "the water held in the soil. It is the largest fresh water resource, but it can only be used in situ, by plants" (Falkenmark and Rockström 2004).

Green Water Management: Entails strategically blended nature-based mechanisms, including Soil and Water Conservation (SWC) hydro-policies and "Payment for Environmental Services" (PES) (Shisanya, Luwesi and Obando 2014).

Payment for Environmental Services" (PES) scheme: "a voluntary transaction in which a well-defined environmental service (ES), or a form of land use likely to secure that service is bought by at least one ES buyer from a minimum of one ES provider if and only if the provider continues to supply that service (conditionality)" (Wunder 2005). When a PES scheme is implemented within the limits of a catchment area, it is usually called "Payment for Watershed Services (PWS) scheme (Luwesi, Shisanya and Obando 2012; Ortega-Pacheco, Lupi and Kaplowitz 2009).

Soil and Water Conservation (SWC): these are engineering and agronomic measures used to control soil erosion and preserve water resources within a catchment area.

Hydro-policies: are set of strategic and regulatory instruments used in Integrated Water Resource Management (IWRM) (Beyene and Luwesi, 2018)

Integrated Water Resource Management (IWRM): "IWRM is a process which promotes the coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems" (GWP 2015).

Climate Change: climate change is a statistically significant variation in either the mean state of temperature precipitations and other climatic variables or their variability, persisting for an extended period (typically decades or longer) due to natural internal processes or to persistent anthropogenic changes in the composition of the atmosphere or in land use (Harris et al. 2017; IPCC 2014).

Agriculture Adaptation to Climate Change: include both crop/ plant drought resistance and acclimatation. The ability of a crop to grow satisfactorily in areas subjected to water deficits has been termed as *drought resistance*, whereas *acclimatation* involves the ability of a plant to slowly adapt to a new environmental condition, namely flood, drought and dry spell (Arnon 1992).

Crop water requirement: is the total evapo-transpiration of a crop from the sowing to the harvest

Farmer's water demand: is the market value of water actually bought by the farmer for its agricultural activity

Economic Order Quantity (EOQ): is the optimum water supply or demand to be achieved under hypothesized "Above Normal" (ANOR) rainfall regime.

Limit Average Cost (LAC): is the optimum water supply or demand to be achieved under hypothesized "Normal" (NOR) rainfall regime.

Minimum Efficient Scale (MES): is the optimum water supply or demand to be achieved under hypothesized "Below Normal" (BNOR) rainfall regime.

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Executive Summary
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Executive Summary

1 Introduction

The agricultural production in most tropical arid and semi-arid lands (ASALs) is being significantly affected by the changing weather patterns, possibly due human induced activities and other anthropogenic factors. In most African ASALs, rain-fed agriculture has become highly vulnerable to climate change, owing to the depletion of "green water" under the effect of deforestation. This "green water", which represents the two thirds (2/3) of the total amount of fresh water resources, is in fact the soil moisture generated and held in the soil by plants for their own use. The remaining one-tenth (1/3) of all fresh water resources is actually tapped from rivers, streams and groundwater is referred to as "blue water".

To increase agriculture resilience to climate change scientists have suggested communities to put on strenuous efforts for accrue investments in Green Water Saving (GWS) in ASALs to increase the accessible blue water in streams and lakes as well as groundwater by 50% and above. They have since explored different types of GWS technologies ranging from Soil and Water Conservation (SWC) measures to hydro-policies. "Green Water Saving" (GWS) schemes constitute such kind of innovative SWC and hydro-policies being experimented in many ASALs around the globe within the framework of Water Resource Users' Associations (WRUAs). They are strategic mechanisms aiming at the conservation of green water resources within the upper sub-catchment area under the stewardship a Water Resource Users' Association (WRUA). They involve the co-operation of both upstream and downstream stakeholders, upstream farmers being "GWS services' sellers" and their downstream counterparts being "GWS services' buyers". Henceforth, GWS schemes are "pro-poor" schemes initiated at the lowest level of environmental management by local stakeholders. They deal with "Payment for Environmental Services" (PES) by "rich" farmers to "poor" ones in order to foster a green revolution in ASALs through usage of SWC measures and hydro-political strategies (Ortega-Pacheco, Lupi and Kaplowitz 2009). Managing "green water" enhances rainwater infiltration into the soil and groundwater reserves thus resulting in increased water tables and thus surface runoff. They address the ever widening gap between water demand and supply, and ensure agriculture resilience to climate change in most ASALs.
Even though these schemes have been successfully tested in some countries, many watershed managers do neither recognize their performance nor reward their outcomes in Africa in general, and Kenya in particular. There are also quite a few researches on rainwater saving and surface water partitioning with the aim of reducing unproductive evapo-transpiration and thus increasing infiltration and soil moisture to ensure agricultural water efficiency in Africa. Yet, such studies are needed to enhance agriculture resilience in the course of climate change in Africa in general, and Kenya in particular.

Based on the above background, this study assessed agricultural water vulnerability to climate change and farmers' capability to implement GWS schemes in Arid and Semi-Arid Lands (ASALs) of Kenya. It sought specifically to: (i) analyze factors leading to farmers' vulnerability to drought and flood in Ngusishi and Muooni catchments; (ii) assess innovative strategies put in place by farmers to mitigate water stress and sustaining their livelihoods; (iii) evaluate the effectiveness of GWS schemes with regard to the use and management of agricultural water in the selected catchment areas; and (iv) determine the efficiency and ability of GWS schemes to ensure cost recovery in the selected catchments under conditions of droughts and floods. The achievement of these four objectives gave insight on the sustainability of agricultural water in Kenyan ASALs by shedding light on in terms of their biophysical need (Objective 1), their social acceptability (Objective 2 and 3), and their economic viability (Objective 4) of GWS schemes being particularly implemented in Ngusishi and Muooni catchments of Kenya.

2 Methodological Approaches of the Study

The research encompassed an on-farm survey involving 66 and 106 farmers from Ngusishi and Muooni catchments, respectively as well as 15 in-depth interviews in each catchment, one Focus Group Discussion (FGD) in each catchment, and hydro-geomorphologic field surveys. The latter dealt with river discharge and soil moisture measurements *in situ* using *Hydrometrie* current meter and *ThetaProbeML2x* Moisture meter, respectively. The river discharge was computed from estimates of velocity, length and depth of 6 cross-sections of the rivers under study, while the soil moisture was automatically measured by the machine from 30 soil points in each catchment. Besides the above on-farm survey, in-depth interviews, FGDs and field researches, data collection also encompassed large sets of secondary data on rainfall, temperature and discharge, as well as an extensive literature review.

To determine factors leading to farmers' vulnerability to water disasters (Objective 1) the analysis encompassed: (i) The assessment of Land-Use/ Land-Cover Change (LULC) based on satellite imagery's Ground Control Point (GCP) technique; (ii) Hydro-climatic forecast of the variations in rainfall, temperature and discharge using Seasonal Auto Regressive Integrated Moving Averages (SARIMA) and Predicted Probability plots (PP plots); (iii) The prediction of water balance in each catchment using the Water Evaluation And Planning (WEAP) model; and (iv) the quantification of risks and vulnerability rates. The assessment of innovative water saving strategies (Objective 2) was mainly based on descriptive statistics and qualitative methods of pattern analysis. To evaluate the effectiveness and efficiency of GWS schemes put in place by farmers (Objective 3) the study first analyzed the Strengths, Weaknesses, Opportunities and Threats (SWOT) catchment management institutions prior to calculating farmers' capability and to rating water institutions' performance via Performance Management Rating (PMR). Finally, hydro-economic Cost Efficiency Inventory (CEI) and BCR financial mathematical models were utilised to determine GWS schemes' efficiency and cost recovery ability in comparison with Blue Water Supply (BWS) projects (Objective 4).

3 Findings of The Study

3.1 Factors leading to farmers' vulnerability to water disasters (Objective 1)

Results of the Vulnerability-Capability Assessment (VCA) indicate that farmers in general were more vulnerable to drought than flood. This was mostly explained by land-use activities that were inconsistent with SWC, thus leading to subsequent environmental changes. The latter were said to be linked to some extent to the global warming, sea surface temperature rise, ocean currents, and atmospheric winds in the southern hemisphere, commonly known as El Niño flood and La Niña drought.

The forecast of expected mean temperatures for Ngusishi catchment reveal increases of 1.6^{0}C in a century (R^2 = 0.84), which will be accompanied by increased annual rainfall of about 15 mm per century, and decreased river discharge of 0.18% downstream (R^2 = 0.835). Muooni catchment in turn will experience an increase of about 1.0^{0}C of mean temperatures per century (R^2 = 0.863) with subsequent decreases in mean rainfall of about 10 mm per century (R^2 = 0.877) and decreased river discharge of 1.2% downstream (R^2 = 0.667).

The assessment of Land-Use/ Land Cover Change (LULC) clearly emphasized a drastic depletion of natural vegetations, shrubland, grassland and riverine vegetation of about 62% in Ngusishi catchment (from 2,324.83 hectares in 1976 to 883.7 hectares in 2007), whereas the analysis of satellite images for a similar period revealed a re-greening of Muooni catchment of about 19.4% (from 1,191.65 hectares in 1976 to 1,422.99 hectares in 2010). The latter was mainly explained by the effects of agro-forestry within what seemed to be like a "natural forest" (though man-made) from that vantage view.

Results of the prediction of the total water balance in 2010 show a deficit of 27,760.59 m^3 /day in Ngusishi catchment, the upper sub-catchment recording 25,442.59 m^3 deficit /day, and the lower one 2,318 m^3 deficit/day. In contrast, water balance in Muooni catchment resulted into a surplus of +1,007.14 m^3 /day, upstream farmers recording unmet demands of 2,165.24 m^3 /day while their downstream counterparts enjoyed a surplus of 3,172.38 m^3 /day. In fact, the hydrological survey conducted in Muooni catchment shows that more than 66% of the total daily water demand (of 3,008.06 m^3) for domestic and institutional use is abstracted by water projects operating therein. Schools, health centres and local industries were contented with about 15.3%, 5.8% and 12.6%, respectively. Daily water consumption by livestock was estimated to 425.34 m^3 upstream and 519.86 m^3 downstream, goats and cattle consuming about 70% of the total demand. Finally, daily water demand for irrigation averaged 26,752.47 m^3, upstream and downstream farmers requiring 38.4% and 60.6% of the catchment's irrigation water demand, respectively, in the year 2010. In total, upstream farmers needed 10,272.95 m^3/day while downstream ones required 16,479.52 m^3/day.

Concerning Ngusishi catchment, the total household water demand amounted to 2,260.15 m^3/day. Ngusishi Water Resource Users' Association was abstracting 2,201.65 m^3/day, while the remaining 2.6% was allocated to health centres (1.4%) and mini factories (1.2%). Finally, the computed water demand for agriculture averaged 1,232,521.3 m^3 /month, upstream farmers abstracting about 79.3% and downstream ones 20.7%. In total, water demands upstream and downstream represented 32,579.645.7 and 8,504.4 m^3 /day, respectively. Water demand by mini bakeries amounted to 1 m^3/day while restaurants and hotels ordered about 25 m^3 /day, thus making a total of 26 m³ /day. Water demand for livestock was estimated to 29,252 and 35,752 m³ in 2010 for upstream and downstream, respectively. If an environmental Flow Reserve (EFR) of 30% was to be enforced, both catchments would have recorded total deficits in the year 2010. Likewise, none of them is expected to sustain a surplus by the year 2030 and in the long run.

3.2 Assessing innovative water saving strategies (Objective 2)

This study revealed that the two selected catchments displayed a high rate of dependence on surface water resources. Yet, predicted blue water balances for the 2011-2030 period revealed high rates of unmet water demands over years, owing to drought intensity and high water abstraction upstream (for Ngusishi) and downstream (for Muooni). Local stakeholders have thus embraced innovative water saving strategies ranging from traditional Soil and Water Conservation (SWC) measures to modern hydro-policies and technologies. If Muooni stakeholders were lauded for their adherence to SWC measures, Ngusishi farmers have performed in building a strong institution for water resource management, the Ngisishi Water Resource Users' Association (NWRUA). The latter does not only co-ordinate water supply and demand, but also fosters the implementation of GWS schemes in the catchment. Another example of innovative water development in ASALs was given by an automated borehole project activated by mobile phone technology. It was implemented in a catchment neighbouring upstream Muooni (Musingini) by the Danish Pump maker Grundfos Lifelink and the Kenyan mobile operator Safaricom. The implementation of such innovative schemes required a high "Willingness To Pay" (WTP) for GWS services by downstream farmers and a fair "Willingness To Accept compensation" (WTA) for GWS services by upstream farmers. About 46.2% farmers living upstream Ngusishi catchment and 20.6% downstream farmers revealed having been involved in a GWS scheme. Such kind of mechanisms encompassed: (1) the award Green Water Credits (2.4%); (2) cash payments by rich farmers to poor ones for environmental services (24.4%); (3) the donation of clean water by rich farmers to poor ones in time of drought for the sake of environmental conservation (24.4%); (5) the allocation of farming water quantity to all farmers with possibility for one's selling his/her share (24.4%); and (6) the offering of employment for environmental conservation by the State or a large scale farmer (24.4%). Though Muooni farmers were not linked by any GWS scheme's agreement, they demonstrated both their Intention To Pay (ITP) and Intention To Accept compensation (ITP) for GWS scheme. In effect, 25% of farmers upstream and 22.8% downstream have already heard about a specific type of GWS schemes. These farmers wished to implement nine (9) major schemes, namely: (1) Green Water Credits (1%); (2) cash payments by rich farmers to poor ones for environmental services (18%); (3) the transfer by rich farmers of part of their harvest to poor ones for environmental services (5%); (4) the donation of foodstuffs in time of famine by rich farmers to poor ones for environmental services (6%); (5) the donation of clean water in time of drought by rich ones to poor ones for environmental services (17%); (6) the allocation of farming water quantity to all farmers with possibility for one's selling his/her share (24%); (7) employment for environmental conservation by the State or large scale farmers (22%); (8) the transfer of management of a public fund to a private business for watershed conservation (6%); and (9) the leasing of public land for environmental conservation (1%). Nevertheless, Muooni farmers need strong institutional frameworks for managing the whole catchment and increasing their capability to curb the effects of flooding and drought in their catchment.

3.3 Evaluating the effectiveness of GWS schemes (Objective 3)

These decreasing trends in the water balance were associated with high water abstraction patterns and high rates of vulnerability to drought estimated to 53.3% in Ngusishi catchment (against 4.3% of vulnerability to flood), and 97.4% in Muooni catchment (compared to 2.7% of vulnerability to flood). This farmers' vulnerability to drought in Ngusishi catchment was mostly due to the collapse of the available ecosystem under severe drought (94 %), while a fair socio-political impact (54%) and a minor economic impact were (21.9%). Likewise, the bio-physiscal, socio-political and economic impacts of drought in Muooni catchment were rated severe (95 %), major (85%) and fair (51.2%), respectively.

In such conditions, GWS schemes must have been bio-physically needed and their implementation feasible. However, their social acceptability would have depended on their good performance. This was the case for Ngusishi catchment, which overall effectiveness of GWS schemes was rated "good" (76%). These schemes were found effectively "good" for addressing challenges related to high storm intensity or flooding (61.6% capability index and 4.3% vulnerability index). They were said to be "fairly poor" in curbing warming effects resulting from minimum temperatures' increase (29% capability index and 22.4% vulnerability index) and "poor" in addressing drought effects arising from decreased river discharges and soil moisture (24.2% capability index and 53.3% vulnerability index) in Ngusishi catchment. However, the overall effectiveness of GWS schemes in Muooni catchment was rated "fairly good" (54.4%). Their capability ranged from "poor" to "good", owing to the effect of drought on river discharge and soil moisture decrease (2.2% capability index and 97.4% vulnerability index), to the warming effect of increased minimum temperatures (2.7% capability index and 72.4% vulnerability index) and to storm intensity (78.4% capability index and 2.7% vulnerability index) in Muooni catchment. The performance of these GWS schemes in both drought stricken catchment areas was yet not truly felt on the ground. This was due to limited natural, social and economic resources vis-à-vis the high intensity of drought hazards, which are often exacerbated by El Niño and La Niña cycles in both catchments. In such context, increased social networking may increase poor capability to compensate the collapse of its bio-physical systems and economic loss. This will enable a smooth running of GWS schemes in the catchment, particularly in Muooni catchment.

3.4 Efficiency and Cost Recovery of GWS Schemes (Objective 4)

GWS schemes were specifically found to be efficient and economically beneficial under Above Normal (ANOR) rainfall regime rather than conditions of drought, and Blue Water Supply (BWS) projects were just the opposite. In effect, Ngusishi catchment presented a case of subsidized blue water supply, with the price of a cubic meter stabilizing around US$ 0.01 the cubic meter (that is less than KES 1 /m^3) from 2010 to 2030 for annual growth rates of demand and supply of +4.5% and -4.2% for, respectively, under ANOR. Revenues would rather decrease than increase at annual rates of 4% owing to subsided supply and stabilization of sale prices at Hence, losses incurred under the ANOR scenario would likely be attributed to the subsidization of prices, while the catchment would be facing enormous daily unmet demands of 12,425 m^3 in 2030. Under the NOR scenario, Ngusishi farmers will have to contend with unmet demands of about 86,000 m^3 /day in 2030 and average prices ranging from US$ 0.07 /m^3 (in 2010) to US$ 0.08 /m^3 (in 2030). This situation will worsen under the BNOR scenario when the unmet demands will count for 98,234 m^3 /day in the year 2030. Under such conditions, GWS schemes will need to increase their technical and allocative efficiencies to save more excess water during the ANOR rainfall regime (flood) to supplement water deficits under the NOR (normal) and BNOR (drought) rainfall regimes at a fair price.

Surprisingly, such efficiency was partly achieved by BWS projects operating in Muooni catchment, which recorded high technical efficiencies of 277.3% and 100% under the ANOR and BNOR scenarios, respectively in the year 2030. Though burdensome for farmers, these water businesses were charging an average water cost of ten (10) to fifty (50) times higher than Ngusishi under normal and drought conditions, and sometimes under overflow. They were expected to make as high gross profits as US$ 2,191.73 /day in 2030 under the ANOR scenario, demand, increasing quickly than supply by 2.75% in the year 2035. These water vendors will be more profitable under NOR and BNOR scenarios, their record profitability rates ranging from 23% (in 2010) to 161% (in 2030) under the BNOR scenario. This kind of economic mania and greed deplored by Kindelberger and Aliber (2005) lead to panics and are among the causes of unsustainable water supplies in the long run. The latter were predicted to decrease at a rate of from about 60,000 m^3/day in 2010 (under ANOR scenario) to nearly 2,000 m^3/day in 2030 (under BNOR scenario), while the daily water demand was set around 27,000 m^3/day under both scenarios. This situation was finally attributed to the lack of adequate allocative efficiency, in the absence of an institution coordinating the catchment management. Thence, GWS schemes were expected to increase water sustainability and productivity under conditions of flood to achieve an "Economic Order Quantity" (EOQ) of 12,702.7 m^3/day, or a "Limit Average Cost" (LAC) of 5,202.31 m^3/day under normal climatic conditions, or a "Minimum Efficient Scale" (MES) of 7,942.08 m^3/ day under conditions of drought.

A merger between these schemes and cost-effective BWS projects was recommended under conditions of drought to minimize deficits in water productivity and ensure higher Benefit-Cost Ratios (BCR). In effect, BWS projects were found economically rentable than GWS schemes in a water scarce area like Muooni, under normal conditions (NOR) and drought (BNOR), these projects recording BCRs of 3.72 and 2.38, respectively, but lacking economic viability under conditions of flooding (ANOR) with a BCR of 0.23. However, these blue water businesses were not economically viable in a regulated catchment like Ngusishi, neither under the NOR scenario (BCR= 0.17), nor under the BNOR (BCR= -0.70) nor under the ANOR scenario (BCR= - 0.1). Under the alternative scenario, GWS schemes were not found economically viable under conditions of drought or normal conditions. However, these schemes offered higher BCR rates of 15.92 and 5.09 under conditions of flooding (ANOR scenario) for Ngusishi and Muooni catchments, respectively.

Finally, a contingent valuation of GWS schemes' benefit confirmed that these schemes were not financially sustainable. With a WTP of US$ 11.61 times 674 households and a WTA of US$ 108.33 times 1,011 households, the implementation of GWS schemes in Ngusishi would result in a monthly deficit of US$ 101,696.49. Likewise, GWS schemes in Muooni catchment will incur a monthly deficit of US$ 485,816.22 with downstream farmers expressing a Willingness To Pay (WTP) for GWS services of US$ 21.82 monthly (times 2,549 households), against a Willingness To Accept compensation (WTA) by upstream farmers of US$ 259.06 (times 2,090 households per month). GWS schemes operating in Muooni and Ngusishi would thus need to ensure their cost recovery by raising substantial funds from other agencies, thus impeding their financial self sufficiency and economic feasibility in the long run. No wonder that many catchment managers remain sceptical about the ability of these schemes to ensure cost recovery.

4 Conclusions and Recommendations of the Study

The depletion of blue water reserves and rapid changes in Land Use and Land Cover (LULC) in most Arid and Semi Arid Lands (ASALs) of Kenya raise much concern about agriculture resilience in those areas. They are the result of catchment degradation, which is portrayed by the collapse of its biological and ecological systems, reduced social equity and economic efficiency of water projects in the catchment area. The latter are attributed to human induced activities exacerbated by population growth and the effects of cycles of El Niño flood and La Niña droughts as well as the failure by the government to develop surface and groundwater resources. This farmers' vulnerability to drought and drought-flood cycles is predicted to worsen by the year 2030, if no precautionary measure is taken. Tremendous unmet crop water demands are expected under BNOR rainfall regime (drought), and sometimes under normal rainfall regimes (NOR), especially in Muooni catchment, where high water prices have been signalled, even under periods of overflow (ANOR). For that reason, farmers have been using various water saving strategies to curb these hazardous effects of drought and flood in farming. These included traditional Soil and Water Conservation (SWC) measures, modern technological innovations and hydro-policies. The introduction of such innovative water saving strategies in drought stricken areas, particularly in Muooni catchment, has brought some relief to farmers. Yet, some farmers and catchment managers would not fully acknowledge nor reward the effectiveness of such SWC measures, technological innovations and hydro-policies, particularly in Muooni catchment. This was mainly explained by the high intensity of impacts associated to climatic changes, which could not allow them feel the true impact of GWS schemes on the ground nor reward their performance. It was thus suggested that farmers increase social networking in the catchment along with effective co-ordination of its water resource management to increase their capability and compensate the collapse of their biological and ecological systems, social and political inequality and economic loss across the country, and particularly in Muooni catchment. Hence, the creation of strong WRUAs was recommended to be an effective way for spearheading the adoption of GWS schemes and blend them with efficient BWS projects and innovative financial mechanisms such as microfinance, BOT, BOL and BOS. This would enable farmers achieve an "Economic Order Quantity" (EOQ) under flooding conditions (ANOR), a "Limit Average Cost" (LAC) under normal conditions and a "Minimum Efficient Scale" (MES) under conditions of drought (BNOR) to ensure agricultural water sustainability and farming resilience in drought stricken areas.

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Chapter 1. Introduction
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Chapter 1. Introduction

1.1. Background

Several climate scenarios predict a decline in communities' livelihood in dry and marginal lands owing to challenging issues of water availability and decreased quality in the course of climate change (Jones *et al.* 2004; DeWit and Stankiewicz 2006; IPCC 2001; 2007; 2012). In fact, climate change exacerbates rainfall regimes and the distribution of natural resources with regard to the basic needs of communities, thus leading to vulnerability to water disasters and poverty (Shisanya 1996; Pachauri 2004; Stern 2007; Van Aalst 2006; Shisanya and Khayesi 2007; USAID 2009a; Luwesi, Shisanya and Obando 2011). The 2007/2008 Human Development Report (HDR) emphasized that fact by declaring:

> *Climate change will be one of the defining forces shaping prospects for human development during the 21st Century. Through its impact on ecology, rainfall, temperature and weather systems, global warming will directly affect all countries. Nobody will be immune to its consequences. However, some countries and people are more vulnerable than others. In the long term, the whole of humanity faces risks but more immediately, the risks and vulnerabilities are skewed towards the world's poorest people.... The bad news is that forces generated by climate change will be superimposed on a world marked by deep and pervasive human development deficits, and by disparities that divide the 'haves' and the 'have-nots (UNDP 2007a).*

Hence, agricultural production in most tropical Arid and Semi-Arid Lands (ASALs) is not only to be affected by the changing weather patterns, but more significantly by population settlements, deforestation and other Land Use/Land-Cover (LULC) changes (Bates *et al.* 2008; UNEP/GRID-Arendal 2008; USAID 2009b). To ensure agriculture resilience to climate related water disasters, many countries have resorted to increase their investments in surface water saving by building huge dams and other storages (Ledec and Quintero 2003; World Bank *et al.* 2008; Scherr *et al.* 2011). Owing to the high cost of investments in surface water transfer and storage and their side effects on desertification (Reisner 1993), scientists have suggested local communities to put on strenuous efforts for accrue investments in saving "green water" with the prospect of increasing the accessible "blue water" in streams and lakes as well as groundwater by at least 50% through increased water table and finally extensive surface runoff (Dent and Kauffman 2007; Malesu *et al.* 2007; Hoff *et al.* 2010; Immerzeel *et al.* 2010; Luwesi and Bader 2012; Luwesi, Shisanya and Obando 2012). The latter represents about one third (1/3) of the total fresh water resource obtained through direct transfer of rainfall into the soil and aquifers. The remaining two thirds (2/3) is referred to as "green water" and is defined the water held in the soil by plants for their own use (Wilschut 2010; UNEP 2011). Green water is thus "the largest fresh water resource, but it can only be used in situ, by plants" (Falkenmark and Rockström 2004).

Managing green water together gives an opportunity to farmers to work toward safeguarding their "blue water" and assuring their livelihood and food security to all. "Green Water Saving" (GWS) schemes are such strategic mechanisms fostering the participation of both upstream and downstream stakeholders and their partners in a legal contractual agreement commonly known as "Payment for Environmental Services" (PES) (WRMA 2010; PRESA 2012). Within the GWS scheme framework, upstream farmers are considered as "GWS services' sellers" and the stewards of the catchment. They are entitled to payment or any other compensation for implementation of SWC measures in the upper sub-catchment. Their downstream counterparts are referred to as "GWS services' buyers" and considered as potential beneficiaries of the upper sub-catchment conservation. They need therefore to finance the catchment conservation with support from the private sector (microfinance, banks and enterprises), governmental institutions and development partners (WRMA 2010).

The GWS agreement aims to conserve the upper sub-catchment area under the stewardship of a Water Users' Association (WRUA) using different types of mechanisms ranging from Soil and Water Conservation (SWC) measures to hydro-policies (ISRIC 2008; IWMNet 2010). In general, SWC measures applied in a watershed include planting of trees and conservation of water source; control of soil erosion, desiltation of drainage channels and water storages; and control of water pollution at source (Porras *et al.* 2007). Innovative hydro-policies are also being introduced. They mainly deal with the award of Green Water Credits (GWCs) to upstream and midstream stakeholders; the allocation of Evapo-Transpiration Quotas (ETQ) to farmers; Payments for Watershed Services (PWS) and any other kind of compensation by "rich" stakeholders to "poor" farmers who deliver Environmental Services (ES); as well as the promotion of Rain Water Harvesting and Storage (RWHS) and Import of Virtual Water (VW) (Earle 2005; Bastiaanssen and Bingfang 2008). GWS schemes have been experimented in many ASALs around the world including Australia, Bangladesh, Burkina Faso, Kenya, Niger, Palestine South-Africa and Zimbabwe to address the ever widening gap between water demand and supply

(Malesu *et al.* 2008; Mukheibir 2008; Reij *et al.* 2009; Islam *et al.* 2010; Zhang *et al.* 2010; Al-Salaymeh *et al.* 2011). These schemes have enhanced water use efficiency in agriculture by increasing infiltration, reducing surface runoff/ overland flow generation and thereby increasing soil water availability and shifting unproductive evaporation to productive water use.

It shall be noted that GWS schemes are being implemented within the context of Integrated Water Resource Management (IWRM) to overcome the great challenge of moving from "business as usual" to "business not as usual" in the course of climate change (Cap-Net, GWP and UNDP 2007; UNDP 2007b; Berntell 2008). Henceforth, they are "pro-poor" schemes initiated by local stakeholders at the lowest level of environmental management, in lieu of poverty alleviation mechanisms initiated by governmental institutions and their development partners. They are also localised "Payment for Environmental Services" (PES) instead of "Clean Development Mechanisms" (CDMs) that aim to financing a green revolution through trading of Environmental Services (ES) between "rich" and "poor" countries. Thus, GWS schemes have become useful programmes for climate adaptation. These schemes have been successfully tested with a co-benefit in terms of climate mitigation in countries such as Australia, Bangladesh, Burkina Faso, Niger, Palestine and South-Africa to address the ever widening gap between water demand and supply. Hunink *et al.* (2010) demonstrated that the implementation of Green Water Credits (GWCs) in the Upper Tana Catchment of Kenya enhanced cooperation between upstream and downstream stakeholders, thus mitigating conflicts arising on resource utilization (Gleditsch *et al.* 2004). Besides, enhanced rainwater storage and utilization has been identified as one of the key mitigation measures for food security and poverty alleviation in East Africa the poor (Malesu *et al.* 2007). Thus, investing in rainwater harvesting may provide more economic incentives to governments to curb the effects of deforestation and mitigate flood, drought and dry spells through implementation of climate resilient development mechanisms such as GWCs (Rockström 2003; ISRIC 2008).

1.2 Problem Statement and Justification

Climatic changes occurring globally are among factors leading to the transformation most catchments in Kenya. Water stressed and scarce areas represent about 85% of the country and are becoming drier with unpredictable water flows subject to extreme events such as drought, flood and mass movements. Most people living in these areas rely on rainfall as their major source of water for agriculture. The Government of Kenya (GoK) thus initiated a water sector reform in 1999, which culminated with the release of *The Water Act 2002*. The aim of this new policy was to augment water flows and storage in all the drainage systems to sustain agriculture resilience to climate change (Ngurari 2009). The government has ever since increased its water budget line to enable the construction of many dams across the country (bfz, WaterCap and EUWI 2011). Yet, owing to the degradation of most catchment areas, these dams are subject to siltation and pollution. In view of this development, the government has henceforth engaged in the rehabilitation of major catchment areas of Kenya through the Water Resources Management Authority (WRMA) and the Water Resource Users' Associations (WRUAs). A few research organizations have successfully accompanied this process by introducing Green Water Saving (GWS) Schemes in some areas to WRUAs – like in Ngusishi catchment. In areas where no WRUA exist– such as in Muooni catchment- some farmers' associations have been implementing similar mechanisms for decades. Yet, many among those managing the catchments across Kenya do neither recognize the performance of such schemes nor do they reward their outcomes. Though unrecognised and unrewarded, Geertsma, Wilschut and Kauffman (2010) argue that GWS schemes are practically effective, biophysically possible, socially acceptable and economically feasible when it comes to satisfying the needs of both upstream farmers and downstream water users, especially in Sub-Saharan Africa (Wunder 2007). So, why is the concept of GWS scheme not effectively incorporated in social practices and political institutions operating within most catchments of Kenya?

This study was hence justified by the fact that there are quite a few researches evidencing the benefits of pro-poor rainwater saving schemes in Kenya, with the aim of partitioning the available water and reducing unproductive evapo-transpiration to increase infiltration and soil moisture. Moreover, studies explaining the non-performance of these schemes in ASALs are quasi nonexistent. Yet, such kinds of researches are needed to enhance agriculture resilience in the course of climate change in Africa in general, and Kenya in particular. This study is therefore justified to shed light on the biophysical need, the social acceptability and the economic viability of GWS schemes being particularly implemented in Ngusishi and Muooni catchments of Kenya. This will give an insight on the sustainability of agricultural water in these Kenyan ASALs.

1.3. Objectives

The broad objective of this study is to assess agricultural water vulnerability to climate change and farmers' capability to implement GWS schemes in Semi-Arid Lands (ASALs) of Kenya. Specifically, it aims to achieve the following targets:

(i) To analyze factors leading to farming water vulnerability to drought and flood in Ngusishi and Muooni catchments;

(ii) To assess innovative strategies put in place by farmers to mitigate water stress and sustaining their livelihoods;

(iii) To evaluate the effectiveness of GWS schemes with regard to the use and management of agricultural water in the selected catchment areas; and

(iv) To determine the efficiency and cost recovery ability of these schemes in the selected catchments under conditions of droughts and floods.

1.4 Significance of the Study and Scope

This study provides scientific evidence on the sustainability of agricultural water in the course of climate change through implementation of GWS schemes. It sheds more light on the practicality, the biophysical need, the social acceptability and the economic viability of these schemes in Kenyan ASALs. A robust Performance Assessment and Evaluation (PAE) of such schemes was used to explain factors hindering their adoption by those managing catchments. These were assessed to address major issues pertaining to the implementation of the Water Act 2002 in Kenya (Huggins 2002). Nonetheless, the study did not assess each and every scheme to the extent of describing each intervention. Rather, it provided an overall picture of their sustainability in Kenyan ASALs. Hence, findings from this study are expected to contribute to improved socio-political and financing mechanisms of agricultural water development in ASALs. This will enhance farmers' adaptability to water disasters. These encompass among others the dissemination and funding of SWC measures, rainwater harvesting and storage, water allocation plans, small scale irrigation schemes, and other water saving systems by local farmers as well as alternative financing options by public institutions and development partners.
Moreover, the assessment of agricultural water saving mechanisms was focused on Kenyan catchments located in ASALs, where there exists a GWS scheme implemented within the framework of a WRUA or any other farmers' association. The focus was narrowed down to agriculture adaptation to water disasters under conditions of drought and flood occurring in Ngusishi and Muooni catchments. The target group of this research mainly encompassed peasant farmers, especially those who are members of Water Resource Users' Associations (WRUAs), water projects and self-help groups and farmers' associations.

1.5 Limitations of the Study

Data availability is a major issue in most catchments of Kenya. Data used to assess LULC change and predict hydro-climatic patterns (that is rainfall, temperature and river discharge) by the year 2030 were scattered over a period of 40 years (1970-2010), thus resulting in many missing data. These secondary physical data were availed by the regional offices of the Water Resources Management Authority (WRMA) and sometimes by the Water Resource Users' Associations (WRUAs). Agro-economic and social data were gathered using questionnaires, interviews' guides and a guide for Focus Group Discussions (FGDs). This field research covered demographics, farm innovations, soil and water conservation technologies, agro-ecological knowledge and skills used by smallholder farmers in the management of plant water resources in Eastern Province of Kenya. Accessibility to respondents, communication hindrances, and inaccuracies of farmers' responses were some of the limitations to the reliability of the study findings. Owing to these challenges, technological devices were used to fill the gaps in data and apprehend inaccuracies in farmers' responses. Also, four research assistants were hired, two from each selected catchment, to unblock communication barriers.

1.6 Theoretical and Conceptual Frameworks

Achieving agriculture sustainability within the framework of GWS schemes requires an integrated approach of catchment management for decreased farmers' vulnerability to climate change and their enhanced capability to curb water disasters. Hence, the study first applied "DPSIR framework for a strategic marine development assessment" to establish farmers' response to environmental changes (Turner *et al.* 2010) (Fig.1.1).

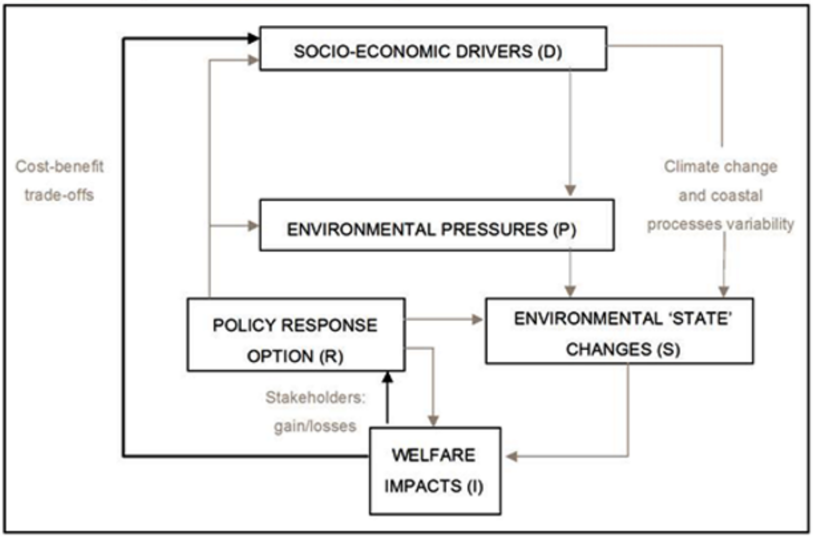

Fig. 1.1 DPSIR Framework Assessment within a Marine Context (Turner et al., 2010)

This DPSIR Assessment Framework has been used to describe "Driving forces" that lead to environmental degradation of the catchment ("Impacts") and innovative mechanisms put in place by local stakeholders ("Responses") to curb a complex of causal links resulting from "Pressures" by anthropogenic and natural (or biophysical) processes leading to subsequent "States" of the catchment degradation. Remarkable was the introduction of "Cost-Benefit Analysis" (CBA) in this DPSIR framework used by Turner *et al.* (2010) to assess local stakeholders' economic gains and losses due to climate change and coastal processes variability

The drivers to farmers' vulnerability and their response obtained from the DPSIR assessment were assessed against the magnitude of such vulnerability and farmers' capability using Downing and Patwardhan (2005) Vulnerability-Capacity Assessment (VCA) framework (Fig. 1.2).

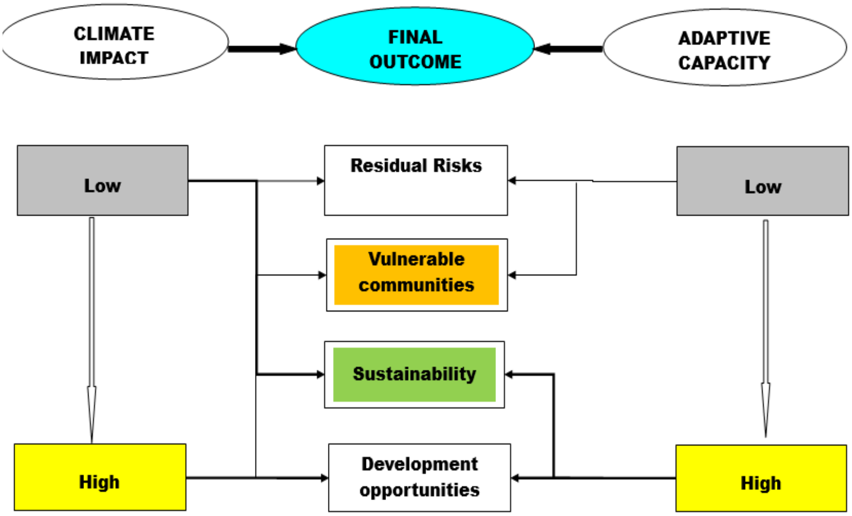

Fig. 1.2 VCA framework (Adapted after Downing and Patwardhan 2005)

Consequently, an integrated framework that combines both farmers' response and their capability was used to provide a complete picture of the study (Fig. 1.3). This re-designed adaptation framework provides a holistic

view of the management of agricultural water resources in the course of climate change in Kenyan ASALs. It integrates the methodological approach for the DPSIR assessment suggested by Turner *et al.* (2010) and Downing and Patwardhan (2005) VCA technique with the WRI (2007) adaptation theory. The latter states that water disaster adaptation programme shall take into consideration a continuum of responses to climate change. These may include: (i) Addressing the drivers of vulnerability, (ii) Building response-capacity, (iii) Managing climate risk, and (iv) Confronting climate change. The new adaptation framework involves two main wings: (i) Drivers to vulnerability; and (ii) Responses to Vulnerability. Each wing embeds issues related the biophysical need of GWS schemes, their socio-political acceptability and their economic viability. The analysis therefore comprises four (4) major steps: (i) A risk assessment of climate change impact on water resources; (ii) A vulnerability assessment of farmers to water disasters; (iii) A socio-political appraisal of GWS schemes acceptability; and (iv) An economic analysis of the viability of GWS schemes' investments under conditions of drought and flood (Van Aalst 2006). In support of this analytical framework, the study used biophysical models, socio-political assessment metrics and economic models to assess upstream and downstream farmers' response and their capability to implement GWS schemes in two catchments of Kenya, namely Ngusishi and Muooni catchments.
For efficient use and holistic management of agricultural water resources, the assessment involved: (i) the computation of the impacts and risks related to water disasters by predicting the micro-climate change, LULC change and the future water balance; (ii) an estimate of the amplitude of vulnerability to drought and flood using mathematical models (ii) an estimate of the amplitude of farmers' capability using similar models for vulnerability, and an appraisal of socio-political acceptability of the success of GWS schemes under conditions of drought and flood using SWOT analysis and "Performance based Management Rating" (PMR) of watershed institutions' management; and (iii) the economic viability of the GWS schemes by providing an estimate of their cost-efficiency and Benefit-Cost Ratio (BCR) compared to Blue Water Supply (BWS) projects, under hypothesised Normal (NOR), Above Normal (ANOR) and Below Normal (BNOR) rainfall regimes.

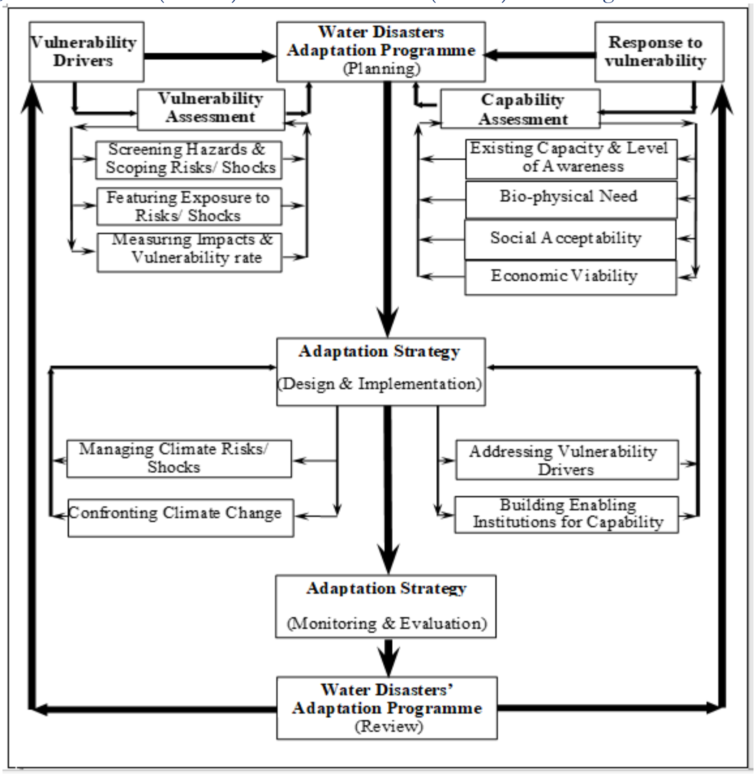

Fig.1.3 Farming water adaptation assessment framework (Luwesi and Shisanya 2017)

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Chapter 2. Literature Review

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2.1 Introduction

The foregoing literature review reveals that very little attention has been paid to the overall performance of green water saving and its "use value" in agriculture in the course of climate change, particularly in Kenyan ASALs. This study attempted to fill this gap by analysing predictions on agriculture adaptation in the course of climate change; the usage of indigenous knowledge by peasant farmers in the context of climate adaptation; GWS schemes implementation in the context of Integrated Water Resource Management (IWRM); and a methodology for needs assessment for successful implementation of GWS Schemes in Kenya.

