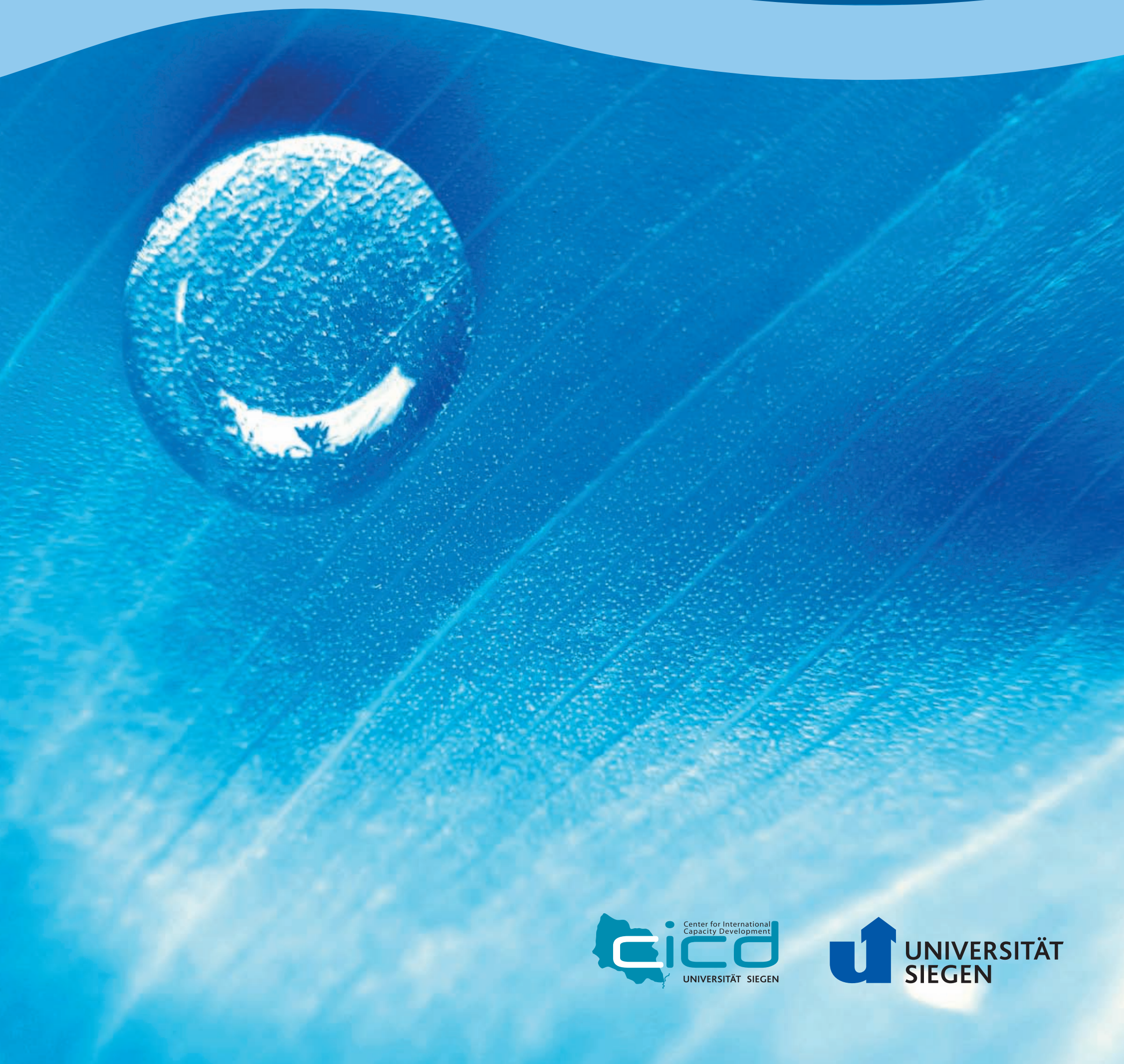
Editor: Gerd Förch

CICD Series

Vol. 9 LARS 2011

Lake and Catchment Research Symposium

Proceedings



CICD Series Vol. 9: Lars Proceedings 2011

CICD Series

Editor

Prof. Dr.-Ing. Gerd Förch,
Universität Siegen
Centre for International Capacity Development,
Paul-Bonatz-Str. 9-11
57076 Siegen

E-Mail: info@cicd.uni-siegen.de

Printing Printing Office, Universität Siegen, Germany

ISSN: 1868-8578

Foreword

The Lake and Catchment Research Symposia (LARS) have been held every three years since 2004; the first two were held in Addis Ababa and Arba Minch, Ethiopia respectively; organised by Siegen University, Water Resources Management Group, in Cooperation with the Arba Minch University; sponsored by German Technical Cooperation (GTZ) and DAAD, the German Academic Exchange Service.
The aim of the symposia was the presentation of research findings in water resources and integrated watershed management, focussing on regional problems, the East African Rift Valley and beyond.

LARS 2011 was held in Nairobi, Kenya; it availed the opportunity for sharing experiences and results on watershed research including sanitation and energy among key stakeholders including researchers, watershed managers and policy makers.

The main topic, Integrated Watershed management (IWM), has been increasingly accepted as a measure of partnership in regional and inter-regional programmes and has become an integrated part of development cooperation. Further on, it became the tool for sub-catchment management planning (SCMP) in the Kenyan water sector reform process.

The forum contributed to the overall development of the watersheds in the East African region within the context of ongoing water sector and energy sector reforms.

Lars 2011 was jointly organised within the context of Integrated Watershed Management Network (IWMNet) by Kenyatta University, Department of Geography, and Siegen University, Centre for International Capacity Development - CICD; EU (ACP/EU Water Facility) and DAAD contributed the major funding; GIZ sponsored local participants; a German supplier of watershed monitoring equipment, EcoTech, sponsored several students to attend.

The following proceedings assemble those papers, presented at Lars 2011, which successfully passed the post-conference review by international scholars. They represent some key research findings of members and collaborators of the IWMNet.

Siegen, June 2012

Gerd Förch

Editor in Chief, CICD Series & Managing Director of CICD

For further information go to www.iwmnet.eu

Contents

1 An Evaluation of Soil and Water Conservation Technologies for Sustainable Management of Ngaciuma Sub-Catchment, Kenya

*Alufah, S.[1]**

Obando, J. A.[1]

Shisanya, C.A.[1]

[1]Department of Geography, Kenyatta University
P.O. Box 43844-00100, Nairobi, Kenya

*Corresponding author (E-mail: alufahds2002@yahoo.com)

1.1 Abstract

The Ngaciuma sub-catchment which forms part of the Upper Tana Catchment is endowed with water and land related resources. Being one of the productive regions of Kenya requires effective management of resources to sustain the Tana River for socio-economic development. It is against this background that this study investigated soil and water conservation (SWC) technologies by farmers for sustainable management in the catchment. Data was collected mainly through a questionnaire administered to 100 household farmers and 20 stakeholder experts and analyzed by the use of descriptive statistics and SWOT analysis. Findings of the research revealed that some farmers have adopted more than one technology. The major SWC technologies were: cover cropping (27%), intercropping/multiple cropping (16%) agroforestry (33%), contour vegetation strip (19%) tree planting (61%) and terracing (65%) with adoption level (76%) and farmers having non of the technologies (24%). The study revealed the challenges hindering effective management of resources in the catchment as: high unemployment rate of the youth, cultural decay on the need to conserve natural resources, local political interference, lack of funds and other resources to implement regulations in the field, inadequate information or awareness on the part of farmers, lack of coordination among various ministries and groups on environmental issues and lack of technical know-how on soil and water conservation measures. However, opportunities such as the existence of a Sub-catchment Management Plan with an active management committee, an established proactive Ngaciuma-Kinyaritha Water Resources User Association for resource conservation, capacity building programmes by Water Resources Management Authority and Kenya Forest Service for local community, the catchment being a pilot area for the European Union Water Facility Project and catchment located within one of the productive regions of Kenya were found to be source of encouragement for resource conservation and management. For sustainable management of the catchment, the Government of Kenya was urged to devise policies to harness the opportunities to reduce the impacts of the challenges or constraints.

Keywords: *Adoption, Kenya, Ngaciuma Sub-catchment, SWOT Analysis, Upper Tana Catchment*

1.2 Introduction

Degradation of soil and vegetative resources threaten agricultural productivity and water availability in many developing countries. About 16% of agricultural land area in developing countries and a higher proportion of crop and dry lands have degraded moderately or severely mainly through soil erosion, nutrition depletion and salinisation (Rezvanfar *et al.*, 2009). This can be facilitated through appropriate land and water management, which enhances infiltration, stabilizes slopes and increases soil moisture. All these constraints directly depend upon the precipitation, runoff and the conservation technologies adopted to prevent soil erosion in the catchment (Vishnudas *et al.,* 2005). In order to attain sustainability in management of watershed resources, there should be change in the attitude towards watershed management from a purely technical approach of conservation to a participatory approach by involving people in all phases of project planning and implementation. This would enhance soil and water conservation (SWC) technology adoption by farmers considering the rich traditional practices and experiences of the farmers. By this, experts and scientists could co-develop appropriate technology jointly with the watershed users or community. Following the sustainability paradigm, 'appropriate' would require that a technology should be ecologically protective, socially acceptable, economically productive and economically viable and reduce risk (Calatrava Leyva1 *et al.*, 2007). Watershed management can be achieved by using a variety of technologies such as vegetation conservation like grass contours, alternative tillage techniques and physical structures like terraces, stone bunds among others (Vishnudas *et al.,* 2005). The World Bank has given more importance in vegetative measures in watershed management. This supports the global trend that favors choosing technologies that are low cost, more farmers friendly and compatible with existing land uses (World Bank, 2001).

In designing different structures for SWC, there is the need to know the conditions under which households choose to invest in building or maintaining SWC technologies. This can be analysed only through the livelihood strategies adopted by the poor, together with policies and structure, which influence these strategies (Chomba, 2004). Literature shows that there is relationship between household's access to assets and SWC. According to Rousan (2007), level of income, labour availability, access to low cost credit, secure land tenure are some of the factors influencing the household's attitude towards conservation. The adoption of SWC represents a decision by households to intensify their agricultural output per unit area through capital investment or an increase in labour inputs. It is essential to recognise that SWC measures impose opportunity costs through their demands on labour, often at times of peak demand (Chomba, 2004). It is often assumed that investing in SWC is automatically beneficial without looking in detail at the costs and benefits, and particularly the on-farm versus off-farm costs of soil degradation. Investments in SWC tend to generate returns in the long term, but do not necessarily result in higher yields or income in the short term (Chomba, 2004).

Most studies in Kenya on SWC and watershed management were carried out in arid and semi-arid areas (Mutisya, 2002; Bett, 2004; Yatich, 2005 and Cheserek, 2005), as soils in these catchments are poorly developed, making them highly susceptible to wind and water erosion which can affect the livelihoods of the inhabitants. The studies attributed severe soil erosion in these arid and semi-arid lands to already fragile ecosystems facing increasing pressure as a result of natural population growth and migration from neighbouring densely populated high potential areas. This indicates clearly that the situation is not better in the high potential areas. The Ngaciuma Sub-catchment in particular is one of the most productive parts of Kenya and receives substantial amount of rainfall (about 1200mm annually) (Jaetzold *et al*., 2007), which causes devastating soil erosion due to the steep slope of the area. With increasing population pressure, fallow periods are shortened, land is over-cultivated, overgrazing takes place and more and more vegetation is cleared for cultivation purposes. These poor agricultural practices weaken further the already poor and thin soils, increasing their susceptibility to erosion and hence creating an urgent need for serious soil conservation. In order to achieve sustainable development in the catchment, sustainable technologies need to be developed, transferred and adopted by the people for effective management of resources. This study assessed SWC for effective management of watershed resources for sustainable development.

1.3 Study Problem

Among the various forms of land degradation, soil erosion is the most important and ominous threat to food security and development prospects of many countries (Bekele, 2003), Kenya included. It induces on-site costs to individual farmers, and off-site costs to society. Accelerated soil erosion can be reduced by a combination of proper land management systems and appropriate SWC efforts. Incentives to promote SWC measures are therefore, among the appropriate areas of intervention to mitigate the adverse effects of soil erosion (GoK, 2008). The problem of soil erosion in the Ngaciuma Sub-catchment has been attributed to high population growth, leading to continuous fragmentation of landholdings, agricultural intensification, shortening of fallow periods and subsequent reduction in soil fertility and crop yields. Soil erosion problem is further exacerbated by the steep slope of the area, high rainfall (1200mm annually), deforestation, overgrazing, low adoption of SWC technologies and unsustainable agricultural activities (Jaetzold *et al.*, 2007). This study addresses the following key questions: (i) What soil and water conservation technologies are being practised by farmers in the Ngaciuma Sub-catchment? (ii) What are the challenges and opportunities of adopting soil and water conservation technologies by farmers and for sustainable management of the catchment?

1.4 Materials and methods

1.4.1 The Study Area

The study was conducted in Ngaciuma sub-catchment of 167 km^2 in Eastern Province of Kenya under Tana River Catchment. It has a population of about 36,000 people (CBS, 2001).Geographically, it is bounded by Longitudes 37.5° E and 37.75° E and Latitudes 0.04°N and 0.15° N. The study area is specifically located within Naari Location (Upper Zone), Munithu Location (Middle Zone) and Thuura Location (Lower Zone) with a total number of households being 7,511 (Jaetzold *et al.*, 2007). The climate of the catchment ranges from humid to semi-humid with Agro-ecological zones. Rainfall is bimodal falling during the long rains from March to May and short rains from October to December. The mean annual rainfall ranges from about 1100 mm in the lower zone to 1300 mm in the upper zone, with annual temperatures ranging from 10ºC to 30ºC. The major soils are nitisols with some gleysols in the wetlands and andosols on hill slopes (Jaetzold *et al.*, 2007). These soils are poorly consolidated hence with the steep slopes are susceptible to erosion and mass movement.

1.4.2 Data Collection

Primary data were collected using a structured questionnaire for heads of household farmers, institutional questionnaire for in-depth interview of stakeholder experts, key informant interview guide for farmers who are well informed about SWC technologies in the catchment and on-farm observation guide to map SWC technologies using Global Positioning System (GPS). A total of 100 households were selected using stratified random sampling procedure. With this sample size for the Sub-catchment, a proportionate stratified random sampling based on the proportion each zone contributes to the total number of households in the Sub-catchment was used. This calculation gives 46 households for Upper Zone, 26 households for Middle Zone and 28 households for Lower Zone. Additional information was collected from 20 representatives of stakeholder institutions, mainly

Ministries of Agriculture, Forest, Water, Environment, and Non-Governmental Organizations (NGOs).

To complement the information gathered, key informants who are mainly opinion leaders in the communities visited were interrogated in a face-to-face interview. This gave the researcher an opportunity to have an insight into the problem of soil erosion and the adoption of SWC technologies in the catchment. Furthermore, Global Positioning System (GPS) receiver and digital camera were used to capture specific SWC technologies in the field. Before the main study, a pilot study was conducted to pre-test the research instruments and to work out the modalities of identifying all stakeholders. After the pilot survey, various items in the research instruments that were inconsistent and redundant were done away with and a final version prepared for the main research. A literature search was undertaken from both published and unpublished materials on the study area, SWC technologies and adoption studies in general. This led to realistic interpretation of results by triangulation.

1.4.3 Data Analysis

Data analysis involved the use of descriptive statistics analysis which dealt mainly with frequencies and percentages. This was performed using the statistical spreadsheets (SPSS and Microsoft Excel). These measurements were used to have an idea of type of SWC technologies being practised by farmers in the Ngaciuma Sub-catchment and also to give an insight into factors influencing the adoption of SWC technologies in the catchment. In order to evaluate the challenges and opportunities of adopting SWC technologies in the catchment and for effective management of resources, a SWOT analysis was employed as an analytical tool.

1.4.4 SWOT Analysis

SWOT analysis was used in the study to evaluate the challenges and opportunities of adopting SWC technologies in general and for the Ngaciuma Sub-catchment in particular. The SWOT analysis is the acronym for Strengths, Weakness, Opportunities and Threats that an organization faces towards realizing its goals (Boseman and Phatok 1989; Khayesi, 1998). Strengths are the internal capacities of an organization's objectives in a reactive and competitive environment. Weaknesses are internal disadvantages that restrict the attainment of organization's objectives. Opportunities are external forces or factors that enable an organization to achieve or exceed its objective or goal. Threats are external factors or forces that might create problems or cause harm to the organization or community. While strengths and weaknesses can be monitored and evaluated by an organization, opportunities and threats cannot be controlled by an organization. The latter can even endanger its capacity to achieve its objectives. SWOT analysis is commonly applied to a number of phenomena or issues because of its varying spatial organizational scales (Khayesi, 1998). It uses systems approach whereby watershed institutional structures are considered as endogenous factors and can be a source of strength or weakness for sustainable management of water and land related resources. However, other socio-economic and political institutions along with the physical environment components are considered as exogenous factors to watershed management, and can be a source of opportunities or threats to it. That is why it was adopted for the study.

1.5 Results and discussion

1.5.1 Results of Soil and Water Conservation Technologies identified

The results revealed that 76% have adopted at least one of the SWC technologies identified with 24% not adopting any of the SWC technologies at all. The high rate of adoption of SWC measures in the catchment might be linked to farmers desire to conserve water and land related resources as a means to improve upon agricultural productivity as the area is one of the productive regions in Kenya. As shown in Figures 1 and 2, terracing (65%), tree planting (61%), agroforestry (33%), cover cropping (27%), intercropping (16%) and contour vegetation strip (19%) are the major SWC technologies being adopted by farmers due to their effectiveness in controlling soil erosion in the catchment. Farmers' choice of these soil erosion control measures are mainly due to the steep slope of the area and these technologies tend to reduce the speed of run-off down slope. Figure 1 depicts the spatial distribution of some of the SWC technologies mapped in the catchment with Global Positioning System (GPS) receiver and Plate 1 depicts the effect of gully erosion in a farm.

Cover Cropping: The study revealed that 27% (Figure 2) of respondents interviewed indicated cover cropping as the means of conserving soil and water resources in the catchment. The main crops grown to cover soil are cow pea, soya bean, sweet potato (Plate 2) in association with maize and other food crops. The choice of these crops in the study area was based on their ability to establish very fast to cover the soil, control run-off and enhance soil structure and texture. For this reason, the planting densities of these cover crops in the field is so close that there is inadequate space between crops for soil exposure to the weather. Cover cropping as a soil and water conservation and management strategy in the study area is further enhanced as the people use beans and maize to prepare a traditional food called 'githerie'. This method of SWC has been found scientifically effective in conserving and managing soil and water resources. This came to light when Thiessen-Martens *et al.* (2005) found that cover crops fix nitrogen into the soil which often provides the required quantity of nitrogen for crop production. Cover crops also enhance the soil structure, water holding and buffering capacity as well as increasing soil carbon sequestration (Kuo *et al.,* 1997; Sainju *et al.,* 2002; Lal, 2003). In terms of water conservation and management, it has been found that cover crops reduce both the rate and quantity of water that drains off the field, increase water infiltration and soil water storage for recharging of aquifers (Dabney *et al.,* 2001; Joyce *et al.,* 2002).

Intercropping/Multiple Cropping: 16% (Figure 2) had chosen intercropping or multiple cropping as their strategy to conserve soil and water resources. This strategy involves a practice of growing more than one type of crop on the same piece of land. The study identified the following crops being grown on the same farmland: food crops (maize, cow pea, and potatoes), cash crops (coffee, banana, khat), vegetables (lettuce, cabbage, onion) and fruits (banana, orange, mango) (Plate 3). Intercropping provides an advantage of total cover of the soil throughout the year to ensure control of soil erosion and soil fertility enrichment. Koskey (2005) explained thus:

> The crops inter-cropped ensured that while some nutrients were taken away from the soil by other species of plants, other forms of nutrients were added to the soil yet by different species of plants. The importance of this farming strategy was to ensure that nutrients were not exhausted and, hence, reduce the quality of the soil. The system also provided cover, which prevented the soil from being eroded.

Further, this SWC measure and farming activity is a diversification strategy adopted by farmers to cushion them against any crop failure due to drought, pests and diseases. Apart from being a risk averse strategy by farmers, intercropping also ensures that the soil is protected by abundant crop canopy of different species of crops (Koskey, 2005).

Agroforestry: As indicated in Figure 2, 33% of the respondents practice agroforestry as a SWC technology in the Ngaciuma Sub-catchment. This technology allows planting of tree species in association with crops on the same piece of land (Plate 4). The study identified these tree species in the farms: eucalyptus, grevillea and calliandra. These tree species are planted because of their ability to grow fast. By growing fast, they protect the soil from erosion, increase nutrients in the soil, and improve the structure of the soil to hold water for crop growth.

Other functions of agroforestry include: provision of fodder for livestock, especially from calliandra, providing cheaper and more accessible fuel wood for domestic use, and constructional materials for building and other construction industry. All these have served as an incentive for farmers to engage in this SWC technology to conserve resources in the catchment. Mugendi *et al*. (2007) in explaining the role of agroforestry in land and water management observed:

> The major service function of agroforestry is its role in soil management, including control of erosion and maintenance and improvement of soil fertility.

Contour Vegetation Strip: 19% (Figure 2) indicated their preference for contour vegetation strip as SWC technology. This technology is used to control soil erosion through creation of barriers along contour lines in farms. In the study area, lines of grasses (Napier grass in particular), stones, crop residues and other organic debris are placed along hillsides to control water and soil erosion (Plate 5). Contour vegetation strips are living barriers of trees and shrubs (eucalyptus, grevillea and calliandra) which are planted along the contour lines of a slope. These lines of vegetation can serve the purpose of soil erosion reduction and can also provide useful products such as food, fuel wood, building poles, and fodder to feed livestock.

The living barriers function in such a way that they provide good ground cover which assist in trapping water flowing downhill carrying soil particles and nutrients. The method depends on local materials, hence making it cost effective as the farmer virtually buys nothing to adopt this technology. Napier grass used as living barrier adds nutrients such as nitrogen (1.97%), phosphorus (0.2%) and potassium (3.8%) to the soil (Gitahi and Mureithi, 2002). This eventually enhances the fertility of the soil for crop production.