2.1 Agriculture Adaptation to Climate Change

Climate change has both direct and indirect impacts on agricultural production and its market. These include "adaptation and land use practices, soil and vegetation conditions, nutrient loss, water availability, physiological conditions, environmental degradation such as environmental pollution and desertification, pests and diseases, transportation, marketing and many other agricultural indicators which are crucial to sustainable national development" (Ogallo, Boulahya and Keane 1999; Hulme *et al.* 2005). IPCC (2007) defines climate change as "a statistically significant variation in either the mean state of the climate or in its variability, persisting for an extended period (typically decades or longer). Climate change may be due to natural internal processes or external forcings, or to persistent anthropogenic changes in the composition of the atmosphere or in land use". Agriculture adaptation to climate change on the other end includes both crop/ plant drought resistance and acclimatation. The ability of a crop/ plant to grow satisfactorily in areas subjected to water deficits can be termed as *drought resistance*, whereas *acclimatation* involves the ability of a crop/ plant to slowly adapt to a new environmental condition, namely flood, drought and dry spell (Arnon 1992). Most climate scientists predict that water related hazards will escalate in regions where forests and wetlands have been depleted, since the latter are known to absorb excess water losses during floods and soften the effects of droughts (Bates *et al.* 2008; IFRC 2005; USAID 2009c). The 2007/2008 Human Development Report (HDR) mentions five (5) interactive transmission mechanisms: (1) the collapse of ecosystems; (2) increased exposure to coastal flooding and extreme weather events; (3) heightened water insecurity; (4) reduced agricultural productivity; and (5) increased health risks. This reports concludes: "While the processes are already apparent in many countries, breaching the 2°C threshold would mark a qualitative shift: it would mark a transition to far greater ecological, social and economic damage" (UNDP 2007a). The ecological disaster was notably explained by extreme moisture or water deficiency in farmlands would lead to excessive water stress or desiccation of crops and plants, soil loss and mass movements, and massive loss of natural habitats (Brown 2001; Pachauri 2004). The social disaster generally attributed to the effect of El Niño Southern Oscillation (ENSO) relates to the worsening vulnerability to flood, drought and dry spells as well as other related extreme events (Downing 2003). Finally, the economic disaster may be quantified in terms of economic externalities emanating from environmental changes (Luwesi 2010; Luwesi, Shisanya and Obando 2011). So, disaster preparedness and risk management are keys toward achieving adaptation to and mitigation of water disasters in agriculture to enable farmers ensure their livelihood and food security in the course of climate change (Hartnady and Hay 2004; IFRC 2009; USAID 2009a)

In support of such a disaster preparedness operational framework, this study suggests the prediction of biophysical (or ecological), socio-political and economic impacts of climate change in a specific catchment area to determine upstream and downstream farmers' response and their capacity and ability to implement GWS schemes therein. In areas where no GWS scheme exists, peasant farmers have since immemorial times been practicing some forms of agricultural adaptation to environmental changes. Hence, it will thus be wise to incorporate a component on appraisal of their "Indigenous Knowledge" (IK).

2.2 Indigenous Knowledge and Adaptation to Climate Change

Peasant farmers remain the bulk of land users expressing their "Indigenous Knowledge (IK) through various agricultural systems (Osunade 1994). "Indigenous Knowledge (IK) is defined as "a systematic body of knowledge acquired by local people through accumulation of informal experiences and intensive understanding of their environment in a given society" (Cheserek 2005). "While this knowledge is not formalized or uniformly distributed, it is a key resource which should be recognized and incorporated in a more participatory wetland management and planning process" (Dixon 2005). Hence, farmers' participation in research has several advantages for the development of environmentally friendly and sustainable production systems (Okali *et al.*

1994). This study puts an emphasis on the role and importance of local knowledge and skills on environmental conservation. The following paragraphs stress the role of Indigenous Knowledge (IK) in achieving sustainable management and utilisation of water and other environmental resources to sustain farmers' livelihoods.

Subramanian (2001) demonstrated that if water shortage problems are solved more quickly in Arid and Semi Arid Lands (ASALs) of India (rather than in humid regions), it is simply because of adaptation of traditional water storage systems to drought, mainly using deep ponds and storage wells. "Water problems in developed countries have been solved only by reservoir storage at different stages of the river flow" (Subramanian 2001). Likewise Cheserek (2005) reported that some populations of Kenya hold in high esteem traditional water conservation techniques. The latter enable them to cope with drought. For instance, the Marakwet agro-pastoralist populations use traditional Soil and Water Conservation (SWC) strategies to protect their water courses against droughts and mitigate subsequent conflicts over the little resource available through equitable allocation plans (Gleditsch *et al.* 2004). Tiffen *et al.* (1994) demonstrated how local communities in Machakos District of Kenya ensured environmental stability and survival of agricultural land uses through effective soil conservation measures. This enabled them to cope with increasing population pressure on land resources. This careful application of IK's techniques was also a key for successful adaptation to environmental changes. Dixon (2005) noticed that the concept of community involvement valued in modern literature for achieving conservation-oriented management goals has in fact a traditional makeup. Yet, this IK's practice is not significantly incorporated in the implementation of the catchment management strategies; hence, local communities do not properly have control over their natural resources. In the same vein, Shisanya (2005) observed that about 58% of people living in rural western Kenya, more precisely in Kakamega area, do not have access to potable water because of lack of technical know-how, and adequate means of transport and finances assuring permanent water supply. These factors increase socio-economic externalities that impact directly on the environment maintenance. Therefore, the author recommended a water policy involving directly local community in water allocation planning and good land husbandry. Flintan and Tamrat (2003) also revealed that efficient water resource conservation and management practices are found in the history of Ethiopian stakeholders. These include afforestation, pollution control, good land husbandry and conflict resolution on the resource. If guided by a philosophy that values such practices, farmers are eager to protect their natural resources. Nonetheless, this IK does not guarantee a foolproof system for sustainable production through better management of water and land resources among small-scale farmers in the course of climate change.

Several scholars admit that IK has become rudimentary due to the high pressure of population growth on natural resources for producing adequate amount of food and supplying water to meet the high demand. Moreover, traditional water allocation and conservation technologies are outdated when considering the effects of "climate change" on natural disasters' escalation. For instance, Benson and Clay (1998) pointed out to extreme climatic events such as storms, hurricanes, tornadoes, floods and droughts, which frustrate the agricultural sector in the tropics. These hazards cost billions of dollars and thousands of lives each year due to maladapted traditional water technologies. To that effect, dams, canals and irrigation schemes have become vulnerable to important siltation, water evaporation and frequent damage by floods leading to constant repair costs (UNU 1997). Shakya (2001) illustrated IK's limitations during exacerbated periods in Khageri Catchment of Chitwan district, Nepal, by "the increased upstream/downstream competition for water in the context of the customary rights of the beneficiaries of the irrigation system". Local populations therein seem to ignore the impact of deforestation on water flowing in the catchment. In the same vein Waswa (2006) proved beyond doubt that local knowledge systems needed to be complimented by formal science, owing to farmers' ignorance, poverty, and lack of technological innovation. The author alluded to two main factors limiting sustainable use of agricultural soils in African resource-poor farms. These encompassed: (1) the selection of a specific land-use; and (2) an appropriate form of land management preventing crops from failure in case of heavy rains and drought, under the threats of soil erosion. Luwesi, Shisanya and Obando (2012) emphasize on water sustainability as a third factor to be taken into consideration. These three factors dictate the biophysical need of GWS schemes in a certain region. But what does the concept of "green water" entail and how is the scheme integrated in the management of a catchment?

2.3 GWS Schemes in the Context of Integrated Watershed Management

2.3.1 Understanding Physical Processes Leading to Green Water

Science has proved beyond doubt that water availability depends on resulting from the water cycle. The latter is a process involving complex interactions between the solar energy, the troposphere, the biosphere, the lithosphere, the hydrosphere and the cryosphere (ice and snow), which regulate rainfall distribution across the globe (Gerten *et al.* 2004; Hartnady and Hay 2004). The total rainfall received on the earth's surface is in majority kept in oceans and lakes as salty water (97.5%). Only 2.5% of the total precipitation is part of what is called "fresh water". Yet, only 0.4% of the world reserve of fresh water is available for production and consumption, the remainder being locked in glaciers and ice lands (2.1%) (Bates *et al.* 2008; Bfz, WaterCap and EUWI 2011). Dent and Kauffman (2007) estimated to about 65% the total accessible fresh water reserves conserved by plants both in agriculture and the environment. Grasslands accounted for 31%, forest and woodlands 17%, crops 4%, other land cover 6% and arid lands keeping 5%. The remaining 38% are referred to as accessible base flow (11%) and storm runoff (27%), which is being partly allocated to irrigation (1.5%) with half of it being constituted as return flows (0.7%) (See also ISRIC 2008). Ericksen (1998) simulated the agricultural water use in the world to 69% of the accessible fresh water reserves, while the industrial share amounted to 23% and households' use for domestic purposes to 8% only. The African share for agricultural use of fresh water was estimated to 88%, industries accounted for 5% and households for 7% only. Consequently, Falkenmark and Rockström (2004) conclude that "green water is the water held in the soil. It is the largest fresh water resource, but it can only be used in situ, by plants". It represents about two thirds (2/3) of fresh water reserves but cannot be diverted to a different use, if it is not for usage by plants or soil moisture alone (UNEP 2011). The remaining one third (1/3) is referred to as "blue water". "Blue water is defined as fresh water that can be tapped, from rivers and streams, or groundwater" though harvest and storage, diversion and pumping (Wilschut 2010). A clear understanding of these processes leads to monitoring changes in the quantity and the quality of water in order to predict, mitigate and adapt to water related disasters. More important, managing green water gives an opportunity to local stakeholders to work together toward safeguarding their "blue water" and assuring food security to all (Rockström *et al.* 2009).

2.3.2 Concept of Integrated Water Resource Management

Integrated Water Resource Management (IWRM) has developed as "a process which promotes the coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems" (GWP 2000). This definition suggests that the management of water resource is to be supplemented a holistic management of other natural resources that depend on the catchment environment in order to enhance the sustainability of agricultural production and other economic activities. Such an approach would not only preserve the vitality of natural ecosystems but also satisfy the needs of human beings toward the achievement of social equity and economic development. Thus, IWRM becomes "an integrated approach of natural resource management, focusing on sustainable protection of water resources to achieve food security and poverty reduction" (Universität Siegen 2005).While IWRM is not a panacea to all water problems, it does provide a holistic and useful framework for action, by acknowledging the complex human-environment interactions and feedbacks in the water system. (Cap-Net, GWP and UNDP 2007; UNDP 2007b; IWMNet 2010; Bfz, WaterCap and EUWI 2011). Owing to the effect of deforestation, which has depleted green water reserves in many ASALs, catchment managers need to face the great challenge of getting to "business not as usual", that is moving from downstream-upstream management of "blue water" to that of "green water" (Berntell 2008). In this case, "Green Water Saving" (GWS) schemes are being suggested as innovative mechanisms for achieving a holistic and sustainable management of water resources in a catchment.

2.3.3 Concept of "Green Water Saving" and its Applications

The concept of "Green Water Saving" (GWS) consists of an avalanche of mechanisms generally evolving around Soil and Water Conservation (SWC) and hydro-policies, which are strategically blended with a scheme dealing with "Payment for Environmental Services" (PES) or any similar compensation mechanism set in a catchment management plan (Universität Siegen 2010; Luwesi and Bader 2012; Luwesi, Shisanya and Obando 2012). Wunder (2005) defines a PES scheme as "a voluntary transaction in which a well-defined Environmental Service (ES), or a form of land use likely to secure that service is bought by at least one ES buyer from a minimum of one ES provider if and only if the provider continues to supply that service (conditionality)". Grieg-Gran, Stacey and Porras (2006) precisely notice that a PES scheme encompass various Environmental Services (ES) including "watershed services, carbon sequestration, biodiversity conservation and landscape beauty". Therefore, when a PES scheme is implemented within the limits of a catchment area and for the sole purpose of rewarding watershed services, it is virtually a "Payment for Watershed Services (PWS) scheme. It involves the implementation of market mechanisms to pay, reward or compensate upstream and midstream landowners in order to maintain or modify a particular land use, which is affecting the availability and/or quality of the downstream water resources (Ortega-Pacheco, Lupi and Kaplowitz 2009; IWMNet 2010).

Nyongesa and Muigai (2012) observe that, for the purpose of enforcement, the entry point for a "Payment for Watershed Services" (PWS) scheme is a legal contractual agreement between upstream farmers and their downstream counterparts, and thus the need for the creation of a "Water Resource Users' Association" (WRUA) to coordinate the scheme. This was the case for the "Equitable Payment for Watershed Services (EPWS)" scheme implemented in Lake Naivasha Basin by The World Wildlife Fund for the Nature in Kenya (WWF-Kenya) in partnership with CARE International – Kenya, as well as the schemes implemented in Malewa and Sasumua Catchments of Kenya and Kibungo-Uluguru Catchment of Tanzania. Upstream farmers were engaged in providing GWS services to their downstream counterparts in view of the rehabilitation and maintenance of riparian zones using awareness creation on environmental changes and conflict resolution, tree planting, grass striping, terracing, reduction in fertilizer and pesticide use. (Universität Siegen 2009; PRESA 2012). Other examples of GWS schemes come from the sub-catchments of the Tana Catchment of the Mount Kenya Region. For instance, stakeholders from Bwathonaro Water Resource Users' Association (BWARUA) and Ngaciuma-Kinyaritha Water Resource Users' Association (NGAKINYAWRUA) were deeply involved in catchment transformation through land use conservation and awareness creation for behaviour change. These schemes were established as pilot projects by the Water Resources Management Authority (WRMA) through partnership with Kenyatta University and the Universität Siegen (Universität Siegen 2007; IWMNet 2010). Similar schemes have also been implemented in countries such as Australia, Bangladesh, Burkina Faso, Niger, Palestine and South-Africa to address the ever widening gap between water demand and supply (Mukheibir 2008; Reij *et al.* 2009; Islam *et al.* 2010; Zhang *et al.* 2010; Al-Salaymeh *et al.* 2011).

All the above agreements were based on hydrological concerns, the water needs of buyers and compensation requirements of sellers, as well as environmental impacts of the scheme on stakeholders' livelihood. In some cases, though institutional, legal and policy frameworks came only later to strengthen the existing schemes, the lack of a specific framework did not deter their formation. Local stakeholders were willing to transact, upstream ones selling GWS services and their downstream counterparts being willing to buy (WRMA 2010).

Hence, the GWS schemes provide a useful framework for action by acknowledging the complex human-environment interactions and feedbacks in the catchment, thus ensuring good management of natural resources, food security and poverty alleviation (Droogers 2006; Grieg-Gran, Stacey and Porras 2006; Dent and Kauffman 2007; Kauffman *et al.* 2007; Hoff *et al.* 2010; Immerzeel *et al.* 2010; Porras *et al.* 2007; Wilschut 2010). They are innovative mechanisms that address both water scarcity and rural poverty through fair payments of GWS services. They are pro-poor schemes initiated by stakeholders at the lowest level of environmental management, in lieu of poverty alleviation mechanisms initiated by the governments and their partners. Finally, they are "Payments for Environmental Services" (PES) schemes instead of "Clean Development Mechanisms" (CDMs) that involve funding flows from rich countries to poor ones for the global environment re-greening.

Nevertheless, the performance of GWS schemes is yet to be fully recognised and nor is their outcome rewarded by all catchment managers (Wunder 2007). The fact is that there are quite a few researches on needs assessment of agricultural water saving in Africa through application of pro-poor schemes (PES, PWS, GWC, etc.). Therefore, this study aims to provide a methodology for assessing the biophysical need (objective 1), social acceptability (objective 2 and 3-Effectiveness part) and economic feasibility (objective 4 and 3-Efficiency part) of GWS schemes in Kenyan ASALs to measure their performance in the course of climate change.

2.4 Needs Assessment for Implementation of GWS Schemes in Kenya

GWS Schemes are first and foremost investments in land and people with a focus on water, vegetation and soil conservation by upstream stakeholders in order to allow free and massive flow of water downstream (Wilschut 2010). There is thus need for assessing: (i) the causes of hindrance to massive flow of water downstream (the biophysical need of GWS scheme); (ii) the type, the suitability and effectiveness of GWS services needed by local stakeholders (social acceptability of GWS schemes); and (iii) the economic sustainability of the scheme dictated by its cost recovery (economic feasibility) (Geertsma, Wilschut and Kauffman 2010).

2.4.1 Biophysical Needs Assessment for GWS Schemes

As noted in the first and second sections of this literature review, both natural and anthropogenic factors contribute to water stress and scarcity. These include mainly the effects of climate change and Land-Use/ Land-Cover (LULC) change. Hence, meteorological, hydrological and other geospatial models are necessitated to assess the biophysical need of GWS schemes (objective 1). These may include statistical forecast models, Soil Water and Water Assessment Tool (SWAT), Water Evaluation And Planning (WEAP) model, Remote Sensing and GIS. For instance Hessel *et al.* (2003) used Limburg Soil Erosion Model (LISEM) to simulate the effects of land use and management strategies for reducing runoff and erosion rates in the Danangou catchment in the Loess Plateau. The study found decreases in runoff and soil erosion of about 5 to 15% after implementation of SWC measures following the existing land use pattern. Nonetheless, there was decrease of 40 to 50% discharge and 50 to 60% soil loss under changing land use pattern in accordance with the steepness of the slope. Similarly, Liu *et al.* (2003) simulated the impact of climate and LULC changes on runoff in the Yellow River for the period 1980–1990 using SWAT model. Their findings show that an increase of 1^{0}C in temperature resulted in decreased runoff of 109% while land use change increased runoff by 10% in the source region of the Yellow River.

Based on similar modelling, Hunink *et al.* (2010) conducted a biophysical assessment of Green Water Credit (GWC) in some selected sites of the Upper Tana Basin of Kenya by quantifying fluxes of green and blue water as well as sediment using SWAT. The study led to identifying potential target areas for awarding GWCs in the pilot operation based on their heterogeneities in terms of precipitation regime, topography, soil characteristics and land use. The SWAT model assisted in estimating the benefits of the management practices on erosion reduction and green and blue water flows in the basin. The analysis revealed that basin-wide implementation of tied ridges would lead to a reduction of sediment input into the Masinga reservoir of about a million tons, while mulching would reduce unproductive soil evaporation by more than 100 million cubic meters per year. The enhancement of groundwater recharge through the different practices would improve the usage of the natural storage capacity in the basin by about 20%. These benefits were quantified based on specific crops and sites. Wilschut (2010) on the other hand used Remote Sensing (RS) to map land use activities going on in the Upper Tana Basin. This RS analysis was applied using two classification methods (rangelands and forest cover) based on the Support Vector Machine method, which proved to be more accurate than the Africover 2000 map that was in use. The study came up with an updated and higher resolution land use map depicting hotspot areas and different land use types for each area, namely rangelands versus cereal farms; and forest cover versus tea, coffee and maize farms). This new land use map was said to be used to improve hydrological and erosion modelling. This would lead to a more accurate estimation of water resources and land degradation as well as improving the choice of GWC target areas.

Finally, Hoff, Stacey and Droogers (2007) used the Water Evaluation And Planning (WEAP) model to develop and test options for matching water supply and water demand, and assessing upstream-downstream links for different options in terms of water sufficiency for un-met demand, costs and benefits in the Tana Basin of Kenya. The study shows all water uses therein have unmet demands, including hydro-power, municipal water utilities and irrigation. For instance, the Masinga Dam had lost over 30% of its capacity from 1982 to 2002. The study concludes that immediate decrease of unmet demands and rationally significant gains in hydro-power generation and urban water supply can be achieved by stopping the siltation of water reservoirs from small areas and farmlands. Hence, the need for GWCs in some targeted areas.

Based on the above findings, this study used the WEAP model to predict water balance in the selected catchments of Kenya by the year 2030 besides comparing different statistical trend-shift detection techniques and LULC changes to assess the micro-climate variability and changes in the selected catchments of Kenya. To predict catchment climate variability, a simulation of changes in temperatures (T^o) and Precipitations (Prec.) over 20 years (2010-2030) was performed using Seasonal Auto Regressive Integrated Moving Average (SARIMA) technique for seasonal time series forecast (Zorita and Von Storch 1999). A comparison of various trend-shift detection techniques shed light on changes of seasonal and annual precipitations as well as temperatures in each catchment (Rodionov 2011). Techniques used in this study included observed and expected probabilistic plots (PP-plots). Results from these forecasts enabled the researchers to determine farmers' vulnerability to past, present and future water disasters predicted by the WEAP model for Ngusishi and Muooni catchments of Kenya.

2.4.2 Socio-political Acceptability Appraisal for GWS Schemes

Downing and Patwardhan (2005) Vulnerability-Capacity Assessment (VCA) framework was recommended as an important for computing the magnitude of farmers' vulnerability to water disasters and their capability to curbing drought and flood using GWS schemes (see the conceptual framework under the sub-section 1.6). To be socially practical and politically acceptable, these GWS schemes need first to demonstrate their performance in the catchment management. Any performing water system is required to yield infrastructure and services that are environmentally sustainable, socially beneficial, economically efficient and delivered at a fair price (Savenije and Van der Zaag 2002; Meijerink *et al.* 2007). Cap-Net (2008) notes that "applying a price to water is not only done because of cost recovery but is equally important as a tool to change behaviour and make sure that water is distributed more fairly". Simply put, the achievement of performance in management necessitates meeting the conventional '3 Es', namely: (i) the **E**conomy of their inputs; (ii) the **E**fficiency of their outputs; and, (iii) the **E**ffectiveness of their impact (UNCDF 2006). Performance based Management (PM) is a process that aims at yielding infrastructure and services that are economically viable and efficient to address effectively the core values of environmental sustainability, social equity, transparency and accountability for resource management (Huggins 2002; Kasambala, Kamara, and Nyange 2006; Ngigi and Macharia 2007). Hence, the PM achieves rational development and equitable distribution of water resources, transparent management of financial resources and their accountability using strategic management tools as well as regulatory and institutional instruments of IWRM. These arrangements include basic requirements of the Water Act (WA) such as Legal and Institutional Frameworks (LIF), Catchment Management Strategies (CMS), Sub-Catchment Management Plans (SCMP), Resource Allocation Plans (RAC), Resource Use and Pollution (RUP) and standardized metrics (Universität Siegen 2005; K'akumu 2008). The implementation of these tools results on the increased capacity to perform and deliver quality infrastructure and services without overshadowing environmental sustainability, social equity, accountability and transparency.

The efficiency of a PM can be assessed using Variance Analysis (VA) embedded in "Performance Assessment and Evaluation" (PAE). It consists of measuring variances between planned items and their related targets through comparison of unit costs for different services or infrastructures delivered under different contexts (e.g. geographical settings, inflation rates, etc.) and periods (e.g. years) (Hatry 2006). This ensures that managers and resource developers are held accountable for the use of funds collected from GWS schemes. A wide variance between funds received and expenditures in relation to planned targets will challenge the organization's ability to plan (particularly to budget) and to deliver GWS services, besides touching its moral integrity. A good governance of these funds will assist in achieving the targets in the plan, while these targets will not be achieved in case of mismanagement of funds. That is where the terms 'sound planning/ management', 'under/over-estimation' and 'corruption' come in (UNCDF 2006). This will send a bad signal to the high management. The latter will necessitate requests for thorough investigations to bring the plan's implementation on the track. Hence, the implementation of GWS schemes requires genuine 'political' leaders to champion transparency and stakeholders' participation in planning, budgeting and implementation, monitoring and evaluation processes, if any good governance is to be achieved in the catchment (Mulwa 2011).

The effectiveness of a PM can be measured in cycles of PAE based on a quarterly, annually or tri-annually plans, programmes and budgets. The PAE herein focuses on continuous improvement of internal core processes across the water sector for the purpose of comparing or benchmarking service delivery in the whole sector without considering individual GWS schemes' standards or requirements from local stakeholders, industries and other interest groups (Paralez 2001). A formative or summative process for making policy adjustments from local initiatives necessitates a "Robust PAE". The latter is needed to monitor and evaluate consistently and on regular basis a consolidated GWS scheme across a basin or a region using gap and trend analyses (UCA 2001) Formalized data collection and monitoring systems are thus required to be put in place to facilitate uniform evaluation of various GWS schemes based on performance metrics (Pulakos 2004). It shall be noted that both simple and robust PAE systems use different approaches to construct consistent effectiveness -based metrics, which objectively quantify the GWS scheme's abilities to attain the goals of the water sector reforms (Rogers 2005). These outcomes help decision-makers to make effective policy adjustments or efficient resource allocations among the WRUAs within a larger basin.

Another approach utilized to evaluate the performance of GWS schemes includes the analysis of Strengths, Weaknesses, Opportunities and Threats (SWOT Analysis). Finally, an overall assessment of the GWS scheme's performance requires a strategic auditing of the catchment management "Strengths" and "Weaknesses" while tracking "Opportunities" and "Threats" from the catchment environment (Boseman and Phatok 1989). The assessment is based on a tool known as the "SWOT" matrix that a catchment manager can easily utilize to analyze regularly potential trends in both the internal management system and the catchment environment (Baker and Start 1989; Doyle 1992). These changes may affect the overall management system and its market share, as well as its competitive, economic, political, legal, technological, social and cultural backgrounds (Ferrell *et al.* 1998; Martinsen 2008). Consequently, a SWOT analysis would enable catchment managers to address areas of weaknesses and consolidate their managerial strengths while avoiding severe threats from the environment to take advantage of prospective opportunities therein (Ansoff 1990; Kotler 1991). The SWOT matrix may therefore become a planning tool for future interventions in the catchment to achieve the sustainability of water resources. It may address issue of provision of basic water requirements, the reduction of risks of shortfall and/ or pollution, the extension of water networks, the conservation of land resources, the development human and financial resources, the enhancement of technological and allocative efficiency, the minimization of costs and maximization of profits, as well as the creation of awareness on the core values of the water sector reforms (Stephenson 2005; Meijerink *et al.* 2007).

This study filled a major gap noted from the literature by conducting a robust "Performance Assessment and Evaluation" (PAE) for GWS schemes operating in the Kenyan ASALs. In fact, most studies merely focus on the strengths and opportunities of the schemes rather than looking at their internal weaknesses as well as possible threats from the environment. Accordingly, a complete analysis of Strengths, Weaknesses, Opportunities and Threats (SWOT) was needed to unveil the reasons why the concept of GWS schemes was not effectively incorporated in social practices and political institutions operating within most catchments of Kenya. It also enabled detecting innovative adaptive measures used by farmers (see Objective 2) and provided scientific evidence of GWS schemes' effectiveness (see Objective 3).

2.4.3 Studying the Economic Viability of GWS Schemes

The designers of a GWS scheme need to provide economic incentives to both upstream and downstream stakeholders to enable them protect their land in order to release enough water downstream and pay for these green water saving services, respectively. For that reason, both conventional and extended Benefit-Cost Analyses (BCA) are used, based on financial mathematical models for Benefit-Cost Ratio (BCR) and Contingent Valuation Methods (CVM), respectively, to determine the scheme's capacity to ensure cost recovery (Rietbergen-Mccracken and Abaza 2000).

The traditional BCA was said to be the best estimate of profits or losses resulting from discounted values of any investment (OAS 1991; Anandajayasekeram 2004; DFT 2011). Yet, this can only be true if carried out under a normal economy (Normal scenario), where market prices prevail and that a proper sensitivity analysis is provided. In the course of climate change, the latter could easily be challenged by unpredicted La Niña droughts (Below Normal scenario) or El Niño floods (Above Normal scenario) (Brown 2001; Hulme *et al.* 2001; Jones *et al.* 2004; Smith *et al.* 2004; Steinemann, Hayes and Cavalcanti 2005; Stern 2007). Therefore, rather than using Data Envelopment Analysis (DEA) or other probabilistic models for production and cost, this study first conducted an hydro-economic Cost Efficiency Inventory (CEI) based on the WEAP linear programming models to simulate operational costs of each GWS scheme (cost of transaction) and its external costs (opportunity cost, cost of water saving and shortage cost) (Lòpez-Baldovin, Gutiérrez-Martin and Berbel 2006; Oduol *et al.* 2006; Barah 2009; Luwesi 2010; Luwesi, Shisanya and Obando 2012). The analysis also employed the "maximin" / "minimax" criteria applied in the "game theory" to select the highest cost and lowest income to be considered in the study from different GWS schemes assessed (Howe 1971; OAS 1991; ADPC 2005). These financial estimates for GWS schemes were compared vis-à-vis costs and benefits for implementing Blue Water Supply (BWS) projects using financial mathematical models for the BCA. This assisted in avoiding beatific expectations that could lead to overestimation of what the scheme really worth under hypothesized Normal (NOR), Above Normal (ANOR) and Below Normal (BNOR) rainfall regimes (Smith *et al.* 2004; Luwesi, Shisanya and Obando 2012). Finally, an average "Willingness To Pay" (WTP) for GWS services was computed from downstream farmers in comparison to the "Willingness To Accept compensation" (WTA) for GWS services delivered by upstream farmers. The difference between the WTP (income) and the WTA (cost) established contingent benefit that determined the financial sustainability of the scheme (Venkatachalam 2003; Meijerink *et al.* 2007).

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Chapter 3. Research Methodology

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3.1 Introduction

To achieve its objectives, the study collected and analyzed primary and secondary data from two semi-arid catchments of Kenya, namely Ngusishi and Muooni catchments. These two catchments experience serious problems of droughts and sometimes flooding episodes. They were purposively selected to build scenarios of vulnerability to and capability to curb water disasters in Arid and Semi-Arid Lands (ASALs) of Kenya, in comparison to wet areas such as those located in the Tana Region, where GWCs are being successfully implemented. The following sub-sections present each study; research design, organization and ethical considerations; sampling techniques; techniques for data collection; techniques for data analysis; and results presentation and interpretation.

3.2 Geographical Setting of the Study Area

3.2.1 Featuring Muooni Catchment

Muooni is a small catchment of 25 km² shared by three administrative sub-locations, namely Isyukoni, Mbee and Kaewa. It is situated in Mitaboni location of Kathiani Division of Machakos County (in the former Machakos District of the Eastern Province of Kenya). Geographically, the catchment is bound by latitudes 1.24° S and 1.28 ° S, and longitudes 37.16 ° E and 37.20 ° E (Figure 3.1).

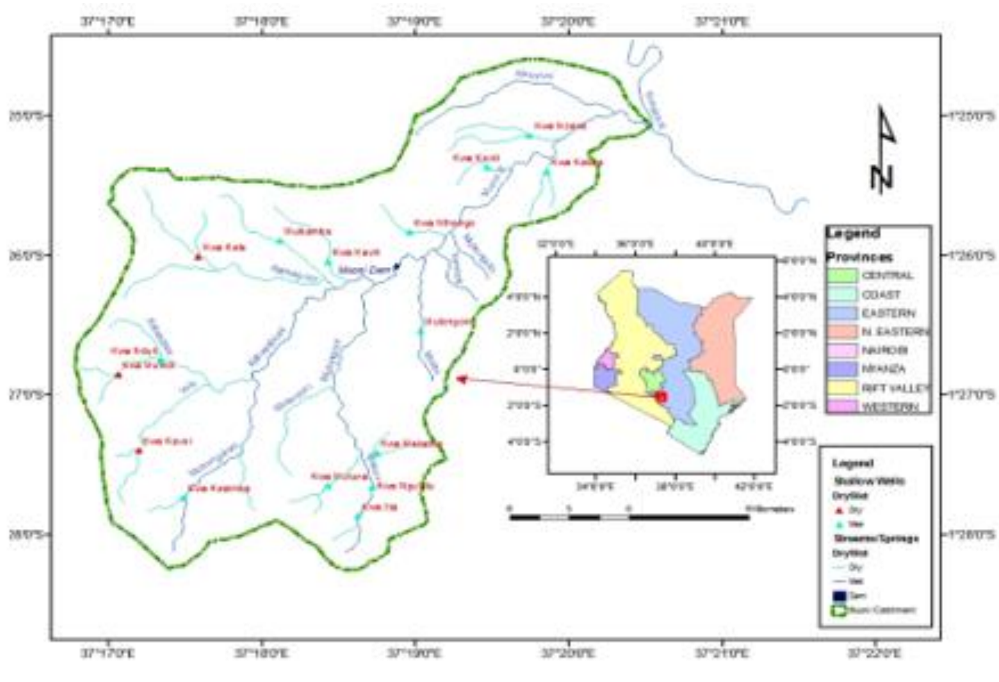

Fig. 3.1 Muooni Catchment Area (Musuva 2010)

The catchment belongs to the eastern highlands topographic area, one of the most important ecosystem of eastern Kenya (Phillips 2002). It is a dry and hilly land rising between 1,434 (near Kathiani) and 2,005 metres (at Mutondoni). The land is intensively cultivated even on the steep slopes (Luwesi, Shisanya and Obando 2011). No doubt that soil erosion, water stress and food insecurity are major concerns of Muooni catchment's stakeholders.

Muooni catchment lies within a medium potential zone: the Upper Midland Agro-Ecological Zone 4 (UM4-AEZ). Climatic conditions in the catchment range from arid to semi-arid. Rainfall is bimodal falling during the long rains (from April to May) and the short rains (from November to December) (Luwesi 2010). Annual temperatures range between 10^0 and 30^0 C, with mean minimum, maximum and average temperatures of 12.0°C, 23.0°C and 17.5°C. Mean annual rainfall is estimated to 540 mm with a reliability of 66% and annual evapo-transpiration of about 1,622 mm (Jaetzold *et al.* 2007; Luwesi**, Shisanya and Obando 2012).**

Muooni catchment is inhabited by Akamba people, of Bantu origin. During the *Kenya 2009 Population and Housing Census*, the population of Kathiani division was estimated to 19,923 persons within 4,539 households, thus making an average population density of 463 persons/ km² (KNBS 2010). However, demographic projections for Muooni catchment indicate a population density of roughly below 10 persons each 100 m²; that is more than 900 persons/ km² (Luwesi 2010; Musuva 2010).

The Akamba people are mainly agriculturalists and livestock keepers. Farming income is generated by the cropping of potatoes, coffee (in altitudes ranging from 1,650 to 1,800 m), early maturing sorghum and foxtail millet, and "marginal crops" (like Tepary beans and Tohono Z16 maize), most of the time associated with livestock farming. Yet, Muooni catchment is mainly suitable for sunflower and maize cropping as it does ecologically belong to the Upper Midland Agro-Ecological Zone 4 (UM4-AEZ) (Jaetzold *et al.* 2007). Nevertheless, it is not generally favourable for intensive rainfed agriculture since it receives less than 1,000 mm of mean annual rainfall. Because of climatic conditions varying with altitude, variable soils have developed at the hill tops (with high rainfall) and at the low plains (with low rainfall). Those soils are poorly consolidated and highly susceptible to erosion, especially on steep slopes (MoW 1987). The high soil moisture and cool climate of the hill tops make them favourable for cropping wheat, maize and pyrethrum. However, these crops most likely fail due to the shortness of the rainy seasons and small size of farms.

From the hydrological point of view, Muooni catchment belongs to the Athi Basin, one of the five major hydrological networks of Kenya. Water in the whole catchment is mainly supplied by rainfall, Muooni River and its dam, the latter being the major source of water in the catchment. Muooni dam is a kind of overflow gravity dam located in a narrow part of the deep valley of Muooni River at Isyukoni sub-location (Mitaboni location, Kathiani Division). Table 3.1 presents some key characteristics of Muooni dam.

Table 3.1: Key design features of Muooni Dam

No	Characteristic	Data	Observations
1.1	Dam site area:	15 hectares	Muooni River, Isyukoni sub-location
2.1	Reservoir capacity (1)	1,559,400m³	Maximum capacity
2.2	Reservoir capacity (2)	836,000 m³	Median capacity (at spillway level)
2.3	Reservoir capacity (3)	119,400 m³	Minimum capacity (threshold)
3.1	Spillway capacity	99 m³/sec	
3.2	Spillway width (1)	20 m	At chute
3.3	Spillway width (2)	30 m	At entrance
3.4	Spillway length	167 m	
4.1	Cutlet tower height	22 m	
4.2	Cutlet pipe diameter	600 mm	
4.3	Cutlet pipe length	132 m	
5.1	Embankment height	22 m	
6.1	Downstream slope	2:1	Protected by grassing
6.2	Upstream slope	3:1	protected with Rip rap/filter cloth layer
7.1	Slope channel velocity (1)	2%	Low
7.2	Slope channel velocity (2)	3%	High

Source: Compiled from MoW (1987) and Luwesi (2010)

WRMA (2008) observed that the dam site was so highly eroded, thus having significant impacts on the siltation of the dam reservoir. Its average storage capacity has decreased due to soil erosion problems, thus having some implications on other productive sectors of the local economy, especially the water economy. This forced women and children to walk long distances (up to 3 km) to fetch water and graze animals, with some implications on their health. For addressing major challenges facing the entire Athi Basin, the WRMA Regional Office in Machakos drafted a Catchment Management Strategy (CMS) in the year 2009. WRMA has already started negotiations with local stakeholders for a "Water Resource Users' Association (WRUA) in Muooni. The incoming WRUA will have to address issues of water stress and food insecurity facing Muooni catchment. Meanwhile, an environmental committee oversees Muooni dam Site and Kauti Irrigation Scheme's Water Users' Association (Kauti IWUA) utilizes water from Muooni dam to irrigate farms at Kauti sub-location and its environs.

3.2.2 Ngusishi Catchment

Ngusishi catchment is located in Mutarakwa Sub-location, Ngusishi Location, Timau Division of Meru County (in the former Imenti North District of Eastern Province of Kenya). It has an area estimated to 45.8 km², which is delimited by longitudes 37° 10' 30" E and 37° 20' 24" E, and latitudes 0° 08' 03" N and 0° 20' 05" N (Figure 3.2).

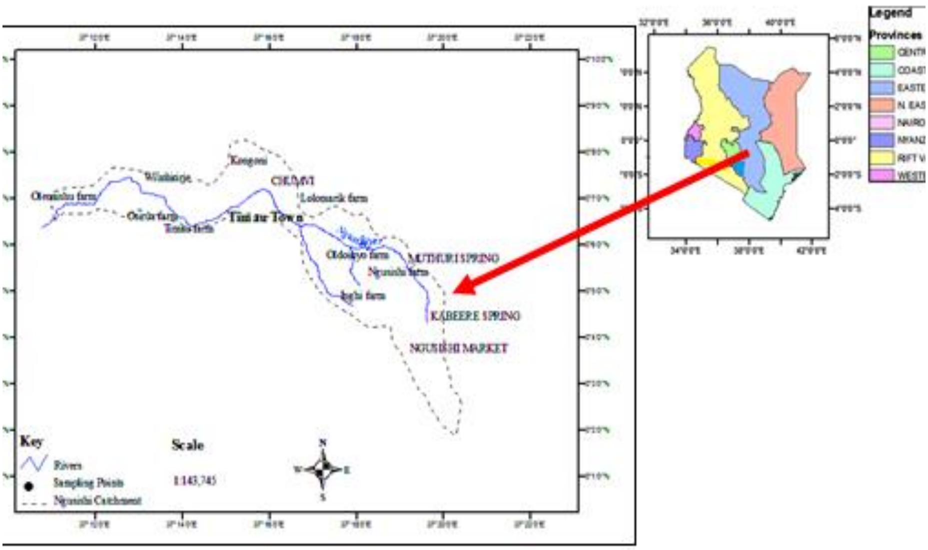

Fig. 3.2 Map of Ngusishi (Digitized by Luwesi and Shisanya 2017)

Hydrologically, Ngusishi is a sub-catchment of Timau catchment, which belongs to the great Ewaso-N'giro Basin. The catchment is dry and comprises a few springs that feed in Ngusishi River, namely Kabeere, Muthuuri and Batian. The catchment lies to the eastside of Mount Kenya Forest and shares its borders with Laikipia District to the west, and Maritati Sub-location to the south. It is a hilly land rising between 2,230 m (near Batian) and 2,430 m (at Kabubungi). It covers the following areas: Batian, Chumvi, Kabubungi, Kabeere, Kongoni, Lobelia, Lucern, Muthuuri, Ole-Naishu, Siraji and Wiumiririe. Average temperatures in the catchment range between 9 and 18°C. Rainfall is herein very scattered, ranging from 700 to 1,000 mm per annum with an average annual precipitation of 746 mm and a reliability of 66%. This situation is mainly explained by the rain shadow and orographic effects of the Mount Kenya as well as by the effects of the western Kenya rainfall patterns (Jaetzold *et al.* 2007).

Population projections in Ngusishi catchment for the year 2012 was estimated to 5,049 people with a total density of 110 persons/ km² distributed across 1,685 households (Luwesi and Shisanya 2017). However, the average population density was enumerated to 89 persons/ km² in Timau Division during the *2009 Population and Housing Census* (KNBS 2010). The population in Timau division is to a large extent low and evenly distributed owing to the vastness of Arid and Semi-Arid Lands (ASALs). It is made of a mixture of diverse cultural backgrounds including populations from the Kikuyu, Meru and Masai communities.

These areas belong to the Upper Highland Agro-Ecological Zone 3 (UH3-AEZ), which is mainly suitable for wheat-barley cropping. In effect, the soil conditions prevailing in Ngusishi makes the catchment unsuitable for maize and other typical smallholder crops but fits for large-scale agriculture, especially in the higher zones where it is too cold for maize. For that reason, the upper catchment abounds in various floricultural farms among which Batian, Lobelia, Lolomarit, Nelion, Oldonyo and Siraji are the biggest. Downstream, there are some pasture and forage well suitable for Merino Sheep and grade beef cattle (Jaetzold *et al.* 2007). Cut flowers, cuttings and plants are widespread than fruits and vegetables. It shall be noted that floriculture has somehow disabled full-time peasant farming, many stakeholders working part-time in the floricultural industry. This industry has also shaped water resources planning and management within the catchment through the creation of the "Ngusishi Water Resource Users' Association" (NWRUA) in 1998, which was fully registered in 2003.

3.3 Research Design, Organization and Ethical Considerations

3.3.1 Research Design

The main concerns of this study can be summarized in the three following questions: "why are Kenyan ASALs vulnerable to water stress? What adaptive strategies are put in place by local stakeholders to mitigate water stress and alleviate poverty in their catchment? Are GWS schemes cost-effective and efficient? And what kind of institutional support exists for smooth implementation of these schemes in ASALs? To attend to these research questions a *quasi-experimental design* was selected (Morra-Imas and Rist 2009). The study examined responses from stakeholders living in Ngusishi catchment (experimental group), where GWS schemes formally exist, in comparison to Muooni catchment (control group), where informal types of GWS schemes exist since the colonial time. These responses were analyzed both at the catchment level and the sub-catchment ecological units (upper and lower zones). Findings provided a clear indication of both causes of vulnerability to water stress and the type of capability treasured by local stakeholders (and institutions) for successful management and development of water and land resources in the course of climate change using GWS schemes.

3.3.2 Field Team and Research Organization

To cover the selected study areas, two research assistants were identified from the Water Resources Users' Associations (WRUAs) working within the catchments. The WRUA representatives were selected based on their education credentials (secondary and above) and ability to communicate fluently in English, Kiswahili and local languages spoken in the study area (Kikamba for Muooni catchment, Kikuyu, Kimeru or Masai for Ngusishi catchment). Trainings for research assistants were conducted in February 2012 to enlighten them on key concepts and methodologies pertaining to the research. Clear issues of the investigation and areas of surveys, in-depth interviews and Focus Group Discussions (FGDs) were successfully tackled to facilitate data collection and sometimes translation in the local language (see Appendices 7.4, 7.5 and 7.6). An emphasis was put on how to ask questions that bring out the three main components of this study, namely: biophysical issues, socio-cultural questions and economic concerns. The next step of this research was to identify other resource persons to be incorporated in the research team. These included: (1) representatives of the water resources management authority (WRMA); (2) agricultural extension officers; and (3) teachers/ other educators and specialists, whose interests are water, plants and agriculture, and could provide facilitation and packaging of various knowledge products.

3.3.3 Research Ethics

In attempting to address issues of drought and water scarcity often raised by local stakeholders since their first interaction with researchers in 2007, researchers looked back to some of the guidelines provided by the Government of Kenya (GoK) with regard to protecting water catchments and allocating of water use rights. In general, a participatory approach and gender equity were recommended and enforced during the Focus Group Discussions (FGDs) to involve at least 50% of female and male members of the community. These same standards were implemented at catchment level when selecting interviewees and respondents to questionnaires. Differences arising from social and ethical background were also considered to avoid disturbance of the discussions. For instance, representatives from WRUAs and other organizations were encouraged to take cultural differences into consideration when selecting group discussions' participants. This was especially the case in Ngusishi where diverse communities live together, including Kikuyu, Meru and Masai. An agreement was also needed prior to mixing both genders during the discussions. Finally, it was agreed that names and some particulars of participants were to be concealed to the general public. In all the cases, researchers always sought permission prior to reporting any sensitive declaration in the reports. Any other ethical issue was addressed according to Kenyatta University Intellectual Property Rights (IPR) ethical clearance, which recommends to:

(1) Identify the communities living in the study area;
(2) Consult with the communities to ascertain interest in the project in allowing access to their resources;
(3) Access to genetic resources embodying their knowledge;
(4) Negotiate agreement with communities on their intellectual property rights (IPR);
(5) Request a third party right for potential use of information gathered and reported;
(6) Provide copies of the report to community representatives; and
(7) Sort out issues related to equitable benefit sharing.

3.4 Sampling Techniques

3.4.1 Sampling Strategy

As mentioned above, this report presents results of the field work conducted in Ngusishi and Muooni catchments. For that reason, Krumme (2006) and Zeiller (2000) sampling techniques were used for sampling the catchments and selecting units during survey, in-depth interviews and Focus Group Discussions (FGDs). Krumme (2006) approach consisted of dividing each catchment area in two homogenous Ecological Functional Units (EFU), namely the Upper Sub-Catchment Area (USCA) and the Lower Sub-Catchment Area (LSCA). Zeiller (2000) random walk strategy involved equal chance of selection for all respondents, both the most accessible from the centre and those far away from main roads and market centres. Nonetheless, it shall be noted that the chance of selection is not always equal even where settlements are uniformly distributed; what matters is a representative sample. Hence, a random sample size was needed with a systematic selection strategy in addition to the random walk and EFU techniques.

It shall be noted that the two Ecological Functional Units (EFU) were situated within one Agro-Ecological Zone (AEZ). Owing to the wide range of farming practices, the researchers avoided complications by assuming that the variations of prices of inputs and outputs were not significant within the same AEZ. This saved time and energy with regard to the computation of crop water requirements, farmers' water demand and their subsequent costs. Also, each EFU was allocated a research assistant to facilitate communication with local stakeholders as a translator.

3.4.2 Sample Size and Selection Strategy

A total sample size of 167 farms was computed for both catchments: 103 farms for Muooni and 64 for Ngusishi. The following Cochran (1977) formula for categorical data was used to determine the number of farms to be selected in each catchment area under study (Bartlett *et al.* 2001):

$$n_{ct} = \frac{n_o}{1 + \frac{n_o}{pop_{ct}}} \qquad [3.1]$$

Where,

pop_{ct} is the total population of farms in the catchment estimated to 5,114 in Muooni and 1,685 in Ngusishi;

n_o is the Cochran's return sample size calculated as follows:

$$n_o = \frac{t^2 * \sigma^2}{\alpha^2} \qquad [3.2]$$

σ^2 is the catchment's variance computed according to formula 4.3 below:

$$\sigma^2 = p*(1-p) \qquad [3.3]$$

With,

p the relative frequency of farms estimated to 45% and 55% in the upper and lower Muooni, and to 65% and 35% in the upper and lower Ngusishi, respectively;

t the t-test statistics' value set at 1.96 (for 95% confidence level) for Muooni, and 1.65 (for 10% confidence level) for Ngusishi

α is the acceptable margin of error the researcher is willing to except for the catchment being estimated, which was set at 12.5% for the upper sub-catchments (where GWS schemes are implemented), and 15% for the lower sub-catchments (hypothesized to be the beneficiaries of the schemes).

Based on formula [3.1] and in conformity with Krumme (2006) approach, 103 farms in total were *a priori* selected in Muooni catchment at 95% confidence level, 61 and 42 farms for the upper and lower sub-catchments, respectively. Likewise, 64 farms were first selected in Ngusishi catchment at 90% confidence level, 38 upstream and 26 downstream. Thus, the total number of farming units involved in the study amounted to 167 units for the two catchment areas.

Using the table of random numbers, the researcher administered 61 and 42 questionnaires within Muooni's USCA and LSCA strata, respectively, while 38 and 26 farmers were surveyed in Ngusishi's USCA and LSCA strata, respectively. Owing to Zeiller (2000) requirement of providing equal chance of selection to all farmers, not-at-home farmers were automatically replaced by their immediate random number. Unfortunately, owing to the inaccuracy and incompleteness of responses among some farmers surveyed, 5 questionnaires were discarded and new respondents were selected, among whom 2 farmers in the upper Muooni, 1 farmer in the lower Muooni, and 1 farmer in each of the two sub-catchments of Ngusishi. Thence, the final sample size figured in this report amounts to 172 farms, 106 for Muooni and 66 for Ngusishi catchment.

3.5 Data Collection

3.5.1 Techniques of Data Collection

Fig. 3.3 The Soil Moisture Meter kit used during geomorphologic surveys
(A photography by Luwesi and Shisanya 2017)

Fig. 3.4 The Current Meter Kit Used During Hydrological Surveys (A photography by Luwesi and Shisanya 2017)

Techniques of data collection encompassed an on-farm survey using questionnaires, in-depth interviews involving local administration officers and Focus Group Discussions (FGDs) (Appendices 7.3, 7.4 and 7.5). Primary physical data were collected *in situ* using a soil moisture meter and a current meter (Figures 3.3 and 3.4). A documentary review assisted to gather information and secondary data. Physical data included land-use and land cover, rainfall, temperatures and discharge. These were needed to establish the bio-physical feasibility of GWS schemes in specified catchments of the study. Other physical and computational data were collected using GPS, photographic devices, satellite images and topographic maps. These secondary data were mainly collected from available hydrological and meteorological stations and relevant ministerial departments (KMD and DRSRS), as well as from libraries and the internet.

3.5.2 Data Collected

This report presents key findings from the on-farm surveys, institutional in-depth interviews and Focus Group Discussions (FGDs) as well as hydro-geomorphologic surveys and meteorological data gathered from February to July 2012 in Muooni and Ngusishi catchments. Researchers conducted an extensive documentary review on topical issues pertaining to the study. The latter contains facts and data from 167 farmers, 20 key informants and two (2) FGDs as well as primary data on discharge (in total 15 river points) and soil moisture (30 field points and 30 soil cans). Also secondary data on daily and monthly rainfall (ranging from 1965 to 2010) were collected from 19 rain gauge stations, monthly data on temperature (ranging from 1968 to 2008) were obtained from four (4) meteorological stations and monthly discharge (ranging from 1965 to 2010) were gathered from each sub-catchment.

Besides, physical computational data (raster) on land-use and land-cover included four (4) sets of Landsat 7 panchromatic images of Machakos (11 February 1976, 25 February 1987, 21 February 2000, and 19 August 2010) and Mount Kenya (11 February 1976, 25 February 1987, 21 February 2000, and February 2007) acquired from the Department of Resource Surveys and Remote Sensing (DRSRS), Nairobi, Kenya. Alternative computational data were retrieved from the GIS Lab of the Department of Geography at Kenyatta University, and open sources available from the internet.

Data collected enabled the development of a database in SPSS and MS Excel spreadsheets as well as other ones in ILWIS, Arc View and the WEAP system. ILWIS was mainly used for Landsat imagery and ArcView for mapping. MS Excel/ SPSS spreadsheets recorded and displayed data from on-farm survey (167 cases times 190 variables), the in-depth interviews (20 cases times 140 variables), the two FGDs (264 cross-sectional data from 24 cases), the hydro-meteorological survey plus secondary data on temperature, rainfall and discharge (186 cases times 26 variables), and geomorphologic survey (30 field points and 30 soil cans). The WEAP model contained 10 demand nodes, 2 reservoirs and 2 tributaries for both catchments.

3.6 Data Analysis and Results Interpretation

3.6.1 Introduction

As stated above, data collected were first pre-processed and then analyzed using mainly ILWIS remote sensing software, ArcView GIS software, SPSS 17.0 and MS Excel 2007 spreadsheets as well as the WEAP hydrological model. Each objective of the study was successfully subjected to the analytical procedures described below. Results were interpreted and discussed to the light of factors leading to faming water vulnerability (objective 1); farmers' innovative strategies to curb water disasters (objective 2), the effectiveness of GWS schemes (Objective 3), and GWS schemes' efficiency and cost recovery (Objective 4) in both Muooni and Ngusishi catchments. The following sub-sections provide detailed description of each study objective's analytical framework.

3.6.2 Analysis of Factors Leading to Farmers' Vulnerability

The major goal of this objective was to analyze climatic and spatial trends through simulation of changes in land-use/ cover (LULC), temperatures (T^o), Precipitations (Prec.) and streamflows from 1971 to 2030 in Muooni and Ngusishi catchments. This analysis resulted in some significant indicators and levels of vulnerability to drought and flood which were critically confronted to farmers' own appraisal.

The analysis of land-use/ cover (LULC) change was based on the Ground Control Point (GCP) technique for Landsat imagery. Original satellite images obtained from the Direction for Resource Survey and Remote Sensing (DRSRS) had a small resolution of 182 km x 185 km. These Landsat images were adjusted to 30 m x 30 m ground resolution to fit to the geodetic accuracy using GCP. This helped matching the image to a particular cartographic projection and correct distortions due to relief influences (NASA 1999; NASA, NOAA and USGS 1999). The GCP process dealt with the transformation, radiometric and geometric corrections of orthorectified image data. It was the basic level for image interpretation and thematic analysis, after which came the classification system of LULC based on the image characteristics (tone, texture, pattern, shadow, association, shapes, sizes and site). A synoptic classification system was adopted in this study, which encompassed as many as twelve (12) units that could be identified. The latter included: (i) bare areas; (ii) water body; (iii) settlement; (iv) irrigated agriculture; (v) rainfed agriculture; (vi) rainfed shrub crop; (vii) shrubland; (viii) grassland; (ix) riverine vegetation; (x) closed trees; (xi) natural vegetation; (xii) mixed systems (rainfed agriculture/ shrubs; rainfed agriculture/ closed trees, etc.). This led to the generation of preliminary mapping units and descriptive statistical tables. A 'ground proofing' was carried out in each of the catchments under study during the periods of Focus Group Discussions (FGDs), to corroborate raster data and direct observations with views of local farmers in-situ. Hence, the analysis concluded with the interpretation of the results.

To evaluate hydro-climatic changes from 1971 to 2010 and predict the trend in 2030 a forecast of time series data for temperature (T°), precipitation (Prec.) and discharges (Q) was conducted using the "Seasonal Auto Regressive Integrated Moving Average" (SARIMA) model. The first stage of the prediction was to determine the "date" type, whether annual, quarterly or monthly. In this case, the quarterly period was selected with data arranged in JF, MAM, JJAS and OND seasons. The forecast period ranged from JF 1965 up to OND 2030, in most of the cases. The next step was to define the dependent variable and its predictors (or independent variables). Thence, the "Seasonal Auto Regressive Integrated Moving Average" (SARIMA) model was picked out as the criterion for smoothing the trend and forecasting (predicting) future values. The general linear ARIMA model is Auto-Regressive (AR) to order p (or P) and Moving Average (MA) to order q (or Q) and operates on the d^{th} (or D^{th}) difference of x_t to obtain stationary. It can be represented as polynomials of order p, q and p for regular series, and P, D and Q for seasonal series, respectively. It can be written in compact form as ARIMA (p,d,q) (P,D,Q) and expressed as below:

$$(1-B)^d(1-B^s)\,\varphi(B)\,\Phi(B)\,X_t = \theta(B)\,\Theta(B)a_t \qquad [3.4]$$

Where,

B is the backward shift operator defined as the lag operator

d and D are the order of the first differencing component for removing the trend (for regular series) and the seasonality (for seasonal series), respectively.

s is the period of the season (e.g. for quarterly seasons in a year $s = 4$)

$\varphi(B)$ and $\theta(B)$ are AR and MA operators for regular series of order p and q, respectively

$\Phi(B)$ and $\Theta(B)$ are AR and MA operators for the seasonal series of order P and Q, respectively

a_t is the model residual

For fitting the SARIMA model to the time series a three-stage ARIMA procedure was regularly followed. The ARIMA was associated with Ljung-Box statistic to enable stationarity in a record lag time (Abebe 2009). This procedure was used for both regular (annual) and seasonal series to test whether parameters corresponding to the coefficient of the moving average operator were significantly different from 0 at 95% confidence interval. The model building process used for ARIMA and Ljung-Box included Auto-Correlation Function (ACF), Partial Auto-Correlation Function (PACF), and the Residual Auto-Correlation Function (RACF). An automatic selection criterion was used to keep the model as simple as possible and at the same time provide a goodness of fit to the data series using the normalized Bayes Information Criterion (BIC). Finally, the following fit measures were utilized to assess the strengths of the estimated hydro-climatic models: (i) Stationary R-squared; (ii) R-squared; (iii) Root Mean Square Error (RMSE); (iv) Mean Absolute Percentage Error (MAPE); (v) Mean Absolute Error (MAE); and (vi) Maximum Absolute Error (MaxAE).

Trend-shift detection and occurrence likelihood statistical techniques were used to confirm (or infirm) any allegation of shifting trend in the variations of temperature, precipitation and discharge in the selected catchments. This was mainly achieved using predicted probability distributions for observed and expected hydro-climatic trends (PP-Plots). These results gave a broad idea on risks related to micro-climate and hydrological changes in the selected catchment areas.

The study also established a correlation between these predictions and hydro-climatic risks and geomorphologic impacts observed by farmers. The latter were considered as key factors leading to land degradation in the catchment and thus to vulnerability to water disasters (FAO 1995; Luwesi, Shisanya and Obando 2011). Finally, the computation of the water balance for the year 2010 and the 2011-2030 period confirmed these results on

Vulnerability-Capability Assessment (VCA) for water disasters in each catchment. The potential water balance for the year 2010 was computed according to the procedure suggested by Universität Siegen (2008) and LVBC and WWF-ESARPO (2010), as summarized in table 3.2 below.

Finally, the future water balance was simulated under Above Normal (ANOR), Normal (NOR), and Below Normal (BNOR) rainfall regimes. This exercise consisted of building scenarios in terms of "what if" propositions for different levels of catchment development and water management options based on hydro-climatic conditions previously forecasted for the 2011-2030 period. The Water Evaluation And Planning (WEAP) hydrological model was very useful to that effect (Hoff, Stacey and Droogers 2007). It enabled the design of contingency plans under risk and uncertainty considering three (3) plausible future developments for water supplies and resources in Ngusishi and Muooni catchments, namely: (i) "normal" (hereby referred to as NOR and based on the water supply turnover for April 2010); (ii) "very dry" (hereby referred to as BNOR and based on the water supply turnover for November 2009); and (iii) "very wet" (hereby referred to as ANOR and based on the water supply turnover for December 1981).

Table 3.2: Computational process for the potential water balance

Hydrological Variables	Key Data Required	Source
Groundwater	Groundwater storage	WRMA
Streamflow	Daily streamflow	WRMA
Sub-Total (1): *Potential Water Resource*		
Domestic Demand	-Population data -Consumption Per capita	Kenya National Bureau of Statistics (KNBS)
Livestock Demand	-Number of livestock -consumption per head	Ministry of Livestock and fisheries
Industrial Demand	-Number of industries - Consumption per unit	Ministry of trade and industry
Agricultural Demand	-Rainfall -Potential Evapo-Transpiration -Crop type -Area under crop -Total Irrigated Area - Irrigation water requirement	-Kenya Meteorological Department (KMD) -Ministry of Water and Irrigation/ WRMA
Sub-Total (2): *Potential Water Demand*		
Reserve water for Human needs	10% of Total Flow (1)	
Reserve water for ecological needs	20% of Total Flow (1)	
Sub-Total (3): *Environmental Base Flow*	*30% of Total Flow (1)*	
Potential Water Balance = (1)-[(2)+(3)]		

Source: Adapted after Allen et al. (2000), Universität Siegen (2008), LVBC and WWF (2010)

Depending on the hydro-climatologic characteristics of a catchment, water demands were to expand according to one or more of the five (5) following hypotheses : (i) a maintenance (or reference) scenario ("Business-As-Usual"); (ii) implementation of an environmental reserve flow (EFR); (iii) irrigation expansion; (iv) High/low population growth; and (v) high/low urbanization. The outcome of these predictions gave a signal on the need to implement alternative schemes for sustainable blue water supply in each catchment, including notably Green Water Saving (GWS) schemes.

3.6.3 Farmers' Innovative Strategies for Adaptation to Water Disasters

A descriptive statistics of the different types of GWS schemes measures was conducted to identify innovative methods used on the ground to mitigate water disasters and adapt agricultural water to climate change. The analysis mainly looked at Soil and Water Conservation (SWC) measures and hydro-political strategies in managing the scarce water resource. these included among others techniques and tools for: (i) harvest and storage of rainwater at household level (e.g. aerial or ground tanks); (ii) harvest and storage of rainwater at farm level (e.g. underground tanks); (iii) soil moisture conservation at farm level; (iv) control of soil erosion at farm level; (v) control of soil erosion at catchment level; (vi) storage of river flow at catchment level (e.g. weirs or small dams); (vii) protection of water quality and conservation of its quantity at catchment level; (viii) application of water allocation plans and metrics at catchment level; (ix) implementation of Payments for Watershed Services (PWS) at catchment level; and (x) implementation of ICT based solutions for sustainable water supply; and (xi) the implementation of participatory water management structures, institutions and knowledge systems.

3.6.4 Effectiveness of Farmers' GWS Schemes

This sub-section of the study measured both the capacity and ability of farmers, mainly downstream ones, to adapt to water disasters using Vulnerability-Capability Rating (VCR). It also assessed and evaluated the performance of catchment management institutions (for upstream farmers' capability). The study hypothesized that downstream farmers had the capacity to contend with their vulnerability to drought and flood in each respective catchment, while their upstream counterparts' adaptability largely depended on community organization and strategic plans for adaptation to and mitigation of water disasters. GWS schemes were hypothesized to be the most important implementation mechanisms in Kenyan ASALs. For that reason, a robust Performance Assessment and Evaluation (PAE) was conducted to test the effectiveness of farmers' adaptive strategies vis-à-vis water disasters' intensity and appraise their water institutions' performance. This performance assessment was achieved through an analysis of "Strengths, Weaknesses, Opportunities and Threats" (SWOT) of water management institutions operating in each catchment area. However, the performance evaluation of water management institutions was first conducted by farmers during the Focus Group Discussions (FGDs) following a "Performance based Management Rating" (PMR) system adapted after the Independent Evaluation Group (IEG) of the World Bank (2009) and Kazbekov *et al.* (2009). Farmers' appraisal was based on the contribution of water management institutions to the environmental sustainability, business success, economic development, social equity and institutional development of the catchment. Performance indicators and rating criteria applied during the PMR are set out in Annex 7.5. It shall however be noted the World Bank (2009) suggests six levels of performance evaluation, namely: (1) Highly Unsuccessful; (2) Unsuccessful; (3) Mostly Unsuccessful; (4) Mostly Successful; (5) Successful; and (6) Highly Successful (Table 3.3).

Table 3.4 presents an analogue rating system adopted from Kazbekov *et al.* (2009). This performance rating system was first applied to Water Users' Associations (WUA) in Kyrgyzstan. It assesses actual flows of water services delivery (measured or collected) against the targets or appropriate expected capacity set in the Sub-Catchment Management Plan (SCMP).

Table 3.3 Catchment management performance rating system

Rating Level	Business Success (1)	Economic Development (2)	Environmental Sustainability (3)	Social Equity (4)	Institutional Development (5)
1	Highly Unsuccessful	Highly Unsuccessful	No Actual Impact	No Actual Impact	No Actual Impact
2	Unsuccessful	Unsuccessful	No Opinion Possible	No Opinion Possible	No Opinion Possible
3	Mostly Unsuccessful	Mostly Unsuccessful	Unsatisfactory	Unsatisfactory	Unsatisfactory
4	Mostly Successful	Mostly Successful	Partly Satisfactory	Partly Satisfactory	Partly Satisfactory
5	Successful	Successful	Satisfactory	Satisfactory	Satisfactory
6	Highly Successful	Highly Successful	Excellent	Excellent	Excellent

Source: Adapted after World Bank (2009)

(1) Business Success indicates profitability exceeding an expected average rate

(2) Economic Development refers to productive investments to ensure business development beyond an expected average rate

(3) Environmental Sustainability is related to measures put in place to ensure Environmental conservation beyond an expected average rate

(4) Social Equity encompasses measures put in place to ensure both gender balance and fairness, and which exceed an expected average rate

(5) Institutional Development means both organizational culture and capacity of the organization to adapt to change estimated beyond an expected average rate

To validate this farmers' capability, an estimate of farmers' vulnerability to present and future water disasters was needed. It was given through formula [3.5] adapted after Ragab and Hamdy (2004) and Xie *et al.* (2011):

$$Climate\,Vulnerability\,Index\,(CVI) = Hazard * \frac{Risk\,Value}{capability} \quad [3.5]$$

The risk value was calculated using the following formula for drought risk value (Van Aalst 2006; Abebe 2009):

$$R_{i,t} = P_{i,t} \sum_{j=1}^{n} w_j f_{i,j,t} \quad [3.6]$$

Where,
$R_{i,t}$ the risk in sub-catchment i at time t
$P_{i,t}$ the probability of drought incident in sub-catchment i at time t
w_j the weight of factor j
$f_{i,j,t}$ the factor j in sub-catchment i at time t (e.g. density of population, forest, stream or road; slope of the catchment)
Table 3.4 Evaluation of the performance of a catchment management

Indicator	Good	Fair	Poor
Economic value (1)	95-100%	60-94%	Less than 60%
Effectiveness (2)	Above 90%	50–90%	Less than 50%
Efficiency (3)	Above 80%	40-80%	Less than 40%
Accountability (4)	Above 70%	30–70%	Less than 30%
Social equity (5)	Above 60%	20–60%	Less than 20%

Source: Adopted from Kazbekov et al. (2009)
(1) Economic Value refers to water cost in relation to alternatives
(2) Effectiveness indicates the outcome of the implementation of SCMPs
(3) Efficiency is the ratio of costs to benefits
(4) Accountability is rated as ability to report results and assume their outcome
(5) Social Equity encompasses both gender balance and fairness in allocation

The catchment's capability index share (CI) for a specific climatic hazard (drought or flood) was computed as follows:

$$Climate\ Capability\ Index\ \ (CCI_{tl}) = \frac{TCC_{tkl} * (1 - TCI_{tkl})}{1 + R_{tl}} \quad [3.7]$$

Where,
TCC_{tkl} the total catchment's capacity under l climatic event (flood or drought) computed as the geometric mean of the farming community's capacity in the environmental, social and economic sectors (k) at a certain time (t); and
TCI_{tkl} the total climate impact under l climate event (flood or drought) computed as the geometric mean of impacts in the environmental, social and economic sectors (k) at a certain time (t).
Based on the results from the SWOT analysis, the VCA and other survey results, the researcher validated the farming community's PMR. Ultimately, the effectiveness of farmers' GWS schemes in each catchment was estimated according to the rating scale below (Table 3.5).

Table 3.5 A scale for rating GWS schemes' effectiveness

Vulnerability (Climate Vulnerability Index)	Capability (GWS schemes' Adaptive Capability Index): Poor (25% & below)	Fair (26% -75%)	Good (76% & above)
Frivolous (Below 5%)	Poor	Fair	Good
Minor (5%-27%)	Poor	Fair	Fair
Moderate (28%-75%)	Poor	Fair	Fair
High (76% - 95%)	Poor	Poor	Fair
Severe (Above 95%)	Poor	Poor	Poor

Source: Compiled from Downing and Patwardhan (2005) Kazbekov et al. (2009) and Xie et al. (2011)

3.6.5 GWS Schemes' Efficiency and Ability for Cost Recovery

The study used hydro-economic inventory models to compute efficiency levels of green water to be saved in terms of Economic Order Quantity (EOQ), Limit Average Cost (LAC) and Minimum Efficient Scale (MES) of farming water demand and supply (Harvey 1985; Hardwick, Khan and Langmead 1994; Luwesi 2010). The EOQ was the optimized farming water quantity under Above Normal (ANOR) rainfall regime, while the LAC and MES were its counterparts under a Normal (NOR) and Below Normal (BNOR) rainfall regimes, respectively (Table 3.6).

Table 3.6 Hydro-economic inventory of GWS schemes' efficiency

Rainfall Regime	Total Cost of Farming Water: Cost of Crop water demand		External Costs		Optimum (First Order Conditions)
Normal (NOR)	Cost of Transaction	Opportunity Cost			Limit Average Cost (LAC) $\bar{r}_{no} = \sqrt{2q / Q}$ [3.8]
Above Normal (ANOR)	Cost of Transaction	Opportunity Cost	Saving Cost		Economic Order Quantity (EOQ) $\bar{r}_{an} = \sqrt{2q \ /(2Q-q)}$ [3.9]
Below Normal (BNOR)	Cost of Transaction	Opportunity Cost		Shortage Cost	Minimum Efficient Scale (MES) [3.10] $\bar{r}_{bn} = \sqrt{2}$

Source: Luwesi (2010)

Optima levels of green water to be saved (EOQ, LAC and MES) related costs and incomes in farming were compared to their blue water counterparts to induct farmers' efficiency in implementing GWS schemes under drought and flood scenarios. These computations were based on the Future Value (FV) rating curves derived from linear programming projections of the Water Evaluation and Planning (WEAP) system for the period 2010 to 2030, which were predicted in MS Excel spreadsheet (Lòpez-Baldovin, Gutiérrez-Martin and Berbel 2006; Luwesi, Shisanya and Obando 2012).

Optimum farming water productivities were computed as the ratio of farming incomes expected under EOQ, LAC or MES scenarios to their related optimized farming water supply or demand, irrespective of the farming scale. Scale Efficiency (SE) was computed under ANOR and BNOR as the ratio of Technical Efficiency (TE) obtained under assumption of a LAC to the one obtained under assumption of an EOQ [3.11] and of a MES [3.12], respectively.

$$SE_{an} = \frac{TE_{LAC}}{TE_{EOQ}} \qquad [3.11]$$

$$SE_{bn} = \frac{TE_{LAC}}{TE_{MES}} \qquad [3.12]$$

The Technical Efficiency (TE) under each scenario (*i*) was estimated as the ratio of the incremental optimum green water demand (ΔQ_d^*) to the increment of the optimum blue water supply (ΔW_s^*) (Formula [3.13]).

$$TE = \frac{\Delta Q_{di}^{*}}{\Delta W_{si}^{*}} \qquad [3.13]$$

The incremental optimum green water demand (ΔQ_d^*) was derived from the optimized turnover of farming water demand ($\bar{r}^{GWS}$), where a GWS scheme exists. The increment of the optimum blue water volume (ΔW_s^*) was interpolated from the optimized turnover of farming water supply ($\bar{r}^{BWS}$), where only a BWS project exists. The TE was hence calculated in accordance with formula [3.15]:

$$TE = \frac{\bar{r}_{i\ GWS}}{\bar{r}_{i\ BWS}} \qquad [3.15]$$

A measure of in-put oriented Allocative Efficiency (AE) was residually obtained from the ratio of the total Cost Efficiency (CE) to the Technical Efficiency (TE) under ANOR [3.16] or BNOR scenario [3.17].

$$AE_{an} = \frac{CE}{TE_{EOQ}} \qquad [3.16]$$

$$AE_{bn} = \frac{CE}{TE_{MES}} \qquad [3.17]$$

The total Cost Efficiency (CE) was derived from the ratio of the Marginal Social Benefit (MSB) by the Marginal Social Cost (MSC) of farming water supply or demand. The MSB was calculated as the incremental expected revenue from optimized water supply (ΔR_w^*) by the increment of the available total water volume (ΔW), the MSC being the incremental optimized cost of water supply (ΔTC^*_s) by the increment of the available total water volume (ΔW). Consequently, the CE was simply reduced to the ratio of incremental expected revenue from optimized water supply (ΔR_w^*) to the incremental optimized cost of water supply (ΔTC^*_s) (Formula [3.18]).

$$CE = \frac{\Delta R_{W\,i}^{*}}{\Delta TC_{si}^{*}} \qquad [3.18]$$

Finally, the ability of GWS schemes to achieve cost recovery was estimated using the traditional Cost-Benefit Analysis (CBA) (Howe 1971; Anandajayasekeram et al. 2004). The latter involved an estimate of the Present Value (PV) and Future Value (FV) per type of GWS schemes and Blue Water Supply (BWS) projects retained in the analysis. A projection of the FV of costs, revenues and benefits over a period of 20 years was done based on the WEAP system results and the outcomes of the major BWS project or GWS scheme retained for each catchment. Thence, an estimate of the PV was generated for the GWS scheme and BWS project by discounting the FV values, while the Net Present Value (NPV) was calculated from the difference between the FV and the PV. Finally, a Benefit-Cost Ratio (BCR) was computed as the ratio of the sum of NPV (Benefits) to the sum of NPV (Costs). The latter determined the profitability of GWS schemes and BWS project retained by the analysis. A comparison between the two investment shed light on their economic viability. It served as a basis for adoption of these schemes by farmers and catchment management authorities.

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Chapter 4. Findings and Discussion

4.1 Analysis of Factors Leading to Farmers' Vulnerability

4.1.1 Introduction

Most arid and semi-arid catchments of Kenya are exposed to climate variability and change as well as other environmental and anthropogenic changes (Hulme *et al.* 2005; Ngonzo *et al.* 2010; IPCC 2012). WSP (2011) notably pointed out to demographic expansion and agricultural expansion in Kenya which has triggered high siltation of drainage systems and water pollution through deforestation, use of agro-chemicals and waste disposal (Mogaka *et al.* 2006). To what extent have these factors enhanced the vulnerability of farmers living in Ngusishi and Muooni catchments to water disasters? This study critically looked at the impact of the micro-climate variability and change, Land Use and Land Cover (LULC) change, and the future water balance, on the socio-economic exposure and response of farmers to water disasters.

4.1.2 Micro-Climate Variability and Change

Table 4.1 Seasonal hydro-climatic forecast in the selected catchments[1]

Statistics	Ngusishi			Muooni		
	Temp [°C]	Prec [mm]	Disch [m^3/s]	Temp [°C]	Prec [mm]	Disch [m^3/s]
SARIMA	(102)(011)	(003)(011)	(013)(011)	(003)(011)	(002)(101)	(102)(011)
Constant (a)	26.759	138.919	2.166	22.05	55.553	6.657
Estimate (b)	0.004	0.035	-0.007	0.003	-0.029	-0.012
SE (a)	0.014	0.11	0.020	0.003	0.289	0.314
SE (b)	0.000	0.001	0.000	0.0007	0.064	0.065
t stat (a)	3.002	3.001	142.613	61.383	79.643	7.176
t stat (b)	28.060	28.257	-27.711	9.078	-3.355	-4.795
Sig. (a)	0.000	0.000	0.000	0.000	0.000	0.000
Sig. (a)	0.000	0.000	0.000	0.000	0.000	0.000
MAPE	1.524	22.753	44.624	2.131	27.97	39.14
ACF	0.026	0.040	-0.128	-0.27	0.23	-0.025
R^2	0.840	0.842	0.837	0.863	0.863	0.667

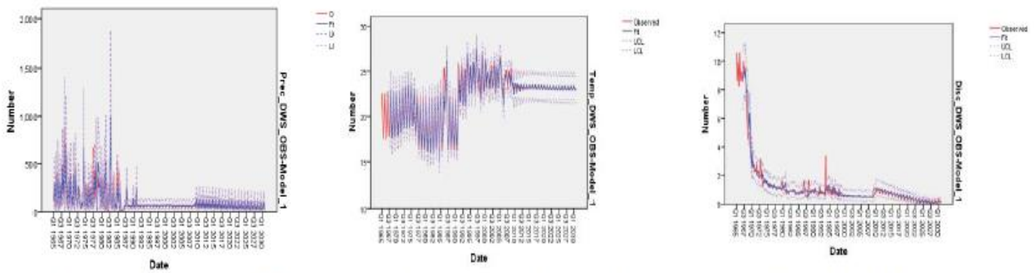
Source: Fieldwork (Luwesi and Shisanya 2017)

[1] forecast per quarter in Ngusishi and Muooni catchments

In general, results of this study show an increase in mean seasonal and annual temperatures in the selected catchments. Whereas Muooni catchment experiences decreasing trend of rainfall and river discharges, Ngisishi expects higher rainfall followed by a decrease of river discharges (Table 4.1).

Table 4.1 predicts mean temperatures for Ngusishi catchment reveal increases of 1.6^{0}C in a century (R^2 = 0.84), which will be accompanied by increased annual rainfall of about 14 mm per century (R^2 = 0.842), and a level off of river discharge of 0.007 m^3/s (R^2 = 0.837). Muooni catchment in turn will experience an increase of about 1.2^{0}C of mean temperatures per century (R^2 = 0.863) with subsequent decreases in mean rainfall of about 12 mm per century (R^2 = 0.863) and lowering river discharge of 0.012 m^3/s downstream (R^2 = 0.667). These forecasts are displayed in Figure 4.1 below.

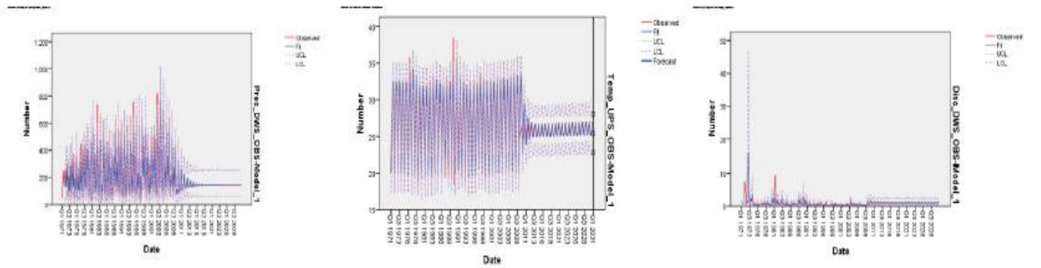
The allegation of shifting trend in the behaviour of these hydro-climatic variables needed to be confirmed using trend detection techniques. In effect, the cumulative probability for observed temperature was remarkably different from expected one in Muooni rather than Ngusishi catchment (Fig. 4.2). Observed cumulative probabilities were higher toward the upper percentiles and lesser toward the lower percentiles, while their expected counterparts were higher in the lower percentiles and lesser in the upper percentiles for all the selected variables, both upstream and downstream. There were no significant change rather than variability in the intensity of the precipitation and discharge in both catchments as well as temperature in Ngusishi catchment. This may explain the high deviations in temperature and discharge were observed during almost all the four (4) seasons, except for precipitations, which presented high variations during the long dry (JJAS) and short rainy (OND) seasons alone. Hence, the likelihood of occurrence of flash floods in Muooni as well as in Ngusishi could not be simply ruled out based on hydro-climatic predictions



Observed and Expected **Precipitation_Muooni**

Observed and Expected **Temperature_Muooni**

Observed and Expected **Discharge_Muooni**

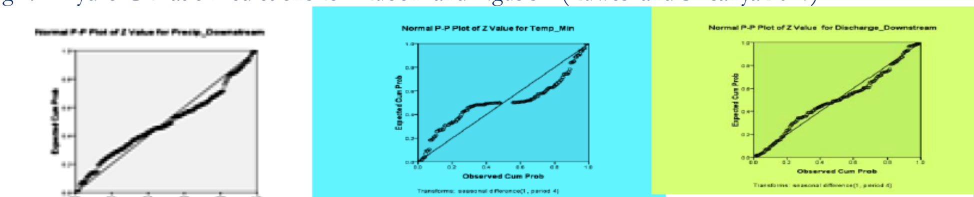


Observed and Expected **Precipitation_Ngusishi**

Observed and Expected **Temperature_Ngusishi**

Observed and Expected **Discharge_Ngusishi**

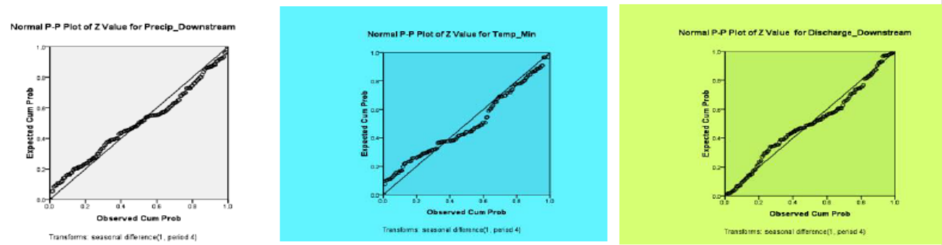
Fig. 4.1 Hydro-Climatic Predictions for Muooni and Ngusishi (Luwesi and Shisanya 2017)



Observed and expected probability for Precipitation_Ngusishi

Observed and expected probability for Temperature_Ngusishi

Observed and expected probability for Discharge_Ngusishi



Observed and expected probability for Precipitation_Muooni

Observed and expected probability for Temperature_Muooni

Observed and expected probability for Discharge_Muooni

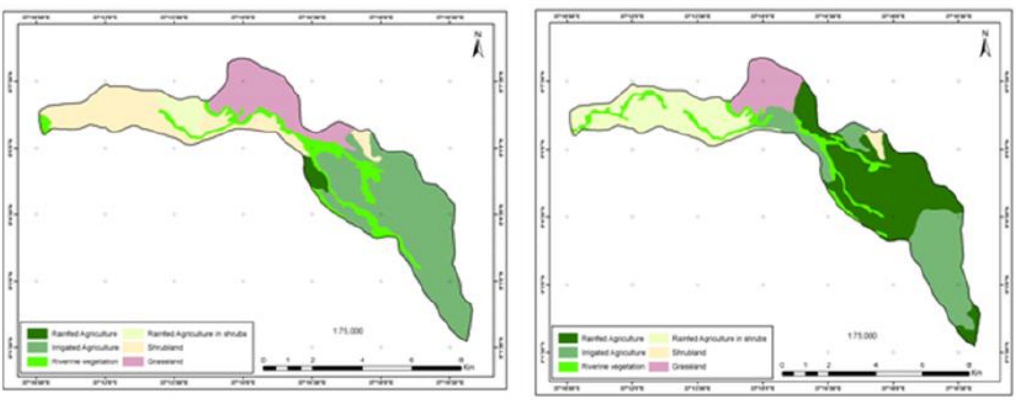
Fig. 4.2 PP-Plots for Climatic Trend-Shift in Ngusishi and Muooni (Luwesi and Shisanya 2017)

As a matter of fact, 53.4% of farmers in Ngusishi and 35.9% in Muooni declared that their catchment areas are likely to experience acute droughts during a La Niña event, while only 6.9% and 1.1% expected an El Niño flood and 5.0% and 29.6% acknowledged high rainfall variability in Ngusishi and Muooni, respectively. Also, 24.6% and 8.4% of farmers in Ngusishi, and 19.8% and 5.1% in Muooni recognized the effects of the global warming and high wind pressure on their catchment degradation and water stress. Besides drought and flood, other hydro-geomorphologic risks of these climatic changes randomly occurring in Ngusishi and Muooni (respectively) included the siltation of drainage systems and reservoirs (20.3% and 26.0%), wildfire and deforestation in the catchment (13.3% and 4.1%), gullies (10.3% and 3.7%), and landslides in the catchment (6.6% and 4.0%), to name but a few. These externalities to farming activities were obstructing farmers' efforts to conserve water and soil in their respective catchment areas (Universität Siegen 2006; Kiteme et al. 2008; Luwesi, Shisanya and Obando 2011). The following sub-sections shed more light on Land Use Land Cover (LULC) changes assessed in the study areas.

4.1.3 Land Use Land Cover Change Assessment

The assessment of Land-Use/ Land Cover (LULC) changes clearly emphasized a drastic depletion of natural vegetations, shrubland, grassland and riverine vegetation of about 62% in Ngusishi catchment (from 2,324.83 hectares in 1976 to 883.7 hectares in 2007), whereas the analysis of satellite images for a similar period revealed a re-greening of Muooni catchment of about 19.4% (from 1,191.65 hectares in 1976 to 1,422.99 hectares in 2010). The latter was mainly explained by the effects of agro-forestry within what seemed to be like a "natural forest" (though man-made) from that vantage view (Tiffen, Mortimore and Gichuki 1994).

Results of spatial analysis of Landsat imagery conducted in Ngusishi catchment show that the natural vegetation of this catchment has experienced a drastic downfall for the period 1976-2007, with 94.7% decrease in scrubland, 39.5% in grassland and 29.9% fall in riverine vegetation (Figure 4.3).



1976 2007

Fig.4.3 Different Land-Use/ Cover Types in Ngusishi (1976-2007)
(Analysis by Luwesi and Shisanya 2017 based Landsat images acquired from DSRSS)

The total area occupied by natural vegetations has been reduced from 2,324.83 hectares (1976) to 883.7 hectares (2007). This was mainly explained by the expansion of rainfed agriculture and rainfed shrub crops (inclusive of floricultural species and likely "Miraa" shrub) by 836.1% with a cumulative area of 2,575.79 hectares in 2007 (against an area 275.17 ha in 1976). Consequently, the irrigated agriculture, which accounted for 1981.94 hectares in the year 1976, has been gradually decreasing to an annual rate of 1.4% in terms of farming area.

In terms of cropping patterns, Ngusishi farmers tend to specialize in one major seasonal crop, mainly maize (97.1%) or French beans (42.9%), and a subsidiary one such as Irish potatoe (14.3%) and sweet potatoe (11.4%). These farmers did not show much interest in multiple cropping of perennial trees, except for banana (20%), avocado (14.3%), grevilia and other shrubs (14.3%) and coffee (11.7%), to some extent (Table 4.2).

Table 4.2 Cropping patterns in Ngusishi catchment

Main perennial crops	% of farms surveyed	Main seasonal crops	% of farms surveyed
Coffee	11.4%	Maize	97.1%
Banana	20.0%	Irish Potatoes	14.3%
Sugarcane	8.6%	Sweet Potatoes	11.4%
Avocado	14.3%	Cassava	8.6%
Mango	2.9%	Cow Peas	5.7%
Guava	2.9%	Finger Millets	2.9%
Eucalyptus	8.6%	Sorghum	0.0%
Grevilia	14.3%	Groundnuts	2.9%
Miraa	8.6%	French Beans	42.9%
Other perennial crops	14.3%	Other seasonal crops	8.6%

Source: Luwesi and Shisanya (2017)

Even though maize cropping was widespread in the lower zone of Ngusishi catchment, soil moisture measured within 10 cm from the topsoil during the long rainy season (from March to May) of the year 2011 show that such cropping cannot, in most of the cases, sustain below a soil moisture value of 0.25 m^3/m^3. Yet, the minimum soil moisture measured downstream Ngusishi catchment was 0.001 m^3/m^3 with a maximum of 0.169 m^3/m^3 and a mean of 0.107 m^3/m^3. Therefore, soil moisture variations and the cropping patterns observed in this catchment would have lasting effects on agriculture sustainability in the course of climate change.