Tree Planting: From Figure 2, 61% of the respondents interviewed were convinced that tree planting is the best method for conserving soil and water resources in the Ngaciuma sub-catchement. Tree planting is a method where farmers plant trees not alongside any other crop, purposely to control soil erosion (Plate 6). The practice takes the form of planting tree species like eucalyptus and grevillea separately or on terraces to conserve soil and water. The trees prevent soil erosion by quickly establishing canopy thereby preventing raindrops from having direct contact with the soil.

The study in the catchment revealed that almost all the tree species planted as boundary demarcation of farmlands and settlements, both small and big tree plantations serve as a resource for the people. For example, eucalyptus is used as fuel wood and constructional material. The financial benefits that accrue to farmers far outweigh that of environmental quality or soundness. This has been a source of incentive or motivation for planting trees in the catchment, especially the fast growing exotic species. This is in agreement with Kenya Forest Service, KFS (2009) as they linked tree planting (Eucalyptus) to the following environmental and economic growth reasons:

> (i) It provides power transmission poles for the expanded rural electrification programme, with the current demand for power transmission poles about 450,000 poles per annum, (ii) It is an alternative source of affordable industrial energy for the tea, tobacco, lime, cement and many other industries, (iii) It provides high quality fibre for pulp, (iv) It is socially acceptable for its wide range of products and benefits, (v) Eucalyptus has formed the backbone of the emerging commercial forestry sub-sector where many large and medium scale land owners are turning to it as the cash crop of choice, (vi) It contributes to increased forest cover, (vii) It contributes to carbon sequestration which mitigates against climate change, (viii) It is good for gully stabilization and rehabilitation of degraded sites, (ix) It reduces the pressure on natural forests by providing forest goods and services in alternative production areas such as private forests, (x) It provides additional services as wind breaks, shelter belts and boundary demarcation.

Terracing: Among the respondents interviewed, 65% acknowledged terracing as their choice of soil and water conservation technology (Figure 2). Terracing as a SWC measure recorded the highest patronage among farmers in the catchment due to its effectiveness in controlling erosion because of the terrain and slope of the area. The terrain and slope of the catchment had made it prone to rill, furrow and gully erosion, hence the need to adopt terracing by farmers to avert its devastating effects. Although there are many types of terraces to control soil erosion, almost all the farmers in the study area construct a type locally called '*Fanya Juu*' (Plate 7). This terrace is constructed by digging a ditch on the contour and throwing the soil on the upslope side to form the embankment (Morgan, 1995). In order to serve its maximum purpose of reducing run-off to the barest minimum, trees and Napier grass are planted on the terrace in order to stabilize the embankment. The vegetation on the terraces enhances infiltration of water into the soil and the excess is safely delivered downhill.

SWOT Analysis of Challenges and Opportunities

This section presents the strengths, weaknesses, opportunities and threats of adopting SWC technologies in the Ngaciuma Sub-catchment in particular and the Upper Tana catchment in general. SWOT Analysis being a strategic planning tool is used to evaluate the challenges and opportunities of the SWC technologies in this study in order to highlight on issues which need special attention for effective management and conservation of resources in the catchment for sustainable development. The results are presented in SWOT analytical matrix as in Table 1.

Table 1: SWOT Matrix for Challenges and Opportunities

Exogenous factors / **Endogenous factors**	**Opportunities (O)** $O_1, O_2, O_3, O_4, O_5, O_6, O_7, O_8, O_9, O_{10}$	**Threats (T)** $T_1, T_2, T_3, T_4, T_5, T_6, T_7, T_8, T_9, T_{10}, T_{11}, T_{12}, T_{13}, T_{14}, T_{15}, T_{16}, T_{17}$
Strengths (S) $S_1, S_2, S_3, S_4, S_5, S_6, S_7, S_8, S_9, S_{10}$	For effective management and conservation, strengths ($S_1, S_4, S_5, S_6, S_8, S_{10}$) need to be maximized to take advantage of these opportunities ($O_1, O_2, O_5, O_7, O_8, O_9, O_{10}$).	There is the need to maximize institutional competences in the catchment ($S_1, S_4, S_5, S_6, S_8, S_9, S_{10}$) to reduce the impacts of the threats ($T_1, T_2, T_3, T_4, T_5, T_6, T_7, T_8, T_9, T_{10}, T_{11}, T_{12}, T_{13}, T_{14}, T_{15}, T_{16}, T_{17}$).
Weaknesses (W) $W_1, W_2, W_3, W_4, W_5, W_6, W_7, W_8, W_9, W_{10}, W_{11}, W_{12}, W_{13}$	To reduce soil erosion and conservation of resources, existing weaknesses ($W_1, W_2, W_3, W_4, W_5, W_6, W_7, W_8, W_9, W_{10}, W_{13}$) must be minimized to make the environmental opportunities effective ($O_1, O_2, O_3, O_4, O_5, O_6, O_7, O_8, O_9, O_{10}$).	For sustainable watershed management, institutions (both internal and external stakeholders) must be empowered through participation giving priority to capacity building and financial sustainability to minimize weaknesses and mitigate threats to the catchment.

Source: Field Survey (2010)

Key to the SWOT Matrix

S = Strengths

S_1: Existence of environmental conservation groups and organizations in the catchment,

S_2: Fertile soils,

S_3: Adequate rains and well distributed throughout the year,

S_4: Allocation of resources from the local authority for conservation purposes,

S_5: Existence of Sub-catchment Management Plan with active management committee,

S_6: The catchment has established and proactive Ngaciuma-Kinyaritha Water User Association for resource conservation,

S_7: Most farmers have soil and water conservation structures in their farms,

S_8: Capacity building programmes by Water Resources Management Authority (WRMA) and Kenya Forest Services for inhabitants,

S_9: Local involvement in water allocation,

S_{10}: Sensitization programmes on the need to conserve the catchment, especially fragile ecosystems, example wetlands.

O = Opportunities

O_1: Existence of development projects in and around the catchment,

O_2: Presence of commercial tree nurseries in the district,

O_3: Vigorous trees planting culture among inhabitants,

O_4: The watershed is sited within a natural forest serving as water source,

O_5: Majority of local communities practice participatory forest management or co-management,

O_6: Presence of Imenti forest which acts as water recharger for all the rivers in the catcment,

O_7: Proximity of the catchment to appropriate stakeholder ministries for professional advice,

O_8: Availability of water, environment, agricultural and forestry technical officers in the catchment,

O_9: The catchment is a pilot area for the European Union Water Facility Project,

O_{10}: Catchment located within one of the most productive regions of Kenya.

W = Weaknesses

W_1: Lack of coordination among various ministries and groups on environmental issues,

W_2: Minimal allocation of resources by the government agencies for conservation purposes,

W_3: Conservation activities in the catchment not well coordinated,

W_4: Farming activities on marginal lands without appropriate soil conservation measures in place,

W_5: Some farmers engage in poor farming practices,

W_6: Indiscriminate cutting of trees (especially indigenous trees) without replacement,

W_7: Lack of technical know-how on soil and water conservation measures,

W_8: Poor maintenance of soil and water conservation structures, especially terraces,

W_9: Farming activities very close to water bodies,

W_{10}: Reclamation of natural water storage sites to agricultural lands or settlements using eucalyptus trees,

W_{11}: Illegal and over-abstraction of water resources for domestic and agricultural purposes,

W_{12}: Conflict on resource use, example water,

W_{13}: Overgrazing by both domestic and wild animals leading to removal of vegetation cover.

T = Threats

T_1: Lack of support by the local community,

T_2: Lack of willingness to attend awareness creation meetings by inhabitants,

T_3: Lack of technical knowledge on environmental issues by inhabitants in the catchment,

T_4: Lack of finance to put appropriate soil and water conservation measures in place,

T_5: Scarcity of labour to construct soil conservation structures,

T_6: Forest fires, both natural and artificial,

T_7: Illegal logging of trees for charcoal burning,

T_8: Encroachment of local communities into natural forests in the catchment,

T_9: Topography of the land and high population leading to degradation and depletion of resources,

T_{10}: Effect of climate change and variability,

T_{11}: Low educational background of inhabitants,

T_{12}: Large family size,

T_{13}: High unemployment rate of the youth,

T_{14}: Cultural decay on the need to conserve natural resources,

T_{15}: Local political interference,

T_{16}: Lack of funds and other resources to implement regulations in the field,

T_{17}: Lack of information or awareness on the part of farmers.

1.6 Summary and Conclusion

From the above discussion, it is evident that the major SWC technologies in the Ngaciuma Sub-catchment are: terracing, tree planting, agroforestry, cover cropping, intercropping/multiple cropping and contour vegetation strip with adoption level considerably on the higher side. High unemployment rate of the youth, local political interference, lack of coordination among various ministries and groups on watershed management issues, lack of technical know-how on soil and water conservation measures, especially terraces were some of the challenges. However, the catchment can boast of an established Sub-catchment Management Plan with active management committee members and a proactive Ngaciuma-Kinyaritha Water Resources User Association for resource conservation. These findings reinforce the facts that in order to achieve sustainable watershed management in the catchment, institutions (both internal and external) must coordinate their activities through effective participation with special attention on capacity building and the socio-economic life of the inhabitants. For sustainable management of the catchment, Officials of Ministries of Agriculture and Forest Services in the catchment should encourage farmers to adopt the SWC technologies identified in the study, especially terracing because of the sloppy nature of the area. Moreover, the Government of Kenya should devise policies geared towards sensitization of all stakeholders, capacity building programmes for farmers in other livelihoods, harmonization of management strategies of government ministries and agencies (Water, Agriculture and Forestry) and effective participation in soil and water conservation matters.

1.7 Acknowledgement

We wish to express our profound gratitude to the German Academic Exchange Service (DAAD), Germany, for their financial support in accomplishing this paper.

1.8 References

Bekele, W. 2003. Economics of Soil and Water Conservation: Theory and Empirical Application to Subsistence Farming in the Eastern Ethiopian Highlands. PhD Thesis. Uppsala, Department of Economics, Swedish University of Agricultural Sciences, Sweden, 49 pp.

Bett, C. 2004. Farm Adoption Decisions of Soil and Water Management Techniques in Semi-Arid Eastern Kenya. A Paper Presented at the 48th Annual Conference of the Australian Agricultural and Resource Economics Society. Melbourne, 11th-13th February, 2004, Australia, 30 pp.

Boseman, G. and Phatok, A. 1998. Strategic Management: Text and Cases. John Wiley and Sons, New York, USA

Calatrava Leyva1, J., Franco Martinez, J. A. and González Roa, M. C. 2007. Analysis of the Adoption of Soil Conservation Practices in Olive Groves: The case of mountainous areas in Southern Spain. Spanish Journal of Agricultural Research, 5(3): 249-258.

Central Bureau of Statistics, CBS 2001. Population and Housing Census: Counting Our People for Development. Population Distribution by Administrative and Urban Centres. Ministry of Finance, Government of Kenya, Government Printer, Vol.1, Nairobi, Kenya.

Cheserek, G. 2005. Indigenous Knowledge in Water and Watershed Management: 'Marakwet' Conservation Strategies and Techniques. In: Förch, G., Winnegge, W. R. and Thiemann, S. (eds.): Results of the Summer School: Participatory Watershed Management Plan for Ngaciuma-Kinyaritha Watershed, DAAD Alumni Summer School 2005: FWU Water Resources Publications, Vol. 3. Siegen, University of Siegen, Germany, pp. 25-33.

Chomba, G., 2004. Factors Affecting Smallholder Farmers' Adoption of Soil and Water Conservation Practices in Zambia. M.Sc. Thesis, Michigan State University. Department of Agricultural Economics.

Dabney, S. M., Delgado, J. A. and Reeves, D. W. 2001. Using Winter Cover Crops to Improve Soil Quality and Water Quality. Journal of Communications in Soil Science and Plant Analysis 32:1221-1250.

Gitahi, F. and Mureithi, J. G. 2002. Green Manure Legume Database. In: Legume Research Network Project Newsletter, No.7. Kenya Agricultural Research Institute (KARI), National Agricultural Research Laboratories (NARL), Nairobi, Kenya, pp. 2-6.

Government of Kenya, GoK, 2008. Vision 2030 Medium Term Plan, Strategy for National Transformation 2008 –2012: Accelerating Equitable Economic and Social Development for a Prosperous Kenya. Government of Kenya, Nairobi, Government Printer, Kenya, pp. 179-193.

Jaetzold, R., Schmidt, H., Hornetz, B. and Shisanya, C. 2007. Part C East Kenya, Subpart C1 Eastern Province. In: Ministry of Agriculture and GTZ (eds.), Farm Management Handbooks of Kenya, Vol. II: Natural Conditions and Farm Management Information. Nairobi, Kenya, pp. 62- 172.

Joyce, B. A., Wallender, W. W., Mitchell, J. P., Huyck, L. M., Temple, S. R., P. N. Brostrom, P. N. and Hsiao, T. C. 2002. Infiltration and Soil Water Storage under Winter Cover Cropping in California's Sacramento Valley. Journal of Transactions of the Asae 45:315-326.

Kenya Forest Service, KFS 2009. A Guide to On-Farm Eucalyptus Growing in Kenya. Government Printer, Nairobi, Kenya, pp. 10-14.

Khayesi, M. 1998. An Analysis of the Patterns of Road Traffic Accidents in Relation to Selected Socio-economic Dynamics and Interventions Measures in Kenya. PhD Thesis, Kenyatta Univeristy, Nairobi, Kenya

Koskey, P. K. 2005. The Use of Indigenous Knowledge and Cultural Values in Sustainable Mangement of Soil Resources in headwater areas by the Kipsigis Community of Kericho District, Kenya In: Prasad, H., Abate, K., and Ondieki, C. M. (eds.), Sustainable Water Resources Management: Research from Africa and India. Varanasi, Tera Book Agency, India, pp. 223-249.

Kuo, S., Sainju, U. M. and Jellum, E. J. 1997. Winter Cover Crop Effects on Soil Organic Carbon and Carbohydrate in Soil. Soil Science Society of America Journal 61:145-152.

Lal, R. 2003. Offsetting Global Carbon Dioxide Emissions by Restoration of Degraded Soils and Intensification of World Agriculture and Forestry. Journal of Land Degradation and Development 14:309-322.

Morgan, R. P. C. 1995: Soil Erosion and Conservation. Longman Group Limited, Essex, UK.

Mugendi, D. N., Munal-Munal, M. W., Waswa, B. and Mugwe J. N. 2007. Agroforestry for Land and Water Management in Kenya. In: Waswa, F., Otor, S., Olukoye. G. and Mugendi, D. (eds.): Environment and Sustainable Development; A Guide for Higher Education in Kenya, Vol 2. School of Environmental Studies and Human Sciences, Kenyatta University, Kenya, pp.122-138.

Mutisya, D. N. 2002. Gender-Related Problems Constraining Women Farmers' Participation in Soil Conservation in the Semi-Arid Areas within the Masinga Dam Catchment, Kenya. In: Proceedings of 12th International Soil Conservation Organization (ISCO) Conference, Volume 1, Beijing, China, pp.12-15.

Rezvanfar, A., Samiee, A. and Faham, E. 2009. Analysis of Factors Affecting Adoption of Sustainable Soil Conservation Practices among Wheat Growers. World Applied Sciences Journal 6 (5): 644-651.

Rousan, L. M. 2007. Factors Influencing Adoption of Improved Farm Practices among Women Farmers in Northern Jordan. American-Eurasian Journal of Agriculture and Environmental Science 2 (3): 220-226.

Sainju, U. M., Singh, B. P. and Whitehead, W.F. 2002. Long-Term Effects of Tillage, Cover Crops, and Nitrogen Fertilization on Organic Carbon and Nitrogen Concentrations in Sandy Loam Soils in Georgia, USA. Journal of Soil and Tillage Research 63:167-179.

Thiessen-Martens, J. R., Entz, M. H. and Hoeppner, J. W. 2005. Legume Cover Crops with Winter Cereals in Southern Manitoba: Fertilizer Replacement Values for Oat. Canadian Journal of Plant Science 85:645-648.

Vishnudas, S., Savanije, H. H. G. and Van der Zaag, P. 2005. A Conceptual Framework for Sustainable Watershed Management. In: Proceedings of the ICID 21st European Regional Conference, 15 – 19 May 2005, Germany, pp. 23-27.

World Bank, 2001. Improving Watershed Management Programmes, Why is a Watershed Approach Necessary? Rural Development Department, World Bank, Washington D.C., USA.

Yatich, T. T.B. 2005. The Role of Communities in the Management of Headwater Resources: The Case of Kadjiado Central and Magadi Divisions with Special Reference to Gender Balance, Kenya. In: Prasad, H., Abate, K., and Ondieki, C. M. (eds.), Sustainable Water Resources Management: Research from Africa and India. Varanasi, Tera Book Agency, India, pp. 125-145.

2. Characterization of Chemical Groundwater Type: A Case of Lumwana Mine and Surrounding Areas

Banda K.E.

Lweya C. M.

Nyambe I. A.

University of Zambia
32379, Lusaka

kawawabanda@yahoo.co.uk

2.1 Abstract

The natural groundwater quality in an aquifer, results from interaction with rocks and minerals comprising the aquifer. Water slowly dissolves soluble minerals adding to the water's concentration of total dissolved solids, which is used as a general indicator of natural water quality. While many aspects of groundwater availability and quality are geologically controlled, society's needs and activities also have an impact. This study characterises groundwater chemistry of fractured rock aquifers in Lumwana Mine and surrounding areas to explain plausible geogenic source and ascertain vulnerability. Three experimental boreholes were drilled and composite samples were taken for analysis. On a statewide basis, calcium is the dominant cation while proportions of sodium and magnesium are about equal. Sulphate and Bicarbonate constitute the bulk of anions present, while chloride was below detection limit. A piper diagram was used to analyse the results for the major ions (Na, Mg, Ca, Cl, HCO_3 and SO_4). The results suggest the aquifer has Calcium, Magnesium Bicarbonate (Ca-Mg-HCO_3) water type attributed to the weathering of plagioclase, biotite and muscovite in an open system which induces precipitation of clay minerals (Kaolinite) in the fracture planes. The finding of this study, recommends that as long as the vast majority of rural population in Zambia are dependent on water from the ground, discussions and policy reforms on protection and strategy of groundwater resources must be underlain by an informed understanding of the hydro-geological dynamics.

Keywords: *Groundwater; Lumwana; Major ions; Water Quality*

2.2 Introduction

Judicious use of groundwater is paramount in rural setting given that it's the cheapest way of reliable supply of clean drinking water. In nature, groundwater occurs in aquifers and is constantly interacting with the environment especially the geology. Mineralogy composition of the lithologies tends to give the water a characteristic signature. This paper describes the mineral water chemistry of groundwater in North - Western Zambia.

2.3 Study area and sampling program

The Lumwana Mine and surrounding area (Figure 2.1) is located in the Northwest Province of Zambia, 220 km west northwest of the Copperbelt town of Chingola and 95 km from Solwezi. Access to the area is via the T5 Road off the Mutanda-Chavuma Road. The area is bounded by Latitudes 11º56'18"and 12º28'57" and Longitudes 25º42'51"and 26º4'47".

The study area comprises a gently undulating, upland plateau. The elevation at Malundwe varies from 1,280 m above mean sea level (amsl) along the Lumwana East River to 1,340 m amsl in the central northern section of the proposed pit. Similar elevations are present at Chimiwungo. The drainage forms a dendritic pattern with the regional flow to the west along the Lumwana East River. This river traverses the southern portion of the proposed Malundwe Pits and has been diverted and canalised. The Lumwana East River is perennial and fed from runoff and accumulated seepage from the adjacent groundwater system along the drainage length. Smaller drainages are ephemeral.

The climate is sub – tropical with a well defined rainy season between November and April. The basin receives very high rainfall, with maximum intensities occurring between December and March. The mean annual rainfall values of greater than 1450mm are recorded in the uppermost corner of the basin. The major part of the basin receives a mean annual rainfall of 1300 mm with average temperatures of 16°C in July and November respectively (IWRM Strategy, 2008). The mean relative humidity is 75% between December and March but ranges between 40 – 70% from September to January respectively. Mean monthly evaporation ranges from 120 mm in February to 217mm in October.

The basin has well-developed tertiary drainage patterns drained by the Kabompo River and its tributaries. The Kabompo River is perennial and drains the northwest portion of the watershed and flows southwest to join the Zambezi River at Lukulu district. Some of the tributaries of the Kabompo include Dongwe, Manyinga, West Lunga, Mwombezi, which are annual streams. The mean annual runoff in the basin is 46mm.

The soils in the upper reaches of the basin are acidic, deeply leached Ferrasols (Ashton, 2001) derived from the influence of parent rock material, climatic features and biological activity.