In contrast, soil moisture measurement conducted downstream Muooni presented maximum values beyond 0.60 m^3/m^3 with at least 25% of soil sample measuring above 0.20 m^3/m^3. Yet, most farmers sustain their livelihoods through intercropping of both perennial and seasonal crops, owing to the devastating effects of drought (Table 4.3). Maize cropping remains one of the most important agricultural activity in Muooni catchment (75% of farms surveyed). Other major seasonal crops encompass cow peas (93.2%), cassava (70.5%), French beans and other seasonal crops (63.6%), sweet potatoe (59.1%), and Irish potatoe (47.7%). Banana (77.2%), avocado (75.4%), coffee (63.2%), mango (42.1%), sugarcane (36.8%) and guava (26.3%) remain among key perennial crops associated to seasonal ones in Muooni catchment.

Table 4.3 Cropping patterns in Muooni catchment

Main seasonal crops	% of farms surveyed	Main perennial crops	% of farms surveyed
Maize	75.0%	Coffee	63.2%
Irish Potatoes	47.7%	Banana	77.2%
Sweet Potatoes	59.1%	Sugarcane	36.8%
Cassava	70.5%	Avocado	75.4%
Cow Peas	93.2%	Mango	42.1%
Finger Millets	11.4%	Guava	26.3%
Sorghum	6.8%	Eucalyptus	54.4%
Groundnuts	11.4%	Grevilia	33.3%
French Beans	63.6%	Miraa	0.0%
Other seasonal crops	63.6%	Other perennial crops	14.0%

Source: Fieldwork (Luwesi and Shisanya 2017)

From a satellite vantage view, most of these land use activities in Muooni catchment appear to be like rainfed agriculture within a "natural forest", though man-made. Though the practice of agro-forestry has slightly decreased by 4.3% (from 218.66 hectares in 1976 to 209.19 hectares in 2010), it represented 67.1% of the total catchment area in 2010. Also, rainfed agriculture outside forest conservation occupied an important space of 228.32 hectares in 1976 but has recorded 86% increase in the 2010. Finally, there has been a construction of a dam going on from April 1986 to June 1987, which occupied 12.24 hectares of land in 1987 and has lost about 13.9% of its coverage area in 2010. Figure 4.4 illustrates the extent of variation of these spatial units in Muooni catchment. It clearly indicates that reforestation is actually widespread in the catchment to the point of re-greening it to a similar status like a "natural forest" (Tiffen, Mortimore and Gichuki 1994; Tiffen and Mortimore 2002).

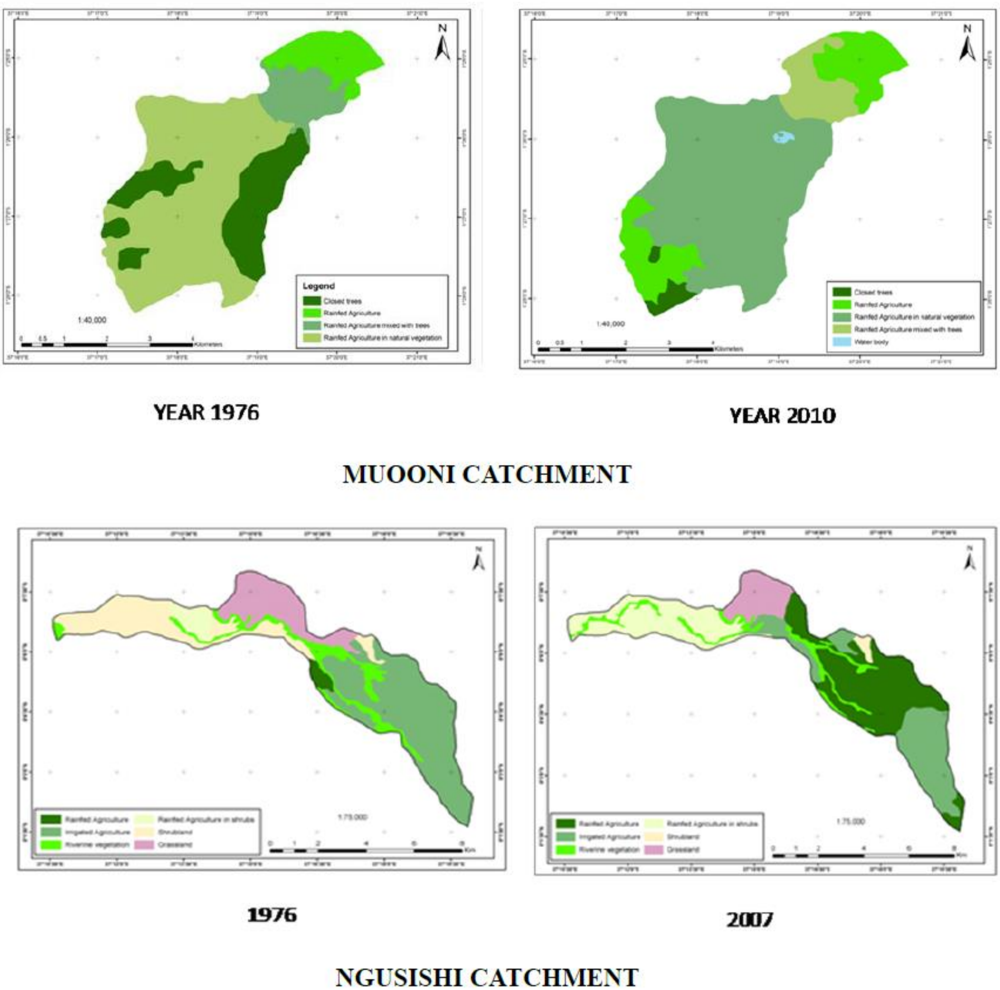


Fig. 4.4 Different Land-Use/ Cover Types in Muooni Catchment (1976-2010)
(Analysis by Luwesi and Shisanya 2017 based on Landsat imagery from DRSRS)

Nonetheless, farming activities are said to be endogenous factors leading to land degradation and water stress in both Ngusishi and Muooni catchments (Kiteme *et al.* 2008; Luwesi, Shisanya and Obando 2012). The most intriguing fact arising from the analysis is the cropping of more than 5 major perennial crops in Muooni catchment, generally on small land of less than ½ hectare. The widespread planting of water unfriendly exotic trees such as eucalyptus (54.4 and 8.6% in Muooni and Ngusishi, respectively) and grevilia (33 and 14.3%) may be a threat to the sustainability of agriculture in such ecosystems. Moreover, most farms are exposed to soil erosion problems and mass movements, which have direct effect on water and land conservation both catchments.

Farmers indisputably interpreted soil erosion as the occurrence in their farmlands of sheets and rills (75.4 and 55.4% in Ngusishi and Muooni, respectively) and gullies (13.1 and 4.0%), while mass movements mainly implied landslides associated with gullies in the farmland (4.9 and 4.0%) and encroachment on wetland by big farms (16.7 and 8.2%) (Table 4.4).

Table 4.4 Key farming impacts on water and land in the selected catchments

Hydro-geomorphologic impacts	Frequency (%)	
	Ngusishi	Muooni
Stagnant water	18	5.0
Sheets/ rills on farmland	75.4	55.4
Encroachment on wetland	16.7	8.2
Sand harvesting potholes/ quarries on farmland	3.3	4.0
Gullies on farmland	13.1	4.0
Landslides on farmland	1.6	0.0
Landslides associated to gullies on farmland	4.9	4.0
Eucalyptus water over-abstraction	21.7	32.7

Source: Fieldwork (Luwesi and Shisanya 2017)

These farming impacts were principally explained by footpaths occasioned by livestock mobility in the catchment (93.4 and 76.2% in Ngusishi and Muooni, respectively), subsistence cultivation with limited irrigation 75.4 and 22.8%) and subsistence cultivation without irrigation (14.8% and 54.5%) (Table 4.5).

Table 4.5 Key land use activities associated with catchment degradation

Land-use activities	Frequency (%)		Type of Impact
	Ngusishi	Muooni	
Fish farming	1.6	18.8	No impact
Tree planting	59.0	88.1	Sheets
Intensive cultivation using water pumps/ tanks	11.5	18.8	Sheets/ Rills
Subsistence cultivation with limited irrigation	75.4	22.8	Sheets/ Rills
Subsistence cultivation without irrigation	14.8	54.5	Sheets/ Rills/ Gullies
Livestock keeping with some cultivation	93.4	76.2	Sheets/ Rills/ Gullies
Livestock keeping without cultivation	0.0	3.0	Sheets/ Rills/ Gullies/ Landslides
Eucalyptus tree planting	8.6	54.4	Water over-abstraction

Source: Fieldwork (Luwesi and Shisanya 2017)

4.1.4 Prediction of the Potential Water Balance by the year 2030

The results presented above have clearly revealed that climate change and human-induced activities are exogenous and endogenous factors leading to land degradation and water stress in the catchments under study. This sub-section focuses on the prediction of the potential water balance in the year 2010 and 2030 in Ngusishi and Muooni catchments. The computation of water demand and water resources was based on projected growth and development expected by the year 2030 in the three Catchments, namely Ngusishi and Muooni (Table 4.6). These projections took into consideration some demographic and economic data. These encompassed factors such as population per capita, population growth rate, number of households, and size of household, These population data enabled the prediction economic variables like the per capita Gross Domestic Product (GDP), average income per household (US$), and income growth rate, cost of water supply and water demand, and the expected development or level of urbanization. Finally, the catchment hydrology was taken into consideration. The water supply turnover was simulated under drought scenario (based on rainfall data for Nov. 2009) and flood scenario (based on rainfall data for Dec. 1981) to enable the simulation of the water balance from specific water demand sites and allocation priorities retained in the WEAP model for each catchment (Table 4.7).

Table 4.6 Projected growth and development in the selected catchments

Variables	Ngusishi		Muooni	
	2010	2011-2030[1]	2010	2011-2030[1]
Gross Domestic Product (GDP) per capita (US$)	582.72	568.26	481.09	447.249
Population (Number of People)	5,049	6,055	20,425	28,582
Number of Households	1,685	2,021	4,639.30	6,491.98
Household Size (Number of People)	3.00	3.00	4.40	4.40
Average Income per household (US$)	1,745.90	1,702.57	2,118.06	1,969.07
Annual Population Growth Rate (%)	1.70	1.70	3.1	3.1
Income Growth Rate (%)	-0.24	-0.24	-0.7	-0.7
Cost of water supply (US$/m^3)	0.0625	0.0629	1.849	1.870
Cost of water demand (US$/m^3)	0.0828	0.0845	8.378	8.598
Development projections (Level of Urbanization)	10	6.5	6	3.873
Supply turnover under drought scenario (Nov. 2009 ratio)	0.063	0.063	0.050	0.050
Cost of water supply under drought scenario (US$/m^3)	1.00	1.0064	12.424	12.57
Cost of water demand under drought scenario (US$/m^3)	1.3244	1.3514	56.30	57.783
Supply turnover under flood scenario (Dec. 1981 ratio)	3.350	3.350	1.826	1.826
Cost of water supply under flood scenario (US$/m^3)	0.0187	0.0188	1.012	1.024
Cost of water demand under flood scenario (US$/m^3)	0.0247	0.0252	4.587	4.708

Source: Fieldwork (Luwesi and Shisanya 2017)

[1] Annual average

Table 4.7 Water demand sites and allocation priorities in the study areas

Variable	Ngusishi		Muooni	
	2010	2011-2030	2010	2011-2030
Domestic urban water demand (priority ranging from 1 to 99)	5.00	5.00	20.00	20.00
Domestic rural water demand (priority ranging from 1 to 99)	15.00	15.00	25.00	25.00
Industrial water demand (priority ranging from 1 to 99)	5.00	5.00	10.00	10.00
Agricultural water demand (priority ranging from 1 to 99)	70.00	70.00	40.00	40.00
Transmission links from supply and resource sites to demand sites (%)	5.00	5.00	5.00	5.00
Demand site monthly share variation (%)	8.33	8.33	11.4	11.4
Demand sites loss rate (%)	20.00	20.00	25.00	25.00

Source: Fieldwork (Luwesi and Shisanya 2017)

Table 4.8 Computed water demand and balance in the study areas (FY 2010)

Variable	Ngusishi	Muooni
Total Water Demand	41,084.045 m³/day	26,752.470 m³/day
Upstream:	32,579.615 m³/day	10,272.949 m³/day
Downstream	8,504.400 m³/day	16,479.521 m³/day
Domestic/ Institutional Demand	2,260.15 m³/day	1,504,030 m³/day
Schools	-	230.380 m³/day
Health Centres	32.50 m³/day	87.500 m³/day
Water Projects	2,201.65 m³/day	996.150 m³/day
Factories	26.00 m³/day	190.000 m³/day
Livestock Demand	65.005 m³/day	340.272 m³/day
Upstream:	29.252 m³/day	153.122 m³/day
Downstream	35.753 m³/day	187.150 m³/day
Agricultural Demand	38,758.89 m³/day	23,404.140 m³/day
Upstream:	30,735.80 m³/day	8,987.190 m³/day
Downstream	8,023.09 m³/day	14,416.950 m³/day
TOTAL WATER RESOURCE	13,323.460 m³/day	27,759.610 m³/day
Upstream:	7,137.060 m³/day	8,107.710 m³/day
Downstream	6,186.400 m³/day	19,651.900 m³/day
TOTAL WATER BALANCE 2010	-27,760.585 m³/day	+1,007.140 m³/day
Upstream:	-25,442.585 m³/day	-2,165.239 m³/day
Downstream	-2,318.000 m³/day	+3,172.379 m³/day

Source: Fieldwork (Luwesi and Shisanya 2017)

Findings from the analysis show a deficit of 27,760.59 m^3 /day in Ngusishi catchment in 2010, the upper sub-catchment recording 25,442.59 m^3 deficit /day, and the lower one 2,318 m^3 deficit/day. In contrast, the potential water balance in Muooni catchment resulted into a surplus of +1,007.14 m^3 /day representing 3.63% of the available water resource. Upstream farmers recorded unmet demands of 2,165.24 m^3 /day while their downstream counterparts enjoyed a surplus of 3,172.38 m^3 /day (Table 4.8).
In fact, the hydrological survey conducted in Muooni catchment shows that more than 66% of the total daily water demand (of 3,008.06 m^3) for domestic and institutional use is abstracted by water projects operating therein. Schools, health centres and local industries were contented with about 15.3%, 5.8% and 12.6%, respectively. Daily water consumption by livestock was estimated to 425.34 m^3 upstream and 519.86 m^3 downstream, goats and cattle consuming about 70% of the total demand. Finally, daily water demand for irrigation averaged 26,752.47 m^3, upstream and downstream farmers requiring 38.4% and 60.6% of the catchment's irrigation water demand, respectively, in the year 2010. In total, upstream farmers needed 10,272.95 m^3/day while downstream ones required 16,479.52 m^3/day.
Regarding Ngusishi catchment, the total household water demand amounted to 2,260.15 m^3/day. Ngusishi Water Resource Users' Association was abstracting 2,201.65 m^3/day, while the remaining 2.6% was allocated to health centres (1.4%) and mini factories (1.2%). Finally, the computed water demand for agriculture averaged

1,232,521.3 m^3 /month, upstream farmers abstracting about 79.3% and downstream ones 20.7%. In total, water demands upstream and downstream represented 32,579.645.7 and 8,504.4 m^3 /day, respectively. Water demand by mini bakeries amounted to 1 m^3/day while restaurants and hotels ordered about 25 m^3 /day, thus making a total of 26 m^3 /day. Water demand for livestock was estimated to 29,252 and 35,752 m^3 in 2010 for upstream and downstream, respectively. If an environmental Flow Reserve (EFR) of 30% was to be enforced, both catchments would have recorded total deficits in the year 2010. Likewise, none of them is expected to sustain a surplus by the year 2030 and in the long run.

In effect, the simulation of the future water balance in Ngusishi catchment disclosed only one best scenario for farmers, the ANOR one. Under this scenario, the catchment's balance sheet displays a surplus from 2011 up to 2017 (Figure 4.5). In effect, under the ANOR scenario, the total water demand in 2011 was valued to 13,394.926 m^3/day, upstream farmers abstracting 10,675.756 m^3 daily while downstream ones being contented with 2,719.170 m^3/day. This water demand was predicted to peak at 41,648.238 m^3/day in 2030, allocational measures remaining practically the same as in 2011. This upward rise was justified by irrigation expansion, representing 96.8% of the total demand, and mainly by upstream farmers. Yet, the total resource available was predicted to decrease from 37,073.14 m^3/day (in 2011) to 12,810.18 m^3/day (in 2030), thus leading to a deficit of 69.2% of the predicted demand (which represent 225.1% of the available resource in 2030).

Table 4.9 Future water balance in Ngusishi under BNOR scenario

Area	Resource	Demand	Balance	%Resource /Demand	%Balance /Demand	%Balance /Resources
			2011			
Upstream	293.78	35,763.783	(35,470.00)	0.82	(99.18%)	(12,074)
Downstream	456.36	9,109.22	(8,652.86)	5.01	(94.99%)	(1,896)
Catchment	750.14	44,873.002	(44,122.86)	1.67	(98.33%)	(5,882)
			2030			
Upstream	280.67	111,198.714	(110,918.05)	0.25	(99.75%)	(39,519)
Downstream	436.00	28,322.88	(27,886.89)	1.54	(98.46%)	(6,396)
Catchment	716.66	139,521.598	(138,804.94)	0.51	(99.49%)	(19,368)

Source: Fieldwork (Luwesi and Shisanya 2017)

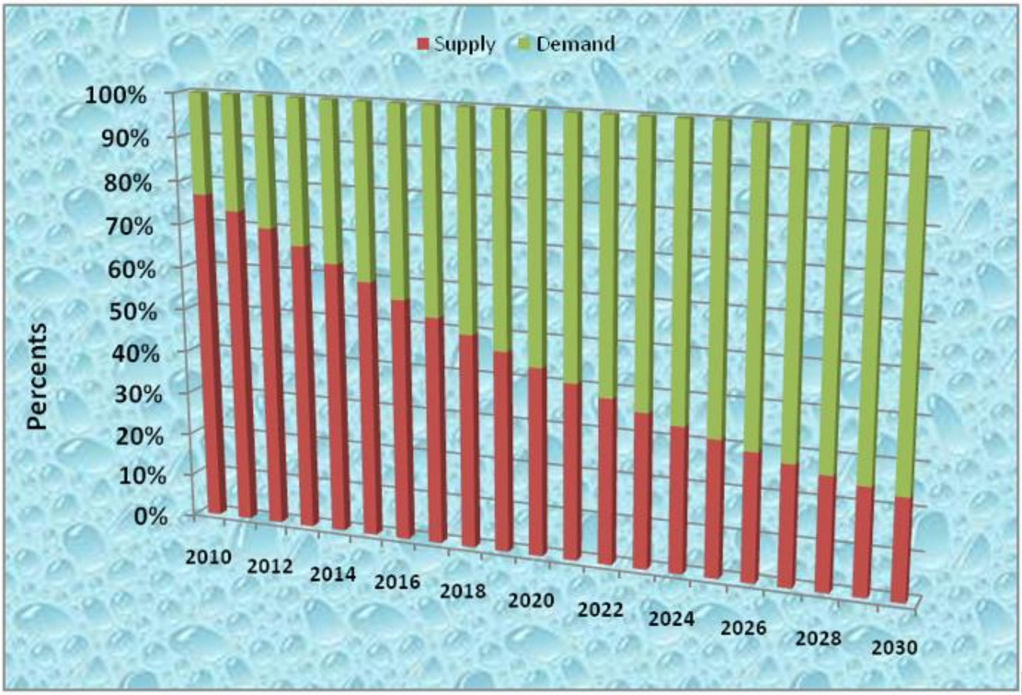


Fig. 4.5 Water demand and supply in Ngusishi under the ANOR (Luwesi and Shisanya 2017)

In view of the above results, normal rainfall regime (NOR scenario) and below normal rainfall regime (BNOR scenario) were likely to be catastrophic, with deficits ranging from 70.4 to 90.8% of the available resource under the NOR scenario for 2011 and 2030, respectively (Table 4.9), and from 98.3% in 2011 to 99.5% in 2030 under the BNOR scenario (Figure 4.6).

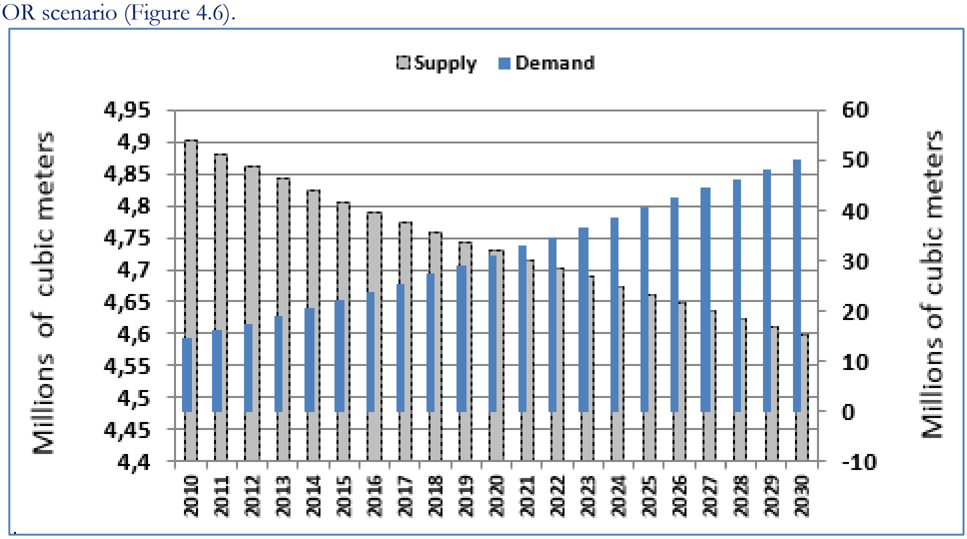


Fig. 4.6 Unmet Water Demand under the NOR Scenario in Ngusishi (Luwesi and Shisanya 2017)

Facing such an acute water stress, if an environmental flow reserve (EFR) would not be imposed by water authorities, Ngusishi would likely experience a total water scarcity accompanied by an acute environmental disaster.

Just like for Ngusishi, the simulated future water balance in Muooni revealed that this catchment will enjoy good harvests and water security under above normal rainfall regime (ANOR scenario). The water balance upstream and downstream will represent about 73.3% and 71.7% of the total demand expressed by local stakeholders (Table 4.10). But this fair situation will not last longer since water deficits are expected to rise by 2028, though part of the lower sub-catchment could still enjoy a surplus, if an EFR would not be enforced.

Table 4.10 Future water balance in Muooni under the ANOR scenario

Area	1	ources	ılance	.esource ʼemand	ıalance emand	ʼalance sources
2011						
Upstream	42.258	242.49	300.24	ʼ4.31%	4.31%	
Downstream	ʼ532.37	644.67	112.30	ʼ52.95%	2.95%	
Catchment	ʼ474.630	887.16	ʼ412.534	ʼ51.15%	1.15%	
2030						
Upstream	ʼ955.028	929.39	ʼ025.64)	1.42%	.58%	ʼ.38%
Downstream	177.86	524.89	ʼ552.97)	6.17%	ʼ3.83%	6.05%
Catchment	ʼ132.885	454.27	ʼ578.61)	8.18%	ʼ1.82%	3.40%

Source: Fieldwork (Luwesi and Shisanya 2017)

However, under a normal (NOR) or below normal (BNOR) rainfall regime, the catchment will experience a ubiquitous situation. The lower sub-catchment will first enjoy more than enough water, its water balance being equal to 2,105.79 m³/day in 2011. If an EFR would be enforced, deficits ranging between 1% to 50% of the total demand would progressively be experienced after 2012. The upper sub-catchment would yet suffer badly in both scenarios. With total demands of 10,852.1 m³/day (in 2011) and 21,832.9 m³/day (in 2030), its unmet demands are expected to range between 25.8% (in 2011) and 67.7% (in 2030) under NOR (Figure 4.6), and 93.6% (in 2011) and 97.2% (in 2030) under BNOR.

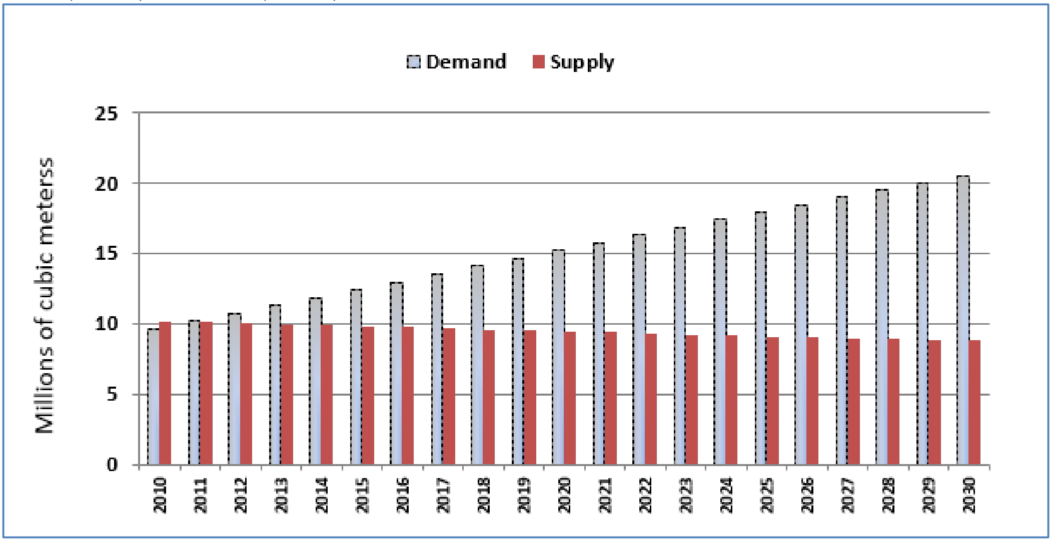


Fig. 4.7 Unmet Water Demand in Muooni under NOR (Luwesi and Shisanya 2017)

Based on the above predictions, conflicts on appropriation of water resources are likely to arouse very early both in Muooni and Ngusishi catchments, even under normal situations; the worse should be expected under drought (Gleditsch *et al.* 2004). It is thus crucial to explore the type of exposure to past and present water stresses experienced by farmers, and the kind of political and institutional response that have that they have accorded these risks in their respective catchments.

4.1.5 Socio-Economic Exposure to Water Stress and Response Characterization

The survey conducted in Ngusishi revealed that 64% among the 64 farmers interviewed were male and aged between 19 to 54 years old. About 72% among these farmers had 4 children and above, while their daily use of water per household amounted to less than 200 litres per day, farmers living upstream having the lion's share (including Wiumiririe, Kongoni, and Chumvi). This situation was explained by the fact most farmers living in the lower sub-catchment (Karimariu, Lucern, Batian, Mutarakwa and Kabubungi) were either pastoralists or peasant farmers (77%) while those living in the upper sub-catchment were generally employed by private investors in the horticultural industry (67%), alongside a number of public servants (27%) and commercial farmers/ businessmen (6%). Consequently, 43% among upstream farmers earned above KES. 100,000 annually (against 21% downstream) and used more than a cubic meter of water per day (against 8% downstream). However, about 23% of farmers surveyed upstream and 57% downstream were living below the poverty line of 1$ a day. Nonetheless, Ngusishi Catchment presented a very positive educational record with 15% upstream and 6% downstream having tertiary education degrees, about 40% and 30% having certificates of primary and secondary educations, 20% having attended professional polytechnics and only 7% did not go to school.

Concerning the 103 farmers surveyed in Muooni catchment, 28% were female while 55% were randomly selected in the upper sub-catchment (Kaewa, Lita and Mbee), the remaining 45% being drawn from Kauti, Muuoni, Isyukoni, Kyuluni, Ithaene, Mathiane, Mathithu and Muthala (downstream). Results show that the average household size upstream and downstream was of 5 and 7 children, respectively. Yet, their daily water use was estimated to 106 and 114 litres per household upstream and downstream, respectively, while a standard household's water use approximates 250 and 350 litres per day at Muooni Dam site and its environs (Musuva 2010). This was a clear indication of farmers' vulnerability to drought, Muooni catchment being a water scarce area. The latter was magnified by the householder's poverty. On average, a farmer living in the upper and the lower sub-catchment earned about KES 66,180 and 81,744 in the upper and lower zones, respectively. These results confirmed findings by Luwesi (2010) indicating an average seasonal income of USD 231 per year (equivalent of KES. 18,480 per quarter in 2010) per farm at Muooni dam site.

These household's incomes were shaped by their professional affiliations, more than 60% among them being active agriculturalists and livestock keepers, whilst 35% were employed by small private businesses and the government, the remainder undertaking their own businesses (less than 5%). These farmers' social and economic characteristics in Muooni catchment were reflected by their level of education. In effect, most farmers have attained some level of formal education (82%), while only 18% alone did not go to school (Luwesi 2010). In total 33.3% among farmers had primary school leaving certificates, 30.3% completed secondary education and 12.1% were holders of professional credentials, while 6.1% had university degrees.

In response to their poverty, farmers living in the lower zone of Ngusishi and those in Muooni have found alternative livelihoods. A majority among Ngusishi farmers have turned to the cropping of narcotic shrubs or euphoric stimulants known as "Miraa" ("Khat" species), especially downstream. Upstream Ngusishi catchment, the floricultural industry has offered several opportunities for employment to poor farmers. This industry has also shaped the catchment management therein through the creation of Ngusishi Water Resources Users' Association (NWRUA) in 1998, which was fully registered in 2003. It has also constructed a weir at Kakubungi village and a pipeline network to allocate water equitably to all and enable enforcing water rules on the EFR on behalf of the Government of Kenya (G.O.K). Consequently, the NWRUA has successfully managed to put in place a system for planning, managing, monitoring and evaluating water resources within Ngusishi catchment. This has considerably reduced cases of social injustice, corruption and theft in Ngusishi catchment.

Fig. 4.8 Soil Erosion and Sand Harvesting at Muooni Dam Site
(Photos by Luwesi and Shisanya 2017)

Muooni farmers however rely on a dam built by the government in 1987. Yet, settlements' encroachment on farmlands, deforestation and droughts, and cycles of drought-flooding often amplified farmers' poverty and resulted in inconsistent farming methods and the miniaturization of the cropping area for the purpose of leasing or settlement (Jaetzold *et al.* 2007; UNEP 2009). These factors had a negative impact on agricultural productivity, thus leading to soil infertility, crop failure and livestock mortality in both selected catchments, especially downstream Ngusishi and in the whole Muooni. Owing to the smallness of their farming areas, most farmers have abandoned fallowing and did not have sufficient means to cater for mineral soil fertilizers. This factor was widely associated with land degradation and the sedimentation of river courses and other water storages in the selected catchments (FAO 1995). Hence, farmers have discovered various small scale businesses to sustain their lives in time of distress. These include among others harvesting building stones and sand for sale (Figure 4.8).

Besides, a widespread practice of over-land flow irrigation upstream threatened water availability downstream, especially during the long dry season (June to September). The depleting natural capital (water and land resources) had been pointed out as a major source of conflicts on natural resources between upstream and downstream stakeholders, pastoralists and agriculturalists, human and wildlife, to name but a few, especially in Muooni Catchment (Aeschbacher, Liniger and Weingartner 2005; Universität Siegen 2008; Luwesi, Shisanya and Obando 2011).

As a response to vulnerability to climate variability and change farmers have resolved to Climate Information System (CIS) and Early Warning System (EWS) (Phillips 2003). On average, 89 and 95% of farmers in Ngusishi and Muooni catchments received information on rainfall distribution and temperature from the Kenya Meteorological Department (KMD) through Radio and TV, agricultural extension officers, and their neighbours. The frequency and accuracy of such information being generally questionable, most farmers found it easier to recourse to traditional Early Warning Systems (EWS). The latter were believed to be more effective and had better response for adaptation of food security and agricultural production to conditions of drought and flooding. These EWS encompassed the changing colour and canopy of some specific plants' leaves, the flowering of some well-known indigenous trees (i.e. the Muuti tree), the colouring and motion of clouds, early presence of dew, the croaking of frogs, the migration of different species of birds and animals, the stomp-stamping of insects, high wind pressure, high and low surface temperatures, unusual cool air associated with the variation of spring discharges at some critical periods of the year, and the aching joints of elderly ones. These indicators were differently interpreted as incoming drought spells or heavy rains associated with the risk of flooding. Though some farmers did not totally trust climate forecast by the KMD, more than 50% among them found it useful for predicting rain onset. This allowed them taking preventive measures against soil erosion, flood and drought, and planning to sow. They also suggested that EWS at a local level coupled with their own judgment on KMD climate information were enhancing weather forecast credibility and therefore its adoption. They were not only useful for planting but also for taking preventive measures to ensure food security in case of water disasters.

4.1.6 Discussion on Factors leading to Farmers' Vulnerability to Water Disasters

There is no doubt that most farmers leaving in ASALs of Kenya face challenges related to drought and sometimes to a cycle of droughts and floods (Jaetzold *et al* 2007). Despite several preventive measures taken by farmers to reduce their vulnerability to water disasters, Wise and Murphy (2012) could only stress the challenges faced by small scale farmers and women with limited resources in a climate-constrained world owing to the failure of policies and limited public investments on agricultural development and food production in developing countries. Mogaka *et al.* (2006) attributed this situation to "a combination of the country's very limited natural endowment of water, the high variability with which annual rainfall occurs, the heavy dependence of the economy on water resources, and inadequate preparedness for regularly recurring climate shocks to the economy" (IFRC 2005; 2009; USAID 2009c). Hence, climate variability and change as well as farmers' inconsistent land use changes, poverty and to some extent their ignorance of physical processes, and the lack of appropriate institutional framework for catchment management and water development are key determinants of increased water stress and land degradation in most arid ASALs of Kenya (Morgan 1995; Mutisya 1997; Waswa 2006). Thus, WSP (2011) could conclude that the country needed to strengthen its policy instruments and implementation institutions to channel more investments in the development of alternative water resources. These include groundwater, rainwater and green water using hydro-political instruments that may constitute reliable, renewable and drought resistant water sources. Owing to the weakness of such mechanisms, farmers have found innovative ways of curbing water disasters as detailed in the following section.

4.2 Farmers' Innovative Strategies for Mitigating Water Disasters

4.2.1 Innovative Stream Flow Storage and Allocation in Ngusishi Catchment

Recurrent water stresses and inequitable availability in the upper and lower sub-catchments make Ngusishi farmers naturally vulnerable to water disasters. Yet, this catchment is one of the few catchments of Kenya well-known for better water allocation practices in the ASALs (Aeschbacher 2003; Ehrensperger and Kiteme 2005; Notter *et al.* 2007; Kiteme *et al.* 2008). In effect, irrigated floricultural farms located upstream are the main water abstractors in the catchment to the expense of pastoralists and agriculturalists operating downstream. The floricultural industry was determined to ensure equity in the distribution of water among local stakeholders through good water resource management. This was clearly demonstrated by the creation of Ngusishi Water Resource Users' Association (NWRUA) in 1998 as a self help group registered with the gender, culture and social services (registration No. 183/98) and as an association registered with the office of the attorney general in 2003 (registration No. 22204). The NWUA incorporates voluntary members such as water users, riparian land owners and other stakeholders who have formally decided to associate for the purposes of co-operatively sharing, managing and conserving a common water resource. The association marked a milestone by building of a weir (or small scale dam of 2.059 m^3 storage) in 2007 at Kabubungi Village (Figure 4.9).

Fig. 4.9 A Weir Erected in Ngusishi River at Kabubungi Village
(Photos by Luwesi and Shisanya 2017)

Currently, this weir serves as a common intake for a network of sixteen (16) pipeline projects, namely Batian farms, Batian Flowers, Chumvi, Daisa Farm, Kabeere, Kabubungi, Kongoni, Land A, Lobelia, Lolomarik, Ol Donyo, Ole Naishu, Siraji, TimaFlor, Valley Spring and Wiumiririe. The weir is also a major tool for allocating water equitably to different locations, using water allocation plans and meters, as well as enforcing water rules on the EFR on behalf of the Government of Kenya (G.O.K). The erection of this weir and the strong institutional support from the NWRUA have mitigated the inequitable distribution of natural resources between upstream and downstream in Ngusishi catchment, particularly in time of stress and scarcity. The flow is consistently measured and 30% of the total streamflow is left downstream for EFR purpose (NWRUA 2010). The NWRUA also sets water rationing programmes, timing of abstractions among different user groups and issuing water use guidelines to prevent water shortages, pollution, splinter groups, and destruction of vegetation cover. It is worth noting that the NWRUA was initiated by eight (8) horticultural farmers in 1999. Not only did they initiate the idea, but they also conducted feasibility study and helped registering the NWRUA. They keep providing finances and logistic support for its management (Ehrensperger and Kiteme 2005).

4.2.2 A Revolutionary Groundwater Taping System in Machakos Area

Unlike Ngusishi, Muooni catchment lacks a proper institutional framework for a good governance of the catchment. Yet, the catchment possesses an overflow gravity dam located in a narrow part of the deep valley of Muooni River at Isyukoni with a reservoir area of 15.2 hectares, a maximum capacity of 1,559,400 m^3, a median capacity of 836,000 m³ (at the spillway level) and a threshold of 119,400 m³ (Table 4.11). This dam is the major water source of the catchment. It was built from April 1986 to June 1987 by the Government of Kenya (Ministry of Water) to provide water to Mitaboni, Kathiani, Lita and Nzaikoni (in Kathiani Division), Kyevaluki, Kakuyuni and Kawethei (in Kangundo Division) as well as to Vyalya, Masii, Mwala and Makutano (in Mwala Division). But its average storage capacity have been decreasing by 6.2% annually due to soil erosion problems, thus having some implications on other productive sectors of the local economy, especially the green economy (Luwesi 2010; Musuva 2010).

Table 4.11 Key features of the design of Muooni dam

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

Source: Compiled from MoW (1987) and Luwesi (2010)

Currently, Muooni dam can only supply water to Kathiani divisional headquarters (including the market centre, the hospital and the high school) and surrounding rural areas within a radius of 3 kilometres. This has forced women and children to walk long distances (about 3 km) to fetch water during normal periods. However, during major droughts, when many boreholes in Machakos area are dry or carry salty water, farmers receive water in forms of humanitarian aid. They have to rely on their Indigenous Knowledge (IK) to ensure sustainable management of soil moisture and other natural resources at farm level. However, since 2009, Muooni farmers living upstream relate a revolutionary groundwater project that has redefined the concept of water management and sustainability in the Machakos area (Figure 4.10).

Many stakeholders in the upper zone of Muooni catchment would prefer buying water from Musingini rather than consuming salty water from their own boreholes. In effect, through a partnership between the mobile operator Safaricom (M-PESA section) and Grundfos Lifelink (a Kenya based Danish company specialized in pump making), a project was created to provide clean and safe water resources to communities lacking access these resources. Local stakeholders were more exhilarated to see the technology that made all of this possible. The latter consisted of a smartcard of the size of a KES 20 coin (that is 25 mm), which contains money stored from a mobile phone via M-PESA payment system provided by Safaricom. It activates a solar pump from the customer mobile phone (in Kenya) and a server (in Denmark). The latter draws clean water underground to feed an aerial tank, which feeds back a free-standing pump station, looking like an ATM, via gravity. The smartcard is placed in a slot in the pump station and borehole water runs from the water tank until the card is removed. One needs just to select "M-PESA" on the Menu and click on "Pay Bill", and then enter his/ her "business number"; then his/ her membership "PIN" number; and lastly the amount s/he want to load. Once this information is transmitted to the smartcard, one would wait for two or three minutes to fetch water. To trigger the water flow, the smartcard is placed in any of the three slots on the sides of the pump station and water will run from the connected pipes until money runs out or the smart card is removed. In this last case (when the smartcard is removed), one litre of water will continue to flow before cutting off. The fourth side of the pumping machine has a screen that displays the smartcard balance.

Fig. 4.10 Grundfos Lifelink Automated Borehole Implemnted in Musingini
(Photographies compiled from Karago (2009)

It shall be noted that the solar-powered borehole works on a computerised system managed from Denmark. If it breaks down, engineers receive failure messages and they can immediately alert their subsidiary firm in Kenya to sort out the issue. They can also tell how much water has been used and how much income has been generated. This system costs between Euros 40,000 to 50,000. The M-PESA use secures payments for paying instalments to Grundfos Lifelink, which provided the smartcards and the automated water systems (pumps, maintenance services and other overheads). The Ministry of Water and Irrigation has found it very innovative and efficient. It has since then started working with Grundfos Lifelink to disseminate this project across the country to bring piped water into schools, dispensaries, market places and places of worship to help achieving a universal access to potable water, in line with Millennium Development Goal 7. Though Musingini is not much more than a little shopping centre in Machakos, Karago (2009) reveals that local residents and those from surrounding drought-stricken areas (including Muooni upper zone) have experienced improved health and hygiene, and have benefited economically from potable water through this groundwater project. Now, they can have adequate washing facilities and flourishing vegetables and flowers in their gardens, even during the dry season. The people of Musingini and surrounding areas are cheerful as they see water flowing in their desolate land. Even so, the sustainability of this water system management would depend on an effective catchment management. This will enable a systematic implementation of GWS schemes. Thus, the next sub-section focuses on innovative mechanisms put in place by farmers to deliver GWS services and compensate those delivering these services in Muooni catchment.

4.2.3 Innovative Mechanisms for Delivery of GWS Services in Muooni

This study established that "Green Water Saving" (GWS) schemes were not widely disseminated among farmers living in Muooni catchment. In effect, 25% of farmers upstream and 22.8% downstream have already heard about a specific type of GWS schemes. They wished to see the implementation of nine (9) major schemes in Muooni catchment, namely: (1) Green Water Credits (1%); (2) cash payments by rich farmers to poor ones for environmental services (18%); (3) the transfer by rich farmers of part of their harvest to poor ones for environmental services (5%); (4) the donation of foodstuffs in time of famine by rich farmers to poor ones for environmental services (6%); (5) the donation of clean water in time of drought by rich ones to poor ones for environmental services (17%); (6) the allocation of farming water quantity to all farmers with possibility for one's selling his/her share (24%); (7) employment for environmental conservation by the State or large scale farmers (22%); (8) the transfer of management of a public fund to a private business for watershed conservation (6%); and (9) the leasing of public land for environmental conservation (1%).

Though modern GWS schemes are not yet widespread in Muooni catchment, a study by Tiffen and Mortimore (2002) revealed that such kinds of schemes exist in the Akamba culture and that farmers were intuitively practiced them. In effect, all the 22.8% of downstream farmers having already heard about GWS schemes believed that these schemes were important for adequate water management in the catchment. Nonetheless, 25% estimated that these schemes were mainly important for cash payments by rich farmers to poor ones for their environmental services. Another category of farmers (66.1%) felt that these schemes were only useful for farming water allocation to all farmers with possibility for one selling his/her share. In all the cases, 82.5% of farmers living downstream would agree to compensate other stakeholders engaged in catchment conservation, if asked to do so by the government. Consequently, 46.8% could donate either food or clean water, 44.7% would offer employment in one's farm or cash payments, while 8.5% might give a piece of land for agricultural production. This Intention To Pay (ITP) for GWS services expressed by downstream farmers was an indicator of their preference for the GWS schemes.

Upstream farmers' Intention to Accept Compensation (ITA) for their GWS services was an indicator of their availability to implement GWS schemes in Muooni Catchment. This study revealed 77.3% among the 25% of farmers living upstream, who had already heard about GWS schemes, felt that these schemes were very useful for allocating farming water quotas to all farmers with possibility for one to sell his/her share. However, 22.7% among them found these schemes adequate for water management in the catchment. Still 22.1% believed that these schemes were mainly meant to motivate "rich" farmers to pay cash to "poor" ones, for granted that the latter get involved in environmental rehabilitation of the upper catchment. Furthermore, 19.7% of farmers would prefer using Soil and Water Conservation (SWC) measures to boost agricultural yield while sustaining crops from drought and flood. Only a few among them admitted using mulching (4.7%) and rainwater harvesting (2.3%) as SWC measures to sustain drought (or flood) while preserving soil moisture and water balance. Whatever the case, 75% among upstream farmers would agree to set aside ½ acre of land for tree planting alone, in exchange of compensation from the government. For that purpose, 98.8% among them would ask for material or financial compensation. Types of compensation would include clean water donation (32.5%), employment in the public service (31.3%), tax exemptions on land (20.5%), cash payments (8.4%), food and seed donation (4.8%), and farming water supply (1.2%). These indicators provided evidence that upstream farmers operating in Muooni catchment were willing to implement GWS schemes for granted that equitable and fair compensation was assured to them by the Government and their fellow farmers managing the schemes.