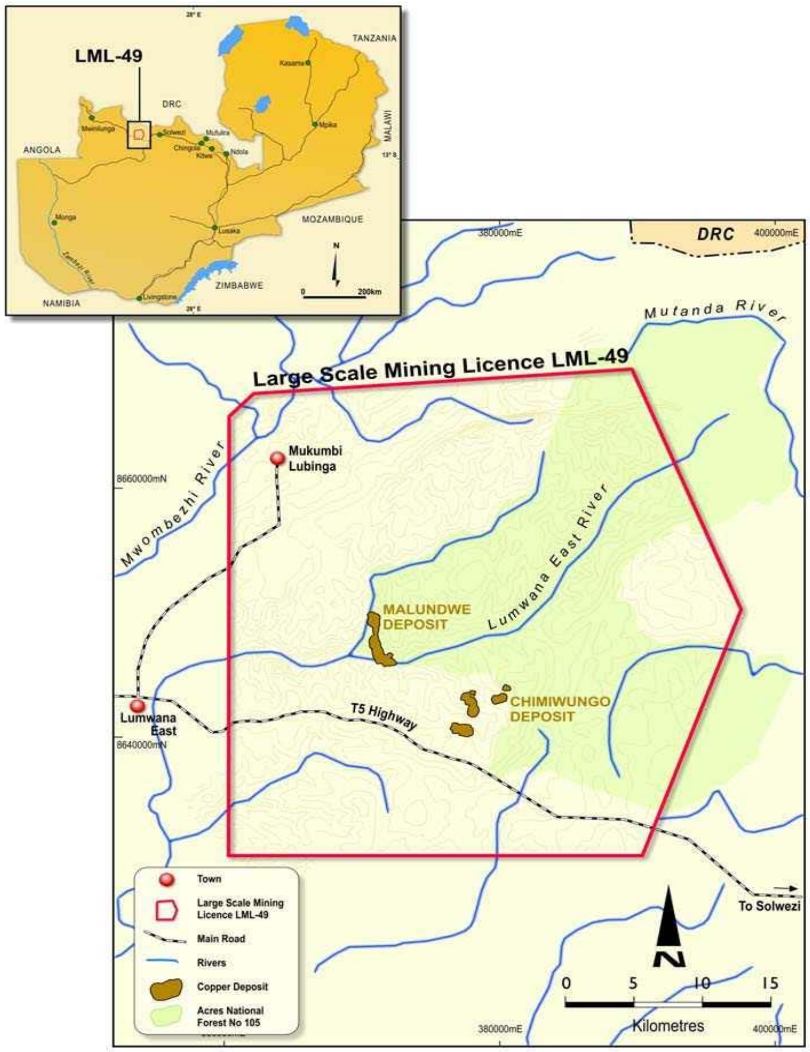


Figure 2.1: Location of the Lumwana Mining area gazetted as Large scale Mining Licence (LML) number 49, North-Western Province, Zambia (Source:Golder) Associaties,2003).

These soils range from clayey to loamy with very low fertility. The lower reaches are characterised with sandy (Kalahari sands) soils. However along streams and Dambo areas, the main soil types are sandy loams.

The Land cover is predominately closed deciduous forest, with scanty deciduous woodlands with some riparian forests near rivers.

The geology of the basin is predominantly underlied with metamorphic and sedimentary rocks in the north-east and south-west respectively. The metamorphic rocks are of Late Precambrian and Palaeozoic age and shows variations in the geological formations. Stratigraphically, these variations include Basement Complex, Lower Roan, Upper Roan and Kundulungu formations which have been affected structurally by the Luflian orogeny (Mulela and Seifert, 1998). The low grade Copper mineralization occurs as disseminated coarse-grained sulphides hosted in Biotite Muscovite-Kyanite-Quartz Ore Schist. The mineralisation occurs in the Lower Roan Formation with a general north-south trend and dipping west. The sedimentary rocks in the south west are predominately Kalahari sands belonging to the Barotse Formation which are Quaternary to Recent in age (Cahen L, 1984).

2.4 Materials and Methods

Three experimental boreholes were drilled in an equilateral triangle 15m apart. Samples were collected in the field for chemical analysis. In the field, pH, EC, DO, Temperature and alkalinity were determined on site. Samples for cations and trace metal analysis were filtered on a 0.45µm cellulose nitrate filter membrane and preserved with 1 % supra pure HNO_3 after several aliquots were initially filtered and used to rinse the filters, filtration equipment, and storage containers to ensure minimum contamination. Samples for H_2S analysis were preserved with 2N Zn $(CH_3COO)^-$ and 1 N of NaOH solution up to a pH of 9. Samples for anion analysis were unfiltered and unpreserved. All the analytical methods used were in accordance with Standard Methods of Examination of Water and Waste Water (Eaton et al., 1995). Accessibility to some sites was the biggest drawback especially that the area was highly undeveloped.

2.5 Results and Discussion

Laboratory analysis of groundwater samples of the study site for the drilled boreholes (A, B and C) are shown in Figure 2.1.

A piper diagram was used to identify the groundwater type in the boreholes. The result is that of the Calcium, Magnesium Bicarbonate (Ca-Mg-HCO_3) water type (Figure 2.2). This water type is attributed to the weathering products of the mineralogy in the schists and gneiss rock types.

Although, the geology in the study site is metamorphic, in which rock weathering would contribute high concentrations of elements such as Na^+, K^+ and Cl^- to the groundwater (Zuurdeeg and Van der Weiden, 1985 as quoted in Appelo and Postma, 2005), the situation is that of carbonate rock weathering. This is attributed to weathering of plagioclase, biotite and muscovite in an open system which induces precipitation of clay minerals (Kaolinite). FT-IR spectroscopy for laterite and weathered gneiss shows a characteristic Kaolinite signature in the samples (Figure 2.3), Doublets at 3700 and 3620 cm^{-1} and a hydroxyl (OH^-) deformation band at 938 and 916 cm^{-1} which was observed in the samples analysed.

Similar results were observed by Pereira M. and Almeida C (2000), in the metasedimentary sequences (phylites, metavolcanics of hercynian shield in the north west of the Iberian Peninsula (NE Portugal).

Their findings show that the most frequent rock-water interaction in metamorphic rocks are the dissolution of plagioclase and biotite or chlorite which induces the precipitation of clay minerals usually kaolinite. The mineralisation of these metasediments is similar to that of the Lumwana Mine and surrounding areas, thus comparable.

In addition, they suggested some lithologies had carbonate minerals present in the cementing material and, in these cases, the mineralisation of the water sample was higher and attributed to easy dissolution of carbonates but this was not the case in the rock formations under study. The Kaolinite Standard has characteristic

2.6 Conclusion

The most common rock water interactions in the metamorphic rocks of Lumwana area are the dissolution of plagioclase and biotite which induce the precipitation of clay minerals, usually Kaolinite. In some lithologies, carbonate minerals are present as cementing material and, in these cases the mineralisation of water samples is higher and attributed to easy dissolution of carbonates.

2.7 Acknowledgements

This project was partially supported by DANIDA in collaboration with the Ministry of Energy and Water Development (MEWD) and the strategic research funds provided facilitated by National Science and Technology Council (NSTC).

2.8 References

Ashton, P., Love D., Dirks P. & Mahachi H.,2001. An overview of the impact of mining and mineral processing operations on the water resources and water quality in the Zambezi, Limpopo and olifants catchments in the Southern Africa. MMSD final

Appelo, C.A.J and D. Postma. 2005. Geochemistry, groundwater and pollution. 2rd ed. Amsterdam: Balkema A.A. Publishers.

Cahen, L. & Snelling N.J., 1984. The geochronology and evolution of Africa, Oxford University Press.

Central Statistics Office (C.S.O.), 2003. Summary report for the 2000 census of population and housing.

Golder Associates, 2008. Environmental Impact Assessment, Lumwana Uranium Project, Project No: 5249.

Government of the Republic of Zambia (GRZ) and Danish International development Aid (Danida), 2008. Integrated Water Resources Management (IWRM) Centre research strategy in Zambia.

Holloway J.M. & Dahlgren R.A., 2001. Seasonal and event scale variations in solute chemistry for four Sierra Nevada catchments. Journal of Hydrology, 250, 106 – 121.

Mulela, d. & Seifert, A.V., 1998. Geology of the Mwombezhi Dome and Jiwundu Swamp Areas, Explanation of the degree sheet 1225 NE Quarter and 1125, part of SE Quarter, Republic of Zambia.

Zuurdeeg, B.W., M.J.J Weiden van der, 1985. “Geochemical aspects of European bottled water.” In: Geothermic thermal – mineral waters and hydrogeology. Theophrastus

Table 2.1: Groundwater chemical analysis results of the drilled boreholes (A, B and C) in the study site, North Western Province, Zambia. Results show high concentrations of calcium and very low concentrations of heavy metals such as copper.

Sample ID	Depth	pH	EC	HCO_3^{2-}	NO_3^-	PO_4^{2-}	SO_4^{2-}	Na	Mg	Ca	Cu	Co	Pb	Zn	Fe	Mn	Al
	m		µS/cm	mg/L	N(5)(mg/L)	P (mg/L)	S(6)	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
A	35	6.84	224	98.82	<0.01	0.22	32.40	1.48	0.86	28.05	<0.01	0.006	<0.01	0.054	0.022	0.935	<0.01
	45	7.113	554	285.48	0.05	0.48	6.80	3.46	4.30	73.70	<0.01	<0.01	<0.01	0.020	0.412	2.36	<0.01
B	5	5.758	91	6.71	0.07	0.37	1.79	0.91	0.23	9.03	0.04	<0.01	<0.01	0.014	0.008	0.05	<0.01
	25	5.57	74.1	37.942	0.01	0.32	55.60	0.89	0.41	11.96	0.02	<0.01	<0.01	0.006	0.005	0.03	<0.01
	35	6.73	345	162.87	<0.01	0.48	43.90	1.24	1.55	35.07	<0.01	<0.01	<0.01	0.015	0.06	0.879	<0.01
	45	6.77	355	261.08	<0.01	0.45	42.40	1.84	2.26	45.93	<0.01	<0.01	<0.01	0.134	0.027	0.827	<0.01
C	5	5.66	89.3	56.73	3.58	0.25	7.80	1.13	0.15	12.33	0.04	<0.01	<0.01	0.008	0.2	0.14	<0.01
	15	6.37	156.2	128.71	0.55	0.45	8.10	1.23	0.29	23.81	0.08	<0.01	<0.01	0.024	0.05	0.33	<0.01
	25	7.16	269	136.64	0.05	0.54	30.90	1.41	1.09	36.95	0.03	<0.01	<0.01	<0.01	0.12	0.42	<0.01
	35	7.08	234	137.86	0.35	0.65	24.80	1.33	0.74	32.76	0.04	<0.01	<0.01	<0.01	0.007	0.44	<0.01
	45	7.38	334	165.92	0.36	0.99	60.00	1.67	1.71	44.89	0.03	<0.01	<0.01	0.003	0.011	0.385	<0.01

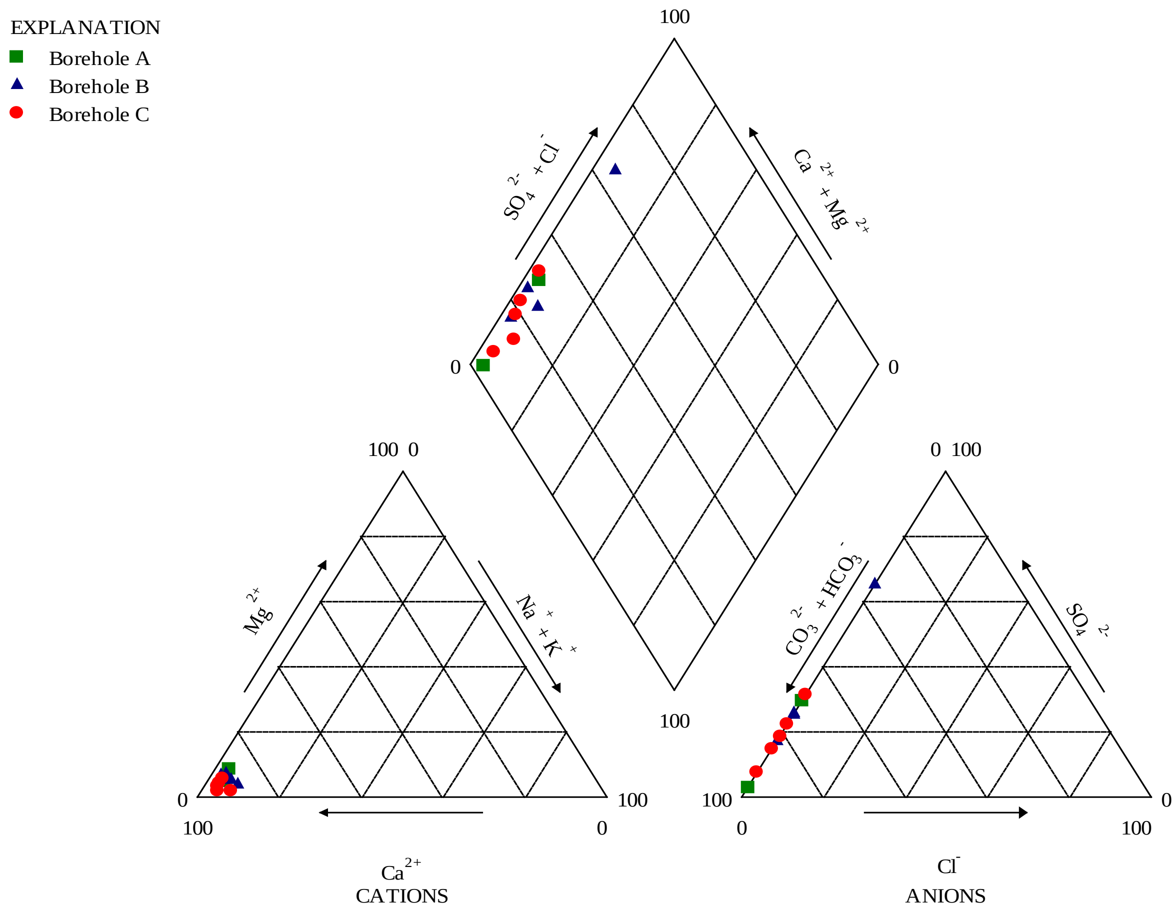


Figure 2.2: Piper diagram of the chemical analysis results from the drilled boreholes (A, B and C), showing a Calcium, Magnesium Bicarbonate (Ca, Mg) $(HCO_3)_2$ water type in the drilled boreholes in the study area, North-Western Province, Zambia.

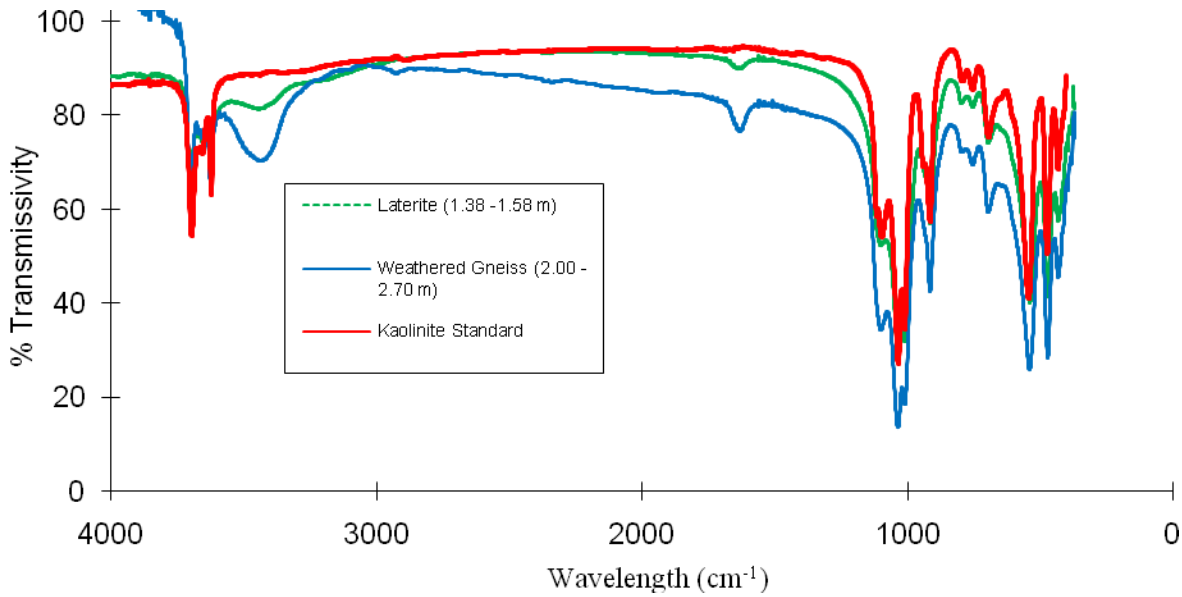


Figure 2.3: Graph shows FT-IR spectrometry results for laterite, weathered gneiss and a standard kaolinite sample. The results have characteristics wavelength properties of Kaolinite in all the samples analysed.

3 Small Holder Irrigation Schemes for Sustainable Agricultural Production

Byaruhanga, Joseph Kadoma[1]

[1] Associate Professor, Mechanical Engineering
Makerere University
jbyaruhanga@tech.mak.ac.ug

3.1 Abstract

This paper describes the initial stages of the Low Cost Irrigation Schemes Project being implemented at Makerere University with the major objective of introducing various water pumping technologies to help boost farmers' production and improve food security in Uganda. This is in context of increasingly unreliable rainy seasons which have been experienced over the last few decades probably because of climate change and farmers dependence on rain fed agriculture. This has often resulted in frequent crop failure and widespread food shortages.

In order to realize the project aims, baseline surveys of existing water pumping technologies were undertaken and also established the farmers' needs for water for production especially during dry seasons or when there has been insufficient rainfall. The project held a series of stakeholder workshops which included farmers and local Government officials involved in production and agricultural advisory services so as to determine specific needs of the farmers who wish to acquire irrigation systems.

From the stakeholder workshops and baseline surveys undertaken, preliminary findings, show that in some cases water is easily accessible on farmers' land but is not used to irrigate crops even when there is rain failure. In most cases it was found that the farmers lacked knowledge of the available water pumping technologies together with its importance to agricultural production and surprisingly the farmers thought that the technologies were too expensive.

Lastly, this paper describes efforts being undertaken to design and manufacture water pumps which will be cheaper than those imported so that the technologies can be widely applied for agricultural production in the East African region. The pumps being designed are initially centrifugal type which can be driven by 1-3 HP motors and easily manufactured using locally available materials and this can deliver about 100 litres per minute which is adequate for a small holder farm.

Key Words: *Small Holder Farmer, Irrigation, Water, Pump, Food Security*

3.2 Introduction

Makerere University through the Faculty of Technology, now College of Engineering, Design, Art and Technology, has been implementing the Low Cost Irrigation Schemes Project since July 2010. This follows an Italian Cooperation funded project which dealt with Technology for Agricultural Mechanization and had a small component of supplemental irrigation. The Low Cost Irrigation Schemes Project is funded by the Government of Uganda under the Presidential Pledge Project known as "Boosting Technological Education &Innovation for Uganda's Industrialization".

The Low Cost Irrigation Schemes Project was initiated against the background of frequent droughts which lead to wide-spread crop failure in Uganda and the region, hence food shortages and loss of livelihoods because over 80% of the population depends on agriculture for their livelihood (GoU, 2010). The project aims to widely disseminate low cost irrigation technologies to rural areas so as to contribute towards food security.

3.2.1 Context

For generations, Ugandan farmers have relied, and thrived, on rainfall to water the land, with irrigation mostly associated with large-scale schemes for crops like rice or sugar canes or flowers for export. But the climate is changing and droughts are becoming more frequent; a government meteorologist recently said that Uganda had suffered at least eight serious droughts in the last 40 years, compared with only three in 60 years leading up to 1970. Many regions of Uganda were hit by food shortages after most of the harvests failed due to drought in the middle of 2009 and 2010.

Presently, the total area under formal irrigation in Uganda is 14,418 hectares (35,612 acres) out of an estimated 560,000 hectares with irrigation potential (GoU, 2010). This represents 2.5%. This can be compared with 26 and 44 percent in India and China respectively (FAO, 2007). One of the reasons for the low levels of irrigation in Uganda has been the reliance on rain-fed agriculture, which has become less reliable with the fluctuations in weather.

If farmers want to cope with the changing climatic conditions especially droughts, they should adopt irrigation. Irrigating crops during droughts, even for scientifically improved crops, is important in case farmers want to achieve good yields (International Water Management Institute, 2006). For all-year cropping, the country must adopt some form of supplemental irrigation. (FAO, 2007).

3.2.2 Problem Statement

A major impediment to developing irrigation programs has been the lack of an energy source to move water from the source to the fields where it is needed especially in hilly terrains found in various parts of Uganda. Water, where available, is typically collected through laborious time consuming manual methods for general family use. The much larger volume of water needed for crop irrigation can only be provided by mechanical means because most parts of Uganda are hilly with the water source below the fields. There is therefore need to use efficient and affordable water pumping technologies for irrigation projects. Irrigation also improves diet and incomes of rural people (Burney, et.al., 2007).

3.2.3 The Low Cost Irrigation Schemes Project

In July 2010, the Faculty of Technology in conjunction with Uganda Gatsby Trust started implementing the Low Cost Irrigation Schemes Project to address the constraints of irrigation though a number of interventions similar to those in other African countries such as Tanzania (Stricklin, 2006).

The major objective of the project is to introduce and widely disseminate affordable water pumping and irrigation technologies to help boost small holder farmers' production and improve food security in Uganda.

The specific objectives include:

- Identify irrigation technologies suitable for the various ecological conditions of Uganda.
- Test the performance of the pumps on trials and modify where necessary
- Modify the existing pumps to suit local environment
- Prove performance on selected trial agricultural sites
- Train the Small Scale Entrepreneurs to produce and maintain the pumps
- Roll out the irrigation technologies to rural communities
- Design and manufacture different types of pumps and irrigation system as an import substitution measure.

3.2.4 Research Questions

The project has the following four research questions:

1. Are there any farmers practicing irrigation in Uganda?
2. What are the challenges faced by smallholder farmers in adopting irrigation?
3. Who are the key stakeholders and the role they could play in adoption of agriculture?
4. What are the capacity gaps which need to be filled to promote adoption of irrigation technologies?

3.3 Literature review

3.3.1 Conditions for irrigation

A number of conditions must be met for successful small-scale irrigated agricultural development to occur:

- Availability of suitable land;
- Availability of water resource;
- Availability of labour;
- Availability of non-irrigation inputs to production;
- Access to markets;
- Capital resources; and
- Appropriate water lifting technology especially where the landscape is hilly and the water source is below the gardens.

3.3.2 Available water pumping technologies

The available water pumping technologies are compared in Table 3.1., while treadle, engine driven and solar powered technologies are shown in Figures 3.1, 3.2 and 3.3 respectively.