4.2.4 Farmers'Effective Strategies for Saving Water in Muooni Catchment

It is no longer a secret that farmers operating in Muooni catchment have to face physical vulnerability to water disasters. To ensure their livelihood, 55% of farmers reported that they would buy water for cropping and/or keeping their animals. A majority among these farmers did not believe in their ability to ensure the efficiency of their farming activities (77.2%). Nonetheless, about 50% among them felt that efficiency in farming was only achieved in some few cases while deficiency was widespread, depending on the type of farming inputs procurement (including fertilizers, manure, insecticides, herbicides, fungicides and rodenticides). Hence, more than 30% attributed agricultural efficiency to the chance of getting farming inputs at a fair price. Also, only 5.3% among them acknowledged having some innovative technological abilities to ensure farming efficiency in time of disasters, especially during a drought occurrence.

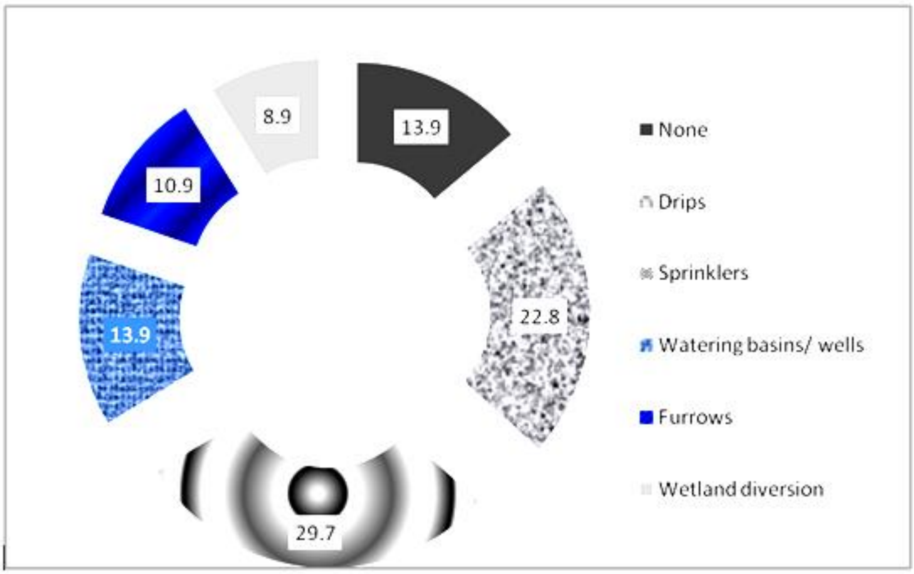


Fig. 4.11 Techniques for Watering Plants in Muooni (Luwesi and Shisanya 2017)

Technological efficiency was linked to effective soil and water conservation measures, some farmers utilizing sprinklers (29.7%) and drips (22.8%), and others using water basins and wells or furrows (13.9%) as well as overland flow from the wetland (8.9%) (Figure 4.11). About 35% among these farmers had water tanks and 17% possessed water pumps, the remainder utilizing other tools of such kind to abstract and save water (Figure 4.12). Nonetheless, many agro-pastoralists would prefer using basins and wells to provide water to their animals (45.5%) or watering animals in the river course, either late in the evening or early in the morning (39.6%). Eventually, a few among them would still prefer watering animals during working hours (11.9%), when householders are still their water for domestic use (Figure 4.13).

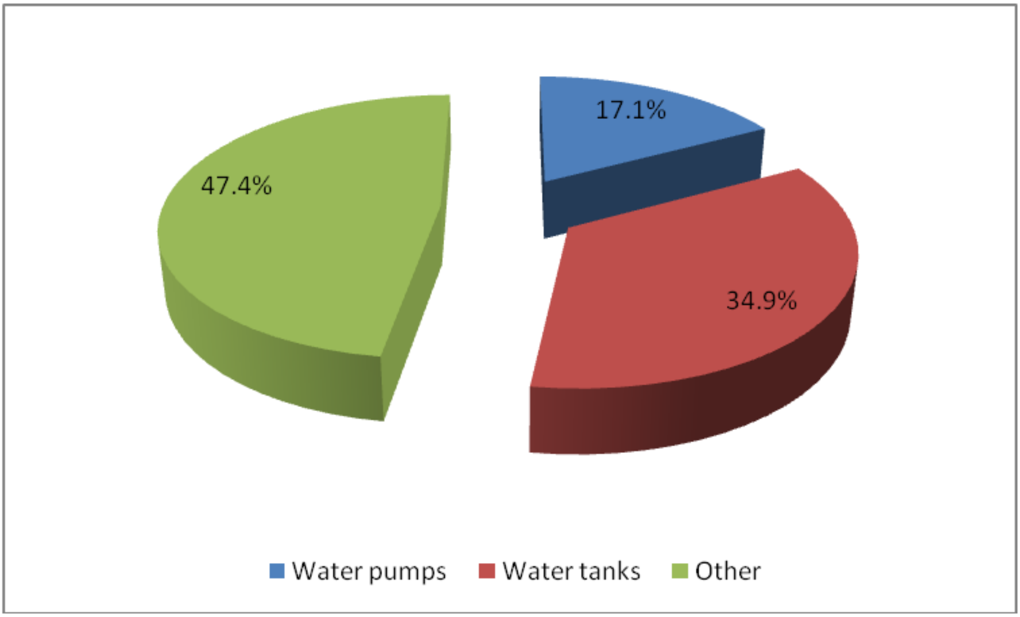


Fig. 4.12 Tools for Abstracting and Saving Water in Muooni (Luwesi and Shisanya 2017)

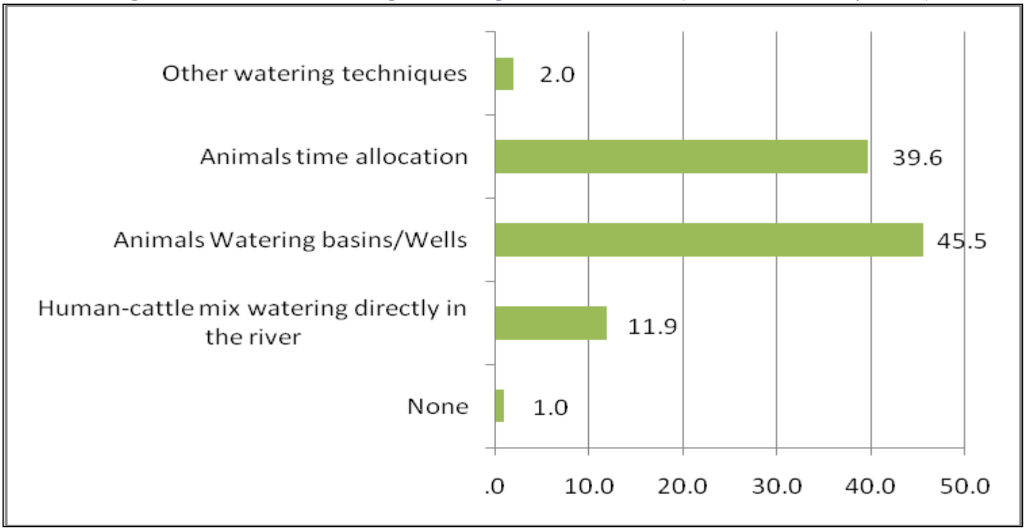


Fig. 4.13 Techniques Used for Watering Animals in Muooni (Luwesi and Shisanya 2017)

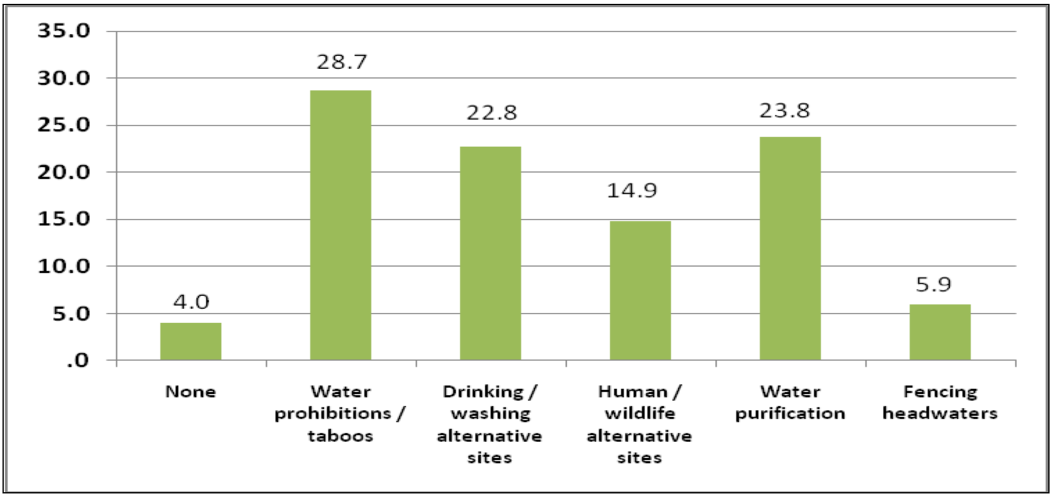


Fig. 4.14 Traditional Measures for Water Hygiene in Muooni (Luwesi and Shisanya 2017)

Regarding hygienic measures used by farmers to keep water clean, Figure 4.14 indicates six (6) main traditional measures taken by the farming community, including (1) water prohibitions and taboos (28.7%); (2) traditional rules for water purification (23.8%); (4) separation between drinking and washing sites (22.8%); (5) separation between human washing and animals' drinking sites (14.9%), and (6) fencing of the headwaters (5.9%).
Modern tools for Rain Water Harvesting and Saving (RWHS) involved roof catchments (19.8%) and underground tanks (10.9%). Even though rainwater harvesting is an important alternative source of water in most ASALs, it is not among the major sources of water in Muooni catchment. Farmers instead employ traditional techniques for tapping and saving stream flow. Tools utilized included plastic basins, buckets, calabashes and such like storages (37.6%), and seasonal wells (29.7%) (Figure 4.15).

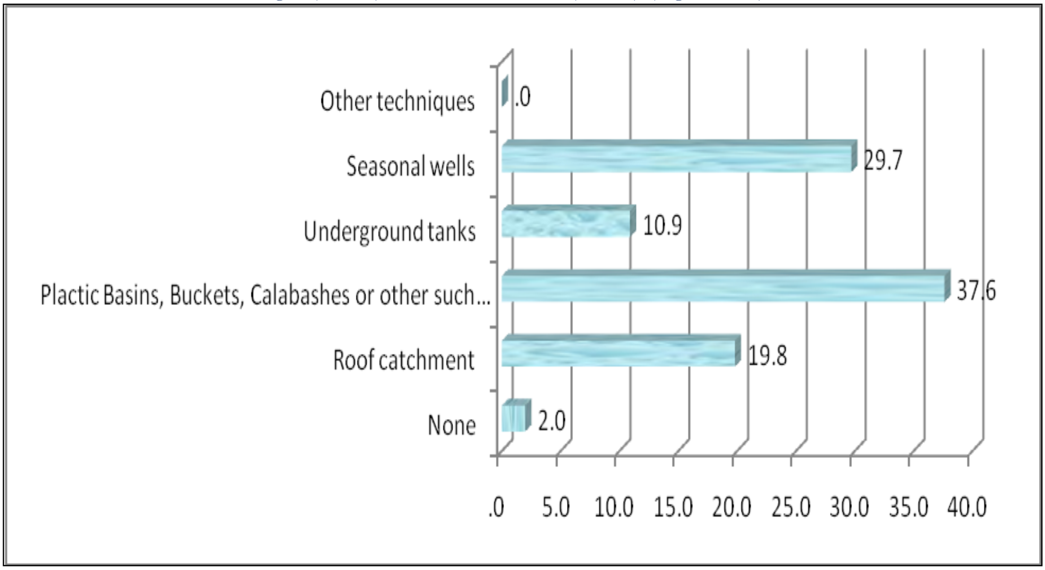


Fig. 4.15 Tools for Harvesting and Saving Rain Water in Muooni (Luwesi and Shisanya 2017)

Finally, soil moisture was mainly conserved using terraces (22.8%), windbreaks (18.8%), contour grasses and trees (17.8%), small dams or runoff cut-outs (15.8%), agro-forestry (6.9%), and fallows or fences around water sources (2.0%) (Figure 4.16). These innovations would not properly work if allocational measures were not put in place to enhance efficiency. Some of these allocational measures may have encompassed: (1) the compliance to water allocation plans; (2) the adjustment of the cropping area in case of streamflow variation; and (3) the increase of farming inputs per parcel of land.

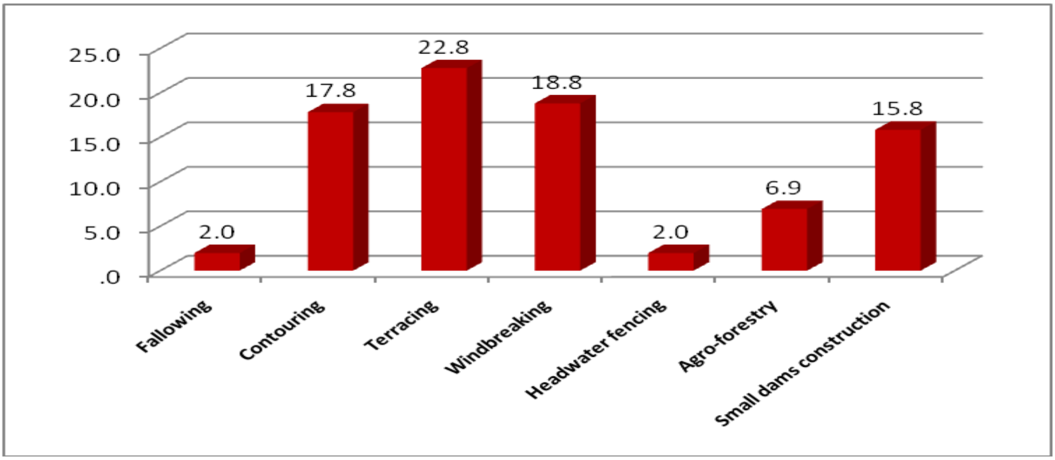


Fig. 4.16 Soil Moisture Conservation Measures (Luwesi and Shisanya 2017)

Farmers mainly relied on: (1) indigenous knowledge to enhance preparedness and compliance to the planting calendar (13.9%); (2) new agronomic technologies and skills (12.9%); (3) irrigation and water saving techniques combined with weather information, water allocation plans and planting calendar (10.9%); (4) enhanced soil conservation measures (9.9%); (5) migration techniques or settlement at an area that is not prone to droughts and floods or where there is a new markets with high demand to avoid high competition (9.9%); (6) savings, subscription to social insurances and crop loss schemes offered by cooperatives and microfinance institutions (8.9%); (7) security measures that consist of watchdogs and watchmen (7.9%); (8) banking loans (6.9%); (9) compost and manure (6.9%); (10) governmental subsidies and non-governmental aids (5.0%); (11) farming inputs sold at a fair price (3.0%); (12) crop selection or the use of improved seeds, early maturing crops and drought resistant crops (3.0%); and (13) ploughing animals and farming machines (1.0%). Beside these 13 coping measures taken by individual farmers, the upper sub-catchment relies on the automated borehole found at Musingini, which uses mobile phone technology and solar energy.

4.2.5 Innovative Mechanisms for Delivery of GWS Services in Ngusishi

Contrary to Muooni, the study established that "Green Water Saving" (GWS) schemes were widely accepted among farmers for equity and fairness in the management of natural resources in Ngusishi Catchment. In effect, 46.2% of farmers upstream and 20.6% downstream have already been involved in a GWS scheme. The latter encompassed six (6) major mechanisms namely: (1) the award Green Water Credits (2.4%); (2) cash payments by rich farmers to poor ones for environmental services (24.4%); (3) the donation of clean water by rich farmers to poor ones in time of drought for the sake of environmental conservation (24.4%); (5) the allocation of farming water quantity to all farmers with possibility for one's selling his/her share (24.4%); and (6) employment for environment conservation by the State or Large scale farmers (24.4%). The study revealed that 26.1% among upstream farmers and 27.8% downstream estimated that these schemes were mainly meant for environmental conservation through cash payments by rich farmers to poor ones.

Naturally, 92% among farmers living downstream, respectively, believed that these schemes were important for adequate water management in the catchment. These farmers expressed their Intention To Pay (ITP) for GWS services in terms of: (1) allocation of farming water to farmers with one's possibility of selling his/her share (66.7 %); (2) offer employment in one's farm or cash payments (46.2%); (3) award of a piece of land for agriculture in compensation of upstream farmers' GWS services (25.6%); (4) donating food or clean water in time of disaster

(15.4%). Hence, 54.8% of farmers living downstream would agree to compensate other stakeholders engaged in catchment conservation, if asked to do so by the government.

Among farmers living upstream Ngusishi, 82.6% believed that GWS schemes were important for adequate water management in the catchment. These farmers expressed their Intention to Accept Compensation (ITA) for their GWS services involving: (1) setting aside ½ acre of land for tree planting (80.8%); (2) Soil and Water Conservation (SWC) at farm level to boost agricultural yield while sustaining crops from drought and flood (67.7%); (3) mulching (20.7%); (4) rainwater harvesting (19%) to sustain drought (or flood) and preserving soil moisture. For that purpose, 97.7% among upstream farmers would expect a material or financial compensation from downstream counterpart or the government in exchange of their GWS services. Types of compensation may include: (1) cash payments (45.5%); (2) employment in the public service (20.5%); (3) Tax exemptions on land (13.6%); (4) the management of a public fund for environmental conservation and other public duties (13.4%); and (5) clean water donation (4.5%). All these indicators are evidence of the social acceptability of GWS schemes in Ngusishi Catchment for equitable and fair management of its natural resources.

4.2.6 Efficient Farming Water Strategies in Ngusishi catchment

Despite their vulnerability to water disasters, 88.3% of farmers operating in Ngusishi catchment reported that they buy water for cropping and/or watering their livestock. Surprisingly, 89.8% among them believed that their farming activities were still efficient. They attributed this efficiency to technological innovation and effective agricultural resources allocation. Efficient technologies mostly used included: (1) improved seeds (14.8% of farms), (2) new agronomic technologies (9.3%); (3) effective soil conservation measures (5.6%); (4) ploughing animals and farming machines (7.4%); (5) composting and manure (3.7%); and (6) water saving techniques (5.6%). The use of sprinklers (50.8%), drips (21.3%) and water basins and wells (13.1%) for irrigation purpose emerged among the most commonly used water saving techniques (Figure 4.17).

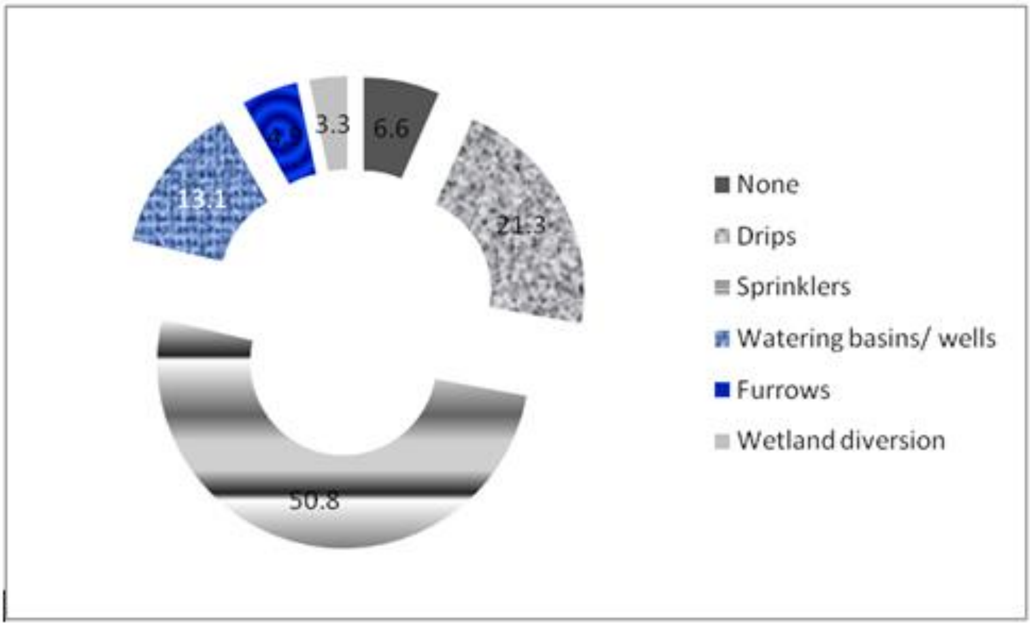


Fig. 4.17 Plant Watering Techniques Used in Ngusishi (Luwesi and Shisanya 2017)

At least 50% among these farmers had water tanks, 12.5% possessed water pumps and the remainder used other similar tools to abstract and save water (Figure 4.18). Nonetheless, many agro-pastoralists preferred basins and wells to provide water to their animals (66.7%). Eventually, quite a number among them would still prefer watering their animals in the river course, either during working hours (23.3%) or late in the evening, even early in the morning (5%), when householders have completed fetching their water for domestic use (Figure 4.19).

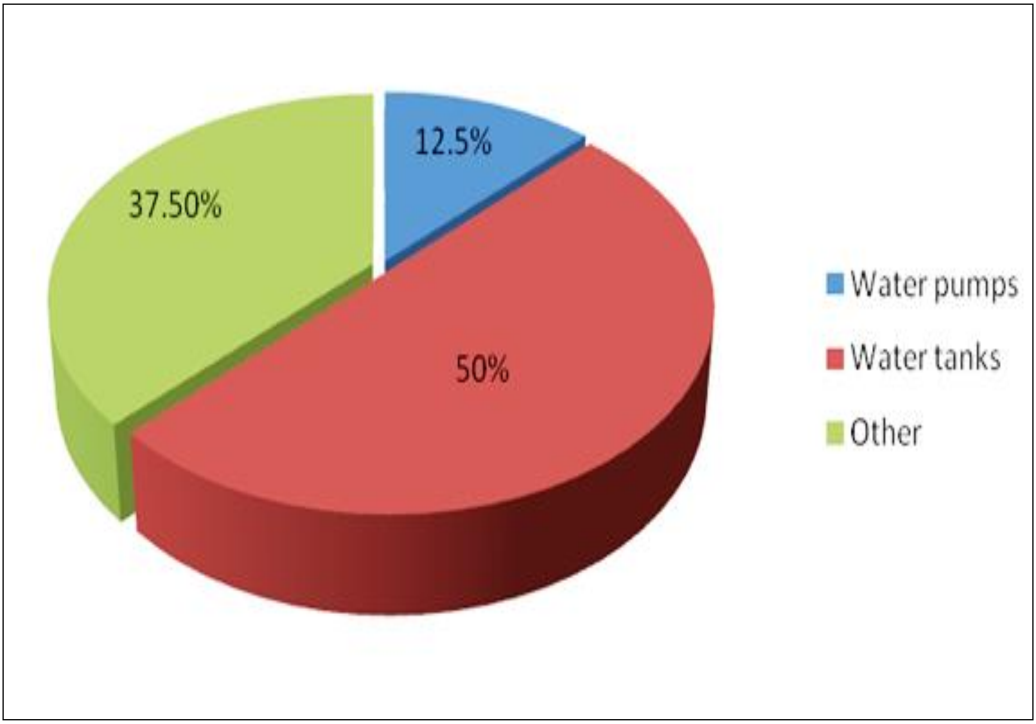


Fig. 4.18 Water Abstraction and Saving Tools Used in Ngusishi (Luwesi and Shisanya 2017)

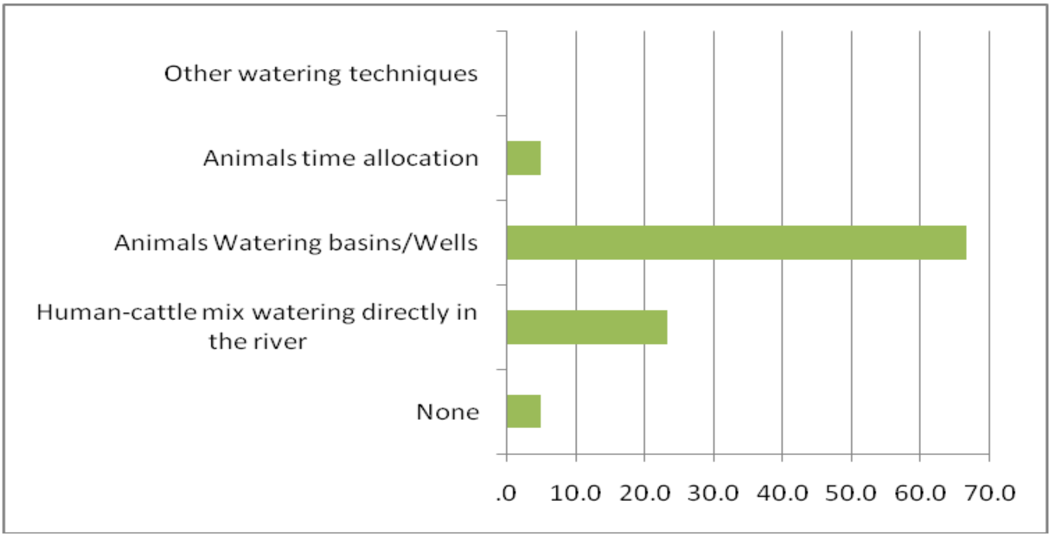


Fig. 4.19 Techniques used in Ngusishi for watering animals (Luwesi and Shisanya 2017)

Whatever the case, Figure 4.20 indicates that, for the sake of hygiene, this farming community still abided to traditional water purification rules (22.4%), water prohibitions and taboos (8.6%), as well as to a set of measures dealing with the separation of drinking and washing sites (37.9%), human washing and animals' drinking sites (6.9%), and the headwaters with the accessible catchment area (15.5%).

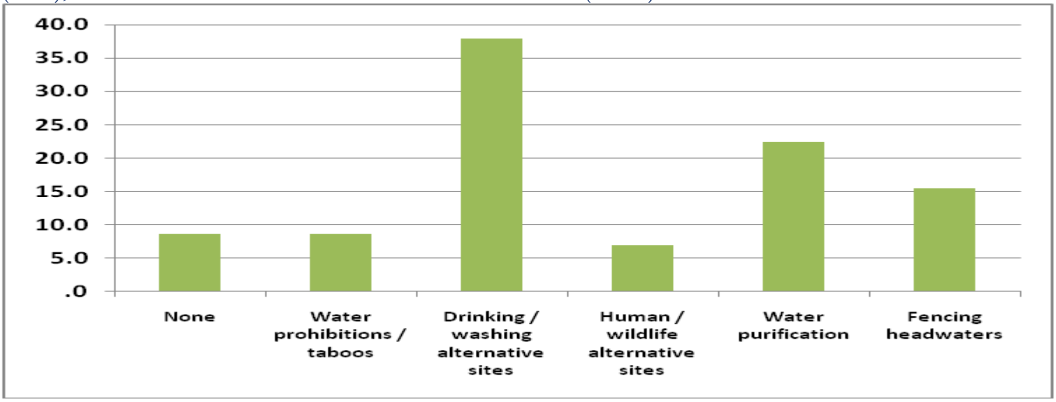


Fig. 4.20 Hygienic techniques used in Ngusishi to keep water clean (Luwesi and Shisanya 2017)

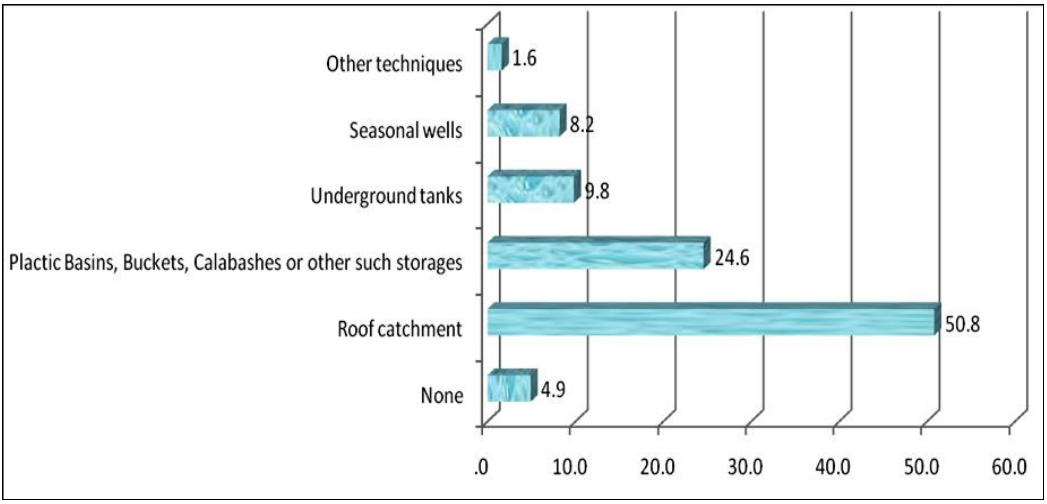


Fig. 4.21 Rain Water Harvesting and Saving in Ngusishi (Luwesi and Shisanya 2017)

Rain Water Harvesting and Saving (RWHS) remained the most important source of water in ASALs. In effect, Figure 4.21 shows that Ngusishi farmers employed roof catchments (50.8%) as their major RWHS technique. Other key techniques included the use of plastic basins, buckets, calabashes and other similar storages (24.6%), underground tanks (9.8%), and seasonal wells (8.2%).

Finally, soil moisture was mainly conserved using terraces (45.8%), contour grasses and trees (20.3%), windbreaks (13.6%), agro-forestry (11.9%), fallows (3.4%), small dams (3.4%) and fences around water sources (1.7%) (Figure 4.22). These SWC measures would not properly work if allocational measures were not put in place to enhance efficiency. Some these allocational measures reported by farmers encompassed: (1) the compliance to water allocation plans (11.1%); (2) the adjustment of the irrigated area in relation with streamflow variation (13%); and (3) the increase of farming inputs per parcel of land (20.4%).

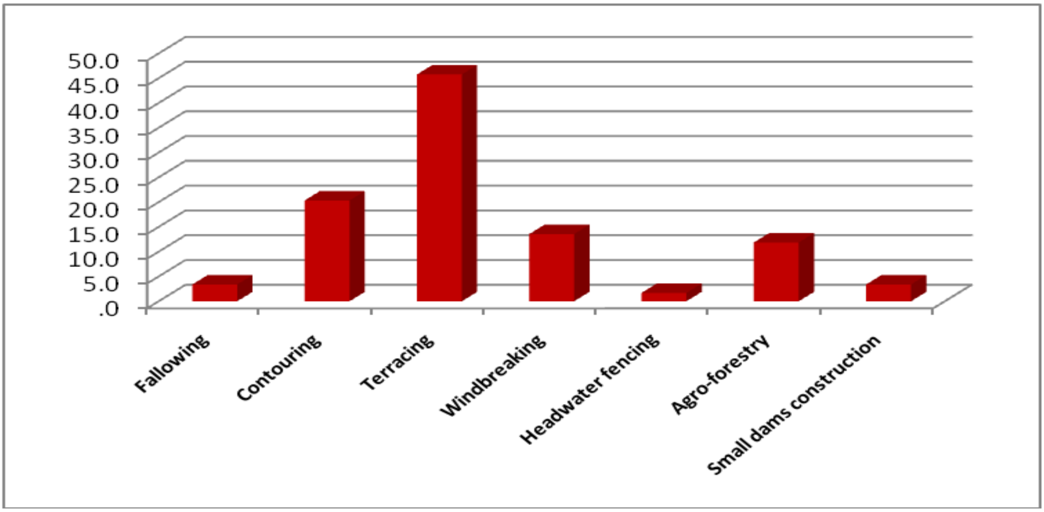


Fig. 4.22 Soil Moisture Conservation Measures in Ngusishi (Luwesi and Shisanya 2017)

The main farming inputs included NPK, DAP and CAN as well as manure among fertilizers. Other inputs indicated by farmers encompassed insecticides, herbicides, fungicides and rodenticides. Also, in time of disasters (mainly drought), farmers had to recourse to coping strategies to maintain their farming efficiency. They valued new agronomic technologies and skills (25%) as their primary strategy for ensuring efficiency. Other strategies consisted of: (1) crop selection or the use of improved seeds, early maturing crops and drought resistant crops (17.9%); (2) irrigation and water saving techniques combined with weather information, water allocation plans and planting calendar (17.9%); (3) security measures dealing with watchdogs and watchmen (16.1%); (4) ploughing animals and farming machines (7.1%); (5) composting and manure (5.4%); (6) enhanced soil conservation measures (3.6%); (7) adjustment of irrigation water with the fluctuations of streamflow (3.6%); (8) (9) use of indigenous knowledge to enhance preparedness and compliance to the planting calendar (1.8%); and (9) migration or settling in an area that is not prone to droughts and floods (1.8%). Yet, whatever the number of measures taken by individual farmers, their effectiveness would depend on their catchment management as a whole environmental entity. Thus, the next section of this study focuses on the existing individual and institutional capability to curb water disasters in Ngusishi and Muooni catchments.

4.2.7 Discussion on Farmers' Innovative Strategies to Curb Vulnerability

UNU (1997) and Shakya (2001) revealed that traditional water technologies alone may not assist in case of hazards involving climate change. These technologies are maladapted to changing climatic conditions and thus cost billions of dollars for constant repairs and maintenance. This study has shown that farmers need innovative ways for sustaining water supply and soil moisture in their farms. They also have to integrate both Indigenous Knowledge (IK) and modern science within the framework of Integrated Water Resource Management (IWRM) to enable the adoption of revolutionary systems for water harvesting, storing, allocation and management. Ngusishi catchment and Musingini Groundwater project provided a clear evidence of successful blending of IK and modern technologies to mitigate vulnerability to water disasters. Yet, these technologies are costly and many government s in the developing world are likely not ready to invest on water development at a small scale catchment like Muooni and Ngusishi (Ledec and Quintero 2003; World Bank *et al.* 2008). Thus, the need for local stakeholders "Willingness To Pay" (WTP) for GWS services and other small scale investments in the water sector (Porras 2006). Applying such a price to water development will not only enable cost recovery but also stimulate a change of behaviour and make sure that water is distributed more fairly (Cap-Net 2008; Universität Siegen 2008). The Government of Kenya (GoK) thus needs, in line with the Water Act 2002, to expedite the creation of watershed institutions for effective investments in GWS schemes and continuous coordination of natural resources management in each catchment (Adger 2000). This will ensure water and food security in the whole country and reduce conflicts on natural resources, especially in many ASALs (Vishnudas 2006; Malesu *et al.* 2008).

4.3 Effectiveness of GWS Schemes in Ngusishi and Muooni

4.3.1 Introduction

The robust Performance Assessment and Evaluation (PAE) used in this study to assess the effectiveness of GWS schemes comprised an analysis of "Strengths, Weaknesses, Opportunities and Threats" (SWOT) of water management institutions, a "Vulnerability-Capability Rating" (VCR) and an evaluation of their performance using "Performance based Management Rating" (PMR). Using the SWOT analysis, the study explored best practices as well as failures in rapport with GWS schemes in the study areas. The research provided an assessment of the catchment management internal strengths and weaknesses as well as opportunities and threats accrue from its external environment. The VCR was thus needed prior to estimate the magnitude of environmental, social and economic risks as well as of capacities treasured by farmers. The PMR gave an insight on the farmers' perception of the performance of their water institutions, which were supposedly, based the implementation of GWS schemes for sustainable water services' provision. These analyses were mainly conducted based on the following four components of hydro-climatic factors retained in the study, namely: (i) Lower maximum temperatures, evaporation/ transpiration and all other factors; (ii) Higher minimum temperatures and evaporation/ transpiration; (iii) Increased storm intensity and number of flash floods (flood severity); and (iv) Decreasing trend of rainfall, river discharges, soil moisture and infiltration rate (drought severity). Ultimately, an effectiveness rate for GWS schemes was derived from the above analyses based on a rating scale adapted after Downing and Patwardhan (2005) and Kazbekov *et al.* (2009). The following sub-sections present the results of each of the above processes from the selected study areas.

4.3.2 SWOT Analysis for Catchment Management in the Selected Areas

Put aside the global warming and increasing temperatures in the catchment, Ngusishi stakeholders face various challenges related to high evaporation and transpiration rates in their catchment. Table 4.12 displays key "Strengths", "Weaknesses", "Opportunities" and "Threats" of the Ngusishi Water Users' Association (NWRUA). It comes out from the analysis that local stakeholders need to invest in effective soil conservation measures (agro-forestry, vegetative filter strips, grass waterways, terraces, contours, runoff cut-outs).

Table 4.12 Ngusishi Catchment's SWOT Matrix

Factor	Variable	S_i, W_i, O_i and T_i Assessed
Higher surface runoff/ storm intensity and other factors	Strengths	S_1: Use of strategies and plans for mitigating disaster at catchment level S_2: Use of early warning systems for disaster prevention S_3: Satisfactory technological capacity
	Weaknesses	W_1: Limited use of engineering and agronomic soil conservation measures (terraces, contours, runoff cut-outs, etc.) to mitigate storm intensity and soil erosion
	Opportunities	O_1: Existing disaster management legislations and policies, institutions, strategies, plans and tools for implementation O_2: Existing Improved technologies O_3: Existing training institution and NGOs
	Threats	T_1: El Niño flood destructions T_2: High risk of soil erosion and mass movements T_3: Water siltation and pollution T_4: Weak public officers' enforcement capability
Higher minimum temperatures / Higher evaporation	Strengths	S_4: Efficient crop protection under water stress S_5: Use of efficient irrigation systems like drip and spiral irrigation S_6: Existing Ngusishi water resource users' association (NWRUA) S_7: Consistent monitoring and coordination of water withdrawal points
	Weaknesses	W_2: Limited practice of reforestation and agro-forestry W_3: Limited use of zero-grazing W_4: Inconsistent Farming methods with soil and water conservation (e.g. excessive multiple cropping, planting eucalyptus in wetlands, multiple open furrows, etc.)
	Opportunities	O_4: Existing legal provisions for the protection of forests and other public lands O_5: Existing agricultural extension services O_6: Existing Carbon trading markets O_7: Existing water legislations and policies, resource management institutions, strategies, plans and tools for implementation at the national level
	Threats	T_5: Catchment warming T_6: Wildfires and water salination T_7: Deforestation and vegetation cover destruction T_8: La Niña droughts T_9: Lack of facilities and basic infrastructure for public services delivery in remote areas
Decreasing trend of river discharge, infiltration and soil moisture rates	Strengths	S_8: Enforcement of water allocation plans and environmental flow reserve S_9: Existing effluent discharge regulations, measuring and charging S_{10}: Use of greenhouses S_{11}: Use of mineral fertilizers to enrich the soil S_{12}: High returns on investments in floriculture S_{13}: Existing weir in the upper sub-catchment at Kabubungi
	Weaknesses	W_5: Limited use of hydropolicies (Rainwater harvesting and storage in tanks and dams) W_6: Limited practice of Public Private Partnership schemes W_7: Limited use of mulching, tillage, crop selection, drought resistant plants W_8: Low returns on investments in other farming types and water supply
	Opportunities	O_8: Availability of governmental support and development partners' funding for developing technical skills and improving the balance sheet O_9: Existing banking loans and private investors' joint ventures O_{10}: Availability of rentable and well equipped horticultural farms in the catchment O_{11}: Existing facilities and basic infrastructure for implementing green water saving schemes in the whole catchment
	Threats	T_{10}: Weak capacity to write bankable proposals or afford consultancy fee

Source: Analysis from fieldwork data (Luwesi and Shisanya 2017)

It is imperative to create new infrastructures to mitigate storm intensity, regulate encroachment to wetlands and other water towers, as well as introduce new technologies for monitoring surface runoffs and reclaiming extra water resources. All of these may be achieved by notably: (i) building a dam and a water treatment plant to be curb adverse effects of drought and storm intensity on water quantity and quality; (ii) increasing vegetation cover through agro-forestry, reforestation or afforestation; and (iii) promoting the practice of zero-grazing. The NWRUA and the farming community living in Ngusishi would likely increase their catchment management strengths if they: (i) set emergency oversight committees to invigilate on wetlands' encroachment and create awareness on sanitation, hygiene and environmental disasters (bushfires, endemics and pandemics); (ii) upgrade the existing hydrological and meteorological equipments; (iii) increase exchanges and knowledge sharing between upstream and downstream farmers to implement effective irrigation schemes downstream; and (iv) search for new funding opportunities to extend the delivery of extension services to remote areas (Annex 7.1). For effectiveness, the NWRUA shall disseminate Rain Water Harvesting and Saving (RWHS) techniques among farmers (including building roof catchments, water storage tanks, reservoirs and dams). It needs to enhance the use of agronomic technologies to increase infiltration and maintain soil moisture (i.e. mulching, tillage, greenhouses, crop selection, drought resistant plants, etc.). Farmers may also explore new markets and PPP schemes' financing options such as grants, lending, and microfinance, Build-Operate-Lend (BOL), Build-Operate-Sell (BOS) or Build-Operate-Transfer (BOT). Finally, the NWRUA shall train its staff on how to initiate PPP schemes, write bankable proposals and set efficient water tariffs to review the current subsidised water charges and enable sufficient public contributions for new infrastructures. Similar results were obtained from the situation analysis conducted in Muooni catchment, despite the fact the catchment does not have a co-ordinating authority for the catchment management (Table 4.13).

Fig. 4.23 Soil conservation measures around Muooni Dam Site (Luwesi and Shisanya 2017)

The analysis acknowledged that the risk of flash floods was only high downstream and for some few affected homesteads. The use of farming methods that were inconsistent with soil and water conservation was put forward as the main cause of such vulnerability to flood. Nonetheless, farmers' usage of soil conservation measures and early warning systems was an asset for preventing and curbing the effects of high surface runoff and flash floods. Yet, excessive multiple cropping and widespread use of open furrows, and the planting of eucalyptus trees in wetlands were among malpractices to be revised in the management of farming water in Muooni catchment (Figure 4.23).