Figure 3.1: Treadle pump

Figure 3.2: Typical 1.5hp two stroke pump set

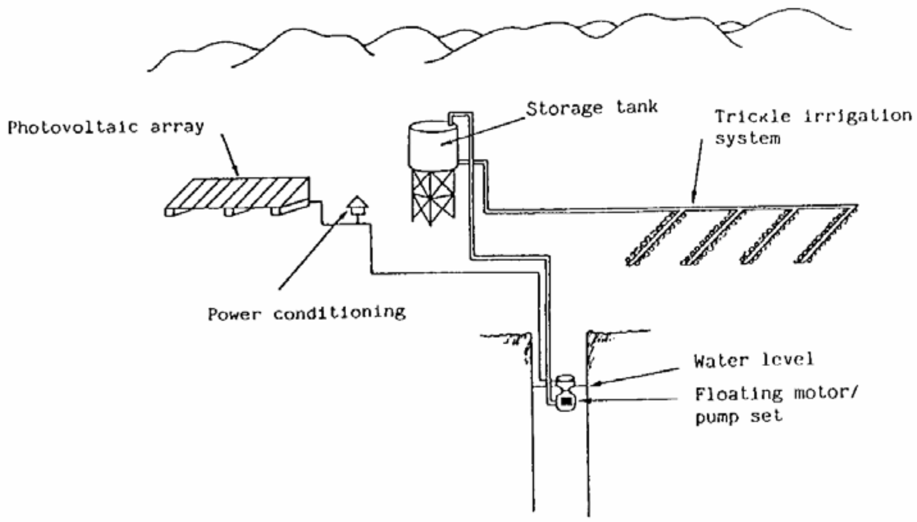


Figure 3.3: Schematic of a solar powered irrigation scheme using a submersible pump

3.3.3 Technical Data of Pumps

The main parameters to be considered for any pump are:

- Water flow rate (water demand)
- Head (water pumping height)
- Suction Head (the depth of water level- the lift)
- Power of drive.

Examples of technical data of selected pumps are given in Table 3.2 below.

Type of Pump	Advantage	Disadvantage
Hand pumps	• Easy to maintain • Low capital Cost • No fuel Costs • Local Manufacture is possible	• Loss of human productivity • Often an inefficient use of boreholes • Low flow rates
Animal driven pumps	• more powerful than humans • lower wages than human power • dung may be used for cooking fuel	• animals require feeding all year round • often diverted to other activities at crucial irrigation periods
Hydraulic pumps (e.g. rams)	• unattended operation • easy to maintain • low cost • long life	• require specific site conditions • low output

	• high reliability	
Wind pumps	• unattended operation • easy maintenance • long life • suited to local manufacture • no fuel requirements	• water storage is required for low wind periods • high system design and project planning needs • not easy to install
Solar PV	• unattended operation • low maintenance • easy installation • long life	• high capital costs • water storage is required for cloudy periods • repairs often require skilled technicians
Diesel and gasoline pumps	• quick and easy to install • low capital costs • widely used • can be portable	• fuel supplies erratic and expensive • high maintenance costs • short life expectancy • noise and fume pollution

Table 3.1: Comparison of pumping techniques

Type of Pump	**Specifications**	**Suction Depth (m)**	**Typical Head (m)**	**Flow Rate (m^3/h)**	**Typical Cost (US$)**	**Coverage (Acres)**
Treadle	Foot Pump	7	7	100 l/min	10 -150	1.5
Engine Powered - Petrol	5 HP	7	30	10.8	350	50
Engine Powered - Diesel	5 HP	7	60	10.8	650	50
Solar PV	11 kWp	20	20	25	6,000	50

Table 3.2: Comparison of technical data of selected pumps

3.4 Methodology

The project was to be implemented in two phases as shown below.

3.4.1 Phase 1

i) Formation of a multi-disciplinary team of experts

ii) Review of related concepts and literature

iii) Formulation of a specific and time bound activity schedule

iv) Conduction of baseline surveys during which, meetings with local administration and farmers were held in order to find out the history of the place and all relevant information on previous interventions, crops grown and challenges faced.

v) Conducting workshops involving all stakeholders (agricultural officers, irrigation officers, farmers, forestry officials). This was an extended platform for idea generation and sharing.

vi) Analysis of findings and results from all field trips and workshops as a basis for design formulation of appropriate interventions in form of technologies and methods.

vii) Designing of appropriate irrigation technologies.

viii) Demonstration of various irrigation equipment preferably on farm

ix) Adapting and modifying existing technologies to suit particular area/sites

x) Establishing demonstration sites from which farmers can learn

xi) Design of irrigation schemes for farmers.

xii) Linkage of farmers to credit/equipment lease schemes

3.4.2 Phase 2

The second phase of the project will concentrate on design of a low cost pump which farmers can afford with the following activities:

xiii) Design and manufacture of water pumps in local workshops

- Preliminary design
- Proto-typing
- Testing
- Modification
- Manufacture of say 100 pumps
- Testing
- Trial in field.

xiv)Establishment of a pump production facility

xv) Dissemination through on farm demonstrations, trade fairs and exhibitions, reports, newspaper supplements, publications and advertisements

3.5 Key Finding

3.5.1 Baseline survey

Visits were made to various districts to conduct baseline surveys and meet with local Government officials relevant to agriculture especially those who regularly deal with farmers. Uganda has a program called National Agricultural Advisory Services (NAADS) which has a coordinator at district level hence this was the contact person for our project. The NAADS coordinator was able to link us to fellow district officials like the Agricultural and Water officers and prominent farmers who are practicing or have potential to adopt irrigation technologies. The baseline also enabled the team to obtain data on crops grown, state of irrigation in the districts and contacts of key stakeholders.

3.5.1.1 Major Crops grown

The following are the major crops grown by the small-scale farmers which are also valued as food security and often cash crops. They include; Maize, Upland Rice, Beans, Mangoes, Bananas, cabbages, egg plant, pineapples, chillies, water melon, flowers, tomatoes, peppers (yellow, red, green), Potatoes, Oranges, Onions, etc. All these flourish when supplied with adequate water. They can also earn farmers good income if they come on the market during the off-season. However, if irrigation is adopted, farmers should be encouraged to grow high value crops which guarantee high returns.

3.5.1.2 Water Sources

In most cases, the farms visited had water in abundant quantities. It was however not being utilised for

Figure 3.4: In 90% of cases water was present, on the farm but was not being used for irrigation

Figure 3.5: A water source being used as a fish pond

irrigating crops and farmers complained of their crops drying when there was rain failure. Such farmers therefore had the possibility to undertake small scale irrigation.

It is also possible to sink boreholes or tube wells to source water for irrigation projects. Although used mostly for storing water for cattle especially in the cattle corridors, valley dams can be a source of water for irrigation.

Figure 3.6: Water source at the bottom of a farm.

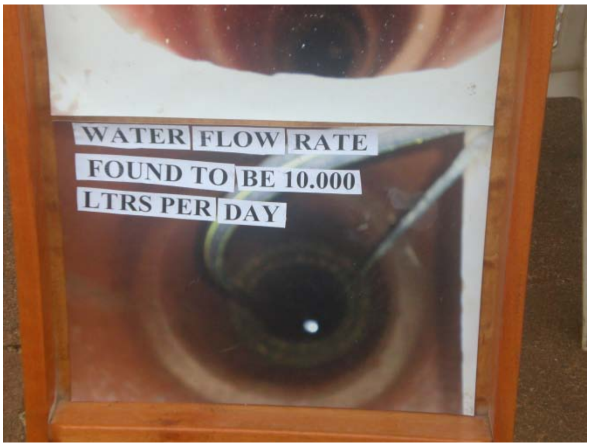


Figure 3.7: A deep well sunk manually

3.5.1.3 Existing Irrigation Schemes

Supplemental irrigation has always been used to counteract effects of little soil moisture but it is always done in a “by-the-way” attitude whereby there would not be a plan to run a crop-field on supplemental irrigation. This has been practiced in very few cases in Uganda e.g.

⇒ Mubuku Irrigation Scheme in Kasese, Western Uganda using water from an all-year round River Mubuku which flows from Mount Rwenzori. This scheme which covers about 600 acres is currently not well managed and has not been replicated.

⇒ Kakira Sugar Works, which carries out sprinkler irrigation of its sugarcane crop using water pumped from Lake Victoria.

⇒ Rice schemes like Kibimba, Doho and Olweny are located in swamps where water is permanently present. This has a negative impact on wetland systems because it affects the natural drainage system.

These schemes are fairly large scale and benefit those who are near or located within. The majority of the small holder farmers scattered over the country cannot access such schemes hence a few use watering can, treadle pumps and in rare cases engine driven pumps.

Figures 3.8 and 3.9: Water intake and channel in Mubuku Irrigation Scheme in Western Uganda. Such schemes can only be established by Government (photos by author)

3.5.2. Stakeholder workshops

The objectives of the stakeholder workshops were:

- To bring together the various stakeholders in agriculture in the sub region
- To identify challenges faced by farmers especially those hindering the adoption of irrigation technologies and propose solutions.
- To identify the roles that can be played by the various stakeholders
- To chart a way forward for wide application of irrigation to improve agriculture production

Five officials and farmers were invited from each district to attend a stakeholders' workshop on a regional basis. So far 8 workshops have been conducted with over 300 participants who included farmers and local government officials relevant to water and agricultural production.

3.5.2.1 Challenges to adoption of irrigation and Proposed Solutions

The challenges hindering the wide adoption of irrigated agriculture and proposed solutions are shown in Table 3.3.:

No.	Challenge	Proposed Solution
1	Knowledge of water sources	Popularize water harvesting technologies
2	Restriction on Nile Water use	Revision of treaties and regulations
3	Subsistence crop production	Mechanization, land tenure laws, high value crops
4	Lack of irrigation equipments	Encourage private/public sector partnership
5	Lack of irrigation knowledge	Establish irrigation demonstration sites

6	Lack of appropriate technology	Popularize treadle pumps and others
7	Shortage of skilled personnel	Training and capacity building of artisans
8	Topography a hindrance	Surveys and farmer technical advice
9	Lack of land ownership	Land tenure and use policies
10	High cost of irrigation technology	Government subsidies
11	Government commitment	Prioritizing irrigation technology
12	Farmer attitudes	Sensitization on the value of irrigation
13	Crop selection	Horticulture and high value crops choice
14	Lack of Finance	Agriculture loans

Table 3.3: Challenges and proposed solutions for adoption of irrigated agriculture

3.5.2.2 Key Stakeholders and roles

The stakeholder workshops were also able to identify the key stakeholders in irrigation and the respective role they would play (see Table 3.4).

3.5.2.3 Capacity Building Needs

The following areas were identified as requiring capacity building;

- Water harvesting and irrigation technologies
- Water reticulation and storage technologies
- Repairs and maintenance of irrigation technologies
- Environmental protection of water sources
- Training of extension workers and other service providers
- Business Management so as to run farms professionally

3.5.3 On-farm demonstrations

Since in Africa, seeing is believing, the project acquired simple irrigation equipment, which is used for demonstrations during seminars and on-farm for farmers (***See pictures below).*** Demonstrations have been attended by over 500 farmers who have appreciated the potential of small scale irrigation in guaranteeing good performance of their crops.

No.	Stakeholders	Proposed Role
1	Private Sector such as traders, dealers, manufacturers	production, distribution and marketing of the technology to farmers
2	Farmer Organizations	group procurement and group marketing

3	District Water Departments	Technical advice on the exploitation and supply of water
4	Extension workers in local government and civil society	Mobilize farmers, provide advisory services, disseminate information, and popularization of technologies
5	Farmers	Technology beneficiary and adoption, sustain technology, provide land and labor, implement irrigation
6	Engineers, Technicians and Artisans	Technology designs, dissemination, research, maintenance, monitoring and evaluation and providing technical guidance
7	Government	Policy formulation and legal framework, subsidies, providing meteorological information and training farmers
8	Development partners	Funding and training
9	Political and civil leaders	Policy formulation, advocacy and community mobilization
10	Banks and Financial Institutions	Tailored Loans and Credit Schemes
11	Media	Disseminating of information on irrigation technologies
12	Researchers and Institutions	Innovations, Training and information dissemination

Table 3.4: Key Stakeholders and their Roles

Figure 3.10: This young man will need a month irrigate the onion field, yet a pump can do it in 1 hour

Figure 3.11: Preparing to pump water from a source

Fig 3.12: Water being delivered 200 m uphill

Fig 3.13: Water being pumped up a hill

Figure 3.12: With a pump, water can be delivered from the water source

#


Figure 3.13: Farmer watering crops using cow to troughs far from the water source

3.5.3.1 Typical Costs of Small scale irrigation schemes

A Solar Powered system with 12 pieces of 120W solar panels delivering 20,000 litres per day with a dynamic head of 30 meters would cost US$15,000 – 20,000 inclusive of storage tank and piping. It can irrigate an area of 10-15 acres depending on water source.

A diesel engine powered system of 5HP, with dynamic head of 60m and flow rate of 660 litres per minute cost about US$5,000 with tank and 400 m of delivery pipe. It can be used to irrigate about 10 Ha.

3.5.3.2 Typical Returns from Irrigated Agriculture

To give an idea on returns, see Table 3.5. It can be seen that very good returns can be realised from the crops especially when irrigated to guarantee a harvest. The returns are sufficient to pay for the costs of production as well repay investments in a short time.

Area	**Crop**	**Yield**	**Unit Price (Shs)**	**Total income ('000 Shs)**	**Total Income ($)**
1 Ha	Paddy Rice	5 Tons husk	1,200,000	12,000 (2 seasons)	5,200
1 Ha	Pineapples	37,500 pcs	1,000	37,500 p.a.	16,300
1 Ha	Cabbages	50,000 heads	500	25,000 per season or 50,000 per year	10,870 21,740

Table 3.5: Typical returns on some crops (Gross Revenues)

3.5.4 Interest of Farmers in Small Scale Irrigation

As a result of stakeholder workshops and on-farm demonstrations, farmers have realised that small scale irrigation systems are not as complicated and expensive as they thought. So far the project has received serious enquiries from over 100 farmers who want to acquire small scale irrigation systems mostly engine driven pump and piping as well as the appropriate technical assistance. Ten of them have actually paid for them at an average cost of US$ 2,000. They need them to overcome the current dry season which will last up to March 2011.

Because of the large number of interested numbers, the project is in the process of linking up with financial institutions to work out a credit scheme from which farmers can access credit to acquire irrigation equipment and technologies.

3.6 Centrifugal Pump Design

A centrifugal pump was designed with a maximum head of **20 m**, flow rate of **0.1m^3/min**, rotational speed of **3000rpm** and with rated power **0.8 KW (1hp)**.The major parts of the design included, the pump casing, impeller and shaft, all the parts are to be casted from Cast iron ,Brass and stainless steel respectively. All parts will be assembled as a complete centrifugal pump with the drive unit as integral part of the complete unit. The shaft carries impeller and sleeve, bearings of ball bearing type are to be selected as this carry all radial and thrust loads, and are installed in sealed housings which retain lubricant and exclude any dirt.

The pump is expected to cost about Uganda Shs 220,000 (US$100) and Shs 480,000 (US$220) with a drive. This compares with an imported Chinese version which costs more than US$300.

Figure 3.14: Explaining the centrifugal pump

Figure 3.15: Running the pump

3.7 Expected Benefits of the Project

The different stakeholders expect the following benefits from the project:

3.7.1 Farmers and Communities

- All year cropping hence can produce high value crops
- Elimination of famine and improved food security
- Improved farm income because farmer will have excess produce for sale
- Job creation due adoption of crop farming as a commercial enterprise.

3.7.2 Central and Local Governments

- Save on funds for relief and disaster as a result of improved food security
- Promotion of technology transfer
- Improved socio-economic conditions
- Improved goodwill

3.7.3 Makerere University

- Promotion of design and research capacity
- Technology transfer from Research and Development
- Improved relevance of university activities to the community
- Improved goodwill towards University

3.8 Conclusions

The first year of the Low Cost Irrigation Schemes Project has found thata irrigation is not widely practiced in Uganda except in a few isolated cases. The major reaons given by the farmers is lack of knoweldge about irrigation technologies and a perception that the technologies are not affordable for smallholder farmers.

So far the project has been able to overcome these challenges through the interacations through stakeholder workshops and on-farm demonstration.

Judging from the interest generated among farmers, the technology is likely to be widely adopted. This will lead to sustainabel anda increased agricultural production anda improved food security of the country.

3.9 Way Forward

Over the first six months the Low cost Irrigation Schems project has made very good progress and is seen as a ray of hope towards food security and prosperity by faremrs. The project has the following way forward:

- Produce and test proto-types of centrifugal pumps
- Install the procured demonstration irrigation systems
- Formulate a scheme for rolling out micro-irrigation schemes to farmers

- Link with bankers to provide credit for acquisition of micro-irrigation schemes by farmers
- Design and demonstrate innovative water harvesting and conservation technologies.
- Organize trainings for framers and artisans on operation and maintenance of irrigation equipment
- Extend design and manufacture to cover other types of pumps, engines, sola panels etc.
- Establish a facility for production of pumps and irrigation equipment which will be spun off to the private sector.
- Interest farmers who acquire irrigation systems in tree planting so that they contribute towards environmental protection.

3.10 References

Burney, J., Woltering, L., Dov Pasternak (2007); Solar powered irrigation systems improve diet and income in rural sub-Saharan Africa,. Proceedings of the National Academy of Sciences.

Food and Agricultural Organization (FAO), 2007, Water Profile of Bangladesh, printed in Encyclopaedia of Earth, Retrieved July 12, 2010. http://www.eoearth.org/article/Water_profile_of_Bangladesh

Government of Uganda (GoU), National Planning Authority, 2010, National Development Plan 2010/11 -2014/215; “Growth, Employment and Socio-economic Transformation”.

International Water Management Institute, Water Policy Briefing- Promoting micro-irrigation technologies that reduce poverty”, Issue No.23, 2006.

Stricklin, A.D. (2006), Pumping water with solar power, Ilunda Ward, Tanzania Water Project, Outreach Africa.

4 Mapping Changes in Lake Victoria Shoreline Inundation for Analysis of Impacts of Extreme Lake Levels

Izdori, F.J.[1]

Kimar, T.A[1]

[1] University of Dar es Salaam
P.O Box 35131 Dar es Salaam

fides@yahoo.com

4.1 Abstract

The lake shore and the few feet of water close to the shore are very important as they support a lot of infrastructure such as inlets for water supply and ports. They are also the breeding sites for fish. All these activities are only operable when the water level in the lake is at certain levels; extreme changes in lake water levels are likely to affect them. This paper established the past and expected future patterns of shoreline changes around the Lake Victoria. Lake level records and 90-m DEM data were used to map areas inundated at different water levels. A simple decision rule was adopted where by all elevations that are lower than the mean lake level were considered to be inundated. Using ArcVIEW GIS, the highest change in the lake area using the historical data record was found to be 0.53%. The sensitive areas are Mwanza gulf, Ermin Pasha Gulf, the entrance of river Grumet and Mara bay. Fish breeding sites located in areas very sensitive to lake level changes are those in Rubafu area in Kagera region and in Mara region.

Keywords: *Inundation, Lake levels, Shoreline, Mapping*

4.2 Introduction

Lake Victoria is a riparian lake shared by three East African countries: Kenya, Uganda and Tanzania. It plays a vital role in supporting the lives of millions of people living around its shores, in one of the most densely populated regions on earth. It serves as a source of water for irrigation, transport, domestic and livestock uses and a source of livelihood to about 30 million people living around the lake (Awange and Ong'ang'a, 2006). Its precious fish (i.e., Tilapia and Nile Perch) is exported the world over. The lake has a surface area of 68,800 square kilometres, a maximum depth of 80 metres and an average depth of 40metres (Awange and Ong'ang'a, 2006).

The lake shore and the few feet of water close to the shore are very important as they support a lot of infrastructure such as inlets for water supply and ports. All these activities are only operable when the water level in the lake and the shoreline are at certain levels; extreme changes in lake water levels are likely to affect them. Extreme lake level fluctuations results to several impacts on the shores of lakes such as Lake Victoria both negative and/or positive. When studying the effects of low lake levels on Lake Michigan, Chicago and Illinois, Changnon et.al (1989) pointed out recreation, commercial harbours, beaches, water intakes and supplies, outfalls and storm water outlets as being the most critical areas. The most common problem caused by lake level fluctuations is erosion. It is well known that the shoreline characteristics vary significantly from flat, low laying areas to high bluff areas that are prone to erosion. Also fluctuating water levels can expose new surfaces to erosion. The flat, low laying areas are more susceptible to flooding during periods of high water.

In hydropower installations, intake points and harbours, decrease from long-term average levels can produce pronounced economic losses through reduced power generation, high cost of dredging the harbours and high cost of modifying the intake points . Natural areas, such as wetlands have evolved as a result of wide variations in water levels. Reducing these variations can have significant environmental consequences.

Hence there is a need to better understand the changes occurring in Lake Victoria shores in combination with other global changes, and their implications to the lake’s operation in order to develop mitigation and adaptation strategies and enable well-informed actions by policy and decision makers. In addition, better knowledge is needed to increase the adaptive capacity of natural and human systems.

Lake Victoria water levels have in the last two years dropped sharply prompting investigation into causes and impacts of the changes to the livelihood of the people directly dependent on it. In addition to the drastic changes in levels observed recently, long term data shows that lake levels have been receding continuously since 1964 when the highest levels were achieved. It is worth noting that the low lake levels causes drought to the local people not only in the immediate vicinity of Lake Victoria basin but along the stretch of Nile River, resulting in people migrations (Nicholson, 1998).

Mapping of lakes is important so as to be able to ascertain any changes occurring in the shorelines or under the water surface over time. Lake mapping provides a visual representation of the shape and depth of lakes. It also provides important information about the lake ecosystem. Awange and Ong'ang'a (2006) pointed out Lake Victoria's parameters including length and surface area as being among the unresolved issues of this lake.

Since the 1950s, lake mapping has evolved to include more precise echo sounders, on board computers, and GPS systems. Ma et al. (2007) conducted a research on Lake Ebinur in North-West China by using a radiometric analysis of SPOT/VEGETATION (VGT) imagery and found that the lake area had increased. Also, Melesse et al (2006) and Hui et al (2006) explored changes in and the Devils Lake (North Dakota) and Poyang lake (China) respectivelly using LANDSAT images. Cai et al. (2005) suggested that NASA Moderate Resolution Imaging Spectroradiometer (MODIS) provides a unique opportunity for monitoring lake area. Several attributes of MODIS, including the daily global coverage, moderate spatial resolution (0.25 to 1 km), rapid availability of various products and cost free status may allow for operational mapping of lakes. However its resolution is coarse when we need to know lake area precisely such as for carrying out hydrological modelling studies. DEM have been used successfully in flood frequency modelling and for modelling spatial extent of inundation (Coreia. Et al, 1998, Qi et.al, 2009).

The main objective of this study, which is centred mainly on the Tanzanian side, was to establish the past and expected future patterns of shoreline changes. The specific objectives were to determine the extent to which water recedes towards open water when water level drops, to determine the extent to which water advances towards land when water level rises in the lake, to determine areas which are highly affected by water level variations on lake Victoria shoreline and investigate the socio-economic impacts of lake level change to local communities around the lake.

4.3 Data and Methods

4.3.1 Study Area

Lake Victoria, also referred as Victoria Nyanza is one of the largest fresh water bodies of the world. The lake is shared by three countries of Tanzania, Kenya and Uganda. Lake Victoria has a surface area of about 68,800 km^2, with a land drainage area of slightly over 184,000 km^2. The mean depth is about 40 m with a recorded maximum depth of 84 m and the volume of water stored is estimated at about 2,750 km^3 (Awange and Ong'ang'a, 2006). The lake is located between latitudes 0°21'N and 3°0'S and longitudes 31°39'W and 34°53'E. It is well known as the source of the longest branch of the Nile River, the White Nile (*New World Encyclopedia).*

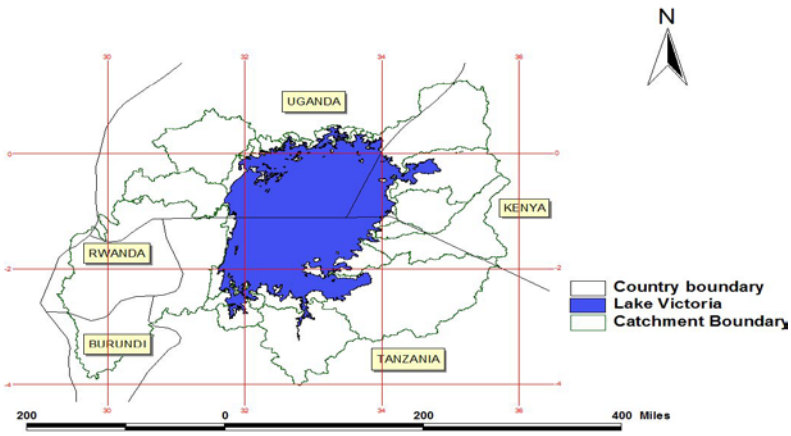


Figure 4.1: Lake Victoria basin

4.3.2Data

4.3.2.1 DEM Data

Digital Elevation Models (DEM data) describes the elevation of any point in a given area at a specific spatial resolution. The DEM data used for this study were downloaded from the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) website (http://www.gdem.aster.ersdac.or.jp/). DEM is downloaded as tiles of 3501X3501 pixels (1 by 1 degrees) at intervals of 1 arc second. The files are in are in a zipped folder. The pieces were joined by using the Mosaicing feature in the Transformation Wizard.

4.3.2.2 Lake Level Records

Monthly data for lake levels at Jinja were obtained from the Water Resources Department (WRED) at the University of Dar es Salaam. This data spans from January 1899 to December 2006 and contains no gaps.

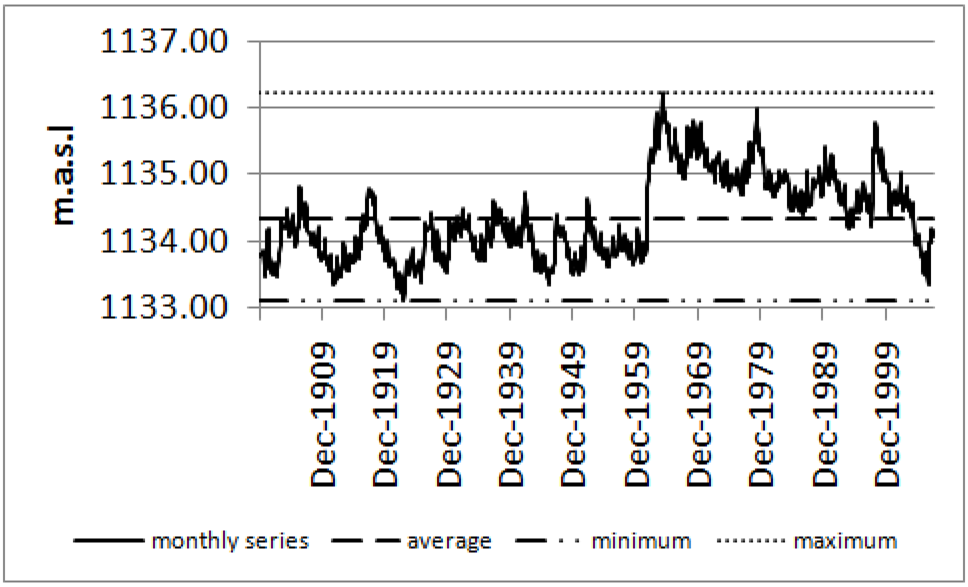


Figure 4.2: Historical fluctuations of Lake Victoria water levels with the long term average, minimum and maximum levels

Processing of DEM

The Digital Elevation Model was analysed using ArcGIS spatial analyst. The spatial analyst tool in ArcGIS can perform land use analysis, determine erosion potential and conduct risk assessment among other several functions. The map algebra functions were used to reclassify the elevations in the Digital Elevation Model to identify potential areas for inundation.

The principle assumption employed here was that, all areas which are adjacent to the lake and have elevations that are lower than a certain recorded or predicted lake level represent the inundated areas. Using data record of Jinja gauging station between years 1899 and 2006, the lowest lake level record is 1131.11m m.a.s.l which occurred in January 1923. The highest water level ever recorded is 1136.22m m.a.s.l which occured in May 1964. However, the average lake surface elevation as recorded in the digital elevation model is 1134m.a.s.l therefore this elevation was adopted as the lake elevation and change in lake surface area was estimated using this elevation and other elevations of interest).

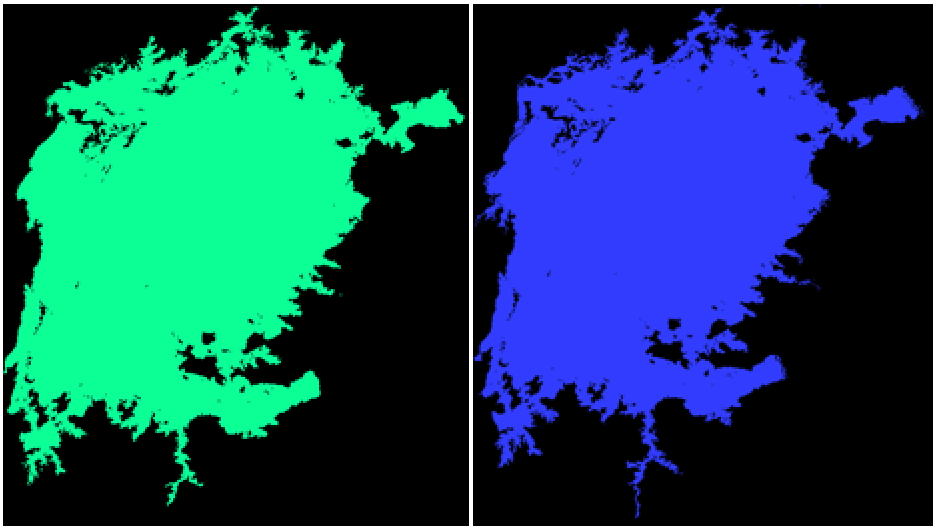


Figure 4.3: DEM presentations of Lake Victoria at two different water levels

Using the average lake level record and the highest water level record, the lake area at intervals of 0.5m change in water level were calculated with the help of spatial analyst extension. Also, the lake areas at exaggerated elevations of up to 1140 m.a.s.l were calculated to identify critical elevations and sensitive areas. Digital elevation models consist of cells each representing the average elevation of a particular area on the ground. In this analysis, each cell elevation was compared with a chosen lake surface elevation (lake level) to check if it is below or above the lake surface elevation. Elevations which were lower or equal to the lake surface elevation represent inundated areas and were assigned a value of 1 while the cells which higher elevations are the non inundated areas and were assigned a zero. For example, to identify inundated areas after the May 1964 rise in water level elevations that represent flooded areas were considered as ranging from 1134m.a.s.l to 1136.22 m.a.s.l. The classification is summarized in the table below:

Lake Area	<1134
Flooded Areas	1134 – 1136.22
Non-Flooded Areas	>1136.22

Figure 4.4: Classification used in delineating the inundated areas by DEM

This classification was applied to the Lake Victoria DEM and the area represented by each lake level was obtained with the spatial analyst extension in Arcview GIS. The areas were obtained by multiplying the number of cells with a particular elevation and the area of one cell which is 0.008579 km^2. Areas sensitive to lake level changes were characterized as those which were inundated more for any particular change in lake level.

4.4 Results

4.4.1 Variations in the Lake area at different water levels

The lake area was defined as any area with an elevation equal to or less than the selected lake level. This area was obtained by first finding the total number of cells with elevations equal to or less than the chosen lake level and then multiplying with the area of one cell. Only cells that were adjacent to the lake were considered. From the lake level records, the highest lake level of 1136.22 m.a.s.l is observed in May 1964 while the lowest lake level is 1134 m.a.s.l. The lake area calculated by taking areas which will be inundated at these water levels are 68211.44 km^2 and 68577.45 km^2 respectively.

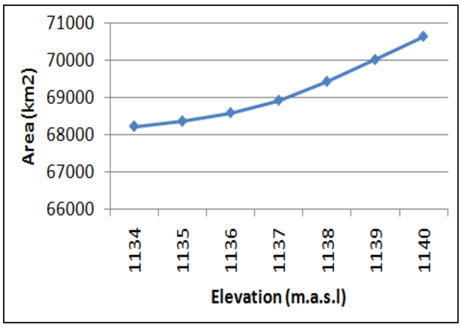


Figure 4.5: Variations of Lake area with lake levels

The lake area increases first mildly as the lake elevation is increased up to 1136 m.a.s.l and then steeply from 1136 m.a.s.l onwards. However, when the lake elevation was raised from 1134 m.a.s.l to 1134.5

m.a.s.l there was not any noticeable change in lake area, same as to when the elevation was raised from 1135 m.a.s.l to 1135.5 m.a.s.l. The change in the lake area after the 1964 high rise in water level was found to be 0.53%.

4.4.2 Potential Flood Inundation Areas

The potential areas for inundation were defined as those areas that will be covered with water at exaggerated lake levels. This was done so as to identify both the critical lake elevations and areas in danger of inundation. Results show that the southern shores of Lake Victoria (Mwanza and Mara regions) are more prone to inundation when the lake water level rises (figure 5 below). In this areas the shoreline is somehow flatter resulting in spreading of water whenever the lake level is raised. Contrary to this, the western part of the shoreline which is in Kagera region is somehow stable and shows no remarkable movement of the shoreline even at high lake elevations of up to 1140 m.a.s.l.

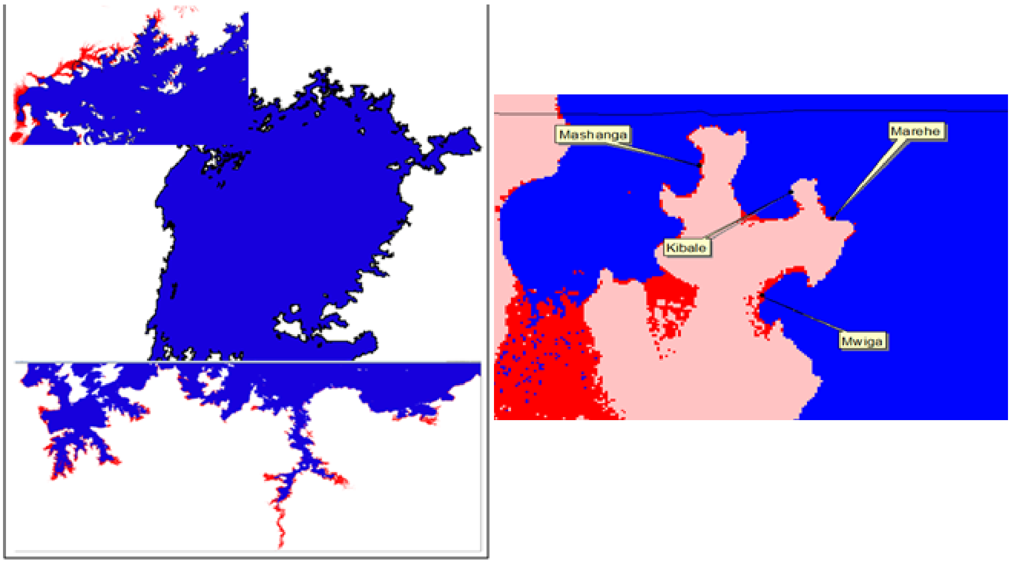


Fig 5: Inundated areas and fish breeding sites in danger

4.4.3 Sensitive Areas

These are the areas that exhibit a larger advancement in the shoreline for an increase in lake level elevation. Specific areas that have been found to be sensitive to changes are Mwanza gulf, Emin Pasha Gulf, the entrance of river Grumet and Mara bay. In Mwanza gulf water moves as far as 16km between highest and lowest lake levels (historical data). Since these areas exhibit a large advancement of shoreline in high levels, it is safe to assume that there will also be a remarkable retreat of shoreline in case of reduced lake levels and therefore these areas are not suitable for locating structures such as water intakes and ports.

4.5 Conclusions and Recommendation

In this study an attempt has been made to use DEM data in determining areas inundated by the lake at different lake levels. Results show that DEM is capable of identifying vulnerable areas to extreme lake levels simply and quickly. Identified area can be further investigated using detailed studies. However, it was not possible to determine how much area will be exposed at low levels (e.g. 1133.11 historical minimum reached in 1923) using this method. This is due to the fact that, the minimum lake level record of DEM is 1134masl (the water surface) and therefore levels below this value cannot be shown. DEM data is capable of quantifying areas inundated at normal range of lake levels above 1134 which is the minimum DEM level for Lake Victoria.

4.6 References

Awange J. L. and Ong'ang'a O. (2006) Lake Victoria: Ecology, Resource and Environment, Springer Verlag. Heidelberg, Berlin, New York, Tokyo.

Cai, G. Y., Xue, Y., Tang, J. K., Wang., J. Q., Wang Y. G., Luo, Y., Hu, Y. C., Zhong, S. B., Sun, X. S. (2004). Experience of Remote Sensing Information Modelling with Grid Computing. Lecture Notes in Computer Science, Vol. 3039. Springer-Verlag, 989-996.

Changnon, S. A., Steven M. L., and Robin, S. (1989). Effects of Past Low Lake Levels and Future Climate-Related Low Lake Levels on Lake Michigan, Chicago, and the Illinois Shoreline. Illinois State Water Survey, Champaign, Report of Investigation 110.

Correia, F. N., Rego, F. C., Saraiva, M. D. S., and I. Ramos, (1998), oupling GIS with Hydrologic and Hydraulic Flood Modeling. Water Resources Management, 12:229–249.

Hui, F, Xu, B, Huang, H, Yu, Q and Gong, P. (2008). Modelling spatial-temporal change of Poyang Lake using multitemporal Landsat imagery. International Journal of Remote Sensing Vol. 29, No. 20, 5767–5784.

Ma, M., Wang, X., Veroustraete, F. and Dong, L. (2007). Change in area of Ebinur Lake during the 1998-2005 period. International Journal of Remote Sensing. Vol 28, No 24. Page 5523-5533.

Melesse, A. M., Nangia, V. and Wang, X. (2006). Hydrology and water balance of Devil's lake basin, Part 2. Grid-Based Spatial Surface Water Balance Modelling. Journal of Spatial Hydrology. 6(1): 133-144.

Nicholson, S.E. (1998). Historical fluctuations of Lake Victoria and other Lakes in Northern Rift valley of East Africa. J. T. Lehman (ed), Environmental Change and Response in East African Lakes, Kluwer Academic Publishers; Netherlands, pp 7-35.

Qi, S., Brown, D. G., Tian, Q., Jiang, L., Zhao, T., Bergen, K.M (2009). Inundation Extent and Flood Frequency Mapping Using LANDSAT Imagery and Digital Elevation Models. GIScience & Remote Sensing, 46, No. 1, p. 101–127. DOI: 10.2747/1548-1603.46.1.101

5 Factors Influencing Adoption and Use of Soil and Water Conservation Measures in Bufundi Sub - Catchment, Kabale District, Uganda

Kaliisa, R.[1]

Makokha, G.

Tenywa, M.M.[2]

[1] Corresponding author; Kenyatta University Department of Geography
email: robertkaliisa@yahoo.com
[2] Makerere University Agricultural Research Institute Kabanyoro (MUARIK)

5.1 Abstract

Soil erosion and declining soil productivity still continue to manifest in most of the agricultural systems found in Sub-Sahara Africa. In Uganda this is attributed to poor land use practices with inadequate soil and water conservation measures. Highland areas of Kabale are reported to be severely affected by soil erosion despite the current farmers' efforts to conserve their soil and water resources. This study examined the factors influencing adoption of soil and water conservation at a scale of a catchment in Bufundi. The study was premised on analysing physical, personal, institutional and social economic factors as they are conceived to strongly influence adoption and use of SWC measures. Ninety five (95) structured questionnaires, key informant interviews and transects were conducted in the month of January 2011 as methods of data collection. The results of the survey show that institutional factors like formation of Bufundi Innovation platform (IP), collective action for SWC and social economic factors like incomes, age, land tenure, perception of soil erosion and IP trainings are among the major factors that positively influence adoption and use of SWC measures. Off-farm activities, sex, farm parcels and family size showed a negative association with adoption of SWC measures in the catchment. It is recommended that institutional demand driven SWC under the IP be supported in addition to farmer market linkages that tap premium prices, profitability and investment in natural resource management.

Keywords: *soil erosion, adoption, innovation platform, SWC*

5.2 Introduction

Globally 20 million hectares of arable land are reported to be degraded by soil erosion each year (Davidson, 1992). Degraded arable land in Asia is estimated to be at 35 % of the total agricultural land, while 45% is in South America, and 74% in Central America (CGIAR, 2003). In Africa 65 % of the arable land is degraded by soil erosion (CGIAR, 2003). Estimates in sub-Saharan Africa show that 320 million hectares of land are affected by human induced soil degradation and this is estimated to cause a damage of US$ 26 billion annually on the continent (Lal, 1994). Tenywa and Bekunda (2008), report that the underlying cause of this degradation is as a result of the destructive, extractive, over-exploitation and inadequate conservation of soil and water resources. In East Africa soil erosion is estimated to affect 50 % of the total arable land area especially in the highland areas (Ovuka, 2000).

In Uganda, highlands occupy around 25 percent of the country's land area (that is Kabale, Kisoro, Mbale, Sironko, Bundibugyo, and Kapchorwa) and contain 40 % of the country's population (Nkonya et al., 2002). Although soil erosion is evident on most of the hill slope catchments in Kabale, SWC technologies have been emphasized since 1920s to date as a means to curb this problem (Miiro, 1999), nevertheless the achievements are still far below the expectations, some hill slope catchments like Bufundi still lose a tremendous amount of fertile top soil and the threat of land degradation is alarmingly broadening (FARA report, 2009). Continued degradation may imply that adoption of corrective technologies is either too slow or limited probably owing to the nature of the technology itself, social-economic and institutional factors (Makokha et al., 1999).

Despite the fact that soil conservation studies have been done in the district: Tukahirwa (1996); Ssali (2001), Briggs and Twomlow (2002) and Siriri et al. (2005), these studies have largely centred on quantifying the rates of soil erosion, nutrient losses and the biophysical effects and in many cases ignoring the social, cultural, economic and institutional determinant for use and adoption of SWC in the district. On the other hand the studies that have targeted social-economic and institutional factors for soil conservation (Nkonya, 2002) have largely remained broad on scale and recommendations for policy rather than at a level of a catchment.

AHI (2002) baseline report concludes that the poor SWC management decisions in most of the catchments in South Western Uganda have not been based on site, institutional and social economic circumstances for adoption and application. This is in line with Boesen et al. (2004) conclusion that in order to improve agricultural production in a catchment, appropriate technology is necessary to suit the local economic, cultural and geographical conditions of that catchment. Ervin and Ervin (1982) summarized the factors that influence adoption of SWC technologies as personal, social, economic, institutional and physical (Figure 5.1).