Table 4.13 Muooni Catchment's SWOT Matrix

Variable	S_i, W_i, O_i and T_i Assessed
Strengths	S_1:Use of terraces, contours and runoff cutouts to mitigate storm intensity/ soil erosion S_2:Existing hydro-meteorological stations in Mitaboni and Uuni S_3: Use of early warning systems for disaster prevention
Weaknesses	W_1: No formal strategy and plan for mitigating disaster at catchment level W_2: Weak technological capacity/ obsolescence of hydro-meteorological equipments W_3: Inconsistent Farming methods with soil and water conservation (e.g. excessive multiple cropping, planting eucalyptus in wetlands, multiple open furrows, etc.)
Opportunities	O_1:Existing disaster management legislations and policies, institutions, strategies, plans and tools for implementation O_2: Existing Improved technologies O_3: Existing training institution and NGOs
Threats	T_1: El Niño flood destructions T_2: High risk of soil erosion and mass movements T_3: Water siltation and pollution T_4: Weak public officers' enforcement capability
Strengths	S_4: Practice of agro-forestry and reforestation to increase vegetation cover and humidity S_5: Existing efficient irrigation systems like drip, sprinkler and spiral irrigation S_6: Existing Kauti irrigation scheme water users' association (Kauti IWUA)
Weaknesses	W_4: Weak agronomic abilities W_5:Inefficient crop protection under water stress W_6: Limited use of zero-grazing W_7:Lack of a formal water institution to coordinate the overall catchment management W_8:Lack of consistent monitoring and coordination of water withdrawal points
Opportunities	O_4: Existing legal provisions for the protection of forests and other public lands O_5: Existing agricultural extension services O_6: Possibility of trading carbon in the international market O_7: Existing national legislations, frameworks and policies, institutions, strategies, plans and tools for implementation at the catchment level
Threats	T_5: Catchment warming T_6: Risk of wildfire emergencies and water salination T_7: La Niña droughts T_8: High risk of escalation of water related conflicts T_9: High risk of prevalence of water borne diseases T_{10}: High risk of mortality (for plants, livestock and human beings) due to water scarcity
Strengths	S_7: Use of efficient hydropolicies (Rainwater harvesting and storage in tanks and dams) S_8: Existing water dam at Isyukoni S_9: Existing water treatment plant in Kathiani. S_{10}: Use of mulching, and tillage S_{11}: Use of zero-grazing, organic and mineral fertilizers to enrich the soil
Weaknesses	W_9: Lack of measuring devices for charging water abstractions/ effluent discharges W_{10}: Lack of sufficient motivation to initiate Public Private Partnership schemes W_{11}: Weak capacity to write bankable proposals, afford consultancy fee/ collaterals W_{12}: Limited use of crop/ plant selection and greenhouses to adapt to drought W_{13}: Low returns on investments in farming and water supply
Opportunities	O_8: Availability of governmental support and development partners' funding for developing technical skills and improving the balance sheet O_9: Existing banking loans and private investors' joint ventures O_{10}: Availability of rentable off-farm activities O_{11}: Existing facilities and basic infrastructure for implementing GWS schemes
Threats	T_{11}: Lack of sufficient motivation from bankers to accord banking products tailored to the needs of smallholder farmers T_{12}: Lack of government backing and sovereign guarantees allowing farmers have access to diversified sources of funding.

Source: Analysis from fieldwork data (Luwesi and Shisanya 2017)

Among other weaknesses, Muooni catchment was lacking proper strategy for disaster mitigation besides having a weak technological capacity due to the obsolescence of hydro-meteorological equipments. In the absence of a registered Water Resource Users' Association (WRUA), these weaknesses could be triggered by threats such as El Niño flash floods, high erosivity and the risk of mass movements, water siltation and pollution, and the weak enforcement capability of public officers in the area. Nonetheless, Kauti Irrigation Scheme's Water Users' Association (Kauti IWUA) could be mandated to: (i) design a strategic action plan for disaster mitigation for the whole catchment; (ii) regulate, measure and charge all water uses at their abstraction or effluent discharge points; (iii) promote agronomic technologies such as greenhouses, crop selection, drought resistant plants, etc.; (iv) promote alternative farming schemes in the form of trusts and cooperatives of production, savings and credits; (v) train farmers on PPPs proposal writing and business literacy; (vi) train farmers on marketing strategies to enable them explore new markets and PPP schemes' financing options, and increase their investments in farming and/or off-farm sectors (Annex 7.2). An estimate of the rate of farmers' vulnerability to and capability to curb drought and flood in both catchments under consideration is provided below to pave the way for estimating GWS schemes effectiveness in the study areas.

4.3.3 Farmers' Vulnerabilty and Capability vis-à-vis Flood and Drought

The analysis found out that Ngusishi catchment undergoes a moderate vulnerability to drought and a minor vulnerability to flood. In effect, the catchment has to get along with a minor vulnerability to flood of 4.3% index share for a hazard frequency of 20% (1 occurrence every 5 years) and a risk value of 14%. Farmers' vulnerability to flood was largely attributed to the impact of flash floods on its economy (21.9% affected), human population (4%) and ecological systems (1%). Regarding its vulnerability to drought, Ngusishi farmers have first to experience a moderate drought (that is a hazard frequency of 20%) under the effects of increasing minimum temperature, evaporation and transpiration. The latter recorded a vulnerability index share of 22.4% and a risk value of 42%. Besides, the farming community has to contend with another moderate drought of 53.3% vulnerability index share and 70% risk value, owing to reduced river discharges, infiltration and soil moisture. Globally, vulnerability to drought results in the collapse of the bio-physical environment (94% affected) and socio-political systems (54%) under drought, while economic resources remain sustainable to some extent (21.9%) (Figure 4.24).

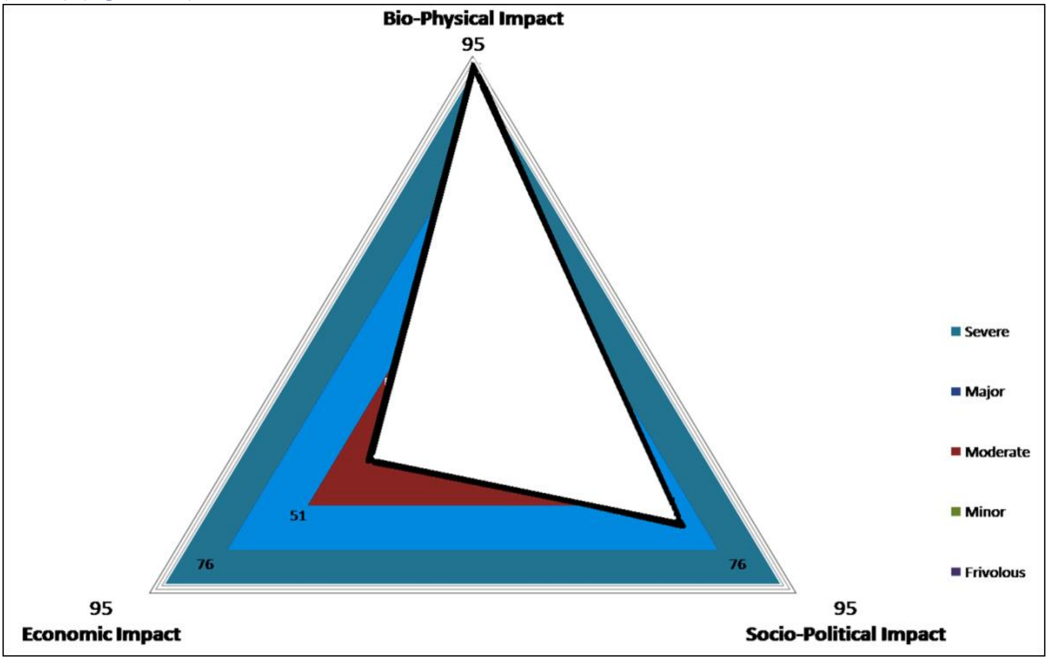


Fig. 4.24 Farmers' vulnerability to drought in Ngusishi [1] (Luwesi and Shisanya 2017)

[1] The white triangle in the centre of the figure shows vulnerability in Ngusishi

The assessment of farmers' capability to adapt to flood and drought in Ngusishi catchment revealed that the farming community had high potentials for adaptation to flood than drought. The catchment recorded a high capability index share of 75.86%, when facing a minor flood frequency of 20% (that is 1 hazard occurrence in 5 years) and a risk value of 14%. Ngusishi's capability to high storm intensity and flash floods was largely attributed to the resilience of its ecological systems (99%), socio-political institutions (96%) and economic recovery (78%). Hence, the impact of flash floods on the catchment's economy was said to be negligible. However, when it came to capability to mitigate drought effects, Ngusishi catchment recorded a fairly poor index share of 29% to overcome a moderate drought of 22.4% caused by higher minimum temperatures, evaporation and transpiration with a hazard frequency of 20% and a risk value of 42%. This capability was poorer (24.2% index share) when facing a moderate drought resulting from reduced river discharges, infiltration and soil moisture (for a drought hazard of 20% frequency and 70% risk value). Hence, an overall fairly poor capability to curb drought was recorded by farmers operating in Ngusishi. It was largely attributed to the slow pace of economic recovery (63%) and reduced resilience of ecological systems (83%) amplified by weaknesses observed in the management of socio-political institutions (95%).

Concerning Muooni catchment, farmers living therein have to experience a minor flood hazard of 21.5% frequency (that is about 1 occurrence every 5 years) with a vulnerability index share of 2.7% and a total risk of 16%. This flood is likely due to increased storm intensity under the effect of El Niño flash floods. It threatens 1% of ecological systems, 2% of human beings and 14.6% of economic assets. However, the catchment has to cope with a moderate drought attributed to higher minimum temperature, evaporation and transpiration. Its vulnerability index share was estimated to 72.4% for a hazard frequency of 23.8% (that is about 5 occurrences every 20 years) and a risk value of 48%. A more severe drought associated with decreasing river discharge, water infiltration and soil moisture rates recorded 97.4% vulnerability index share with a hazard frequency of 23.8% and a risk value of 80%. In general, drought impact in Muooni catchment was appraised as the collapse of ecological systems (95%), the exposure to unhealthy human lives (85%) and the decline of economic assets (51.2%) (Figure 4.25).

Muooni farmers' capability was rated high (78.4%) for curbing a minor flood hazard of 21.5% frequency with a risk value of 16%. The analysis revealed that the farming community had high potentials to achieve ecological sustainability (99%) and increase its social capital (98%) and economic wealth (85%). Yet, this strong adaptability was swept away (2.7% index share) by a moderate drought hazard of 23.8% frequency and 48% risk value. Likewise, capability index share of 2.2% (poor) was recorded when faced with a major drought hazard of 23.8% frequency and 80% risk value. This reduced poor capability was explained by the weakening of ecological systems (5%), socio-political governance (15%) and economic assets (49%).

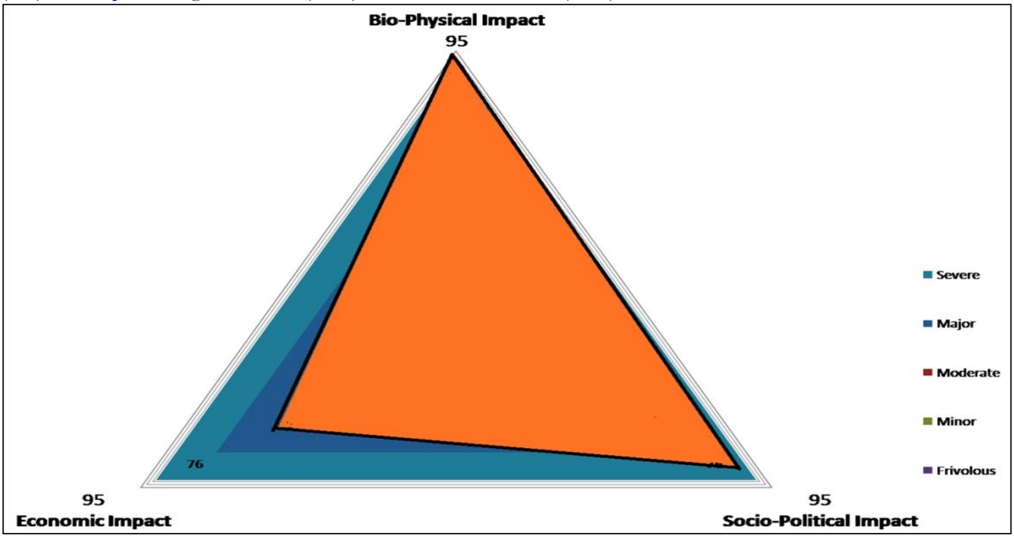


Fig. 4.25 Vulnerability to Drought in Muooni [1] (Luwesi and Shisanya 2017)

[1] The orange triangle in the centre of the figure shows vulnerability in Muooni

It is suggested that increased social networking may increase poor capability to compensate the collapse of its bio-physical systems and economic loss. Therefore, it is crucial to know the performance of catchment management institutions vis-à-vis the intensity of drought in both catchments under consideration. The following sub-section provides results of these organizations' performance as appraised by the farming community and validated by the researchers. This gives insight on the ability of upstream farmers to curb future water disasters using GWS schemes.

4.3.4 Catchment Institutions' Performance Management Rating

The turning point of this study was the Focus Group Discussions (FGDs) that empowered local farming communities to assess the performance of catchment management institutions, which principally determines the capability of upstream farmers to curb water stress/ scarcity in the catchment via GWS schemes. Performance Management Rating (PMR) was used to evaluate: (1) environmental sustainability; (2) business success; (3) economic development; (4) social welfare; and (5) institutional development. These FGDs also involved them to set priorities (desired interventions) for their local catchment management institutions in rapport with the three main issues tackled by the SWOT through Performance Management Rating (Table 4.14).

Table 4.14 Catchment management performance rating in the selected catchments

Indicators	Ngusishi		Muooni	
	Rate	Capacity Rating	Rate	Capacity Rating
Environmental Sustainability	82.50%	Fairly good	55.83%	Fairly poor
Business Success	50.00%	Fairly poor	33.00%	Fairly poor
Economic Development	76.67%	Fairly good	80.00%	Fairly good
Social Equity	100.00%	Good	84.17%	Fairly good
Institutional Development	90.00%	Good	60.63%	Fairly poor
AVERAGE	79.83%	Good	62.73%	Fairly poor

Source: Fieldwork (Luwesi and Shisanya 2017)

Table 4.14 shows that Ngusishi Water Resource Users' Association (NWRUA) was granted a rated fairly good capability (73.7%) by local stakeholders for water resources management under normal situations. In fact, it had insufficient capacity to manage wastes and pollutants despite its good technological capacity to innovate and conserve the environment. Environmental sustainability was hence rated 82.5% (fairly good). Likewise, farmers' business success was as well rated fairly poor (50%) due to the fact that farmers had fairly high profitability and solvability, as well as accessibility to and affordability of quality water services. However, the NWRUA did not have the ability to collect sufficient revenue from water services to develop new infrastructures, though the burden of these investments was taken in charge by a few big horticultural farmers. However, the NWRUA did to some extent favour economic development, which was rated fairly "good" (76.7%). Nonetheless, the NWRUA did not do enough to build farmers' capacity to mobilize sufficient resources and develop their businesses. Besides, the NWRUA had championed social equity (100%) by providing a platform for achieving social consensus, equity and fairness, as well as gender balance and effective Public-Private Partnerships (PPP) at local level. The institutional development was also rated good (90%) since it had updated strategic plans with average quality of standards and specifications, and good capacity for implementation using participatory approaches.

Muooni Catchment on the other hand presented a puzzling case. Whereas the catchment had various uncoordinated catchment management institutions, namely Muooni Dam environmental committee, Kathiani Water Treatment Plant, Kauti Irrigation Scheme's Water Users' Association (Kauti IWUA) and several other water projects, to name but a few, their contribution to environmental sustainability, social welfare and economic development was rated fairly poor (62.7%) under normal conditions. This rate was partly perceived as an average of their compliance to environmental regulations, even though "user pays" and "polluter pays" principles were not effectively implemented in the catchment along with public safety measures in time of disaster. Nonetheless, there was a high potential for technological innovation, waste management and environmental conservation. In the same vein, business success was rated fairly poor (33%). This was as the resultant of very good affordability of water services and of the quality of water services, while the regularity of water revenues and customers' payment was very negligible, and farmers' profitability and solvability were said to be insufficient even inexistent. However, catchment management organizations' contribution to economic development in the catchment was rated 80%, meaning fairly good. This resulted from the perception of the farming community that it had sufficient capacity to mobilize resources, create public relations and develop businesses in the catchment. Likewise, farmers' contribution to social peace and welfare was perceived to be fairly good (84.2%). This was attributed to the respect of local culture and application of equity and fairness doctrine by catchment management organizations. Also, their structures were gender balanced, with women playing a role in the management and youths being promoted.

Finally, Public-Private Partnerships (PPP) were being effectively used at the local level. Herein, farmers declared to have achieved social consensus, equity, fairness and gender balance with an average motivation to initiate PPPs at the local level. Finally, catchment management institutions needed to develop their adaptive capacities in view of change, though their institutional development was globally rated fair (63%). This was a result of good organizational culture and institutionalization of public involvement. The organizational culture received quite a good mark (83%), since farmers confessed that water projects and institutions were legally recognized, had sound policies and procedures as well as quality standards and specifications. However, the development of adaptive capacities was poor and needed to be updated (30%), existing strategic plans being generally out of date (meaning no frequent strategic reviews). Lastly, the institutionalization of public involvement was acknowledged to be fairly poor (60%). Catchment management institutions were reputed of being very weak in implementing participatory approaches for decision-making but they had public trust, owing to their good reputation and regularly of meetings with their members. Globally, catchment management institutions' contribution to environmental sustainability, business success and economic development, social welfare and institutional developments was rated fairly poor (62.7%) in Muooni catchment.

This farmers' appraisal needed to be validated based on survey results of the SWOT analysis and the VCR. The starting point of this validation exercise was an estimate of the contributions by water management institutions to business success and economic development. Farmers' capability to raise more Marginal Farming Revenue (MfR) was an indicator of their business success, while the rate of water saving or economy of water use (t_e) was a good estimator of water economy development. Then, the validation of environmental sustainability, social equity and institutional development followed. The latter was based on figures retrieved from the SWOT analysis and survey results. A comparison between estimates by farmers during the FGDs and validation rates from the SWOT analysis and survey data of the selected catchments is provided on Table 4.15.

Table 4.15 Validated catchment management institutions' performance

Indicator	Ngusishi		Muooni	
	FGD Rate	Validation Rate	FGD Rate	Validation Rate
Environmental Sustainability	82.50%	62.50%	55.83%	37.50%
Business Success	50.00%	68.3%	33.00%	75.05%
Economic Development	76.67%	81.54%	80.00%	68.65%
Social Equity	100.00%	95.83%	84.17%	75.00%
Institutional Development	90.00%	71.88%	60.63%	15.63%
AVERAGE	79.83%	76.01%	62.73%	54.37%

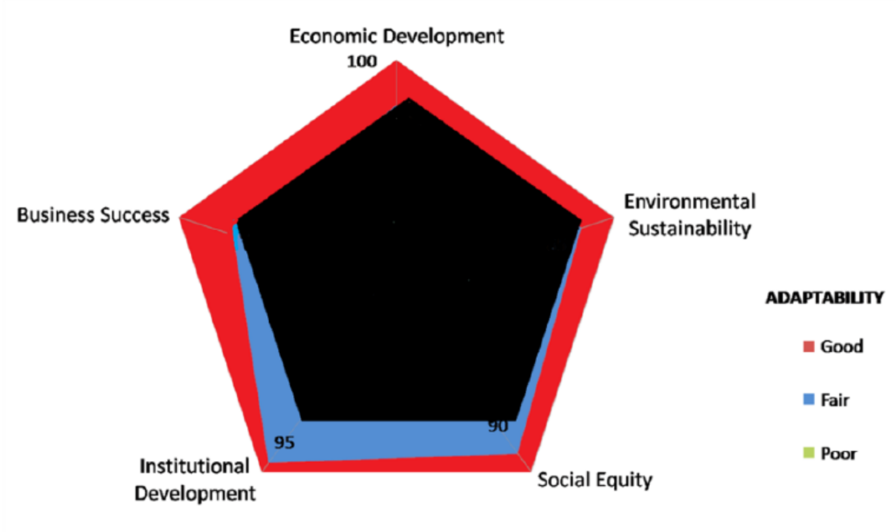
Source: Fieldwork (Luwesi and Shisanya 2017)

The computation of the Marginal Farming Revenue (MfR) revealed that Muooni catchment had high potentials for business success (75.1%) than Ngusishi (68.3%). In fact, a marginal farmer in Muooni Catchment was earning KES. 508.6/ month (US$ 1 = KES 80) while the same farmer in Ngusishi would have earned KES. 352.2 per month, respectively. This was a result of higher prices of outputs due to recurrent water scarcity in Muooni. However, the marginal farming water demand was much higher in Muooni Catchment than anywhere else. Muooni recorded a mean of 27.6 m^3 (with a standard deviation of 47.7 m^3) against a mean of 7.9 m^3 in Ngusishi (with a standard deviation of 26.5 m^3). When translated into the rate of water use economy (t_e) Ngusishi and Muooni performed better with respective rates of 81.5% and 68.7%. This water economy rate meant that at least 81% of farmers in Ngusishi can daily afford 7.9 m^3 of water for farming, while 68.7% in Muooni can secure 27.6 m^3 of farming water on average per day. These rates also established the average contribution of upstream farmers to the catchment management economy through conservation of the upper sub-catchment and release of sufficient water for cropping downstream (in Muooni Catchment), which irrigation schemes are mainly located upstream.

A comparison between farmers' appraisal of catchment management's environmental sustainability in Ngusishi (82.5%) showed huge gaps with estimates from the surveys (62.5%). However, when it came to social equity and institutional development, Ngusishi presented figures of 100% and 90% to the FGDs, with average rates of 95.8% and 71.9% respectively. Hence, globally, Ngusishi emerged with 76% as a "good" performance for catchment management (Figure 4.26).

Muooni catchment recorded similar results for environmental sustainability (55.8% for FGD against 37.5% validated). Nonetheless, institutional development in Muooni catchment was poorly rated (15.6% validated from the 60.6% FGD's rate), though its social equity received corresponding rates (75% validated from the 84.2% FGD's rate). Globally, Muooni catchment performed fairly well in catchment management with a validated rate of 54.4% (Figure 4.27).

Fig. 4.26 Capability to Curb Drought in Ngusishi Catchment [1]



[1] The black shadowed polygon in the centre of this figure shows capability in Ngusishi

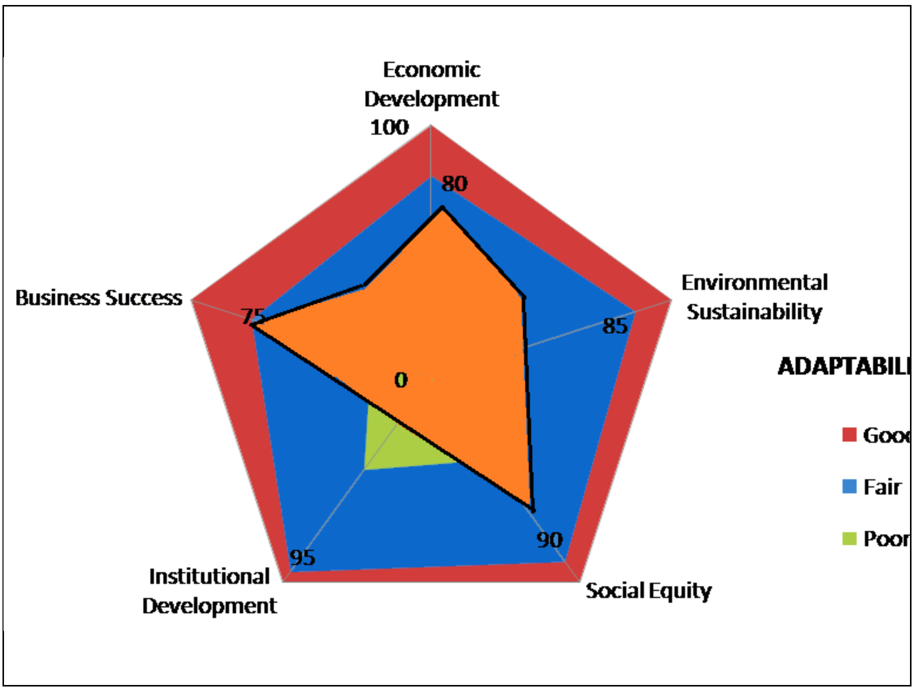


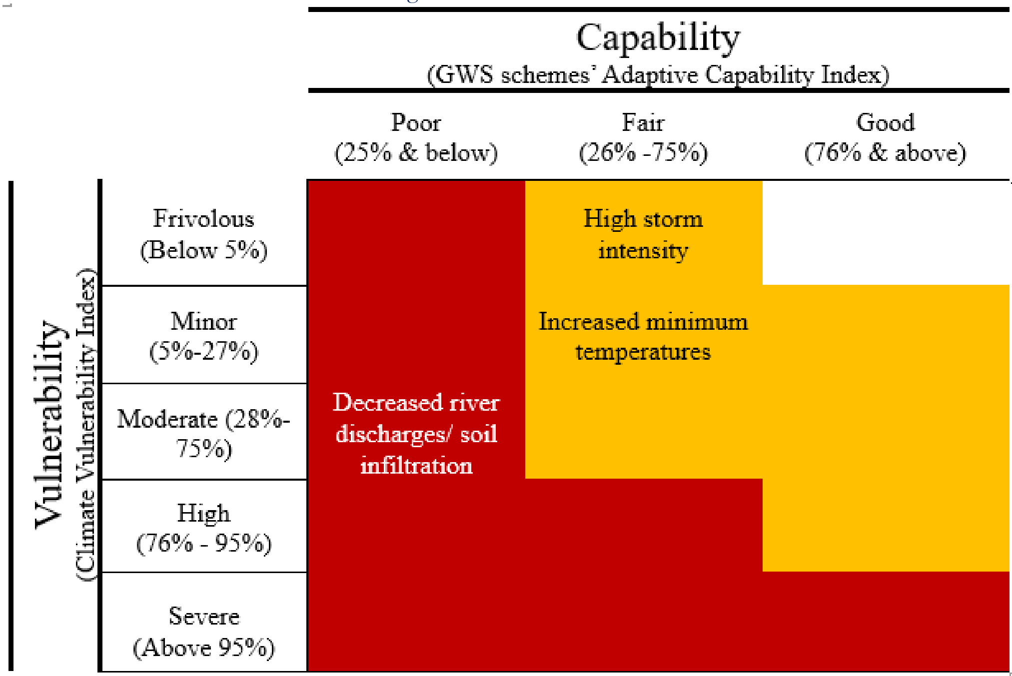
Fig.4.27 Capability to curb drought in Muooni Catchment[1]

[1] The orange shadowed polygon in the centre of this figure shows capability in Muooni

These validated performance rates were interpreted as an expression of the public commitment in the catchment management ("institutional sustainability") through valorization of water ("success of business") and other natural resources ("environmental sustainability") and their efficient use for enhanced agricultural production, energy generation and other utilities ("economy of inputs"). This was possible because of the existence of leading to equitable sharing of water management benefits among all stakeholders in the catchment ("social equity"). However, this performance is likely achieved in most ASALs because of the implementation of GWS schemes. The following sub-section focuses on the derivation of GWS schemes' effectiveness from farmers' vulnerability and capability rates as well as catchment management institutions' performance.

4.3.5 Induction of GWS Schemes' Effectiveness

Table 4.16 GWS schemes' effectiveness in Ngusishi catchment[1]



Source: Fieldwork (Luwesi and Shisanya 2017)

[1] Red cells indicate "poor" effectiveness; the yellow ones refer to "fair" effectiveness; and the white cell signals "good" effectiveness

An overall rating of the effectiveness of GWS schemes was done for both small scale farms and institutions of catchment management at a large scale in the study areas. Table 4.16 and 4.17 presents the effectiveness of Soil and Water Conservation (SWC) measures put in place by farmers to curb the effects of flood and drought in Ngusishi and Muooni catchment, respectively. Table 4.17 shows that SWC measures implemented by farmers in Ngusishi catchment were effectively fairly good (51-75%) to mitigate the impact of high storm intensity (flood) on their farming production. When it came to the increased minimum temperatures (in case of a moderate drought) d and decreasing trends of river discharge and soil moisture (in case of a severe drought), the effectiveness of SWC measures was subsided to fairly poor (26-50%) and poor (25% and below). However, when considering GWS schemes as the main tools used by catchment management institutions, their effectiveness ranged from good (76% and above) to fairly poor (26-50%). These schemes were found effectively good for addressing challenges related to flooding (or high storm intensity). Yet, they were said to be fairly poor in curbing drought effects resulting from both increased minimum temperatures and decreasing river discharges and soil moisture in Ngusishi. Concerning Muooni, Table 4.17 reveals that Muooni farmers were effectively good (76% and above) in implementing SWC measures.

Table 4.17 GWS schemes' effectiveness in Moony catchment[1]

Vulnerability (Climate Vulnerability Index)	Capability (GWS schemes' Adaptive Capability Index): Poor (25% & below)	Fair (26% -75%)	Good (76% & above)
Frivolous (Below 5%)			High storm intensity
Minor (5%-27%)			
Moderate (28%-75%)	Increased minimum temperatures		
High (76% - 95%)			
Severe (Above 95%)	Decreased river discharges/ soil infiltration		

Source: Fieldwork (Luwesi and Shisanya 2017)

[1] Red cells indicate "poor" effectiveness; the yellow ones refer to "fair" effectiveness; and the white cell signals "good" effectiveness

If Muooni eases the effect of high storm intensity (flooding) through SWC measures, it is however poor (25% and below) in addressing the impact of a moderate to severe drought brought about increased minimum temperatures and decreasing trends of river discharge and soil moisture, respectively. The effectiveness of GWS schemes ranged from poor to fairly good, owing to the intensity of storm (2.7% vulnerability index and 54.4% valid capability), minimum temperatures' increase (72.4% vulnerability index and 54.4% capability index) and river discharge and soil moisture decrease (80% vulnerability index and 54.4% capability index) in Muooni catchment.

4.3.6 Discussion on GWS Schemes' Effectiveness in the Study Areas

The SWOT analysis confirmed the fact that farmers practice both traditional and innovative Soil and Water Conservation (SWC) measures in the selected catchments using GWS schemes. Yet, they were sometimes inconsistent with water and land conservation. In general, ill-planned farming, the introduction of exotic trees, shrubs, crops and weeds in most marginal, human settlement, agriculture and other induced activities exacerbate vital functions of ecosystems and wetlands (UNU. 2005). Even where crop coverage and agro-forestry could provide land protection against soil erosion, the cropping of exotic trees, notably eucalyptus grandis or blue gum in Muooni (Figure 4.28) and Miraa shrub in Ngusishi.

Fig. 4.28 Matured Eucalyptus Grandis in Eastern Province of Kenya (Luwesi and Shisanya 2017)

These factors were associated with water stress and scarcity in their respective catchments (Kitissou 2004; Ojwang 2008). They were also said to be linked to the global warming, to sea surface temperature, ocean currents, and atmospheric winds in the southern hemisphere, commonly known as El Niño flood and La Niña droughts (WRI *et al.* 2007). These changing hydro-climatic conditions resulted in high social, political and economic risks and impacts depicted by the SWOT analysis, the VCR and the PMR, which weakened the effectiveness of GWS schemes. For instance, they had a negative impact on farmland productivity, and water quality and quantity in river channels and other water storages (Terer 2004; Van Aalst 2006; Heurtefeux *et al.* 2011).

Hence, it comes out from the analysis that individual farmers' capability to adapt to future disasters largely depend, not on their endowed capacity (or resources) but on institutional capability to integrate communities' preparedness and adaptation to climate disasters in their planning and management processes (Miller *et al.* 1997; Adgar 2000; Pelling 2004; Luwesi, Shisanya and Obando 2012). These institutions are entitled to enforce the creation of sustainable farming mechanisms, including Green Water Saving (GWS) schemes to ensure land and water conservation at all time (Kauffman *et al.* 2007; Malesu *et al.* 2007; Hoff *et al.* 2010; Immerzeel *et al.* 2010; Luwesi and Bader 2012). These schemes may enhance farmers' ability to initiate Public Private Partnerships (PPPs) and build strong institutions, which will ensure that water is availed to all equitably in normal times as well as under situations of stress (Berg 2007; Agrawal and Perrin 2008).

No wonder that, some farmers and catchment managers, especially within the ASALs, remain skeptical about the significance of the value added of GWS schemes compared to traditional conservation, especially when it comes to addressing drought severity, owing to decreasing rates of river discharges and water infiltration in the soil (Wunder 2007; Rockström *et al.* 2009). Some even question their impact on the increased surface runoff ("overland flow") and storm intensity (flood severity) (Mutisya 1997; Luwesi 2010; Luwesi, Shisanya and Obando 2011). These results consolidates findings by Lal (1993), Mutisya (1994), Ehrensperger and Kiteme (2005), Mogaka *et al.* (2006), Waswa (2006), Kiteme *et al.* (2008), Rockström *et al.* (2009), Luwesi (2010), Ngonzo, Shisanya and Obando (2010), Luwesi, Shisanya and Obando (2011), WSP. (2011), IPCC (2012), and Luwesi, Shisanya and Obando (2012), especially with regard to the situation in the Kenyan Arid and Semi-Arid Lands (ASALs).

4.4 GWS Schemes' Efficiency and Cost Recovery Ability by the Year 2030

4.4.1 Introduction

The last section of this study dealt with the computation of the efficiency, costs and benefits of Green Water Saving (GWS) schemes operating in Ngusishi and Muooni catchments compared to their Blue Water Supply (BWS) projects counterparts. These computations were based on hydro-economic inventory models of the use value of blue and green waters in farming in each of the selected catchments. Equations presented hereby were derived from the linear programming system of the WEAP predictions for 2011-2030 period (Lòpez-Baldovin, Gutiérrez-Martin and Berbel 2006; Luwesi, Shisanya and Obando 2012). Cost efficiency and recovery models took into consideration the vulnerabilities and capabilities of each catchment under Above Normal (ANOR), Normal (NOR), and Below Normal (BNOR) rainfall regimes.

Based on the results from the WEAP system, the analysis predicted rating curves in terms of Future Value (FV) for daily water supply (W_s), demand (W_d), their total costs (TC_s and TC_d) and the total revenue from supply (R_w) under the three scenarios of rainfall fluctuation. For the convenience of the study, it was assumed that the quantity of inputs for producing a cubic meter of water was the same for both BWS projects and GWS schemes. It was also hypothesized that inputs remained constant over time in each catchment under the three climatic scenarios. The following sub-sections present results of Cost-Efficiency Inventory (CEI) and Benefit-Cost Analysis (BCA) for BWS projects and GWS schemes, respectively, as well as Contingent Benefit Valuation (CBV) for GWS schemes.

4.4.2 Cost-Efficiency Inventory for GWS Schemes versus BWS Projects

The study used hydro-economic inventory models to determine operational functions of blue water supply and demand for farming in Ngusishi (GWS scheme) and Muooni (BWS projects). For that reason, a turnover for water orders (*r*) was simulated in each catchment from discharges observed in December 1981 (ANOR scenario), April 2010 (NOR scenario) and November 2009 (BNOR scenario) (Table 4.18). The latter were hypothesized to reflect the variations of farmers' water demand and supply under predicted hydro-climatic conditions prevailing in each catchment.

Table 4.18 Water order turnovers under different rainfall regimes in the study areas

Catchment	ANOR Turnover (r_{an})	NOR Turnover (r_{no})	BNOR Turnover (r_{bn})
Ngusishi	3.350	0.530	0.063
Muooni	1.826	0.571	0.050

Source: Fieldwork (Luwesi and Shisanya 2017)

A prognosis of the economic viability of farming activities in 2010 was established (Table 4.19). Farmers' annual income statement showed that farmers in Ngusishi and Muooni catchments spent 0.37% and 2.94% of their total farming cost on water, respectively. High farming expenditures on water in Muooni catchment were an indicator of their vulnerability to low rainfalls and drought, in the absence of GWS schemes. However, Ngusishi catchment disclosed a bit of reliability of farming water supply from rainfall and any other source, GWS schemes included. Nevertheless, crop water requirements in general were not properly met, even under normal rainfall regimes (Table 4.20).

Table 4.19 Farmers' annual income statement in the selected catchments (FY-2010)

N°	TITLE	INCOME & COST (in US$) [1]	
		Ngusishi	Muooni
1.0	Farming Income		
1.1	Total Income (per sample surveyed)	119,749.35	64,740.47
1.2	Average Income (per farmer)	1,963.10	640.99
1.3	Marginal Income (per Catchment)	331.16	11.58
2.0	Farming Cost		
2.1	Total Farming Expenditures (per sample)	112,699.49	118,264.64
2.1.1	Seeds	8,603.40	6,460.21
2.1.2	Fertilizers	25,269.08	20,842.95
2.1.3	Pesticides	3,630.05	1,016.57
2.1.4	Water	414.53	3,475.91
2.1.5	Water Pumps Fuel	2,776.02	18,519.80
2.1.6	Wages	32,250.80	28,910.03
2.1.7	Transport	28,699.17	28,472.50
2.1.8	Food	11,056.45	10,566.64
2.2	Total Farming Cost(per sample)	112,699.49	118,264.64
2.3	Average Cost (per farmer)	1,847.53	1,170.94
2.4	Marginal Cost (per Catchment)	788.37	90.62
3.0	Farming Profit		
3.1	Total Profit (per sample surveyed)	7,049.86	-53,524.17
3.2	Average Profit (per farmer)	115.57	-529.94
3.3	Marginal Profit (per Catchment)	-457.21	-79.04

Source: Fieldwork (Luwesi and Shisanya 2017)

[1] US$ 1 = KES 80

Table 4.20 Farmers' water demand and crop requirements in the study areas in 2010

Catchment	(1) Annual farming Water Demand (m^3)	(2) Annual crop water requirement (m^3)	(3) = (2)-(1) Gap (m^3)	(4)=100*(3)/(2) Percentage Gap (%)
Ngusishi	2,544.45	38,758.89	36,214.44	93.44%
Muooni	709.35	23,404.14	22,694.79	96.97%

SOURCE: Fieldwork (Luwesi and Shisanya 2017)

Farming water demands represented only a ratio of 6.56% and 3.03% of the annual crop water requirements for Ngusishi and Muooni catchments, respectively, computed in the year 2010. Yet, these farmers' crop water requirements and their estimated costs formed the basis for valuation of green water supply and demand in the catchment. It was referred to as blue water supply and demand for agriculture irrigation under co-ordination by a Green Water Saving (GWS) scheme. The analysis hence hypothesized that the GWS scheme would maintain blue water supply throughout the year, under whatever seasonal variations. This would increase water productivity and revenues in farming (in case of a drought or flood), and decrease water cost per unit of agricultural yield.

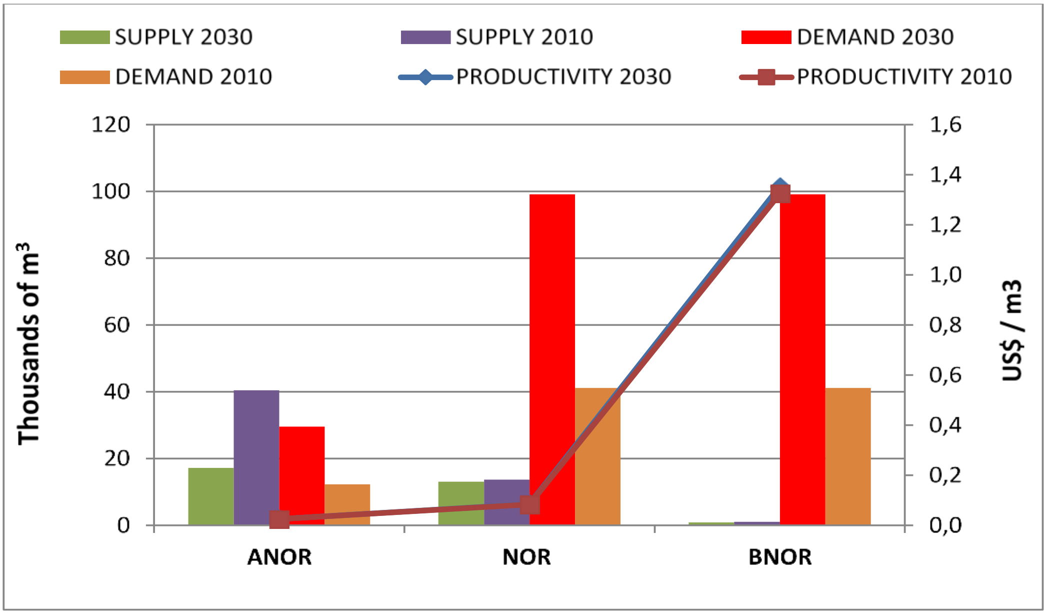


Fig. 4.29 Farming Water Demand and Supply in Ngusishi by 2030 (Luwesi and Shisanya 2017)

Figure 4.29 provides a panorama of the analysis of blue water demand and supply for farming in Ngusishi catchment under fluctuating rainfall regimes. The catchment presented a case of subsidized water supply under regulation by a GWS scheme, the unit cost per cubic meter remaining stable from 2010 to 2030.

Daily farming water demands were predicted to increase at higher speed than supply under the three hydro-climatic scenarios (ANOR, NOR and BNOR). Annual growth rates of +4.5% and -4.2% for demand and supply, respectively, were foreseen under the ANOR scenario. Hence, daily water demand that amounted to 12,264 m^3/day in 2010 was expected to increase to 29,577 m^3/day in 2030, while daily water supply was to fall from 40,457 to 17,152 m^3/day. Yet, this higher demand increase would not fuel increased daily revenues. Revenues would rather decrease at annual rates of 4% owing to subsided supply and stabilization of sale prices at US$ 0.01 the cubic meter (that is less than KES 1 /m^3). In the meantime, the cost of farming water supply would have gone up from US$ 0.02 to 0.03 the cubic meter. Hence, losses incurred under the ANOR scenario would likely be attributed to the subsidization of prices, while the catchment would be facing enormous daily unmet demands of 12,425 m^3 in 2030.

GWS schemes and farmers operating in Ngusishi will also have to endure serious water stresses and shortages under normal (NOR) climatic conditions and drought (BNOR), respectively. Under the NOR scenario, water demand and its cost will keep growing at the same rates as under ANOR scenario. Nonetheless, water supply decreasing annual rates will stabilize at -0.2% and the cost variation at -0.01% with revenues decreasing at annual rate of 1%. In such conditions, Ngusishi farmers will have to contend with unmet demands of about 86,000 m^3 /day in 2030 and average prices ranging from US$ 0.07 /m^3 (in 2010) to US$ 0.08 /m^3 (in 2030). This situation will worsen under the BNOR scenario when the unmet demands will count for 98,234 m^3 /day in the year 2030. In effect, daily water supply will pass from 1,046 m^3 /day (in 2010) to 856 m^3 /day (in 2030), while demand will have shot up from 41,084 to 99,083 m^3 /day. The cost of water supply is foreseen to increase at an annual rate of 0.14%, thus resulting in average daily cost of water consumption of US$ 1.32 /m^3 in 2010 and US$ 1.35 /m^3 in 2030. This situation will be a burden for both farmers and GWS schemes, the first being incapable of affording the cost of new prices while the second will be incurring tremendous losses in the year 2030. Hence, estimated daily revenues of US$ 1,386 (for 2010) will decrease at 3% annual rate to close at US$ 753.7 in 2030, while the cost of production will have to jump from US$ 1,046 (in 2010) to US$ 1,075.68 (in 2030).

On its part, Muooni catchment offers a case of high economic vulnerability of the agricultural sector to drought with subsequent prolific blue water businesses or vendors (BWS projects), the average cost of water under normal conditions and even under overflow being ten (10) to fifty (50) times higher than Ngusishi catchment (Figure 4.30).

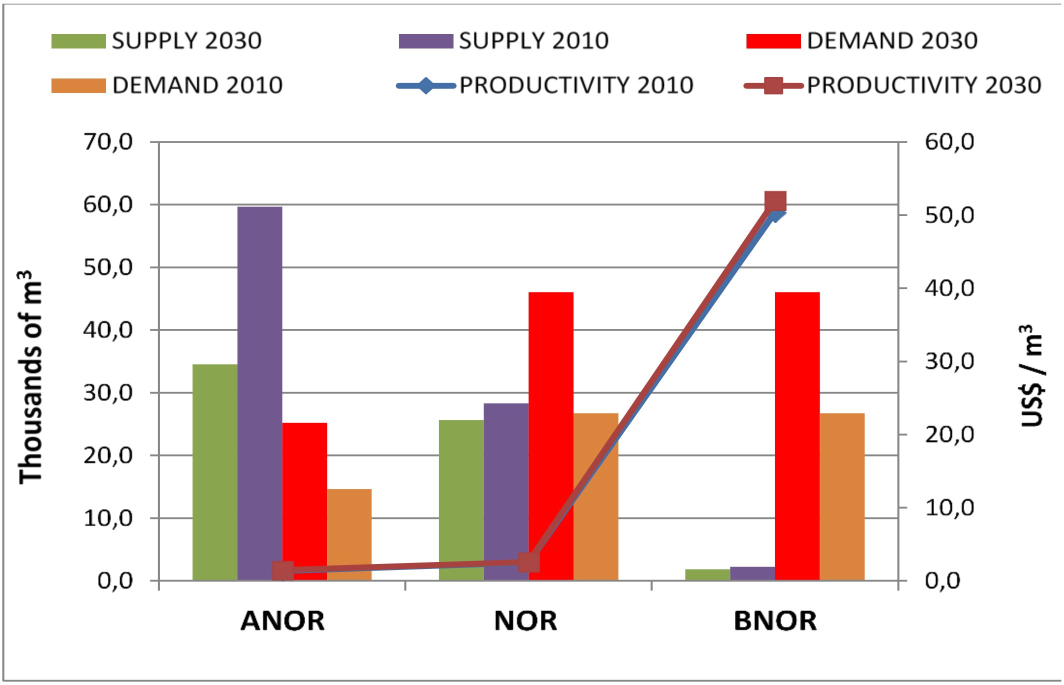


Fig. 4.30 Blue Water Demand and Supply in Muooni by 2030 (Luwesi and Shisanya 2017)

It comes out from the analysis that daily water prices per cubic meter in Muooni catchment are still high, even under ANOR when there is overflow (US$ 1.37 and 1.48 in 2010 and 2030, respectively). Demand, increasing quickly by 2.75%, is expected to surpass supply by 2035, which is expected to decrease by more or less an equivalent rate. Hence, Muooni catchment will be facing water stress some years after 2030 under ANOR scenario due to increased unmet demands. Though burdensome for farmers, this situation will be profitable for water vendors, who will make as high gross profits as US$ 2,191.73 /day in 2030. These water businesses will be more profitable under NOR and BNOR scenarios with decreased supply from 28,338 to 2,246 m^3/day (in 2010), respectively, at subsequent rates of 0.9% and 0.4% per annum, and a daily demand of 26,753 m^3/day under both scenarios.Water vendors are expected to record profitability rates ranging from 23% (in 2010) to 161% (in 2030) under the BNOR scenario. With this increased profitability, farmers will incur an average cost of US$ 50.4 to 52 /m^3, while the supply cost will vary between US$ 10.08 to 30.86 /m^3 in 2010 and 2030, respectively. However, the NOR scenario offers a more humanistic situation whereby average water supply prices are predicted to vary between US$ 2.50 and 2.56 /m^3 in 2010 and 2030, respectively. Decreased annual rate of productivity change are expected as a result of dropping revenues from US$ 466,881 /day (in 2010) to US$ 430,916.35 /day (in 2030). Average water supply cost is predicted to US$ 0.5 /m^3 (in 2010) and 0.51 /m^3 (in 2030). In such a situation, both farmers and water vendors benefit from the stabilization of the catchment economy.

At this point, the study turned to the optimization of water order turnovers (*r*) to determine hydro-economic inventory models that would generate optimum blue water supply levels in each catchment under ANOR (EOQ), NOR (LAC) and BNOR (MES) scenarios. These optimal values were obtained from operational marginal cost functions (Table 4.21). The latter provided a basis for computation of optimum value for farming water supply, productivity and efficiency under predicted hydro-climatic conditions in each selected catchment.

Table 4.21 Optimal blue water turnovers under rainfall fluctuation in the study areas

Catchment	ANOR Turnover (r_{an})	NOR Turnover (r_{no})	BNOR Turnover (r_{bn})
Ngusishi	1.000	1.229	1.414
Muooni	1.173	0.246	1.414

Source: Fieldwork (Luwesi and Shisanya 2017)

Table 4.22 illustrates the efficiency levels of blue water supply in Ngusishi catchment under fluctuating rainfall regimes. The total Cost Efficiency (CE) and Allocative Efficiency (AE) for farming water supply under co-ordination by Green Water Saving (GWS) schemes operating in Ngusishi catchment represented about 41% (in 2010) and 27% (in 2030) under BNOR rainfall regime with high Technical Efficiency (TE) of 100%. Daily water revenues, cost and profit (deficit) amounted to US$ 20,053, 16,341 and US$ -3,712 in the year 2010 under BNOR, with a water productivity of US$ 3.28 per m³. However, due to decreased revenues (US$ 466,881) achieved at higher cost (US$ 14,169) under the NOR scenario, these GWS schemes were incapable of achieving even 10% of their CE and AE efficiencies under BNOR though being credited with very high TE of 123.2%. Likewise, under the ANOR scenario, a CE rate of 0.2% was expected in 2010 with an AE rate of 0.7% and a TE of 27.3%, despite a high Scale Efficiency (SE) of 451.2%.

Table 4.22 Optimal farming water supply in Ngusishi under different rainfall regimes

Optimum Level	Horizon 2010					Horizon 2030				
	Qnty (m^3)	Water productivity	Total Cost Efficiency	Technical Efficiency	Allocative Efficiency	Qnty (m^3)	Water productivity	Total Cost Efficiency	Technical Efficiency	Allocative Efficiency
EOQ	391.12	4.64	0.002	0.273	0.007	260.17	4.64	0.002	0.273	0.007
LAC	734.41	3.77	0.021	1.232	0.017	666.74	3.77	0.019	1.232	0.015
MES	798.77	3.28	0.406	1.000	0.406	830.14	3.28	0.268	1.000	0.268

Source: Fieldwork (Luwesi and Shisanya 2017)

For high economic efficiency, optimal blue water supplies for farming in 2010 were estimated to 391.12 m³, 734.41 m³ and 798.77 m³ per day under ANOR, NOR, and BNOR rainfall regimes, respectively, to enable achieving an EOQ of 260.17 m³/day, a LAC of 666.74 m³/day and a MES of 830.14 m³/day in the year 2030. The analysis confirmed the fact that farming water operational costs were highly variable in Ngusishi catchment under the BNOR regime rather than under any other rainfall regime. Modest profits and efficiency rates of farming water supply were achieved under BNOR in Ngusishi, owing the presence of a water regulatory body that subsidizes costs related to water shortage. Hence, GWS schemes tend to increase their technical efficiency to maintain their cost efficiency in the long run. Though being socially acceptable to farmers (or water demanders), this practice of subsidization may seriously threaten the economic viability of farming water supply in Ngusishi catchment in the long run owing to increased deficits incurred by the GWS schemes.

The efficiency of blue water supply for farming in Muooni catchment is presented below under the ANOR, NOR and BNOR rainfall regimes (Table 4.23).

Table 4.23 Optimal farming water supply under different rainfall regimes in Muooni

Optimum	2010					2030				
	Qnty (m^3)	Water productivity	Total Cost Efficiency	Technical Efficiency	Allocative Efficiency	Qnty (m^3)	Water productivity	Total Cost Efficiency	Technical Efficiency	Allocative Efficiency
EOQ	26,336.47	1.98	0.172	2.773	0.062	12,702.7	6.98	0.049	2.773	0.018
LAC	13,930.39	16.51	0.998	0.132	7.558	5,202.31	78.93	0.213	0.132	1.613
MES	4,654.05	33.22	1.517	1.000	1.517	7,942.08	68.06	0.453	1.000	0.453

Source: Fieldwork (Luwesi and Shisanya 2017)

BWS projects operating in Muooni catchment recorded CE rates of 100% and above 150% under NOR and BNOR rainfall regimes, respectively. In effect, their daily water revenues, costs and profits (or deficits) under the ANOR scenario amounted to about US$ 20,053, US$ 16,341 and US$ 3,712, respectively, in the year 2010. These water projects expected a water productivity of US$ 1.98 per m^3 with a CE rate of 17.2%. However, due to increased revenue (US$ 466,881) achieved at a lower cost (US$ 14,169) under the NOR scenario, water vendors would be capable of achieving about 99.8% CE rate. Likewise, under the BNOR, a rate of 151.7% CE would be expected by Muooni water businesses. These rates were projected to decrease by more than 75% by the year 2030 with optimum water demands estimated to 12,702.7 m^3 EOQ (compared to 26,336.47 m^3 in 2010), 5,202.31 m^3 LAC (versus 13,930.39 m^3 in 2010) and 7,942.08 m^3 MES (against 4,654.05 m^3 in 2010).

These results show that BWS projects tend to maximize short-term benefits in Muooni catchment to take advantage of drought, since there is no formal institution coordinating water prices, allocation and management, on one end. On the other end, farming water supply under co-ordination by a GWS scheme generally displayed high water productivities under the ANOR and NOR rainfall than the BNOR regime. Yet, due to the high demand of water for irrigation and the limited technical efficiency of GWS schemes to save sufficient excess water under the ANOR for allocation and use during periods of deficits (the NOR and BNOR rainfall regimes), the total cost of farming water supply was higher under NOR and BNOR rainfall regimes than the ANOR. Nonetheless, the existence of a GWS scheme ensured both equity and fair prices in farming water supply to enable farmers attain a full cost recovery, even though the scheme would need substantial income for infrastructure development.

4.4.3 Benefit-Cost Analysis for GWS Schemes versus BWS Projects

A 7-step Benefit-Cost Analysis (BCA) was applied in this study to determine the ability of GWS schemes to achieve cost recovery in comparison to their BWS projects counterpart. This BCA approach encompassed notably: (step 1) the specification of water situation "with" and "without" GWS schemes; (step 2) the description of costs and benefits over the project period; (step 3) the valuation of cost and benefit streams; (step 4) the computation of the discounted project values; (step 5) the adjustment of discounted project values to risk and adaptive capacity values; (step 6) sensitivity analysis; and (step 7) the prospection of tangible and intangible socio-economic and biophysical impacts of GWS schemes.

Concerning the first step, it was observed that "Blue Water Supply" (BWS) Projects have collapsed over years due to the costs of floods and droughts brought about by climate change (Shakya 2001). The study considered options that will enable water supply in the whole catchment within the limits of blue water availability in the main river and in case of drought. As "Business As Usual" (BAU) a small dam excavation and construction, operations and maintenance (BWS project) was considered to fit to the needs of Ngusishi area, while a borehole with an ICT mobile phone activated pump (Grundfos Lifelink type) was appropriate for Muooni catchment. The alternative "Not As Usual Business" (NAUB) project was a set of Soil and Water Conservation (SWC) measures featuring a GWS scheme. The SWC were limited to agro-forestry, runoff cut-outs, terraces and grass waterways. The sequential aforementioned steps for a BCA are described below, starting by the description of the nature of costs and benefits.

Regarding step 2, the study applied the "game theory" criteria of "maximin" and "minimax" in the selection of costs and incomes of GWS schemes, respectively (Howe 1971). Under the "Business As Usual" (BAU) scenario, the total cost for investing in a dam (1) in Ngusishi and ten (10) Grundfos Lifelink's automated boreholes in

Muooni amounted to US$ 1,368,400.60 and 797,317.64, respectively. Thus, annual maintenance costs were predicted to US$ 126,557.73 in Ngusishi and US$ 256,015.70 in Muooni. Average variable operating costs for water supply were approximated to US$ 0.063 /m^3 in Ngusishi and US$ 0.51 /m^3 in Muooni. Average m^3 price was set to US$ 0.085 /m^3 in Ngusishi and US$ 2.57 /m^3 in Muooni.
Table 4.24 presents the projected costs for implementation of Green Water Saving (GWS) schemes in each catchment under the "Not As Usual Business" (NAUB) scenario.
Table 4.24 GWS schemes' cost of implementation in the selected catchments (FY-2010)

Cost	Ngusishi	Muooni
GWS capital costs (US$ annual share)	2,041.96	2,166.62
GWS fixed maintenance costs (US$)	1,701.63	1,805.52
Variable operating farming costs (US$/$m^3$)	3,113,414.38	5,432,341.94
Total Cost FY-2010	3,117,157.96	5,436,314.08

Source: Fieldwork (Luwesi and Shisanya 2017)
GWS scheme's capital cost represented 96% of the maximum cost of implementation for agro-forestry extended over 167 hectares of land in Ngusishi and 177 hectares in Muooni. It comprised the cost of tree seedlings (20%), manure (14%), fertilizers (12%), tillage (10%), and the cost of farmer's training on agro-forestry (40%). The remaining 4% was attributed to the cost of maintenance of agro-forestry. The capital and maintenance costs for agro-forestry were chosen because agro-forestry was more costly than terraces, runoff cut-outs and grass waterways in each of the tree catchments. Besides, the analysis assumed that the variable water price per m^3 was identical to the cost, since the scheme was set by farmers to stabilize water prices in case of seasonal variations. The average variable operating costs for water supply were approximated to US$ 0.0008 /m^3 in Ngusishi and US$ 0.019 /m^3 in Muooni. Table 4.25 shows predicted green water revenues in the selected catchments.
Table 4.25 Revenues accrue to GWS schemes in the selected catchments (FY-2010)

Cost	Ngusishi	Muooni
Fixed revenues (US$)	-	-
Variable farming revenues (US$)	3,308,170.24	2,973,744.91
Variable Blue water revenues (US$/$m^3$)	11,451.60	159,659.99
Total Cost FY-2010	3,319,621.84	3,133,404.9

Source: Fieldwork (Luwesi and Shisanya 2017)
The valuation of cost and benefit streams (Step 3), involved the derivation of rating curves for daily water supply, cost and revenue in each catchment and each scenario. Under the "Business As Usual" (BAU) scenario, the following functions were obtained from the analysis of farming water data from Ngusishi:

$$W_s(t) = 13{,}618\ (0.998)^t \qquad [4.1]$$

$$TC_s(t) = 851\ (0.9999)^t \qquad [4.2]$$

$$R_w(t) = 1{,}127\ (0.99)^t \qquad [4.3]$$

Similar rating curves were derived for daily water supply, its cost and revenue (t = 0 for the year 2010) from Muooni catchment's data:

$$W_s(t) = 28{,}338\ (0.995)^t \qquad [4.4]$$

$$TC_s(t) = 14{,}169\ (0.996)^t \qquad [4.5]$$

$$R_w(t) = 66{,}881\ (0.996)^t \qquad [4.6]$$

Streams of benefits were derived from the difference between water revenue (R_w) and the total cost for water supply (TC_s).

Similar computations were done under the "Not As Usual Business" (NAUB) scenario. The following rating curves for daily green water supply in Ngusishi catchment were obtained:

$W_s\ (t) = 38{,}758.89\ (0.998)^{t}$ [4.7]

$TC_s\ (t) = 8{,}658.77\ (0.9999)^{t}$ [4.8]

$R_w\ (t) = 9{,}221.17\ (0.99)^{t}$ [4.9]

Finally, rating curves for daily green water supply in Muooni catchment were as follows:

$W_s\ (t) = 23{,}404.14\ (0.995)^{t}$ [4.10]

$TC_s\ (t) = 15{,}100.87\ (0.996)^{t}$ [4.11]

$R_w\ (t) = 8{,}703.90\ (0.996)^{t}$ [4.12]

Streams of benefits were derived from the difference between water revenue (R_w) and the total cost for water supply (TC_s).

The next step (4) of this analysis was to discount future values (FV) for costs and benefits computed under normal climatic conditions (NOR) to measure what Green Water Saving (GWS) schemes and Blue Water Supply (BWS) projects worth that day in dollars (US$) in terms of "Net Present Values" (NPV). Operational costs and benefits were discounted at a real interest rate matching the opportunity cost of capital in each catchment. Hence, a real interest rate of 12.66 % per annum was derived from the analysis of the Kenyan borrowing market. The said discount rate was in fit with the opportunity cost of capital mostly used for developing countries, and which ranges between 8 and 15 percent in real terms (OAS, 1991).

Under the "Business As Usual" (BAU) scenario, the sum of NPV for costs and benefits in Ngusishi catchment amounted to US$ 10,903.96 and 1,860.62, respectively, with a BCR of 0.17. This meant also meant that blue water projects were not economically viable in this catchment. However, Muooni catchment presented an NPV (cost) of 172,909.38 against a NPV (Benefits) of 643,263.4, thence displaying a BCR of 3.72. This ratio meant that blue water businesses are economically rentable in a water scarce area like Muooni and even under normal climatic conditions.

Under the "Not As Usual Business" (NAUB) scenario, the BCR was negative in both Muooni and Ngusishi. Compared to BWS projects, GWS schemes operating in Muooni offered a higher BCR rates than GWS schemes in Ngusishi catchment, even though the two projects were not viable economically. NPV sums of US$ 110,945.763 (for cost) and US$ - 6,505.37 (for benefits) were recorded, thus generating a negative BCR of -0.06. Similarly, sums of NPV (cost) and NPV (benefits) in Muooni catchment amounted to US$ 184,281.32 and -78,064.51 respectively, with a BCR of - 0.42.

Using hydro-economic inventory models, the analysis determined operational functions for costs, revenues and benefits of Blue Water Supply (BWS) under the BAU and the NAUB scenarios (Step 5). Water order turnovers (r) simulated from discharges observed in November 2009 (under drought) and December 1981 (under flooding) were used for adjusting each catchment's values (Table 4.26).

Table 4.26 Water supply turnovers under drought and flood in the study areas

Catchment	Drought turnover (r_{an})	Flooding turnover (r_{bn})
Ngusishi	0.063	3.350
Muooni	0.050	1.826

Source: Fieldwork (Luwesi and Shisanya 2017)

Under the Business As Usual (BAU) scenario, the following rating curves for water supply were derived from analysis of Ngusishi catchment's dataset under drought:

$TC_s\ (t) = 31{,}046\ (1.0014)^{t}$ [4.13]

$R_w\ (t) = 1{,}386\ (0.97)^{t}$ [4.14]

Sums of NPV (Cost), NPV (Benefit) and BCR generated under drought in Ngusishi were of US$ 13,656.97 US$ - 1,367.32 and - 0.1, respectively. Under flooding conditions, the following rating curves were computed for water supply in Ngusishi catchment:

$TC_s\ (t) = 755\ (0.983)^{t}$ [4.15]

$R_w\ (t) = 303\ (0.96)^{t}$ [4.16]

Sums of NPV for BWS obtained under conditions of flooding in Ngusishi catchment were estimated to US$ 7,843.68 (for cost) and US$ -5,460.77 (for benefits), thus generating a negative BCR of -0.70. Hence, BWS was perceived to be economically viable neither under drought nor under flood in Ngusishi catchment.
Finally, rating curves for water supply derived from Muooni catchment under drought are presented below:

$$TC_s\,(t) = 22{,}639\ (0.999)^{t} \quad [4.17]$$

$$R_w\,(t) = 113{,}193\ (0.967)^{t} \quad [4.18]$$

Sums of NPV for BWS cost and benefit generated US$ 286,825.1 and 681,200.21, with a BCR of 2.38. This BCR demonstrated once more that water business is very rentable in Muooni catchment under drought rather than flood. In effect, Muooni catchment's rating curves for water supply under conditions of flooding were as below:

$$TC_s\,(t) = 16{,}341\ (0.974)^{t} \quad [4.19]$$

$$R_w\,(t) = 20{,}053\ (0.974)^{t} \quad [4.20]$$

Estimated sums of NPV for BWS under flooding in Muooni catchment valued US$ 152,089.67 (for cost) and US$ 34,548.49 (for benefits), with a positive BCR of 0.23. This ratio showed the lack of economic viability of water businesses in Muooni catchment under conditions of flooding.
Under the "Not As Usual Business" (NAUB) scenario, the following rating curves for green water supply under drought were obtained for Ngusishi catchment:

$$TC_s\,(t) = 138{,}382.91\ (1.0014)^{t} \quad [4.21]$$

$$R_w\,(t) = 5{,}360.98\ (0.97)^{t} \quad [4.22]$$

Sums of NPV (Cost), NPV (Benefit) and BCR generated under drought in Ngusishi were US$ 1,806,779.76, US$ -1,759,243.99 and -0.974, respectively. Under flooding conditions, the following rating curves were computed for green water supply in Ngusishi catchment:

$$TC_s\,(t) = 28{,}981.79\ (0.983)^{t} \quad [4.23]$$

$$R_w\,(t) = 647{,}656.87\ (0.96)^{t} \quad [4.24]$$

The sums of NPV obtained for Ngusishi GWS schemes under conditions of flooding were estimated to US$ 301,091.1541 (for cost) and US$ 4,792,340.03 (for benefits), thus generating a negative BCR of 15.92. Hence, the study concluded that GWS schemes are economically viable in Ngusishi catchment under conditions of flood rather than drought.
Finally, the following rating curves for green water supply in Muooni catchment were obtained under drought:

$$TC_s\,(t) = 304{,}230.94\ (0.999)^{t} \quad [4.25]$$

$$R_w\,(t) = 1{,}191.99\ (0.967)^{t} \quad [4.26]$$

NPV sums for green water supply cost and benefit were US$ 3,854,457.77 and US$ -3,844,263.89, with a BCR of -0.997. This BCR demonstrated once more that GWS schemes are not rentable in Muooni catchment under drought condition. Nevertheless, these schemes are economically feasible under conditions of flooding. In effect, Muooni catchment's rating curves for green water supply under conditions of flooding were as below:

$$TC_s\,(t) = 27{,}568.93\ (0.974)^{t} \quad [4.27]$$

$$R_w\,(t) = 167{,}982.73\ (0.974)^{t} \quad [4.28]$$

Estimated sums of NPV for GWS schemes under flooding in Muooni catchment were US$ 256,590.74 (for cost) and US$ 1,306,865.42 (for benefits), with a positive BCR of 5.09. This ratio showed high economic viability of GWS schemes in all the selected catchments under conditions of flooding rather than drought.
A Sensitivity analysis (step 6) was conducted to test the variations of GWS schemes NPV and BCR under assumptions of alterations of operating costs and expected benefits under the hypothesized drought or flooding. In Ngusishi catchment, Expected NPV (cost), NPV (benefits) and BCR were estimated to US$ 42,770.43, US$ 2,593,844.43 and 60.65 under flooding, respectively, and those for drought amounted to US$ 13,656.97, US$ -1759243.99 and -128.82. Hence, switching values represented 4 times higher the flood BCR and 132 times less than the drought BCR. Expected NPV for cost and benefits under flooding in Muooni catchment amounted to US$ 152,089.67 and 1,306,865.42, thus generating a BCR of 8.59. This value was nearly 2 times the previous BCR. Expected NPV (cost), NPV (benefits) and BCR under conditions of drought were approximated to US$ 286,825.1, US$ -3,844,263.887 and a ratio of -13.4. This ratio was 13 times less than the previous one. These results confirmed the fact that GWS schemes are economically feasible under conditions of flood than drought.
Lastly, prospective impacts of GWS schemes were assessed from the farmers' viewpoint (direct or tangible impacts) and that of the Government of Kenya (indirect or intangible impacts) in Ngusishi and Muooni catchments (step 7). Prospective success of GWS schemes from local stakeholders expectations were assessed against the 5 key performance measurements stated under objective 3 above, namely: (1) environmental sustainability; (2) business

success; (3) economic development; (4) social equity; and (5) institutional development. The following direct and tangible benefits were suggested: (i) sustained crop growth high yield, and land cover / ecosystem diversity due to soil stability and enhanced water availability (for environmental sustainability); (ii) increased farming output and market, water use efficiency, and land and farming inputs efficiency (for business success); (iii) high farming yield and returns on capital (for economic development); (iv) social sustainability and improved social welfare (for social equity); (v) good governance and on-farm management (for institutional development).

Definitely, from the government's viewpoint, these schemes are intended to eradicate poverty and augment compliance to water use charges and effluent discharge thresholds while improving water availability and accessibility in the catchment as well as its economic efficiency in farming (WRMA, 2010). Owing to increased water productivity and profitability, stakeholders would be more inclined to pay their public duties and taxes. This would result in an improved macro economy and stabilization of prices in the markets (goods and services, foreign exchange, etc.) across the catchments through increased balance of payments and employment creation in the country.

4.4.4 Contingent Valuation of GWS Schemes' Benefits

During the on-farm survey conducted in Ngusishi catchment, downstream farmers were asked whether they would be willing to pay upstream farmers involved in the conservation of the catchment, and how much? Eventually, an average commercial farmer aged 42 years old was willing to offer US$ 11.61 monthly (with a standard deviation of US$0.99), while his/ her average farming income was estimated to US$ 96.89 (with a standard deviation of US$ 123.07) (Table 4.27).

Table 4.27 Downstream farmers' willingness to pay (WTP) in Ngusishi [1]

Variable	Mean	Std. Deviation	N
Cash payments a farmer is willing to give (KES/month)	928.57	79.39	35
Sex of farmer (Male)	63.6%	49%	35
Age of farmer	41.76	0.689	35
Farmer household size	4.12	1.430	35
Water total cost (KES/month)	78.6207	248.82	35
Farming average income (KES/month)	7,751.4	9,845.32	35
Would you agree to compensate other stakeholders engaged in catchment conservation, if the government asked you to do so?	54.8%	50.5%	35

Source: Fieldwork (Luwesi and Shisanya 2017)

[1] US$ 1 = KES 80

The analysis also reveals that an average peasant farmer of 42 years old was willing to accept a monthly allowance of US$ 108.33 (that is KES 8,666.67 with a standard deviation of KES 653.2), while his/ her average farming income was estimated to US$ 91.21 (that is KES 7,297.11 with a standard deviation of KES 4,307.33) (Table 4.28).

Table 4.28 Upstream farmers' willingness to accept (WTA) GWS services in Ngusishi [1]

Variable	Mean	Std. Deviation	N
Compensation a farmer is willing to ask (KES/month)	8,666.667	653.197	29
Average Farming income (KES/month)	7,297.107	4,307.333	29
Sex of farmer (Male)	65.3%	48.5%	29
Age of farmer	41.692	0.838	29
Farmer household size	4.462	1.392	29
Water cost (KES)	14.8	16.154	29
Would you agree to set aside ½ acre of land for tree planting alone, if the government asked you to do so?	80.8%	40.2%	29

Source: Fieldwork (Luwesi and Shisanya 2017)

[1] US$ 1 = KES 80

With a WTP of US$ 11.61 times 674 households and a WTA of US$ 108.33 time 1,011 households, the implementation of GWS schemes in Ngusishi would result in a monthly deficit of US$ 101,696.49. To ensure their cost recovery, GWS schemes will need to raise substantial funds from the government, other local public and private institutions as well as development co-operation agencies. This will impede their financial sustainability and economic viability in the long run.

On their part, Muooni farmers revealed a Willingness To Pay (WTP) for GWS services of US$ 21.82 monthly (times 2,549 households), against a Willingness To Accept compensation (WTA) of US$ 259.06 (times 2,090 households per month), thus leading to a total deficit of US$ 485,816.22 per month. In effect, an average commercial farmer aged 42 years old was willing to offer US$ 21.82 monthly (That is KES 1,745.46 with a standard deviation of KES 456.45), while his monthly farming income was estimated to US$ 80.95 (That is KES 6,475.92 with a standard deviation of KES 3,458.02) (Table 4.29**).**

Table 4.29 Downstream farmers' willingness to pay in Muooni [1]

Variable	Mean	Std. Deviation	N
Cash payments a farmer is willing to give (KES/month)	1,137.5	310.73	61
Sex of farmer (Male)	67.4%	44.3%	61
Age of farmer	42.11	0.84	61
Farmer household size	5.03	1.41	61
Water total cost (KES/month)	6,681.25	7,555.82	61
Farming average income (KES/month)	6,475.92	3,458.02	61
Would you agree to compensate other stakeholders engaged in catchment conservation, if the government asked you to do so?	82.5%	35.5%	61

Source: Fieldwork (Luwesi and Shisanya 2017)

[1] US$ 1 = KES 80

The analysis also revealed that an average male farmer aged 42 years old would accept a monthly allowance of US$ 259.06 (that is KES 20,725 with a standard deviation of KES 6,942.47), while his average farming income was estimated to US$ 71 (that is KES 5,679.55 with a standard deviation of KES 2,891.67) (Table 4.30).

Table 4.30 Upstream farmers' intention to accept GWS services in Muooni [1]

Variable	Mean	Std. Deviation	N
Compensation a farmer is willing to ask (KES/month)	20,725	6,942.47	48
Average Farming income (KES/month)	7,297.107	4,307.333	48
Sex of farmer (Male)	99%	46.2%	48
Age of farmer	42.02	0.76	48
Farmer household size	5.00	2.71	48
Water cost (KES)	5,673.077	4,528.9	48
Would you agree to set aside ½ acre of land for tree planting alone, if the government asked you to do so?	75%	20.2%	48

Source: Fieldwork (Luwesi and Shisanya 2017)

[1] US$ 1 = KES 80

Just like in Ngusishi, GWS schemes operating in Muooni would ensure their cost recovery by raising substantial funds from other agencies, thus impeding their financial self sufficiency and economic feasibility in the long run.

4.4.5 Discussion on GWS Schemes' Efficiency and Cost Recovery Ability

This study has shown that many farmers in Muooni and Ngusishi were unable to meet the natural water requirements of their plants, especially under BNOR rainfall regime (drought), and sometimes under normal conditions of rainfall (NOR). Hence, high water prices, even under periods of overflow (ANOR), specifically in Muooni catchment, were burdensome for farmers but profitable for water businesses that make high profits. The absence of a co-ordinating authority in this catchment gave rise to opportunistic water businesses or vendors (BWS projects), which were charging arbitrary prices under drought. This lack of a formal regulation of water prices result in "crashes, mania and panics" deplored by Kindelberger and Aliber (2005), which often lead to financial crises in the water sector (Sehring 2006). This kind of economic greed also results in unsustainable water supplies in the long run, which were mainly explained by the lack adequate technical and allocative efficiencies.

This situation was predicted to worsen by the year 2030. The little storage of water per capita in Kenya was attributed to the failure by the government to develop surface and groundwater resources, which in turn exacerbates the country's vulnerability. "Consequently, there is very little stored water per capita so when severe droughts occur water storage areas are rapidly drawn down" (WSP 2011). There is thus need for a paradigm shift in the course of climate change, which is predicting increased extreme droughts across the continent, and mostly in ASALs. The existence of a GWS scheme may ensure both equity and fair prices for farming water supply to enable farmers attain a full cost recovery, even though these schemes need substantial funding from other agencies to finance their operations and infrastructure development.

"UNEP believes rainwater harvesting could be a cheap and effective way to 'climate-proof' some communities and go some way to achieving its millennium development goal to provide water for half of those people who don't have access to water today" (*b. spirit!* 2008: 20).

'Green water" can be used to sustain water running off therein, notably because of their low vegetation cover, and thus low soil moisture content. It is believed that efforts in investing in green water saving contributes to increased accessible blue water in streams and lakes. This can boost a "green revolution" in Kenya like it was the case in South-East Asia (India, China, etc.) in the 1960s (Vishnudas 2006; *GRAIN Briefing* 2007; Bastiaanssen and Bingfang 2008). Similar results have also been obtained in Australia, Bangladesh, Burkina Faso, Niger, Palestine and South-Africa to address the ever widening gap between water demand and supply (Mukheibir 2008; Reij *et al.* 2009; Islam *et al.* 2010; Zhang *et al.* 2010; Al-Salaymeh *et al.* 2011).

Yet, Green Water Saving (GWS) schemes are not a panacea to all Kenyan farmers' water problems. Results showed that these schemes are more efficient upstream and economically feasible under normal conditions and flooding rather than drought. However, Blue Water Supply (BWS) is more efficient downstream and economically feasible under normal conditions and drought rather than flooding. There is need for a combination of efficient BWS projects and effective GWS schemes to enable farmers achieving an "Economic Order Quantity" (EOQ) under flooding conditions (ANOR), a "Limit Average Cost" (LAC) under normal conditions and a "Minimum Efficient Scale" (MES) under conditions of drought (BNOR) (Harvey 1985; Hardwick, Khan and Langmead 1994). This will result in an improvement of the actual farming water use to avoid crop failure, especially under BNOR rainfall regime (drought), when the shortage costs are excessively high (Musick *et al.* 1986; Harris et al. 2017; Luwesi, Shisanya and Obando 2011).

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Chapter 5. Conclusions and Recommendatios

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5.1 Conclusions

The depletion of blue water reserves and supplies in most Arid and Semi Arid Lands (ASALs) of Kenya raises much concern about agriculture resilience in those areas. This study predicted that this situation will worsen in the course of climate change, by the year 2030, with expected rapid changes in Land Use and Land Cover (LULC) brought about by human populations and their induced activities. Nonetheless, vulnerability to drought and drought-flood cycles was attributed to the failure by the government to develop surface and groundwater resources. Farmers recorded tremendous unmet crop water demands under BNOR rainfall regime (drought), and sometimes under normal rainfall regimes (NOR), especially in Muooni catchment, where high water prices have been signaled, even under periods of overflow (ANOR). Though burdensome for most farmers, this situation was profitable for water businesses (BWS projects), in the absence of a catchment co-ordination authority. Thence, the need for a paradigm shift was felt by most stakeholders living in the ASALs.

It is in that context that the introduction of effective Soil and Water Conservation (SWC) measures, particularly in Muooni catchment, has brought some relief to this drought stricken area, even though some farmers and catchment managers may sometimes not feel their true impact on the ground, owing to the high risks of droughts associated to climatic changes (Van Aalst 2006). The creation of a "Water Resource Users' Association" (WRUA) has also been a blessing for Ngusishi farmers, since it helps coordinating water demands and supplies, the catchment management and the regulation of water prices, thus creating an environment that is conducive for equitable distribution of water resources. These GWS schemes have prevented cupid water vendors to take advantage of water stress and shortages to shoot up farming water prices, like in Muooni catchment. They have also enabled farmers attain a full cost recovery in their farming activities. Nevertheless, GWS schemes were not a panacea to the water scarcity experienced by these ASALs.

Even though these schemes were biophysically well thought and feasible, and socially acceptable and equitable, their implementation in most ASALs, especially in Ngusishi catchment, has resulted in the subsidization of water prices, especially under periods of scarcity. Consequently, tremendous deficits and lower Benefit–Cost Ratios (BCR) have been recorded by these schemes. This was mostly attributed to inadequate technical and allocative efficiencies, to weak Willingness To Pay (WTP) and excessive Willingness To Accept compensation (WTA) for GWS services by farmers. This economic inviability of GWS schemes in the ASALs of Kenya has led to the raising of substantial funding from public and private agencies as well as international organizations to finance the schemes operations and infrastructure development. No wonder that many catchment managers remain reluctant to embracing such hydro-political mechanisms in Kenya.

5.2 Recommendations

It is suggested that increased social networking coupled with effective co-ordination of water resource management may increase the capability of poor farmers to compensate the collapse of their biological, ecological, social, political and economic systems across the country, and particularly in Muooni catchment. Hence, the creation of strong WRUAs is recommended to be an effective way for spearheading the adoption of GWS schemes to ensure agricultural resilience in drought stricken areas. WRUAs are mandated to foster the planning, measuring and allocation of water supplies, charging of water demands and effluent discharges, monitoring and evaluation of the catchment management in order to save over flows during above normal rainfall regimes and release them during periods of scarcity. These WRUAs shall combine effective GWS schemes with efficient BWS projects, to enable farmers achieve an "Economic Order Quantity" (EOQ) under flooding conditions (ANOR), a "Limit Average Cost" (LAC) under normal conditions and a "Minimum Efficient Scale" (MES) under conditions of drought (BNOR). The implementation of such a strategy will require adopting new technologies, such as the Grundfos Lifelink's automated groundwater projects in Musingini (Machakos area), as well as effective hydro-political strategies, including Rain Water Harvesting and Saving (RWHS). There is also need for blending GWS schemes with other innovative financial mechanisms such as microfinance, BOT, BOL and BOS. Finally, in line with the *Kenya Vision 2030,* farmers, particularly those living in Muooni, ought to embrace crop selection and specialization (to 2 or 3 crops per plot) to avoid over-abstracting water through cropping of water unfriendly crop species such as eucalyptus (KNBS 2007). By so doing, they would increase their agricultural production within the Production Possibility Frontier (PPF) and expect achieving higher BCRs to ensure the resilience of their farming activities under conditions of drought and flood. This will foster food security and poverty alleviation and ensure adaptation to climate change in the ASALs.

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References
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References

Adger, W.N. 2000. Institutional adaptation to environmental risk under the transition in Vietnam. *Annals of the Association of American Geographers*, 90 (4): 738-758. Massachusetts: Blackwell Publishers.

ADPC. (2005). *A Primer Disaster Risk Management in Asia*. Bangkok: Clung Wicha Press Co. Ltd.

Aeschbacher, J. 2003. Development of water use and water-shortage in the Naro Moru catchment (Upper Ewaso Ng'iro Basin, Kenya). Masters'. Thesis, Institute of Geography, University of Berne, Berne.

Aeschbacher, J., Liniger, H.P. and Weingartner, R. 2005. Increasing water shortage in the Mount Kenya Region – A case study of a typical highland-lowland system. *Mountain Research and Development* 25 (2): 155-162.

Agrawal, A. and Perrin, N. 2008. Climate adaptation, local institutions and rural livelihoods. *IFRI Working Paper*, 081-6. Michigan: School of Natural Resources and Environment, University of Michigan.

Al-Salaymeh, A., Al-Khatib, I. and Arafat, H. 2011. Towards Sustainable Water Quality: Management of Rainwater Harvesting Cisterns in Southern Palestine. *Water Resources Management,* 25, 1721-1736.

Allen, R.G., Pereira, L.S., Raes, D. and Smith, M. 2000. *FAO Irrigation and Drainage Paper No. 56: Crop Evapotranspiration (guidelines for computing crop water requirements).* Rome: FAO, Water Resources, Development and Management Service.

Anandajayasekeram, P., Rooyen, Van C.J. and Liebenberg, F. 2004. *Agricultural Projects Planning and Analysis: A source book*. Ghent: University of Ghent.

Ansoff, I. 1990. *Implanting Strategic Management* (2nd edtion). Englewoods Cliffs, New Jersey: Prentice-Hall.

Arnon, I. 1992. Agriculture in dry lands: principles and practice. *Development in Agricultural and Managed-Forest Ecology* 26. New York: Elsevier.

b. sprit!. 2008. "All about Water". Issue of Sept-Oct 2008, No.17: 12-22.

Baker, M.J. and Start, S. 1989. *Marketing and Competitive Success*. London: Philip Allen.

Barah, B.C. 2009. Economic and ecological benefits of system of rice intensification (SRI) in Tamil Nadu. *Agricultural Economics Research Review*, Vol. 22 (July-December 2009), pp 209-214.

Bartlett, J.E., Kotrlik, J.W. and Higgins, C.C. 2001. Organizational Research: Determining Appropriate Sample Size in Survey Research. *Information Technology, Learning, and Performance Journal*, Vol. 19, No. 1, Spring 2001, 43-50.

Bastiaanssen, W. and Bingfang, W. 2008. Hai Tide: Tapping Green Water in Northern China. *Stockholm Water Front,* No 1, April 2008, 12-13.

Bates, B.C., Kundzewicz, Z.W., Wu, S. and Palutikof, J.B. 2008. *Climate Change and Water*. A Technical Paper of the Intergovernmental Panel on Climate Change (IPCC). Geneva: The IPCC Working Group II Technical Support Unit, IPCC Secretariat.

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

Berg, S.V. 2007. Conflict resolution: benchmarking water utility Performance. *Public Administration and Development,* 27 (1): 1–11.

Berntell, A. 2008. Getting to Business Not as Usual. *Stockholm Water Front,* No 1, April 2008, 1-2.

Beyene, A. and Luwesi, C.N. (eds).(2018). *Innovative Water Finance in Africa –A Guide for Water Managers – VOL. 1: The Context of Water Finance Innovations*. Uppsala: Nordiska Afrikainstitutet, Uppsalla University, 164 p. (ISBN 978-91-7106-815-6)

Bfz, WaterCap and EUWI. 2011. *Innovative Ways in Financing the Water Sector*. SWAP/bfz Workshop Report, edited by C.N. Luwesi, 7-11 November 2011, Mombasa.

Biswas, A.K. 2004. Integrated water resources management: A reassessment - A water forum contribution. *Water International* 29 (2): 248–256, June 2004.

Boseman, G. and Phatok, A. 1989. *Strategic Management: Text and Cases*. New York: John Wiley & Sons Ltd.

Brown, L.R. 2001. *Eco-Economy: Building an economy for the Earth*. W.W. New York: Norton and Company Ltd.

Cap-Net, GWP and UNDP. 2007. IWRM plans - Training Module. Available at: http://www.cap-net.org/tmuploadedfiles/filefor67/iwrm_plans.doc (Accessed July 4, 2007)

Cap-Net. 2008. Economics in sustainable water management, Training manual and facilitators guide. available at: http://cap-net.org/sites/capnet.org/files/Economics%20of%20water%20FINAL.doc (Accessed Nov. 23, 2008).

Cheserek, G. 2005. Indigenous knowledge in water and watershed management: 'Marakwet' conservation strategies and techniques. *FWU Water Resource Publications*, 3: 25-33.

Dent, D. and Kauffman, S. 2007. The spark has jumped the gap: Green Water Credits proof-of-concept. In *Green Water Credits Report 7*, edited by D. Dent. Wageningen: ISRIC -World Soil Information.

DeWit, M. and Stankiewicz, J. 2006. Changes in surface water supply across Africa with predicted climate change. *Science Express,* 2 (March 2006).

Downing, T.E. 2003. Linking sustainable livelihoods and global climate change in vulnerable food systems. *Die Erde,* 133, 363-378.

Downing, T.E. and Patwardhan, A. 2005. Assessing vulnerability for climate adaptation. Available at: http://www.vulnerability.org (Accessed May 11, 2007).

Droogers, P. 2006. Basin scale hydrology scenarios to explore Green Water Credits opportunities. Paper presented during the First Green Water Credits Workshop, ISRIC - World Soil Information, Wageningen.

DFT. (2011). Cost Benefit Analysis TAG Unit 3.5.4. London: Department for Transport (DFT). Available at: www.dft.gov.uk/webtag (Accessed Jun. 3, 2011)

Doyle, P. 1992. "What are the excellent companies?". *Journal of Marketing Management*, 8 (2), April 1992.

Earle, A. 2005. "Hydropolitics in Southern Africa: What is the prognosis for peaceful development of shared watercourses?" *FWU Water Resource Publications*, vol. 3: 55-68.

Ehrensperger A. and Kiteme, B.P. 2005. *Upper Ewaso Ngiro River Basin Water Management Information Platform - Survey on Development Priorities, Information Needs and Conflict Management Efforts*. Nanyuki: CETRAD.

Ericksen, S.H. 1998. Shared river and lake basins in Africa: Challenges for cooperation. *Ecopolicy, Series,* 10. Nairobi: ACTS Press Ltd.

Falkenmark M. and Rockström J. 2004. *Balancing water for humans and nature*. London: Earthscan.

FAO. 1995. Planning for sustainable use of land resources: towards a new approach". *FAO Land and Water Bulletin,* 2:25-46.

Ferrell,O., Harline, M., Lucas, G. and Luck, D. 1998. *Marketing*. Orlando, Florida: Dryden Press.

Geertsma, R., Wilschut, L. and Kauffman, S. 2010. Review for the Green Water Credits Pilot Operation in Kenya. In *Green Water Credits Report 8*, edited by S. Kauffman. Wageningen: ISRIC -World Soil Information.

Gerten, D., Schaphoffa, S., Haberlandtb, U., Luchta, W. and Sitcha, S. 2004. Terresterial vegetation and water balance-hydrological evaluation of a dynamic global vegetation model. *Journal of Hydrology* 286 (2004), 249-270.

Gleditsch, N.P., Owen, T., Furlong, K., and Lacina, B. 2004. Conflicts over shared rivers: resource wars or fuzzy boundaries? Paper presented during the 4th Annual Convention of the International Water Studies Association, 4 March 2004, Montreal.