According to Ervin and Ervin (1982), the decision-making process for adoption of SWC starts with recognition that there is an erosion problem. This perception is later influenced by personal factors (human capital) as well as physical factors of the land (physical capital) and institutional factors (awareness raising). Posthumus (2005) concludes that this conceptual model is a simplification of the adoption process, as in real life the decision process is continuous and dynamic. Despite the fact that (social-cultural, economic, institutional and physical) strongly influence farmers decisions for SWC elsewhere, in this study it was not clear how the same factors influenced SWC decisions at a level of

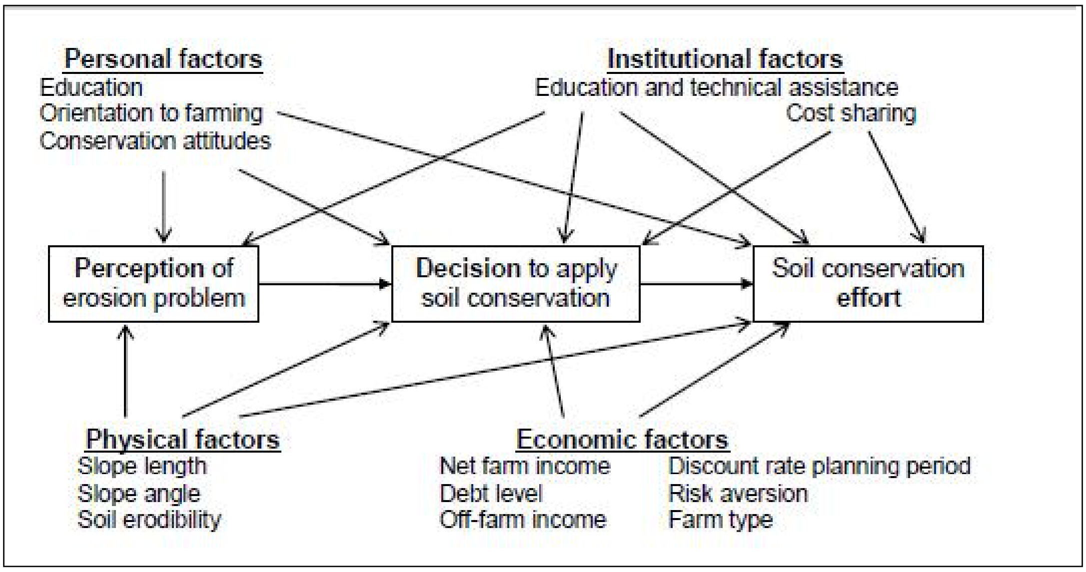


Figure 5.1: Factors influencing SWC adopted from Ervin and Ervin (1982)

a catchment thus forming a basis for this study. Also it was not clear which of the bio-physical, institutional and social economic factors had the greatest influence on farmers' decisions to practice SWC and whether these factors influenced their decisions variably thus forming the basis for this study.

5.3 Materials and Methods

In order to understand how the physical, social, cultural, institutional and economic factors influence use and adoption of SWC in the catchment, a survey was conducted in the month of January 2011 using a structured questionnaire administered to 95 households out of the 1800 households living in the sub-catchment (FARA, 2009). The selection of this sample size was based on a standard sampling procedure proposed by (Glenn 1992), in addition three FGDs of 6-10 people were conducted for some selected key informants representing the existing institutions involved in SWC namely: Innovation platform stakeholders, local government leaders, NGOs and religious institutions. In addition, 160 farms were visited along three transects in the upper, middle and lower parts of the sub-catchment using an observation guide. After collection of data, analysis of data was done using two analytical tests (a chi-square non parametric test and a logistic regression model) which are commonly used in adoption studies.

Bufundi Water Catchment is geographically located in Kabale district and it covers an area of up to 20 square kilometres. The terrain is dominated by hills and valleys ranging between 12 to 50% but some as great as 80% (FARA, 2009). Average annual rainfall in the catchment varies between 900 mm to

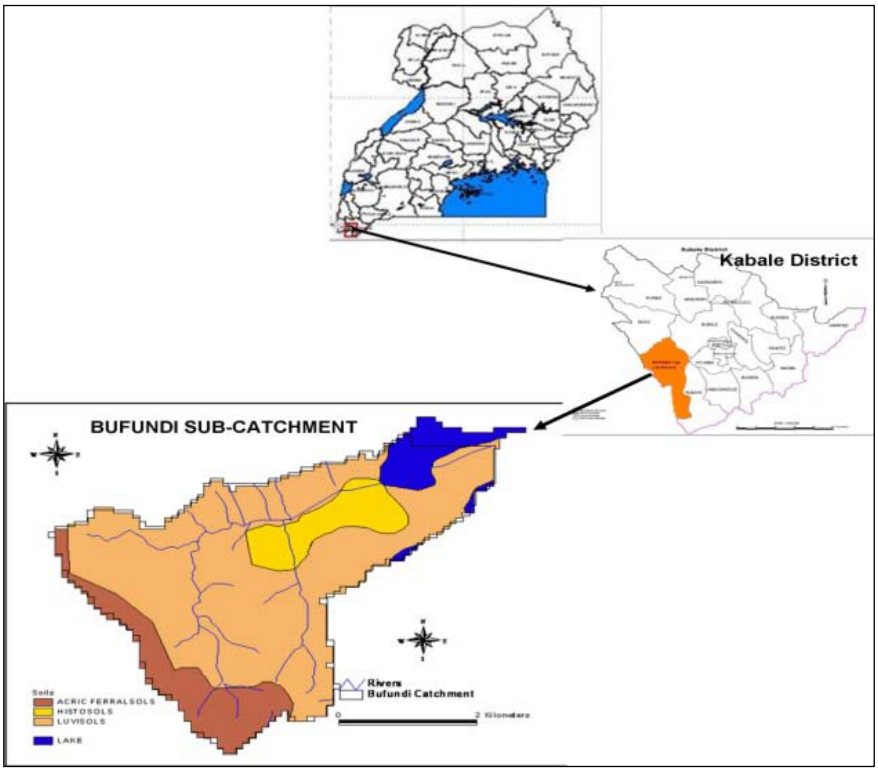


Figure 5.2: Map of the study area

2200 mm with a mean annual temperature of 16.7°C and the soils are predominantly luvisols, which are relatively fertile but susceptible to extreme soil erosion (FARA, 2009).

5.4 Results and Discussions

The soil and water conservation technologies in the sub-catchment include use of bench terraces (93%), traditional cutoff drains (31%), trees (61%), fallowing (23%), fanya juu trenches (12%), animal manure (39%) and crop residues (56%). The percentages were computed from the 160 farms that were visited. The study did not address itself to a specific soil erosion management practice but aggregates them together as "Soil and Water Conservation Technology".

5.4.1 Personal factors in relation to adoption of SWC in the catchment

Sex: The chi-square test proved that sex is independently not significant when it comes to adoption of SWC measures in the catchment (X^2 = 0.095, df=1, p=0.758). This implies that sex is independent of adoption of SWC measures. Whether male or female, both sex do not significantly influence adoption of SWC measures in the catchment. Although women are more involved in farming activities than men they may remain constrained by labour intensive measures like digging bench terraces and information yet men are more involved in off farm activities than SWC, a similar case is also reported by Amsalu and de Graaff (2006).

Perception of soil erosion: Farmers who perceive soil erosion as a problem having negative impacts on productivity and who expect positive returns from conservation are likely to decide in favor of adopting available conservation technologies (Gebremedhin and Swinton, 2003). On the other hand, when farmers do not acknowledge soil erosion as a problem, they will not expect benefits from controlling erosion and it is highly likely that they will decide against adopting any conservation technologies. The chi-square test indicated a significant relationship between adoption of SWC technologies in the study area and perception of the problem of soil erosion ($X^2 = 29.568$, df = 1, p = 0.000). Majority of the farmers (71%) acknowledge that soil erosion is indeed a problem on their farms and such farmers are expected to be in position to adopt technologies proposed for SWC.

Training in soil erosion control: Farmers cannot adopt technologies if they do not have access to all the relevant information, but the information they are given is often incomplete, focusing only on the technical aspects and overlooking some key criteria from a farmer's point of view (Fikru, 2009). The chi-square test proved that adoption of SWC is dependently significant with different sources of information that farmers use in Bufundi sub-catchment ($X^2 = 47.667$, df=4, p=0.000). Most of the farmers reported using farmer to farmer means as the most used source of information about SWC, however, during the FGDs and the non formal interviews it was discovered that promotion of farmer to farmer means of communication for SWC was being promoted by the IP.

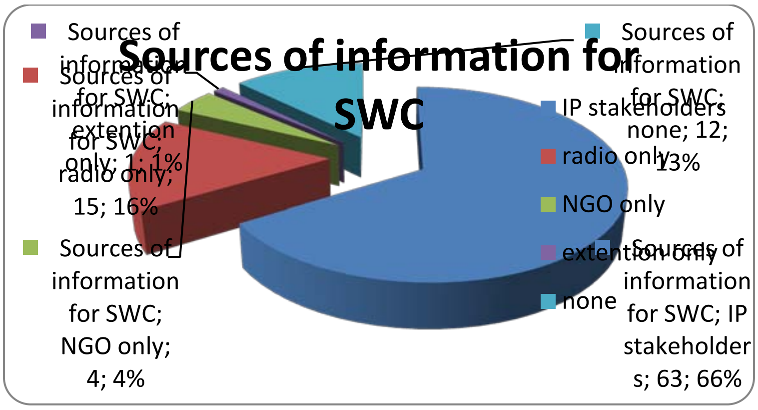


Figure 5.3: Different sources of information for SWC

Visits of extension agents to households are likely to increase their awareness about the effects of land degradation and the knowledge about the SWC technologies and their benefits (Nkonya, 2002). However, from the survey it was reported that extension services for SWC were still weak. Similarly Boyd *et al.* (2000) reported that the notion of promoting SWC is not necessarily high on the agenda of local administrations, as they have limited capacity and expertise to promote SWC. Support from agricultural extension staff is limited by retrenchment, low motivation and a shortage of resources.

Land tenure: Land in the study area is scarce mainly due to population pressure. On average, farmers have between 0.25-3 acres of land (FARA, 2009). Most of the land was individually owned by farmers in a form of tenure known as customary-individual ownership. In most of the non-formal discussions with farmers, land tenure insecurity was not a problem hindering farmers to invest in sustainable SWC practices. Thirty eight (38%) of the respondents had inherited their land while 37% had inherited some of the plots and purchased some of the plots (Figure 5.4)

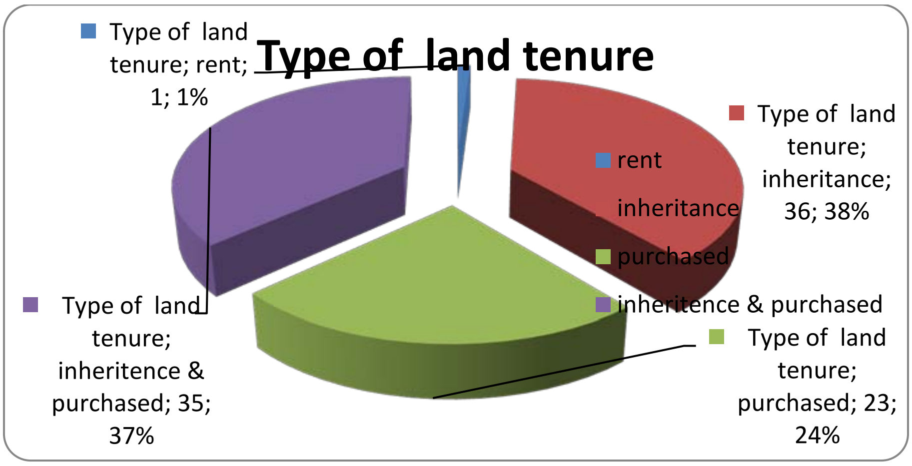


Figure 5.4: Types of land tenure in the catchment

The chi-square test also proved a strong relationship between adoption of existing SWC technologies and land ownership (X^2 = 33.463, df = 3, p = 0.000). This explains the current levels of adoption of SWC technologies as farmers who own their land tend to invest in SWC measures because of perceived tenure security. Because of the small farm size, fallow lands are not common and there is also a shortage of grazing land as reported during the non-formal interviews

5.4.2 Sources of money to invest in SWC activities

The major source of money for investing in soil conservation in Bufundi by farmers is after sale of agricultural products. sixty eight (68%) of the farmers reported their main source of income as sale of their agricultural out and22% through off-farm activities yet 5% used group savings. The chi-square test indicated that a significant relationship exist between adoption of SWC technologies in the study area and the sources of income for investing in SWC (X^2=145.789, df=4, p=0.000). This is attributed to sales that farmers reap from their annual crops (beans, potatoes and sorghum) that are highly demanded. All the farmers interviewed had never accessed any form of loan from a bank or the rural micro-financial agencies. However, efforts to link farmers under the IP to input dealers, NAADS, and banks for credit were under negotiations with support from FARA, ODLN and COL.

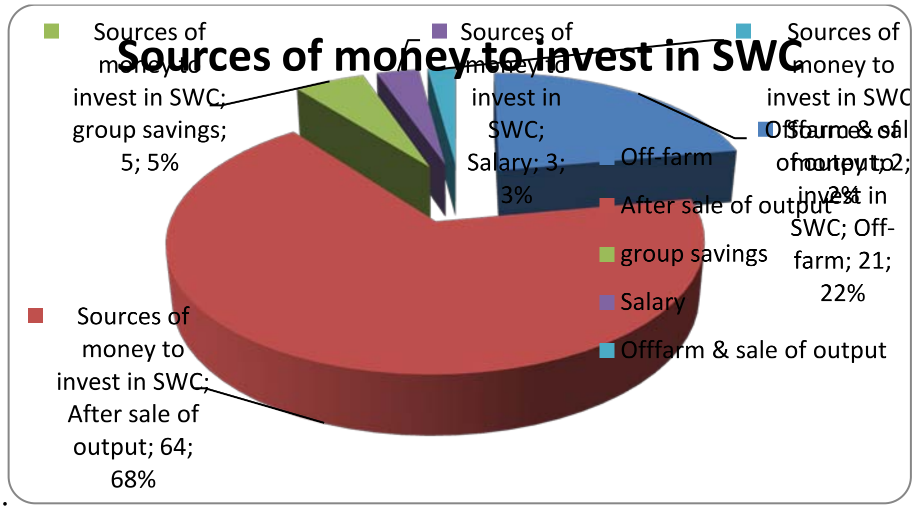


Figure 5.5: Sources of money farmers use to invest in SWC

Diagne and Zeller (2001) reported that Poor rural households in developing countries lack adequate access to credit, on the other hand Nkonya (2002) and Tenywa *et al.* (in press) report that when farmers are linked to markets, they are attracted to take credit and meet market demands and in the process they adopt SWC technologies. Access to agricultural inputs was reported to be individualistic rather than group and institutional based. Ninety five percent (95%) of the farmers accessed agricultural inputs individually according to an individual's base of income, involvement in off-farm activities and access to the market.

5.4.3 Off-farm activities as a determinant for SWC

The relationship between off-farm employment and adoption performance of SWC is poorly understood according to Kessler, (2006). Off-farm activities may have a negative effect on the adoption behavior of SWC due to reduced labour availability. When the farmer and family members are more involved in off-farm activities, the time spent on their farmland will be limited and hence the family is discouraged from being involved in construction and maintenance of SWC structures. On the other hand, off-farm activities can be a source of income and might encourage investment in farming and SWC. The survey showed that only 39% of the farmers were not involved in any forms of off-farm activities. That means 61% of the respondents were involved at least in a certain form of off-farm activity. Thirty nine percent (39%) were involved in small scale trading especially men, other forms of off farm activities were artisan 7%, civil service 3% and others 17%

Men contributed the highest category of household members involved in off-farm activities (25.3%) when compared to women. 21.1% of the household member categories were not involved in any form of off-farm activities as shown in (Table 5.1).

Table 5.1: Category of Household members involved in off-farm activities

Household member	Frequency	Percent
Man only	24	25.3
Woman only	8	8.4
All family members	17	17.9
Children only	16	16.8
Man and woman	10	10.5
None	20	21.1
Total	95	100.0

Despite the fact that 61% of the respondents were involved in off-farm activities, there was no significant relationship between SWC activities and a category of a household member involved in off-farm activities from the chi-square test (X^2=11.421, df=5, p=0.044). That means any category of household members involved in off-farm activities is independent to invest (neither time nor money) in SWC activities/measures. Each household member category involved in off-farm activities does not translate into investment in SWC activities but rather it is a form of contribution to household food and other needs given the high numbers of family members.

5.4.4 Perception on institutional innovations for SWC

Social capital has been shown to have important economic effects at the micro and macro levels (Nyanena, 2005). Social capital is generally interpreted as the degree of trust, cooperatives, norms and networks and associations within a society. Collective action for SWC was reported instrumental in information dissemination on soil erosion and training in SWC as well as promotion of new SWC technologies in the catchment. Various arguments have been advanced as to why higher levels of social capital can lead to improved economic performance; these include the reduction of monitoring and enforcement costs, improving information flows, fostering of exchanges for mutual benefits by developing reputation dissemination and promotion of consultative decision making and collective action that minimizes negative externalities and promotes the production of public goods.

The chi-square test proved that there was a significant relationship between adoption and use of SWC technologies and the perception of people about the changes brought by the IP on SWC activities (X^2 =42.811, df=3 p=0.000). Fifty (50) of the respondents reported some form of change within the community members on SWC technology use and adoption (Table 5.2)

Table 5.2: Perception on SWC changes and why there are these changes

Perception of change	Reasons for the changes in the catchment								
	IP formation	Collective labour	Collective marketing	Attitude Change	IP leaders	By-laws by IP	Inputs from IP	No reason	Total
No change	0	4	0	1	0	2	0	16	23
Some change	12	8	5	6	5	12	1	1	50
Remarkable change	2	3	0	1	1	2	0	1	10
Do not know	0	4	0	1	1	2	0	4	12
Total	14	19	5	9	7	18	1	22	95

The change in perception and attitude can be attributed to the adoption of a multi-stakeholder catchment approach that is demand driven for SWC and this is the IP. Tenywa *et al* (in press) report that most of the SWC approaches in SSA are supply-driven in nature rather than being demand-driven, and predominantly use the linear research-extension-farmer technology transfer model as opposed to the economic and institutional approach at a level of a catchment. According to Lopez (1977) supply driven approaches strengthen the bond between poverty and land degradation whereas market driven approaches provide incentives for formation of new institutions like IP that invests social capital in promoting use of demand driven SWC sustainable technologies. The IP is recognized as a new institution that has emerged to protect and conserve the catchment from soil erosion.

5.5 Choice of a logistic regression model and why it was used

Farmer traits like age, years of experience in farming, level of education, membership of IP, number of children in a household, slope and farm parcels owned were all hypothesized to influence SWC in the study area and they were analyzed using a logit model regression analysis.

Feder, Just and Zilberman (1985) show that many models used in adoption studies fail to meet the statistical assumptions necessary to validate the conclusions based on the hypothesis tested, and they advocated the use of also qualitative response models. The two models used in adoption studies are the logit and probit. The advantage of these models is that the probabilities are bounded between 0 and 1. Moreover, they compel the disturbance terms to be homoscedastic because the forms of probability functions depend on the distribution of the difference between the error terms associated with one particular choice and another. Usually a choice has to be made between logit and probit, but as Amenya (1981) has observed, the statistical similarities between the logit and probit models make such a choice difficult.

Although in practice, there are no strong reasons for choosing one model over the other, for this study a logit model was used because the dependant variable is dichotomous and the model is computationally simpler. Following Gujarati (1999), the logistic regression model characterizing adoption by the sample households in Bufundi sub catchment is specified as:

$$P_i = F(\alpha + \beta X_i) = \frac{1}{1 + e^{-(\alpha + \beta X_i)}} \tag{1}$$

Where: subscript i denotes the i-th observation in the sample,

P_i is the probability that an individual will make a certain choice given X_i,

e is the base of natural logarithms and approximately equal to 2.718

X_i is a vector of exogenous variables

α and β are parameters of the model (β1, β2,…..βk) are the coefficients associated with each explanatory variables X_1, X_2… X_n)

The above function can be rewritten as:

$$I_i = \text{In}\left[\frac{P_i}{(1-P_i)}\right] = \beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} \ldots . \beta_k X_{ni} + e_i \tag{2}$$

Where: e_i is a disturbance term and the parameters

β_1 are estimated using maximum likelihood techniques.

It should be noted that the estimated coefficients do not directly indicate the effect of change in the corresponding explanatory variables on probability (P) of the outcome occurring. Rather the coefficients reflect the effect of individual explanatory variables on its log of odds.

Where the expression for log of odds is given as:

$$In\left[\frac{P}{(1-P)}\right] \tag{3}$$

The positive coefficient means that the log of odds increases as the corresponding independent variable increases (Neupane et al., 2002). The coefficients in the logistic regression model are estimated using the maximum likelihood estimation method.

For this study, the empirical model is specified as:

$$CLAD_i = \beta_0 + \beta_1\text{EDU}_i + \beta_2\text{HHM}_i + \beta_3\text{IPM}_i + \beta_4\text{AGE}_i + \beta_5\text{PER}_i + \beta_6\text{SLP}_i + \beta_7\text{YOF}_i + \text{e}_i \tag{6}$$

Where: β_0 is the constant term

β_1 to β_7 are unknown parameters estimated

e_i is the disturbance term

5.6 Results of the Logistic Regression Model

The empirical results are presented in this section where the model was tested for multicollinearity. The correlation matrix presented in Table 5.3 show that multicollinearity was not a source of concern, since none of the explanatory variables were strongly correlated with each other.

Table 5.3 Correlation matrix of the variables in the logit model.

	CLAD	EDU	HHM	IPM	AGE	PER	SLP	YOF
CLAD	1.000							
EDU	-0.236	1.000						
HHM	-0.016	-0.240	1.000					
IPM	-0.057	-0.106	-0.087	1.000				
AGE	0.265	0.113	0.061	0.297	1.000			
PER	-0.075	0.138	0.057	0.186	0.087	1.000		
SLP	0.007	0.022	0.022	-0.074	-0.153	-0.139	1.000	
YOF	0.038	-0.039	0.094	0.028	-0.131	-0.014	0.373	1.000

Table 5.3 shows the logit estimates of the probability to adopt SWC technologies in Bufundi Sub-catchment.

Variable	Coefficient	Std. Error	z-Statistic	Prob.
C	1.063	3.504	0.303	0.761
EDU	-0.766	0.294	-2.601	0.009
HHM	-0.286	0.262	-1.088	0.276
IPM	-2.147	1.131	-1.898	0.057
AGE	0.168	0.063	2.663	0.007
PER	-0.010	0.177	-0.061	0.951
SLP	0.106	0.529	0.201	0.839
YOF	0.058	0.055	1.058	0.290
Mean dependent var	0.855	S.D. dependent var		0.357
S.E. of regression	0.323	Akaike info criterion		0.8110
Sum squared resid	6.403	Schwarz criterion		1.0700
Log likelihood	-19.98108	Hannan-Quinn criter.		0.9138
Restr. log likelihood	-28.55279	Avg. log likelihood		-0.2891
LR statistic (7df)	17.143	McFadden R-squared		0.3002
Probability(Lstat)	0.0164			

Source: Field Survey (2011)

The strength of the regression model was assessed using the Mc Fadden's R-Squared. This is a pseudo R-Square which significant values are between 0.2-0.4, therefore the Mc Fadden's R-Squared of 0.3 (Table 5.3) indicates that the model was better to predict adoption and use of SWC technologies in the catchment.

Education (EDU)

This variable was expected to take a positive sign; rather, it took a negative sign but significant. The basis of this was that highly educated farmers are expected to be better adopters of SWC technologies than the less educated ones. Educated farmers are presumed to have exposure to new technologies and innovations, and are more receptive to new ideas and more willing to adopt, hence the null hypothesis that education has positive correlation with SWC technology adoption (Caswell et al., 2001). This implies that adoption of SWC technologies in the catchment is negatively influenced by the level of formal education attained by a household head at primary, secondary and tertiary levels. Most of the respondents had stopped at primary level yet others had never attained any form of formal education. These finding differ with the findings of Krishana et.al (2008) who found that education of the household head was positively related to the adoption of improved SWC technology. The significant association of education in the model explains that there exists a strong relationship in adoption and use of SWC technologies with the level of education attained by a household head in terms of years in school and exposure to trainings in SWC facilitated by members of the multistakeholder IP.

Household Member (HHM)

This variable was expected to take a positive sign; rather, it took a negative sign and insignificant. The basis of this was that families with a large number of members are expected to be better adopters of SWC technologies in the catchment than those with fewer members since they are in position to provide labour required for SWC (Caswell et al., 2001). The results in the model reveal that household member's composition is negatively associated with adoption and use of SWC technologies. This might be due to the large numbers of family members of which 61% are being involved in off-farm activities. On average households have between 0-15 members of which 56% are below the age of 15 years and 43% between 16-64 years. Wagayehu and Lars (2003) indicated that in the large families with greater numbers of mouths to feed, competition arises for labour and investment in SWC technologies thus priority and labour is diverted to off-farm activities that generate food. Therefore, during slack season, opportunity cost of labour for the household with greater size will be higher (Wagayehu and Lars, 2003).

Innovation Platform member (IPM)

This variable was expected to take a positive sign, rather, it took a negative sign but significant to adoption and use of SWC technologies. This implies that an individual's membership in the existing innovation platforms does not automatically guarantee that a farmer will adopt all the necessary and required SWC measures in the short run especially if profitability and productivity of the technology are not assured. The significant association of membership in innovation platforms implies that a strong correlation between SWC technology adoption and membership of the innovation platform exist if a farmer is assured of higher benefits from efforts of their SWC activities. Farmers who are members of the newly formed innovation platform among others are better placed to adopt soil conservation technologies than those who did not belong to even any organization. Membership to such organizations enables farmers to acquire information on proper agronomic practices, credits, productive inputs as well as trainings. As noted by Dikito (2001), self-help grouping and formation of cooperatives is a more reliable and pragmatic means of achieving social capital and ensuring dissemination and adoption of innovative technologies.

Age of the respondents (AGE)

The relationship between age category and adoption of SWC is mixed in findings and opinions of different scholars. Age of the household head was expected to have either positive or negative effect on adoption of SWC technologies. Older farmers were likely to be relatively reluctant in their decisions to take up new technologies because of their short planning horizon (Sidba, 2005). However, it is also true that older farmers were likely to have more farming experience and would therefore be likely to be more receptive to new SWC technologies (Wagayehu and Lars, 2003). On the other hand, Chomba (2002) found out that young farmers do not utilize existing SWC technologies due to the opportunity costs linked with small land size and off-farm activities. Others like Sidba (2005) reported that younger household heads have a higher probability of using new SWC where younger farmers would be more accommodative to new ideas and would invest in new and long term innovations and hence may be more likely to invest in conservation. In the model age took a positive sign and was significant. Therefore as a farmer's age increased it also increased the likelihood of a farmer to indentify soil erosion indicators and threats and thus adoption of SWC measures.

Percels of land owned (PER)

The average land holding ranges between 0.25-3 acres fragmented across the different landscapes (FARA, 2009). Inconsistent with other studies and with theory, PER is negatively associated with adoption of SWC technologies in the catchment. This is expected, as the number of farm parcels of a farmer increase, the attention and care given to proper farming practices reduces drastically, affecting adoption of improved technologies and maintenance of existing structures (Kessler, 2006). Similarly, SWC structures are known to take some area that would have been used for farming. Farmers who operate on larger farms can allocate some part of the land than those who have small farms. Given the fact 70% of the farmers in Bufundi own less than 0.5 acres of land, their adoption of some SWC measures like fanya juu trenches was generally low

Slope of land (SLP)

As expected, the variable SLP took the hypothesized positive sign, but not significant. This implies slope of land influence adoption and use of SWC technologies positively. This is because slope is an indicator of soil and water loss from the farmland. This implies that farmers cultivating vulnerable fields (steep slopes) are more likely to adopt and use SWC technologies in their farms than those cultivating less vulnerable lands (low lands). This is consistent with other studies by Wagayehu and Lars (2003) and Bett, (2004).

Years of farming (YOF)

As expected, the variable YOF took the hypothesized positive sign, but not significant. This implies that the number of years a farmer has spent farming influence adoption and use of SWC technologies positively. From the study findings the mean years spent farming was 23.67 with a minimum of 3 years and a maximum of 50 years in farming. Fitsum and Holden (2003) reported that experienced farmers in farming are likely to manage their land in a better way than the less experienced farmers. On the other hand, it is also observed that as the age of household head increases, the ability of applying fertilizer and any conservation measure decreases (Fitsum and Holden, 2003).

5.7 Conclusions

The study revealed that farmer perceptions of the likely benefits in SWC, assured market, personal and institutional innovations of the IP significantly influence use and adoption of SWC than any other factor in the catchment. These findings reinforce the facts that in order to create a win-win for SWC adoption, institutional innovations for SWC and economic factors should be given special attention in the sub-catchment and this should be under an integrated watershed management planning approach. We argue that for sustainable investments efforts should focus on strengthening the existing IP.

5.8 Recommendations

From the findings of the study, we recommend to the Innovation Platform multi stakeholders that extension services in addition to farmer innovations that target fertility management be promoted in the sub-catchment. This should be coupled with collective access to both input and output markets under the IP as well as training on organic fertilizer use especially for marketable crops like potato and sorghum. Therefore Farmer market institutional linkages should be supported more to tap premium prices, profitability and integrated soil fertility management.

A crop-livestock interaction needs to be promoted as a sustainable soil fertility management practice. A similar recommendation is reported by Nkonya (2002) as a cost effective alternative in both the short term and long term SWC especially for small holder farmers.

On observation most of the farms looked exhausted especially in the upper and middle slopes however on almost all the farms visited the terraces were collapsing with little or no management at all yet all the farmers reported no use of inorganic fertilizers. It is recommended that a nutrient balance study is conducted in the sub-catchment in relation to benefits of SWC.

5.9 References

African Highland Initiative, AHI 2002. Strengthening institutional innovations for integrated natural resource management in the highlands of East and Central Africa Phase 4: AHI participatory research. African Eco-regional Programme, ICRAF- Nairobi.

Amsalu, A. and de Graaff, J. 2006."Determinants of adoption and continued use of stone terraces for soil and water conservation in an Ethiopian highland watershed". In: Journal of Ecological Economics 20: 30-45. Available at: http://www.sciencedirect.com. Accessed on: 5th /01/2011.

Boyd, C., Turton, C., Hatibu, N., Mahoo, H.F., Lazaro, E., Rwehumbiza F.B., Okubal, A .P. and Makumbi, M.B. 2000.The contribution of soil and water conservation to sustainable livelihoods in semi-arid areas of Sub-Saharan Africa. Agricultural Research and Extension Network Department for International Development (DFID) UK.

Briggs, L. and Twomlow, S.J. 2002. Organic material flows within a small holder highland farming system in South West Uganda. Agriculture, Ecosystems and Environment 89:191-212.

Carswell, G. (2000). Farmers and fallowing: Agricultural change in Kigezi district, Uganda. *Geographical Journal* 168 (2):130-140.

Chomba, G. N. 2004. Factors affecting smallholder farmers adoption of soil and water conservation practices in Zambia. MSc thesis, Department of agriculture.

Consultative Group on International Agricultural Research, CGIAR. 2003. Water and people in catchments. Challenge program on water and food. Cali, Colombia, 56 PP.

Davidson, J. 1992. No time to waste: Poverty and the global environment: Oxford oxfarm.

Diagne, A. and Zeller, M. 2001. *Access to credit and its impact on welfare in Malawi.* International Food Policy Research Institute (IFPRI), Washington, D.C., USA

Dikito, M. S. (2001). Social capital: empowering women to achieve food security. International Food Policy Research Institute (IFPRI), Brief 9 of 12, Washington DC, USA.

Ervin, C. A. and Ervin, D. E. 1982. "Factors affecting the use of soil conservation practices: Hypotheses, evidence and policy implications." Land Economics 58 (3): 277–92.

Feder, G., Just, R and Zilberman D 1985 Adoption of agricultural innovations in developing countries. A survey, Economic Development and Cultural Change 33 (2), 255-298.

Fikru, A.M. 2009. Assessment of adoption behaviour of soil and water conservation practices in the Koga watershed, high lands of Ethiopia. Masters thesis, Cornell University.

Fitsum, H. and Holden, S. 2003. Tenure security, resource poverty, risk aversion, public programs and household plot level conservation investment in the highlands of northern Ethiopia: http://www.arts .cornell.edu/econ/75devconf/papers/hagos doc accessed on 10th November 2010

Forum for Agricultural Research in Africa, FARA. 2009. Status of natural, social, financial, human and physical capital in the Lake Kivu Pilot Learning Site. Sub-Saharan African Challenge Programme. Accra, Ghana.

Glenn, D.I. 1992. Sampling the evidence of extension program impact. Programme Evaluation and Organization Development, IFAS, University of Florida. PEOD-5.

Gujarati, D. 1999. *Essentials of econometrics*. Irwin/McGraw-Hill, Boston, USA

Kessler, M. 2006. "Decisive key-factors farm households' soil and water conservation investment". Journal of Agriculture, Ecosystem and Environment 65: 95-102.

Lal, R. 1994. Methods and guidelines for assessing sustainable use of soil and water resources in the tropics. Soil Management Support Services. USDA Soil Conservation and USAID, SMSS

Technical Monograph No. 21.

López, R.E. 1977. "Productivity Measurement: A Market Equilibrium Approach," in Developing a Framework for Assessing Future Changes in Agricultural Productivity, Resources for the Future, Washington, D.C.

Makokha, M., Odera, H., Maritim, H.K., Okalebo, J.R. and Iruria, D.M. 1999. Farmers' perception and adoption of soil management technologies in western Kenya. African Crop. Science Journal. 9.7(4) 549-558.

Miiro, R. 1999. Factors enhancing terrace use in the highlands of Kabale district Uganda. In: Stott, D.E, Mohtar, R.H and Steinhardt, G.C (eds) 2001. Sustaining the global farm: 356-361, paper for the 10th International Soil Conservation Organization Purdue University.

Neupane, R. P., Sharma, K. R. and Thapa, G. P. 2002. "Adoption of agro forestry in the Hills of Nepal: A logistic regression analysis". Journal of Agricultural Systems No.72, Vol.3: 177- 196.

Nkonya, E. 2002. Soil conservation practices and non-agricultural land use in the south western highlands of Uganda. The International Food Policy Research Institute (IFPRI) 2033 K Street, N.W. Washington, D.C. 20006.

Ovuka, M. 2000. 'More people, more erosion? Land use, soil erosion and soil productivity in Murang'a District, Kenya Land Degradation and Development, 11 111-124.

Pindyck, R. S., Rubinfeld, D. L. 1998. Econometric models and economic forecasts. McGraw-Hill, London, UK.

Posthumus, H. 2005."Adoption of terraces in the Peruvian Andes." Ph.D. thesis, Wageningen University.

Siriri, D., Tenywa, M. M., Raussen, T. and Zake, J. K. 2005. Crop and soil variability on terraces in the highlands of South Western Uganda. Land Degradation and Development Volume 16 Issue 6, Pages 569 - 579 John Wiley and Sons, Ltd. New York.

Ssali, H. 2001. Soil organic matter in Uganda and its relationship to major farming system. A resource paper submitted to the International Food policy Research Institute (IFPRI).

Tenywa, M.M., Rao, KPC., Majaliwa, M.J. G., Cyamweshi R.A., Fungo, B., Kuule M., Luswata K.C., Kaliisa, R. and Gabiri. G 2011. Market Driven Natural resource Management; a key to sustainable Agricultural Development: Case study of Bufundi sub-county, Kabale district; Uganda, Sub Saharan African-Challenge Programme.

Tukahirwa, J. M. B. 1996. Status and trends in soil and water conservation in Uganda. In: Tenywa, M. M and Bekunda, M. A (Eds.), Proceedings of the workshop on the past, present and prospects of soil and water conservation in Uganda. Kampala: Soil and Water Conservation Society.

Wagayehu, B. and Lars, D. 2003. "Soil and water conservation decision of subsistence farmers in the Eastern Highlands of Ethiopia: A case study of the Hunde-Lafto". Journal of Agricultural Economics 18:125-133.

6 Improving SWAT model performance in poorly gauged catchments

Kilonzo, F.

Obando, J.

Bauwens, G.W.

Email address??

6.1 Abstract

Hydrological modeling is a challenging task in ungauged or poorly gauged areas, whereby both meteorological and flow measurements may be lacking. Although many data interpolation techniques, algorithms and tools are available, most of them become inapplicable when the percentage of missing data is too high or when the modeler lacks the computational skills to use complex algorithms.

In view of the simulation of the hydrological processes of the upper Mara river basin with the Soil and Water Assessment Tool (SWAT) different data infilling techniques have been compared. For precipitation data, the used techniques are the inverse distance weighting method (IDW), the nearest neighbor (NN) method and a newly proposed simple computationally undemanding cluster and average (CA) method. For the stream flow data, missing data was filled using the long term mean of each day in a year method. The performance of the SWAT model, using the different infilling techniques was assessed using the Nash-Sutcliffe efficiency (NSE) for the flow simulations and by visual inspection There was a marked improvement on the NSE value in the SWAT model as a result of application of different data interpolation techniques. The IDW infilling gave the best NSE at 0.66, while CA and the NN interpolations resulted in NSE of 0.62, and 0.43 respectively. The worst results, NSE of 0.18 were obtained with infilling missing flow data using long term mean, compared to simply running the model simulations with unfilled individual stations data with NSE of 0.29. The use of simple, fast data interpolation and manipulation processes resulted in an improved model performance to a satisfactory level of the objective function, and make the hydrological model usable for further simulation and predictions. Furthermore, missing data in flow series is better left unfilled than using the long term mean for the day.

Keywords: *hydrologic modeling, missing data, clustering, geostatistics, data interpolation, data infilling*

6.2 Introduction

The challenges faced by model users in applying hydrological modeling tools on poorly gauged and/or ungauged catchments, especially in Eastern Africa, have been noted by Jayakrishnan et al. (2005), Ndomba et al., (2005), Mulungu and Munishi, (2007), Ndomba et al. (2008), Ndomba and Birhanu

(2008). Cho et al. (2009) stated that “as the number of rain gauges used in the simulation decreases, the uncertainty in the hydrologic and water quality model output increases exponentially”.

The Soil and Water Assessment Tool (SWAT) model was originally developed to operate in large-scale ungauged basins with little or no calibration efforts (Arnold et al., 1998). In SWAT, the weather station nearest to the centroid of each sub-basin is taken as the location for the precipitation to be used in the model. Schuol and Abbaspour (2007) noted that unrealistic weather data are generated by SWAT if a weather station is assigned to a sub basin that has only a few measured values or many erroneous values.

Geostatistical and nongeostatistical data techniques, algorithms and tools for spatial analysis of rainfall are available, with different interpolation methods yielding data of varying quality, which can strongly influence the modeling results (Van der Heijden and Haberlandt, 2010). The latter study lead to the conclusion that the higher the network density, the smaller the differences between the interpolation methods. According, to Grimes and Pardo-Igúzquiza (2010), the benefits of geostatistical analysis for rainfall include ease of estimating areal averages, estimation of uncertainties, and the possibility of using secondary information (e.g., topography). The biggest limitation of available geostatistical tools is the computational skill required. “PCP_SWAT” is a GIS program, which incorporates nearest neighbor (NN), inverse distance weighting (IDW), simple kriging (SK), ordinary kriging (OK), simple kriging with local means (SKlm), regression kriging (RK), kriging with external drift (KED), and co-kriging (CK) (Zhang and Srinivasan, 2009). The tool facilitates automatic spatial precipitation estimations using observed rain gauge data and other external variables. Elevation and spatial coordinate information are e.g. used as auxiliary variables in the SKlm, RK, KED, and CK methods. This study compares the use of different methods to interpolate available point rainfall, with an aim of preparing data full SWAT model input files from rainfall stations with missing data.

6.3 Materials and methods

6.3.1 The study area

The 2900 km^2 study area, which is 25% of the entire Mara river basin, represents the headwaters of the basin and is responsible for almost all the recharge into the basin (Fig. 6.1). It is characterized by bimodal rainfall ranging from 700 mm in the lower areas to 1800 mm in the mid and upper sections. The elevation changes from the flat plains at 1500 m above sea level to the high Mau escarpments at 3000m. The main soil types are loams and clay loams (andosols). The main socio-economic activities (land use types) are determined by the hydro-climatic and ecological zonations with pasture and herding restricted to the lowlands, commercial mechanized agriculture (mostly large scale maize and wheat cultivation) in the flood plains, subsistence maize production in the midsection, tea and forestry in the high rainfall areas and vegetable production in the upper sections.

Hydro-climatic data is both scarce and scanty. Officially, rainfall data is available from the Kenya Meteorological department, although private concerns (including hotels, lodges, and tea estates) have been known to collect and keep especially rainfall and temperature data. River flow data is collected and management by the Water Resources Management Authority (WRMA), and its parent Ministry of Water and Irrigation. While addressing the data scarcity problem in the study area, Gann (2006) characterized the data as "non-existent, non accessible, limited accessible, with gaps, not very accurate, and in different formats and no standards". He therefore concluded that "Calibration of a SWAT model with these data delivers only limited satisfactory results, exaggerating discharge for large parts of the basin". To overcome the challenge in the wider Lake Victoria region, various researchers have used different manipulation techniques. Mutie et al. (2006) used the IDW technique for rainfall and the long term daily mean for the flow, while Ndomba et al. (2008) used the long term daily mean for the flow. This study aims at manipulating the available data to make areal inputs for SWAT model calibration. The study therefore seeks to validate the techniques that have been used by researchers in the lake region as well as to compare them with a simple clustering and averaging technique developed for this study area. The study further takes cognizance of the fact that primary data generation, archiving and documentation is imperative and, that "no calibration can substitute the missing processes of a catchment to develop a physical based hydrologic model like SWAT." (Van Griensven et al. 2007).

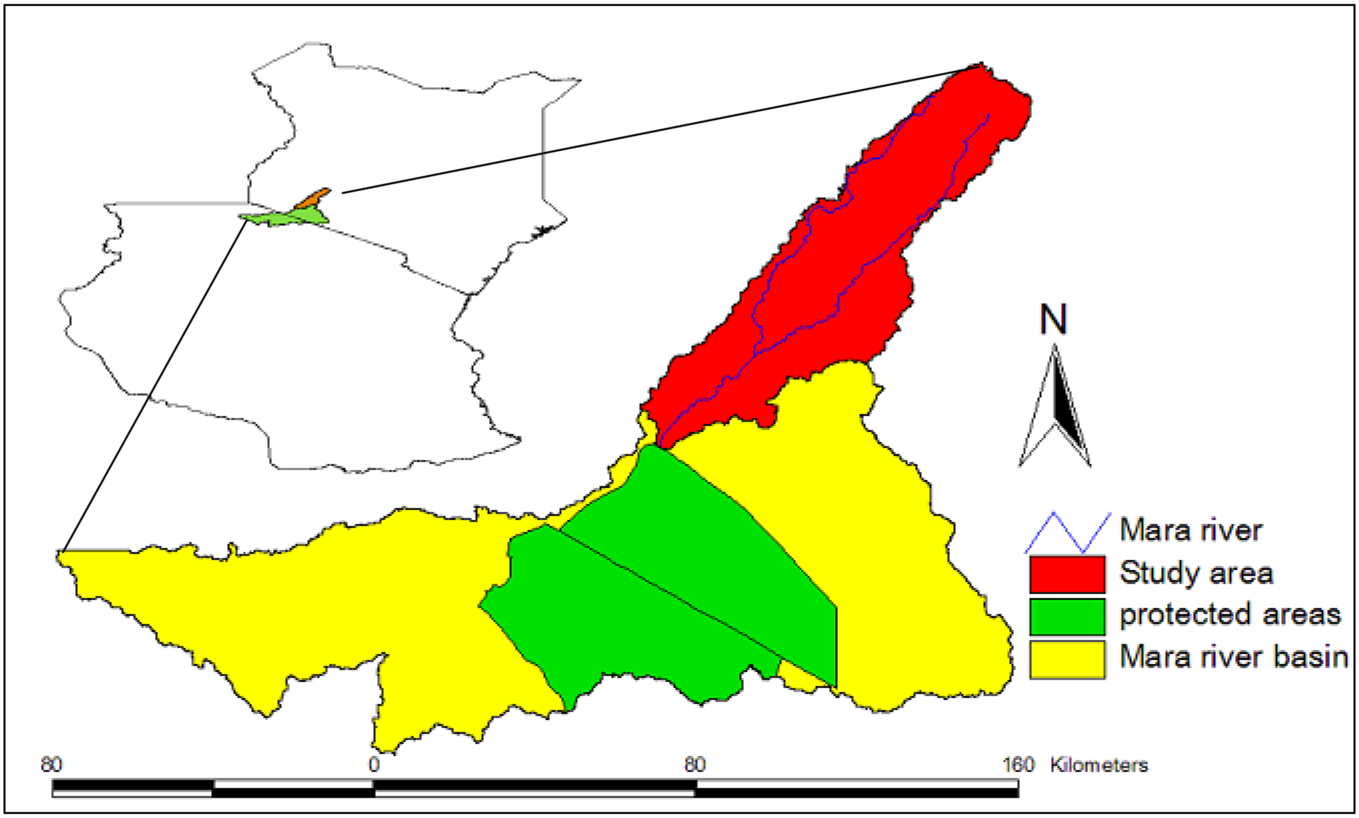


Figure 6.1: The study area as part of the larger Mara river basin

6.3.2 Model input data

Input data required to set up and calibrate a SWAT model include landuse, soil type, digital elevation model (DEM), rainfall and flow data. The Kensoter 1:1000000 soil map was accessed from, http://www.isric.org/UK/About+ISRIC/Projects/Track+Record/SOTER+Kenya.htm, while the shuttle radar topography mission (SRTM) 90m X 90m digital elevation model (DEM) was obtained from the global landcover facility. A land use map was developed from Landsat satellite imagery of 1976 obtained from the Glovis database. Raw climatic and streamflow data inputs were sourced from the Kenya meteorological department and the Water Resources Management Authority respectively. Figure 6.2 shows the entire network of hydrometeorological stations within the study area. Some of the stations were discarded for this study, mainly due to the large percentage of missing data. Finally, rainfall data for 17 stations located on the Kenyan side of the Mara river basin, was used in this study. The rainfall stations have data series of varying lengths and different levels of missing data. Data series of the 1970-1977 period provided the most complete data series and were used for this study.