Global Water Partnership (GWP). (2015). Integrated Water Resources Management in Eastern Africa: Coping with 'Complex Hydrology'. In Technical Focus Papers (TFP) No 7. (ISSN: 2001-4023; ISBN: 978-91-87823-21-3). Stockholm: Elanders, 51 P (Authors: Gerd Foerch, Moses Tenywa, Alex Zizinga, Cush Luwesi, Abebe Mekuriaw, Omar Munyaneza, Nele Foerch).

GRAIN Briefing. 2007. A New green revolution for Africa?. November 2007 Issue. Available at: http://www.grain.org/briefings/. (Accessed Feb. 23, 2010).

Grieg-Gran, M., Noel, S. and Porras, I. 2006. Lessons from Payments for Environmental Services. In *Green Water Credits Report 2*, edited by D. Dent. Wageningen: ISRIC -World Soil Information.

Hardwick, P., Khan, B. and Langmead, J. 1994. *An Introduction to Modern Economics*. Singapore: Longman Group Ltd.

Harris, J.M. Roach, B. and Codur A.M. 2017. *The Economics of Global Climate Change*. Medford, MA 02155: Global Development And Environment Institute (GDAE), Tufts University. Available at: http://ase.tufts.edu/gdae

Hartnady, C. and Hay, R. 2004. Integrated water resource management (IWRM) and disaster reduction. Paper presented during the Africa Regional Consultation on Disaster Reduction Workshop, 2-3 June 2004, Johannesburg.

Harvey, J. 1985. *Mastering Economics*. The Macmillan Press, London.

Hatry, H.P. 2006. *Performance Measurement: Getting Results* (2nd Edition). Washington, D.C.: The Urban Institute Press.

Hessel, R., Messing, I., Liding, C., Ritsema, C. and Stolte, J. 2003. Soil erosion simulations of land use scenarios for a small Loess Plateau catchment. *Catena*, 54 (1–2), 289–302.

Heurtefeux, H., Sauboua, P., Lanzellotti, P. and Bichot, A. 2011. Coastal risk management modes: The managed realignment as a risk conception more integrated. In *Risk Management in Environment, Production and Economy,* edited by M. Savino. Rijeka: InTech, pp. 3-26.

Hoff, H., Stacey, N. and Droogers, P. 2007. Water use and demand in the Tana Basin: analysis using water evaluation and planning tools (WEAP). In *Green Water Credits Report 4*, edited by D. Dent. Wageningen: ISRIC -World Soil Information.

Hoff, H., Falkenmark, M., Gerten, D., Gordon, L., Karlberg, L., Rockström, J. 2010. Greening the global water system. *Journal of Hydrology*, 384, 177-186.

Howe, C.W. 1971. Benefit-cost analysis for water systems planning. *Water Resources Monograph, 2*. Washington, D.C.: American Geophysical Union.

Huggins, C. 2002. Water policy and law in a water-scarce country. In *The Changing Face of Irrigation in Kenya*, edited by Murray-Rust and Blank. Colombo: International Water Management Institute.

Hulme, M., Doherty, R., Ngara, T., New, M., Lister, D. 2001. African climate change: 1900 – 2100. *Climate Research,* 17, 145–168.

Hulme, M., Doherty, R., Ngara, T. and New, M. 2005. Global warming and African climate change. In *Climate Change and Africa*, edited by P.S Low. Cambridge: Cambridge University Press, 29-40.

Hunink, J.E., Immerzeel, W.W., Droogers, P. and Kaufmann, S. 2010. Green Water Credits for the Upper Tana Basin, Kenya. Phase II - Pilot Operations: Biophysical assessment using SWAT. In *Green Water Credits Report 10,* edited by D. Dent. Wageningen: ISRIC-World Soil Information.

IFRC. 2005. World disasters report 2005: focus on information in disasters. Available at: www.ifrc.org/publicat/wdr2005/index.asp (Accessed March 04, 2009).

IFRC. 2009. Disaster preparedness: training manual. Available at: www.ifrc.org/Docs/pubs/disasters/preparing-disasters/ (Accessed March 04, 2009).

Immerzeel, W.W., Van Beek, L.P.H. and Bierkens, M.F.P. 2010. Climate change will affect the Asian water towers. *Science*, Vol 328, 11 June 2010 Issue. Available at: www.sciencemag.org (Accessed Sep. 13, 2010).

IPCC. 2001. *Synthesis Report: Third Assessment Report*. Geneva: IPCC Secretariat-WMO.

IPCC. 2007. *Synthesis Report: Fourth Assessment Report*. Geneva: IPCC Secretariat-WMO.

IPCC. 2012. Managing the risks of extreme events and disasters to advance climate change adaptation. In *A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change (IPCC)*, edited by C.B. Field, V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley. Cambridge: Cambridge University Press.

IPCC. *Climate Change 2014*: *Impacts, Adaptation, and Vulnerability – Part A : Global and Sectoral Aspects. Working Group II Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*; Cambridge University Press: New York, NY, USA, 2014. Available at: www.cambridge.org/9781107641655

IOB. 2008. Clean and sustainable? An evaluation of the contribution of the clean development mechanism to sustainable development in host countries. *IOB Evaluations*, April 2008, No. 310, 1-189.

Islam, M., Chou, F., Kabir, M., Liaw, C. 2010. Rainwater: a potential alternative source for scarce safe drinking and arsenic contaminated water in Bangladesh. *Water Resources Management,* 24, 3987-4008.

ISRIC. 2008. Green water credits: policy brief. Wagenigen: ISRIC–World Soil Information. Available at: http://www.isric.org/UK/About+ISRIC/Projects/Current+Projects/Green+Water+Credits.htm (Accessed Oct. 14, 2009).

IWMNet. 2010. Capacity Building in Integrated Watershed Management in East Africa. Available at: www.iwmnet.eu (Accessed Aug. 15, 2011)

Jaetzold, R., Schmidt, H., Hornetz, B. and Shisanya, C. 2007. *Farm Management Handbooks of Kenya: Natural Conditions and Farm Management Information*, Vol. 2, Part C, Subpart C1. Nairobi: Ministry of Agriculture and GTZ.

Jones, R.G., Noguer, M., Hassell, D.C., Hudson, D., Wilson, S.S., Jenkins, G.J. and Mitchell, J.F.B. 2004. *Generating High Resolution Climate Change Scenarios Using PRECIS*. Exeter: Met Office Hadley Centre.

K'akumu, O.A. 2008. Mainstreaming the participatory approach in water resource governance: The 2002 water law in Kenya. *Development,* 51, 56-62.

Karago, C. 2009. A lifeline of water. *The Option*, Dec. 2009- Feb. 2010, pp.12-15

Kauffman, S., Droogers, P., Odada, E., Macharia, P., Gicheru, P., Dijkshoorn, J.A. 2007. Green and blue water resources and assessment of soil and water management scenarios using an integrated modelling framework. In *Green Water Credits Report 3,* edited by D. Dent. Wageningen: ISRIC-World Soil Information.

Kazbekov, J., Abdullaev, I., Manthrithilake, H., Qureshi, A. and Jumaboev, K. 2009. Evaluating planning and delivery performance of water user associations (WUA) in Osh Province, Kyrgyzstan. *Agricultural water management* 96: 1259-1267.

Kindelberger, C.P. and Aliber, J. 2005. *Crashes, Manias and Panics - A History of the Financial Crises*. New York: Harper-Row.

Kiteme, B.P., Liniger, H., Notter, B., Wiesmann, U. And Kohler, T. 2008. Dimensions of global change in African mountains: The example of Mount Kenya. *IHDP Update* 2.2008: 18-22

Kitissou, M. (2004). "Hydropolitics and geopolitics: Transforming conflict and reshaping cooperation in Africa", *Africa Notes*, Issue of November-December 2004.

KNBS. 2007. Kenya Vision 2030. Available at: http:// www.investmentkenya.com/Documents/Publications/vision_2030_BROCHURE_July_2007. pdf (Accessed Sep. 24, 2008).

KNBS. 2010. *Kenya 2009 Population and Housing Census*. Nairobi: Government Print.

Kotler, P. 1991. *Marketing Management: Analysis, Planning and Control* (8th edition). Englewoods Cliffs, New Jersey: Prentice-Hall.

Krumme, K. 2006. EFU–ecological functional units: A basis for sustainable development planning. *FWU water resources publications*, Vol. 5, 17-27.

Lal, R. 1993. Agricultural sustainability and soil resilience. *Desertification Control Bulletin,* 23, 26-43.

Ledec, G. and Quintero, J.D. 2003. Good dams and bad dams: environmental criteria for site selection of hydroelectric projects. In *Latin America and Caribbean Region Environmentally and Socially Sustainable Development Working Paper 16*. Washington D.C.: The World Bank.

Lipsey, R.C and Steiner, P.O. 1978. *Economics*. New York: Harper-Row.

Liu, C.M., Li, D.F., Tian, Y., Hao, F.H. and Yang, G.L. 2003. An application study of DEM based distributed hydrological model on macroscale watershed. *Progress in Geography* 22 (5), 437–445.

Lòpez-Baldovin, M.J., Gutiérrez-Martin, C. and Berbel, J. 2006. Multicriteria and multiperiod programming for scenario analysis in Guadalquivir river irrigated farming. *Journal of the Operational Research Society,* 57, 499-509.

Luwesi, C.N. 2010. *Hydro-economic Inventory in a Changing Environment – An assessment of the efficiency of farming water demand under fluctuating rainfall regimes in semi-arid lands of South-East Kenya*. Saarbrüken: Lambert Academic Publishing AG & CO.KG.

Luwesi, C.N., Shisanya, C.A. and Obando, J.A. 2011. Toward a hydro-economic approach for risk assessment and mitigation planning for farming water disasters in semi-arid Kenya. In *Risk Management in Environment, Production and Economy*, edited by M. Savino. Rijeka: InTech, pp 27-46.

Luwesi, C.N., Shisanya, C.A. and Obando, J.A..2012. *Warming and Greening - The Dilemma Facing Green Water Economy under Changing Micro-Climatic Conditions in Muooni catchment (Machakos, Kenya)*. Saarbrüken: Lambert Academic Publishing AG & CO.KG.

Luwesi, C.N. and Shisanya, C.A. 2017. Downstream-Upstream Farmers' Response-Capability for Implementation of Green Water Credits in Eastern Province of Kenya. Fieldwork Report (Unpublished).

Luwesi, C.N., Obando, J.A. and Shisanya, C.A. 2017. The impact of a warming micro-climate on Muooni farmers of Kenya. *Agriculture* 2017, 7(3): 1-20 (Special Issue "Options for Agricultural Adaptation to Climate Change"); doi:10.3390/agriculture7030020

LVBC and WWF-ESARPO. (2010). Assessing Reserve Flows for the Mara River – Kenya and Tanzania. Final Report. Nairobi and Kisumu.

Malesu, M.M., Oduor, A.R. and Odhiambo, O.J. (eds.). 2007. *Green Water Management Handbook - Rainwater Harvesting for Agricultural Production And Ecological Sustainability*. Nairobi: The World Agroforestry Centre/ ICRAF.

Malesu, M., Oduor A., Cherogony, K., Nyolei, D., Gachene, C.K.K. and Karuma, A. 2008. *Investing in Rainwater harvesting to boost food security in East Africa*. Technical Paper. Nairobi: World Agroforestry Centre/ ICRAF.

Martinsen, C. 2008. Social marketing in sanitation- More than selling toilets. *Stockholm Water Front* No. 1, April 2008:14-16.

Meijerink, G., Muchena, F., Njue, E., Noel, S., Onduru, D. and Porras, I. 2007. Political, institutional and financial framework for green water credits in Kenya. In Dent D. (ed), *Green Water Credits Report 6*. Wageningen: ISRIC -World Soil Information.

Miller, K.A., Rhodes, S.L. and Macdonnell, L.J. 1997. Water allocation in a changing climate: Institutions and adaptation. *Climate Change* 35: 157-177.

Mogaka, H., Gichere, S., Davis, R. and Hirji, R. (ed.). 2006. Climate variability and water resources degradation in Kenya - Improving water resources development and management. *The World Bank Working Paper No. 69*. Washington, D.C.: The International Bank for Reconstruction and Development/ The World Bank.

Morgan, R.P.C. 1995. *Soil Erosion and Conservation*. Essex: Longman Group.
Morra-Imas, L.G. and Rist, R.C. 2009. *The Road to Results: Designing and Conducting Effective Development Evaluations*. Washington, D.C.: The World Bank.
Mukheibir, P. 2008. Water Resources Management Strategies for Adaptation to Climate-Induced Impacts in South Africa. *Water Resources Management,* 22, 1259-1276.
MoW. 1987. Muooni dam construction: Final report (Unpublished). District Office of the Ministry of Water (MoW), Machakos.
Mulwa, F.W. 2011. Participatory Monitoring and Evaluation of Community Projects (3rd Print). Nairobi: Paulines Publications Africa.
Musick, J.T., Jones, O.R., Stewart, B.A. and Dusek, D.A. 1986. Water-Yield Relationships for Irrigated and Dryland Wheat in the U.S. Southern Plains. *Agronomy Journal* 86: 980-986.
Musuva, P. 2010. Effects of Land Use on Water Resource Availability in Muoni Sub-Catchment, Machakos District, Kenya. Masters' Thesis, School of Pure and Applied Sciences, Kenyatta University, Nairobi.
Mutisya, D. 1997. Socio-economic and agronomic factors influencing soil erosion in the Masinga dam catchment. PhD Thesis, Faculty of Arts, Kenyatta University, Nairobi.
MWI. 2003. *Water Supply Manual*. Nairobi: Ministry of Water and Irrigation (MWI), Government Print.
NASA. 1999. Landsat7. Press Kit (April 1999). Available at URL: http://landsat.gsfc.nasa.gov/pdf_archive/landsat7_1999presskit.pdf (Accessed Feb. 16, 2011).
NASA, NOAA and USGS. 1999. Science Writers' Guide to Landsat7 (March 1999). Available at URL: http://landsat.gsfc.nasa.gov/pdf_archive/Landsat7_writer_guide.pdf (Accessed Feb. 16, 2012).
Ngigi, A. and Macharia, D. 2007. *Kenya Water Sector Overview*. Nairobi: IT Power East Africa.
Ngonzo, C.L., Shisanya, C.A. and Obando, J.A. 2010. Land use and water demand under a changing climate: Experiences of smallholder farmers from Muooni. In *Climate Change*, edited by S.P. Saikia. Assam: International Book Distributors, pp. 117-140.
Ngurari P. (ed.). 2009. Water Crisis: How Safe is Your Water?. *Health Today,* Issue of Nov-Dec. 2009, pp.13-19.
Notter, B., McMillan, L., Viviroli, D., Weingartner, R. and Liniger, H.O. 2007. Impacts of environmental change on water resources in the Mt. Kenya region. *Journal of Hydrology* 343 (3-4): 266-278.
Nyongesa, J.M. and Muigai, P. 2012. Promoting green development and growth through linking downstream water users to upstream land managers. In *Payment for Environmental Services-PES scheme in Naivasha Basin-Kenya*, edited by WWF Eastern Africa Regional Programme Office and CARE-Kenya, Payment for Watershed Services, Nairobi.
NWRUA. 2010. Ngusishi Water Resource Users' Association (NWRUA). Available at: http://www.ngusishi.com (Accessed on Aug. 17, 2010).
OAS. 1991. *Primer on Natural Hazard Management in Integrated Regional Development Planning*. Washington, D.C.: Organization of American States (OAS).
Oduol, J.B.A., Hotta, K., Shinkai, S. and 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.
Ogallo, L.A. Boulahya, M.S. and Keane, T. 1999. Applications of seasonal to interannual climate prediction in agricultural planning and operations. *Agricultural and Forest Meteorology*,103 (2000): 159–166.
Ojwang, J. 2008. Eucalyptus suspected to be causing water shortage in parts of Nile Basin. *Nile News*, Vol. 5, Issue 1, January-March 2008, pp 6-7.
Okali, C., Sumberg, J., and Farrington, J. 1994. *Farmer participatory research; rhetoric and reality*. London: Intermediate Technology Publications/Overseas Development Institute.
Ortega-Pacheco D.V., Lupi F. and Kaplowitz M.D. 2009. Payment for environmental services: Estimating demand within a tropical watershed. *Journal of Natural Resources Policy Research*, Vol. 1 (2), 189–202.
Osunade, M.A. 1994. Community environmental knowledge and land resource surveys in Swaziland. *Singapore Journal of Tropical Geography, 15*, 157-170.
Pachauri, R.K. 2004. Climate and humanity. *Global Environment Change*, 14, 101-103.
Pelling, M. 2004. Social capital and institutional adaptation to climate change. *RCC Working Paper 2*. University of Liverpool, Liverpool.
Phillip's. 2002. *The Atlas*. Nairobi: E.A.E.P Publishers Ltd.

Phillips, J.G. 2003. Determinants of forecast use among communal farmers in Zimbabwe. In *Coping with Climate Variability: The Use of Seasonal Climate Forecasts in Southern Africa*., edited by K. O'Brien and C. Vogel. Burlington: Ashgate Publishing Company, pp. 111-127.

Porras I. 2006. Lessons from Payments for Environmental services. Paper presented during the First Green Water Credits Workshop organized by ISRIC - World Soil Information, Nairobi.

Porras, I., Grieg-Gran, M. and Meijerink, G. 2007. Farmers' adoption of soil and water conservation: potential role of payments for watershed services. In *Green Water Credits Report 5*, edited by D. Dent. Wageningen: ISRIC -World Soil Information.

PRESA. 2012. Equitable Payment for Watershed Services (EPWS) in Lake Naivasha Basin, a partnership between The World Wildlife Fund for the Nature in Kenya (WWF-Kenya) and CARE International- Kenya. Available at: http://presa.worldagroforestry.org/blog/2012/10/22/impacts-of-pes-on-livelihoods-in-naivasha/ (Accessed May 21, 2012).

Pulakos, E.D. 2004. *Effective Guidelines -Performance management: A Roadmap for Developing, Implementing and Evaluating Performance Management Systems*. Alexandria, Virginia: SHRM Foundation.

Ragab, R. and Hamdy, A. 2004. Water management strategies to combat drought in the semiarid regions. Available at: http://ressources.ciheam.org/om/pdf/b47/05002266.pdf (Accessed Nov. 12, 2010)

Reij, C., Tappan, G. and Smale, M. 2009. Re-Greening the Sahel: Farmer-led innovation in Burkina Faso and Niger. In Spielman D. and Pandya-Lorch R. (eds.), *Millions Fed*. Washington D.C.: International Food Policy Research Institute (IFPRI), pp. 53-58.

Reisner. M. 1993. *Cadillac Desert: The American West and its Disappearing Water*. New York: Penguin Group (USA) Inc.

Rietbergen-Mccracken, J. and Abaza. 2000. *Environmental Evaluation*. London: Earthscan publications Ltd.

Rockström, J. 2003. Managing rain for the future. In *Rethinking Water Management- Innovative Approaches to Contemporary Issues*, edited by C.M. Figueres, C. Tortajada and J. Rockström. London: Earthscan Publications Ltd., pp. 70-101.

Rockström, J., Falkenmark, M. Karlberg, L., Hoff, H., Rost, S. and Gerten, D. 2009. Future water availability for global food production: The potential of green water for increasing resilience to global change. *Water Resources Research*, 45.

Rodionov, S. 2011. A brief overview of the regime shift detection methods. Available at: http://www.beringclimate.noaa.gov/regimes/rodionov_overview.pdf (Accessed Mar. 17, 2011).

Rogers, J.W. 2005. A standardized performance assessment and evaluation model for community water systems. PhD Thesis, University of Virginia, Virginia.

Savenije, H.H.G. and van der Zaag, P. 2002. Water as an economic good and demand management: paradigms with pitfalls. *Water International* 27 (1), 98-104.

Scherr, S.J. Wallace, C. And Buck, L. 2011. Agricultural Innovation for Food Security and Poverty Reduction in the 21st Century: Issues for Africa and the World. In: Ecoagriculture Partners (eds.), *State of the World 2011: Innovations that Nourish the Planet*. Washington, D.C.

Sehring, J. 2008. The pitfalls of irrigation water pricing in Kyrgyzstan. *Development,* 51, 130-134.

Shakya, N.M. 2001. Impact of forest clearing on hydrology: Mathematical modelling of Khageri River. In *Ecohydrology*, edited by V. Subramanian and Al Ramanathan. New Delhi: Capital Publishing Company, pp. 355-368.

Shisanya, C.A. 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, Faculty of Geosciences, Universität Trier, Trier.

Shisanya, C.A. 2005. An analysis of accessibility and pricing of water supply in rural watersheds: a case study of kakamega district, Kenya. *FWU Water Resource Publications*, vol. 5: 161-172.

Shisanya, C.A. and Khayesi, M. 2007. How is climate change perceived in relation to other socio-economic and environmental threats in Nairobi, Kenya. *Journal of Climate Change*, 85, 271-284.

Shisanya, CA., Luwesi, CN. and Obando, JA. (2014). "Innovative but Not Feasible: Green Water Saving Schemes at the Crossroad in Semi-Arid Lands". In: OSSREA (eds.), *Innovative Water Resource Use and Management for Poverty Reduction in Sub-Saharan Africa: An Anthology* (ISBN: 978-99944-55-75-1), Addis Ababa, Ethiopia, pp. 137-172

Smyth, A.W., Altay, G., Deodatis, G., Erdik, M., Franco, G., Gukan, P., Kunreuther, H., Lus, H., Mete, E., Seeber, N. and Yuzugullu, O. 2004. Probabilistic Benefit-Cost Analysis for Earthquake Damage Mitigation: Evaluating Measures for Apartment Houses in Turkey. *EERI Earthquake Spectra* 20 (1): 171-203.

Steinemann, A., Hayes, M.J. and Cavalcanti, L. 2005. Drought indicators and triggers. In *Drought and Water Crises: Science, Technology, and Management Issues*, edited by D. Wilhite. New York: Marcel Dekker.

Stephenson, D. 2005. *Water Services Management*. London: IWA Publishing.

Stern, N. (2007). *Economics of Climate Change: The Stern Review*. Cambridge: Cambridge University Press.

Subramanian, V. 2001. Water quality and quantity. In *Ecohydrology*, edited by V. Subramanian and Al Ramanathan. New Delhi: Capital Publishing Company, pp. 241-264.

Terer, J. 2004. *The Study of Hydrologic Characteristics and Management Practices in Agricultural River Catchments: The case of Nyorongores River Catchment, Mara River Basin, Kenya*. Nairobi: ACTS Press.

Tiffen, M., Morimore, M. and Gichuki, F. 1994. *More People, Less Erosion: Environmental Recovery in Kenya*. Nairobi: ACTS Press.

Tiffen, M. and Mortimore, M. 2002. Agroecosystems regaining the high ground: Reviving the Hillsides of Machakos. In *World Resources 2000-2001*, pp. 149-158.

Tittonell, P., Corbeels, M., van Wijk, M., Vanlauwe, B., and Giller, K. 2008. Combining organic and mineral fertilizers for integrated soil fertility management in smallholder farming systems of Kenya: Explorations using the crop-soil model FIELD. *Agronomy Journal*, 100 (5), 1511-1526.

Turner, R.K., Hadley, D., Luisetti, T., Lam, V.W.Y., Cheung, W.W.L. and CSERGE, UEA. 2010. An Introduction to Socio-Economic Assessment within a Marine Strategy Framework. London: Department for Environment, Food and Rural Affairs (DEFRA). Available at: archive.defra.gov.uk/environment/marine/documents/legislation/msf-socioeconomic.pdf (Accessed May 15, 2011).

UNCDF. 2006. *Achieving Results: Performance Budgeting in the Least Developed Countries*, edited by R. McGill. New York: United Nations Capital Development Fund (UNCDF).

UNDP. 2007a. *Human Development Report 2007/2008 - Fighting Climate Change: Human Solidarity in a Divided World*. New York: Palgrave Macmillan.

UNDP. 2007b. Integrated Water Resources Management Plans. URL: http://www.undp.org/mdg/ (Accessed July 13, 2008).

UNDP. 2010. *Human Development Report 2010 -20th Anniversary Edition- The Real Wealth of Nations: Pathways to Human Development*. New York: Palgrave Macmillan.

UNEP. 2002. *Success stories in the struggle against desertification: A holistic and integrated approach to environmental conservation and sustainable livelihoods*. Nairobi: UNEP-DEPI. Available online at URL: www.unep.org/desertification/successstories (Accessed Feb. 02, 2007).

UNEP. 2009. *Kenya: Atlas of Our Changing Environment*. Nairobi: United Nations Environment Programme (UNEP), Division of Early Warning and Assessment (DEWA).

UNEP. 2011. *Towards a Green Economy: Pathways to Sustainable Development and Poverty Eradication*. Available online at URL: www.unep.org/greeneconomy (Accessed Jun. 25, 2012).

Universität Siegen. 2005. DAAD alumni summer school 2005: topics of integrated water resources management. Final Report, edited by G. Förch, R. Winnegge and S. Thiemann. *Weiterbilding in Siegen*, No. 18.

Universität Siegen. 2006. DAAD alumni summer school 2006: participatory water resources management plan. Final Report, edited by G. Förch, R. Winnegge and S. Thiemann. *Weiterbilding in Siegen*, No. 20.

Universität Siegen. 2007. *DAAD Alumni Summer School 2007: Participatory Monitoring of Sub-Catchment Management Plan – Bwatonaro Watershed, Kenya*. Final Report, edited by G. Förch, R. Winnegge and S. Thiemann. Siegen: Universität Siegen.

Universität Siegen and Kenyatta University. 2008. *DAAD Alumni Summer School 2008: Water Demand in Participatory Watershed Management – Ngaciuma-Kinyaritha Watershed, Kenya*. Final Report, edited by G. Förch, R. Winnegge and S. Thiemann. Siegen: Universität Siegen.

Universität Siegen. 2009. *DAAD Alumni Summer School 2009: Climate Change And Food Security: Integrated Watershed Management as Adaptive Planning Tool – Kabale, Uganda*. Final Report, edited by G. Förch and R. Winnegge. Siegen: Universität Siegen.

Universität Siegen. 2010. *DAAD Alumni Summer School 2010: Financial Aspects of Integrated Watershed Management – Moshi, Tanzania*. Final Report, edited by G. Förch and R. Winnegge. Siegen: Universität Siegen.

UNU. 1997. *Freshwater Resources in Arid Lands*, edited by J.I. Uitto and J. Schneider. Tokyo: United Nations University Press.

UNU. 2005. *Sustainable Management of Headwater Resources: Researches from Africa and India*, edited by Jansky, L., Haigh, M. and Prasad, H. Tokyo: United Nations University Press.

USAID. 2009a. Water disaster preparedness. Available at: www.usaid.gov/our_work/environment/water/disaster.html (Accessed Jun. 06, 2009).

USAID. 2009b. Climate change, climate variability and natural disasters. Available at: www.usaid.gov/our_work/environment/water/climate_change.html (Accessed Jun. 06, 2009).

USAID. 2009c. Economic growth and food security. Available at: www.usaid.gov/our_work/environment/water/econ_growth.html (Accessed Jun. 06, 2009).

Van Aalst, M.K. 2006. The impacts of climate change on risk of natural disasters. *Disasters*, 30, 5-18.

Venkatachalam, L. 2003. The contingent valuation method: a review. *Environmental Impact Assessment Review*, 24: 89–124

Vishnudas, S. 2006. *Sustainable Watershed Management: Illusion or Reality? A Case of Kerala State, India.* PhD Thesis. Delf: Technische Universiteit Delf, Eburon Academic Publishers.

Waswa, F., Otor, S. and Mugendi, D. 2006. Environment and Development Nexus. In *Environment and Sustainable Development*, vol. 1, edited by F. Waswa, S. Otor and D. Mugendi. Nairobi: School of Environmental Studies and Human Sciences, Kenyatta University, Kenya, pp. 1-19.

Wilschut, L.I. 2010. Land-Use in the Upper Tana: Technical Report of a Remote Sensing Based Land Use Map. In *Green Water Credits Report 9*, edited by B. Macmillan, S. Kauffmann and R. De Jon. Wageningen: ISRIC - World Soil Information.

Wise, T.A. and Murphy, S. 2012. Resolving the Food Crisis: Assessing Global Policy Reforms Since 2007. Massachusetts: Global Development and Environment Institute (GDAE) and Institute for Agriculture and Trade Policy (IATP), Tufts University. Available at: http://www.ase.tufts.edu/gdae/Pubs/rp/ResolvingFoodCrisis.pdf (Accessed Jun. 12, 2012).

World Bank. 2007. Water Topics: Monitoring and Evaluation. Available at: http://www.worldbank.org/html/fpd/water/topics/m&e.html (Accessed on March 04, 2008).

World Bank. 2009. Independent Evaluation of IFC's Development Results 2009: Knowledge for Private Sector Development – Enhancing the Performance of IFC's Advisory Services. Washington, D.C.: Independent Evaluation Group (IEG), World Bank, Available at: http://www.ifc.org/ieg (Accessed on Aug. 02, 2010).

World Bank, AfDB, FAO, IFAD and IWMI. 2008. *Investment in Agricultural Water for Poverty Reduction and Economic Growth in Sub-Saharan Africa – A Synthesis Repo*rt. Washington, D.C.: World Bank.

WRI. 2007. *Weathering the storm: Options for framing adaptation and development*, edited by H. Mcgray, A. Hammill, R. Bradley, E.L. Schipper and Jo-E Parry. Washington, D.C.: World Resource Institute (WRI).

WRMA. 2008. Muooni Catchment. Internal Report (Unpublished). Regional Office of the Water Resources Management Authority (WRMA), Machakos.

WRMA. 2010. *Enforcement of Water Use Charges and Water Quality Thresholds in Kenya*, Training Workshop Report, 24-28 January 2010, edited by J. Onyando, N. Förch, C.N. Luwesi and H. Sitati for the Water Resources Management Authority (WRMA), Meru.

WSP . 2011. Kenya groundwater governance case study. In *Water Papers*, June 2011, edited by A. Mumma, M. Lane, E. Kairu, A. Tuinhof, and R. Hirji. 2011. Washington, D.C.: Water Partnership Program (WSP), The World Bank. Available at: http://www.worldbank.org/water (Accessed March 23, 2012).

Wunder, S. 2007. The efficiency of payments for environmental services in tropical conservation. *Conservation Biology* 21 (1): 48-58

Xie, M., George, D., Huan, Y. and Kleine, A. 2011. *A Climate Risk Matrix Management for Agricultural Water Management.* Washington, D.C.: The World Bank Institute - Climate Change Unit (WBICC).

Zhang, Y., Grant, A., Sharma, A., Chen, D., Chen, L. 2010. Alternative Water Resources for Rural Residential Development in Western Australia. *Water Resources Management*, 24, 25-36.

Zeiller, M. 2000. *Methods of socio-economic analysis of rural development. Institute of Rural Development.* University of Göttingen. Available at: http://www.childinfo.org/files/chap06.pdf (Accessed in Feb. 21, 2010).

Zorita, E. and Von Storch, H. 1999. The analog method as a simple statistical downscaling technique: comparison with more complicated methods. *Journal of Climate*, vol. 12: 2472-2489.

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Appendices
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Appendices

7.1 Consolidated SWOT Matrix for Ngusishi Catchment

Factor	Strengths[1]	Weaknesses[1]	Opportunities[1]	Threats[1]	Strategic Actions
Increased storm intensity / number of flash floods & other factors **(Rated Unlikely)**	S_1, S_2, S_3, S_4	W_1,W_2,W_3	O_1, O_2, O_3, O_4, O_5,O_6	T1, T2, T3, T4, T5, T6, T7, T8, T9	•Use effective soil conservation measures (terraces, contours, runoff cut-outs, etc.) •Build new infrastructure to mitigate storm intensity •Regulate encroachment to wetlands and other water towers •Introduce new technologies for monitoring surface runoffs and reclaiming extra water resources •Create a water treatment plant
Higher minimum/ maximum temperatures & evaporation/ transpiration **(Rated Likely)**	S_1, S_2, S_3, S_4, S_5, S_6, S_7	W_1,W_2,W_3, W_4	O_1, O_2, O_3, O_4, O_5,O_6, O_7	T_1, T_2,T_3, T_4, T_5, T_6, T_7, T_8, T_9,T_{10}	•Increase vegetation cover through agro-forestry, reforestation or afforestation •Promote the practice of zero-grazing on farms •Set an emergency oversight committee to invigilate and create awareness on sanitation, hygiene and environmental disasters (bushfires, endemics and pandemics, etc.) •Upgrade the existing hydrological and meteorological equipments •Increase exchanges and knowledge sharing between upstream and downstream farmers to implement effective irrigation schemes downstream •NWRUA to search for new funding opportunities to extend its service delivery to remote areas
Decreasing trend of river discharges (streamflow), soil moisture and infiltration **(Rated Very Likely)**	S_1, S_2, S_3, S_4, S_5, S_6, S_7, S_8, S_9,S_{11}, S_{12}, S_{13}	W_1, W_2, W_3, W_4, W_5, W_6, W_7	O_1, O_2, O_3, O_4, O_6, O_7, O_8, O_9, 0_{10}, O_{11}	T_1, T_2,T_3,T_4 T_5, T_6, T_7, T_8 T_9, T_{10}	•Train farmers on rainwater saving techniques (building roof catchments, water storage tanks, reservoirs and dams, etc.) •Explore new markets and PPPs financing options (grants, lending, microfinance, BOL, BOS, BOT, etc) •Train NWRUA staffs on PPPs and proposal writing •Enhance the use of agronomic technologies to increase infiltration and maintain soil moisture (i.e. mulching, tillage, greenhouses, crop selection, drought resistant plants, etc.) •Review the current water use charges to enable sufficient contributions from the public for building new infrastructures

Source: Luwesi and Shisanya (2017)

[1] A key for interpretation of S_j,W_j, O_j and T_j acronyms is provided in Table 4.12

7.2 Consolidated SWOT Matrix for Muooni Catchment

Factor	Strengths[1]	Weaknesses[1]	Opportunities[1]	Threats[1]	Strategic Actions
Increased storm intensity/ number of flash floods, & other factors (Rated Unlikely)	S_1, S_2, S_3	W_1,W_2,W_3,	O_1, O_2, O_3	T_1, T_2, T_3, T_4	•Kauti IWUA to design a strategic action plan for disaster mitigation in Muooni catchment •Train its staff on disaster monitoring and prevention •Install new hydro- meteorological stations/ upgrade existing equipments •Intensify sensitization meetings and awareness creation campaigns on climate change and water conservation
Higher minimum/ maximum temperatures & evaporation/ transpiration (Rated Likely)	S_1, S_2, S_3, S_4, S_5, S_6	W_1,W_3,W_4, W_5,W_6,W_7, W_8	O_1, O_2, O_3, O_4 ,O_5,O_6, O_7	T_1, T_2,T_3, T_4, T_5, T_6, T_7, T_8, T_9	•Intensify sensitization on the use of effective agronomic technologies for soil water conservation (i.e. mulching, tillage, greenhouses, crop selection, drought resistant plants, etc.) •Kauti IWUA to introduce in-situ demonstrations to upgrade farmers' knowledge) •Promote the use of zero-grazing •WRMA Office in Machakos to initiate consultations with the public for the creation a WRUA that will coordinate the overall catchment management • WRMA to map all water resources and demarcate them from protected forests and other public lands as well as settlements •WRUA to implement participatory approaches for water resource allocation and management by involving all the relevant institutions •WRUA to create awareness on the water sector reforms
Decreasing trend of river discharges (streamflow), soil moisture and infiltration (Rated Very Likely)	S_1, S_2, S_3, S_4, S_5, S_6, S_7, S_8, S_9,S_{11}	W_1, W_3, W_4, W_5, W_6, W_7, W_8, W_9,W_{10}, W_{11},W_{12}, W_{13}	O_1, O_2, O_3, O_4, O_6, O_7, O_8, O_9, 0_{10}, O_{11}	T_1, T_2,T_3,T_4 T_5, T_6, T_7,T_8 T_9, T_{10}, T_{11}, T_{12}	•The new WRUA to regulate, measure and charge all water uses at their abstraction points or effluent discharge points by setting meters and tariffs •Train farmers on PPPs and proposal writing Promote alternative farming schemes in the form of trusts and cooperatives of production, saving and credits •Farmers to explore new markets and PPPs financing options (grants, lending, microfinance, BOL, BOS, BOT) •Promote agronomic technologies such as greenhouses, crop selection, drought resistant plants, etc. •Increase investments in off-farm sectors •Train farmers on business literacy

Source: Sishanya and Luwesi (2012)

[1] A key for interpretation of S_j,W_j, O_j and T_j acronyms is provided in Table 4.13

7.3 Performance Based Management Rating Scale Used during the FGDs

Rate water projects and other watershed institutions in Muooni/ Ngusishi catchment following the marking scheme below:

Marking Scheme

MARKS	MEANING
100%	t (or PERFECT)
75%	r ABOVE AVERAGE)
50%	FIFTY-FIFTY)
0%	r NIL)

Performance Based Management Rating System

CONTRIBUTION TO ENVIRONMENT SUSTAINABILITY:	Rate (%)
Compliance to environmental laws and regulations:	
Payment of taxes (water charges and Effluent Discharge):	
Technological innovation:	
Respect of public safety:	
Waste management:	
Environmental conservation:	

Comment:

BUSINESS SUCCESS	Rate (%)
Cost of water services (affordability):	
Quality of water services:	
Customer payments (Regularity):	
Revenue out of water services (sufficiency):	
Profitability:	

Comment:

CONTRIBUTION TO ECONOMIC DEVELOPMENT:	Rate (%)
Resource mobilization (revenue):	

Public relations effectiveness:	
Business development	

Comment:

Performance Based Management Rating System, Cont'd

CONTRIBUTION TO SOCIAL PEACE /WELFARE:	Rate (%)
Respect of public culture:	
Application of equity and fairness doctrine:	
Local public-private partnerships:	
Gender balance in the structure:	
Role of women in the management:	
Promotion of youth:	

Comment:

INSTITUTIONAL SUSTAINABILITY	Rate (%)
Organizational culture:	
Legal Recognition of the water project:	
Policies and procedures soundness:	
Quality of standards and specifications:	
Adaptation to change:	
Existence of updated strategic plans:	
Frequency of strategies' review:	
Public Involvement:	
Public trust & reputation:	
Regularity of meetings:	
Community participation to decision-making:	

Comment:

TOTAL PERFORMANCE	

7.4 In-Depth Interviews' Guide

Date……………….........……………..............................Time…...........……
Name of Water Project………………..................................Location ....
Persons to be contacted: ……………………………………..............................

1. What roles did your project/ organization play in the conservation and management of the catchment?

.....................…………………………………………………………………
.....................…………………………………………………………………

2. Are you a member of a Water Resource Users' Association?

□ YES
□ NO

3. If NO, how effectively do you manage to implement the water sector reforms towards achieving sustainability in your catchment? ....……………………………………...……….. ....…………………………………………………………………

4. In your opinion, what aspects of the water sector reforms need to be improved on?
.....................……………………………………………………………………………….....................…………
…………………………………………………….

5. How is your project/ institution organized?
.....................……………………………………………………………...
.....................…………………………………………………………………

6. How effectively and efficiently do you face floods and droughts?
.....................……………………………………………………………………………….....................................…
……………………………………………………

7. How effectively and efficiently do you fight corruption in case of emergency aids?
.....................……………………………………………………………………………….....................................…
……………………………………………………

8. Is the process of water allocation effective within your current institutional framework?

.....................……………………………………………………………………………….................................
....…………………………………………………

9. If yes how does it operate?

....

10. What are the strengths and weaknesses of water projects/ organization in this catchment?

Strengths...………………………………………………………………..
.....................…………………………………………………………………

Weaknesses...……………………………………………………………..
.....................…………………………………………………………………

7.5 Farm Survey Guide

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

Name of Interviewer:……………………………………………………………

Person Interviewed:…………………….……………………………………..

Date & time of Interview:……………………………………………………..

1. What are the main regulations and policies governing water resource management in this country? (*Plse, continue on separate sheet to complete your answers)*

..…………………………………………………………………………………...

……………………………………………………………………………………....

2. What are the main regulations and policies governing water disasters management in this country? (*Plse, continue on separate sheet to complete your answers)*

……………………………………………………………………………………....

……………………………………………………………………………………....

3. What is the importance of the agriculture sector in the catchment?……………………...

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

No	Nature of Cost	Monthly Cost (in $/ acre)	Annual Cost (in $/ acre)	Comments
1				
2				
3				
4				
5				

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

No	Type of Crop	Annual Yield (per acre)	Average Price (in $/ Kg)	Annual Income (in $)
1	Cabbage			
2	Cow peas			
3	French Beans			
4	Groundnuts			
5	Sorghum			
6	Finger millets			
7	Maize			
8	Banana			

9	Irish Potatoes	
10	Sweet Potatoes	
11	Sugar cane	
12	Coffee	
13	Eucalyptus	
14	Mango	
15	Guava	
16	Miraa	
17		
18		
19		
20		

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

How much per month?………………………………US $/ per m^3

7. What socio-economic problems related to agricultural production have you observed?
……………………...
…………………………………………………………………………………………

8. What environmental problems related to agricultural production have you observed?
……………………...
………………………………………………………………………………….......

9. What may be the responsibility of farmers on physical processes going on around the catchment?..……..
....

10. What are some strategies put in place by farmers to cope with water disasters and maintain their efficiency in farming?
....
…………………………………………………………………………………
…………………………………………………………………………………

11. How does the government plan to solve environmental challenges facing farmers?
………………………………………………………………………………….
………………………………………………………………………………......

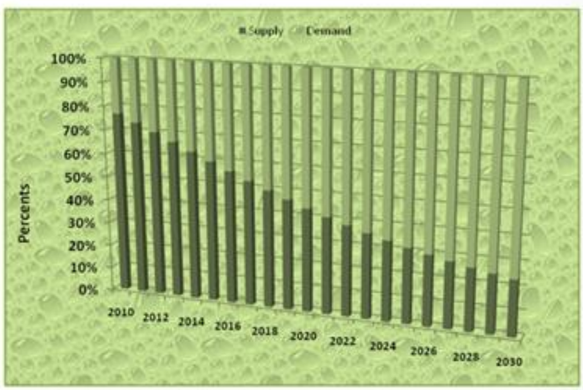
12 What can you suggest for improving farmers' preparedness to water disasters in our country in general and in this catchment in particular?
....…………………………………………………………
……………………….........................…………..……………………………………………………………
……….....................................

FINAL COMMENTS ON CLIMATE CHANGE AND DISASTER MANAGEMENT

Why Green Water Saving is not Fully Rewarded by Farmers in Mount Kenya Region

A Research Frontier of Pure: Applied Sciences and Engineering

INTERNATIONAL JOURNAL WATER SCIENCE AND ENVIRONMENT TECHNOLOGIES (IJWSET)



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Rainfed agriculture has become highly vulnerable to the depleting water resources in most arid and semi-arid tropics (ASATs) of Mount Kenya under the effect of climate change. The impact has certainly been very high in Ngusishi catchment where more than 99% of the natural forest has been cleared. The farming communities have created various innovative ways of coping with a warming environment to increase their resiliency to drought and foster agriculture. These include, among others, rain water management, reforestation and agro-forestry. This study used statistical forecast techniques to unveil the past, current and future variations of the micro-climate in Ngusishi catchment, and determine relevant factors casting doubt on the performance of Green Water Management (GWM) schemes. In view of the current trends of the population growth and urbanization in Ngusishi by the year 2030, agricultural expansion and farmers' resilience to drought are seriously threatened if no appropriate policy, extension service and science-based emergency measures are put in place by the Government of Kenya. No wonder that, some farmers and watershed managers, especially within the ASALs, remain skeptical about the significance of the value added of GWS schemes compared to traditional conservation, especially when it comes to addressing drought severity, owing to decreasing rates of river discharges and water infiltration in the soil.

Keywords: Agriculture, Micro-Climate; Climate Adaptation; Climate Vulnerability, Drought, Green Water, Watershed Management

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