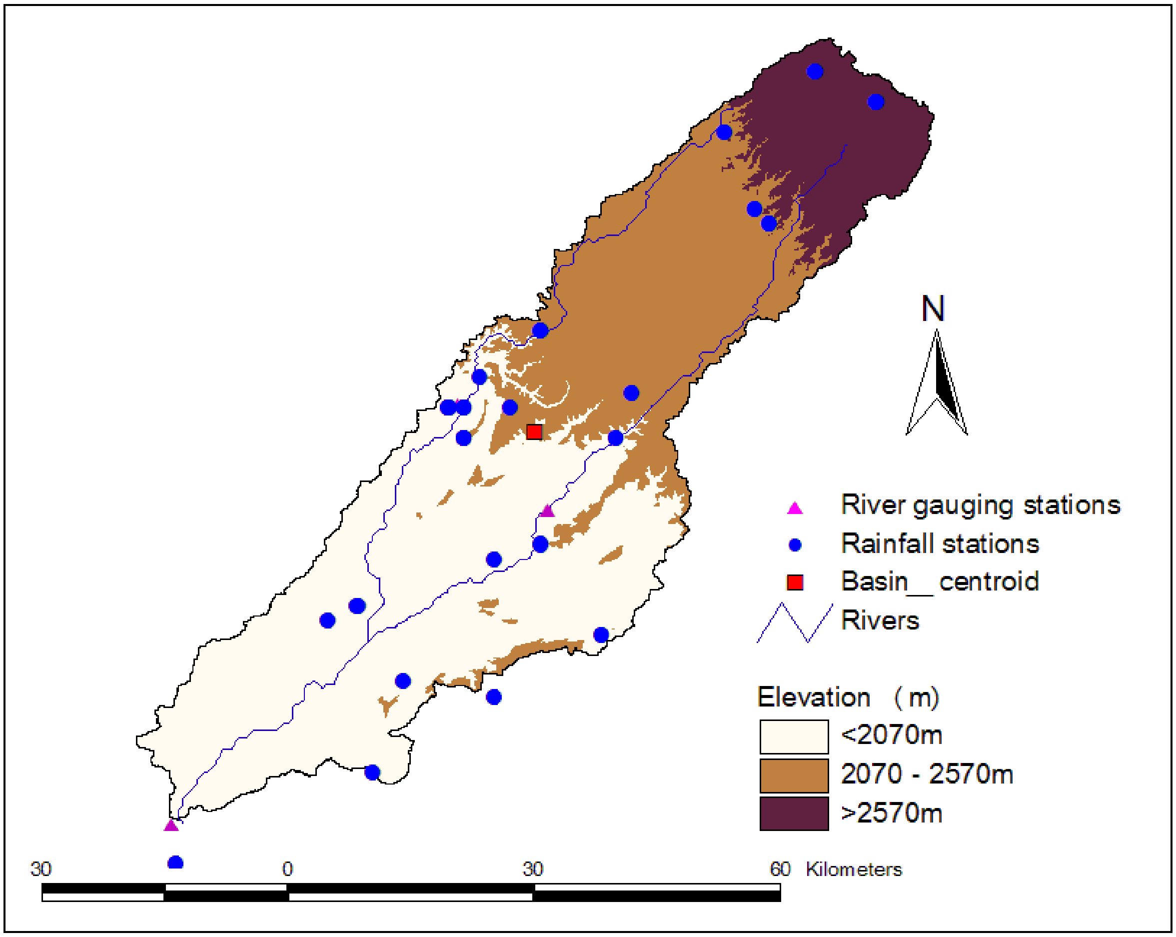


Figure 6.2: Location of all rainfall and river gauging stations

6.3.3 Data interpolation

Three data manipulation methods were used to fill in the missing rainfall data. The nearest neighbors (NN), the inverse distance weighting (IDW), and the proposed cluster and average (CA) methods. As the river basin under study is considered as an entity in our SWAT model (no subbasins) and as SWAT allow only one rainfall station for each subbasin, at least one "average" rainfall series had to be constructed for the model.

For the IDW method, all 17 stations were used to calculate the average rainfall, considering a weight for each station that is inversely proportionate to its distance from the centroid of the basin (eqn 1). When data of a station are missing, its weight is set to 0.

$$Px = \frac{\sum_{i=1}^{N} \frac{1}{d^2} p_i}{\sum_{i=1}^{N} \frac{1}{d^2}} \quad \text{-----(1)}$$

where,

Px = rainfall at the centroid

Pi = rainfall at station i

N = No. of stations

di = distance from station i to the entroid of the basin

In the nearest neighbor method, the rainfall stations closest to the determined centroid of the basin (fig 6.2) and with long term data records, were used to create a single rainfall station. By using values of the nearest stations, the rainfall time series for a new station was generated by unweighted averaging of the daily rainfall amounts of the nearest stations using eqn 2. Any missing data in one station is compensated by omitting the missing value in eqn 2 and filling in the value of the new station with data from the other stations. The principle of shared similarities of the stations to the centroid due to close spatial proximity is assumed.

$$P_{at} = \frac{1}{N}(P_{1t} + P_{2t} + P_{3t} + \cdots + P_{Nt}) = \frac{1}{N}\sum_{i=1}^{N} P_{it} \quad \text{--- (2)}$$

Where:

Pat = estimated average areal rainfall at time t for new station

Pit = individual point rainfall values at station i (for i = 1,N) and time,t

N = total number of point rainfall stations considered

The CA method involves the clustering of the rainfall stations in a scatter plot. The average annual rainfall (mm) is plotted against the elevation (m), fig 6.3. Using the clustering principle where, "patterns within a valid cluster are more similar to each other than they are to a pattern belonging to a different cluster" (Jain et al. 1999), three cluster classes were qualitatively established. Once the clusters are identified, the rainfall stations are then used to get new stations by averaging the stations in each cluster. The validity of the formed clusters was confirmed graphically by use of areal interpolation of the annual rainfall using the ordinary Kriging techniques with aid of Kriging Interpolator extension.

Data for four stream flow gauging stations located on the Mara river is available, albeit with a large degree of missing data. The period 1970 to 1978 has the best data for the four stations. According to Marsh, 2002, including suitably flagged estimates of flow is preferable to leaving gaps.

6.3.4 The SWAT model

The SWAT model (Arnold et al 1995), a physically based, deterministic, continuous, watershed scale, spatial distributed hydrological simulation model, was used in this study. The SWAT model applies a water balance equation as a driver for everything that happens in the watershed. The USDA-SCS runoff curve number is used to estimate surface run- off from daily precipitation. SWAT can also be run on a sub-daily time step basis using the Green-Ampt infiltration method. Other hydrologic processes simulated by the model include evapotranspiration, infiltration, percolation losses, channel transmission losses, channel routings, and surface, lateral, shallow aquifer, and deep aquifer flows. The ArcView SWAT (AVSWATX), a complete preprocessor, interface and post processor of the hydrological model SWAT2005 (Di Luzio, 2004) was used for the model setup. With all the SWAT model inputs, SWAT simulations were performed for six different model input scenarios; three rainfall based, one flow based, one combined rainfall and flow based, and one using raw data from individual stations within the basin. The model simulation was performed for the period between 1970 and 1977. 1970 was used to warm up the model, 1971-1974 to calibrate, and 1975-1977 to validate the model. Autocalibration was performed using the inbuilt ParaSol algorithms in the AVSWATx model (van Griensven and Meixner, 2006).

6.3.5 Model performance

The acceptability and usability of a model to predict or simulate physical processes depends on how well the model results compare to observed data. According to Chang and Hanna (2004) three statistical evaluations are commonly used: comparing modeled and observed time-averaged values; evaluating modeled and observed values at a specified time, and examining the arrival and departure times of the observed and modeled values. Two performance measures, a metric and a non metric indicator are used in this study. The Nash-Sutcliffe efficiency (NSE) is a normalized statistic that determines the relative magnitude of the residual variance as compared to the measured data variance (Nash and Sutcliffe, 1970). NSE indicates how well the plot of observed versus simulated data fits the 1:1 line.

$$\mathrm{NSE} = 1 - \left[\frac{\sum_{i=1}^{n} \left(Y_i^{obs} - Y_i^{sim} \right)^2}{\sum_{i=1}^{n} \left(Y_i^{obs} - Y^{mean} \right)^2} \right] \qquad \text{......} \ (3)$$

NSE ranges between−∞ and 1.0 (1 inclusive), with NSE=1 being the optimal value. Values between 0.0 and 1.0 are generally viewed as acceptable levels of performance, whereas values <0.0 indicates that the mean observed value is a better predictor than the simulated value, which indicates unacceptable performance.

The NSE is recommended for use by the American Society of Civil Engineers (Moriasi et al, 2007), and due to its widespread usage, it provides extensive information on reported values. It was found by Sevat and Dezetter (1991) to be the best objective function for reflecting the overall fit of a hydrograph. For the hydrological model performance, a several recommended satisfactory NSE values include; Moriasi et al. 2007, 0.50 - 0.65, and Santhi et al. 2001 > 0.5.

A graphical comparison between simulated and observed hydrographs should always be undertaken in any study involving computed and simulated hydrograph comparisons (Green and Stephenson, 1986). Despite its obvious shortcomings of subjectivity and hence irreproducibility and inapplicability in large data sets, visual inspection is a “powerful expert system for simultaneous, case specific multi-criteria evaluation which provides results in close accordance with the user’s needs” (Ehret and Zehe, 2010).

6.4. Results and discussion

6.4.1 Rainfall Interpolation

A single rainfall station for the study area was generated both for the nearest neighbors and the IDW methods, the coordinates of this station was given as the centroid of the basin. For the CA method three stations were established. The relation betweeen the topographic elevation and the mean long term annual precipitation for the rainfall stations was a polynomial fit. Three clusters were distinguised, Cluster 1; Low altitude- low rainfall, cluster 2; Medium altitudes – high rainfall, and cluster 3; High altitudes – medium rainfall. Figure 6.3 represents the clustering of eleven (11) point stations based on elevation and rainfall. The selection of the clusters was performed qualitatively by visible subject analysis of the plots. Some stations which do not fall into any of the clusters were dismissed as noise.

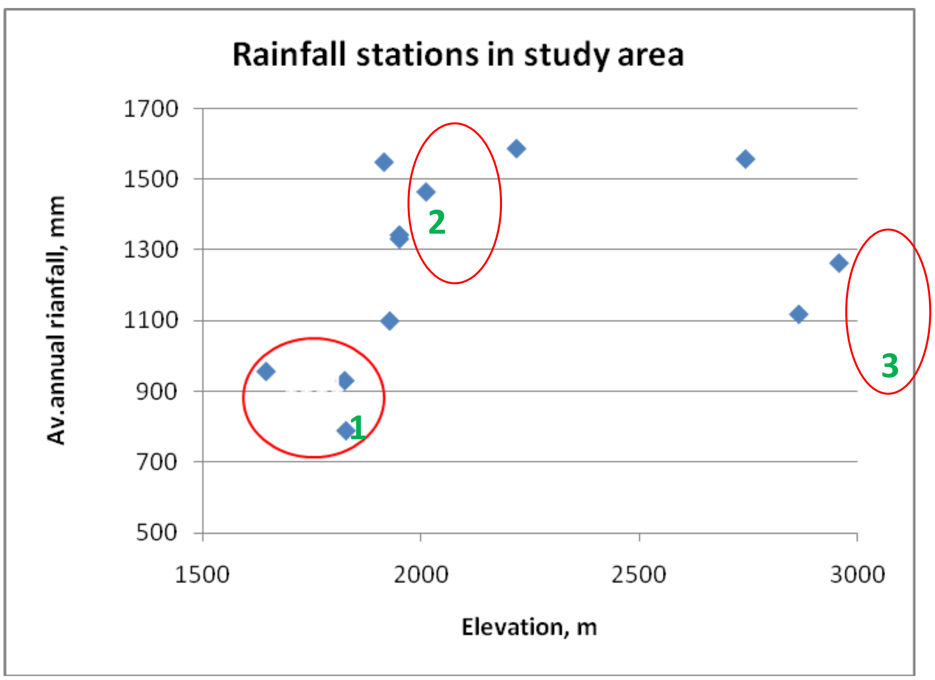


Figure 6.3: Mean annual precipitation against the elevation of the stations

Using the ordinary kriging technique with a gaussian transformation, all the point rainfall stations were interpolated to a spatial distribution of rainfall over the study area. After re-classification, three zones were produced, fig 6.4. The zonings generated by the kriging interpolation were consistent with the clusters produced with the simple scatterplot clustering. The spatial interpolation indicates that the majority of the area upstream of the midsection experience higher than average rainfall, while areas downstream of the midsection had lower rainfall. In SWAT modelling the cluster where the centroid falls into cluster 2 station (Pcp_medd), was used as the input station for the model simulation.

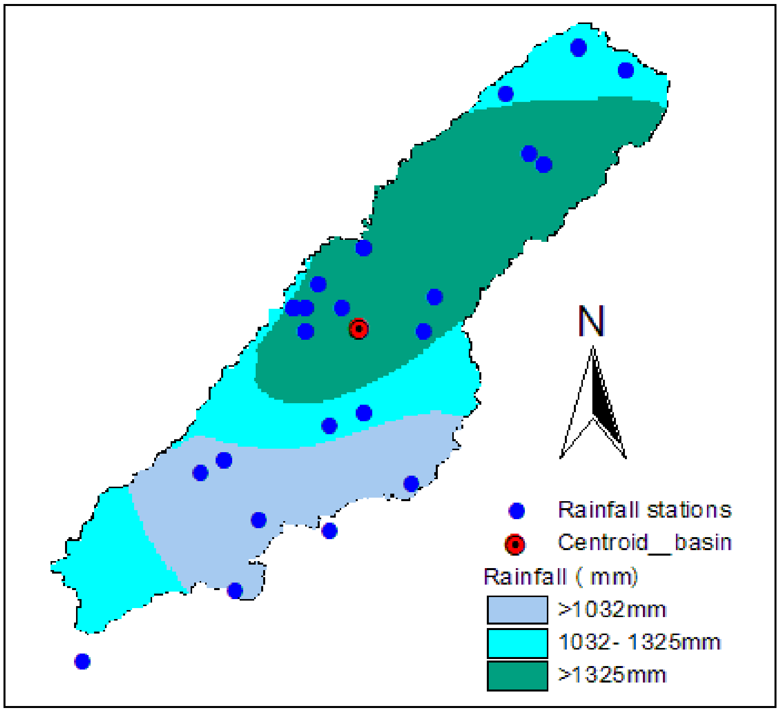


Figure 6.4: Areal rainfall distribution using ordinary Kriging

Three new stations were establish through the interpolation representing the three zones, Low altitude low rainfall, Medium altitude high rainfall, high altitude medium rainfall (Table 6.1), by simple averaging of the daily values of the stations with long term data series within each cluster.

Table 6.1: Stations used to generate new precipitation stations with CA method

ID	LAT	LONG	Av.rfall	Elevation	New station	Description new station
9035079	-0.75	35.37	1465	2012		
9035260	-0.82	35.35	1627	1916	Pcp_medd	Medium altitude high rainfall
9035227	-0.78	35.33	1332	1951		
9035265	-0.78	35.35	1343	1951		
9035241	-0.42	35.73	1118	2865	Pcp_high	High altitude medium rainfall
9035228	-0.45	35.8	1263	2957		
9135008	-1	35.23	956	1646	Pcp_loww	Low altitude low rainfall
9135019	-1.1	35.38	788	1829		

6.4.2 Flow infilling

Single mass curves of the flows for the four flow gauging stations along the river Mara, fig 6.5 show all the curves are flattening out at various points due to missing data. The R^2 values are below 90% indicating poor association of the flows. Double mass curves fig 6.5 indicates that the old mara bridge (herein "Mara") and the Mara mines gauging stations have a strong correlation (R^2 0.96). However the fact that the individual stations have a poor accumulation works against using the Mara mines station to fill in the missing data for the old Mara sites. The low coefficient of correlation between the stations makes the regression method unfit for flow data imputation. The long term mean of each day in a year was used to fill in missing data on stream flow discharge data. This method has also been applied in the Mara river basin by Mutie et al 2006, Mati et al 2008, and the larger lake region by Ndomba et al 2008.

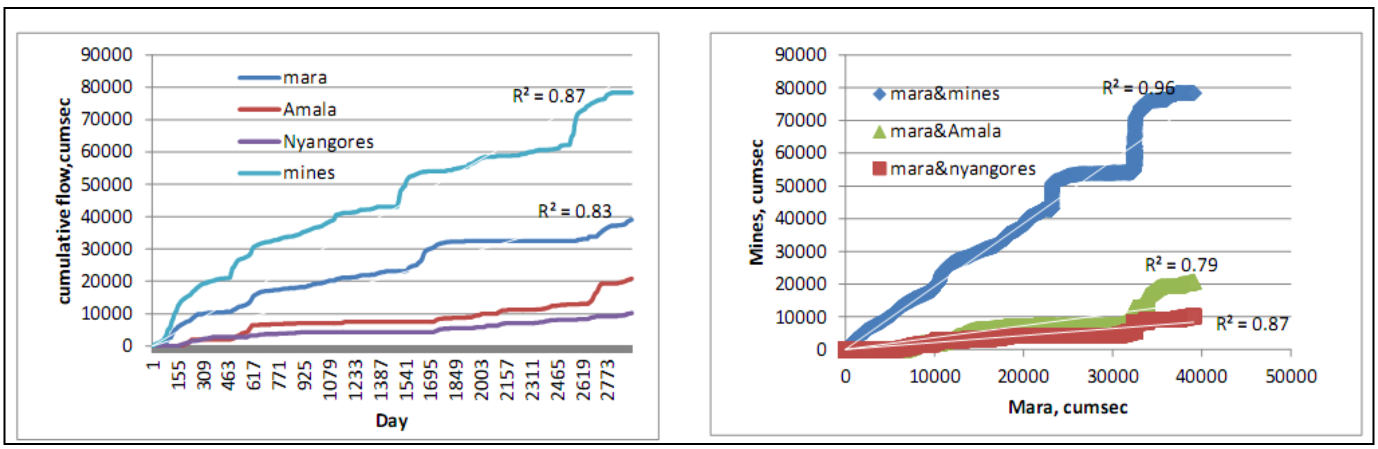


Figure 6.5: Accumulated flow for the period 1970-1977 for four stations along the Mara river in single (right) and double (left) mass curves

6.4.3 SWAT simulation

The SWAT simulation results for the various data manipulations for the model calibration showed that, the interpolation of the rainfall data to smoothen the orographic effects and compensate for scarcely located rainfall measuring stations led to an improvement of the model performance, (table 6.2). Although no algorithm to factor in secondary influences was used, the cluster of the stations with elevation under consideration made a marked improvement of the model performance. The creation of artificial rainfall stations based on areal interpolation produced the greatest improvement of >100%, while filling the flow data had worsening effect on performance -38% compared to the unfilled flow. The combined use of filled in rainfall and flow produced results no better than filling in rainfall data alone. Creutin and Obled (1982), Tabios and Salas (1985), Lebel et al. (1987), Goovaerts (2000) have all demonstrated that the estimation of rainfall by appropriate geostatistical tools gives more accurate results than other forms of interpolation.

Table 6.2: The NSE for the model calibration after different imputation

Method	**Inputs manipulated**	**NSE**	**R^2**	**% change on NSE**
IDW	Rainfall only	0.65	0.55	+124
CA	Rainfall only	0.62	0.57	+114
NN	Rainfall only	0.43	0.41	+48
CA & FA	Rainfall + Flow	0.40	0.55	+38
FA	Flow	0.18	0.18	-38
RS	none	0.29	0.30	Baseline

Abbreviations: *CA - cluster Averaging, NN – Nearest neighbor, CA&FA – cluster averaging + Flow averaging, FA - Flow averaging, RS – Raw data series.*

Visual inspections of simulated results show that the SWAT model response to the different inputs was also very different. For the flow based simulations, although the filled in data corresponded fairly well with the original dataset the simulations using the flow mean (FA) greatly overestimated the flow and the shape of the peaks/dips do not follow in the observed flow hydrograph, (Fig 6.6). The poor simulation from the flow based simulation may have been caused by the seasonal and interannual variation of rainfall which affects the extreme events (peaks) more than the average annual flow.

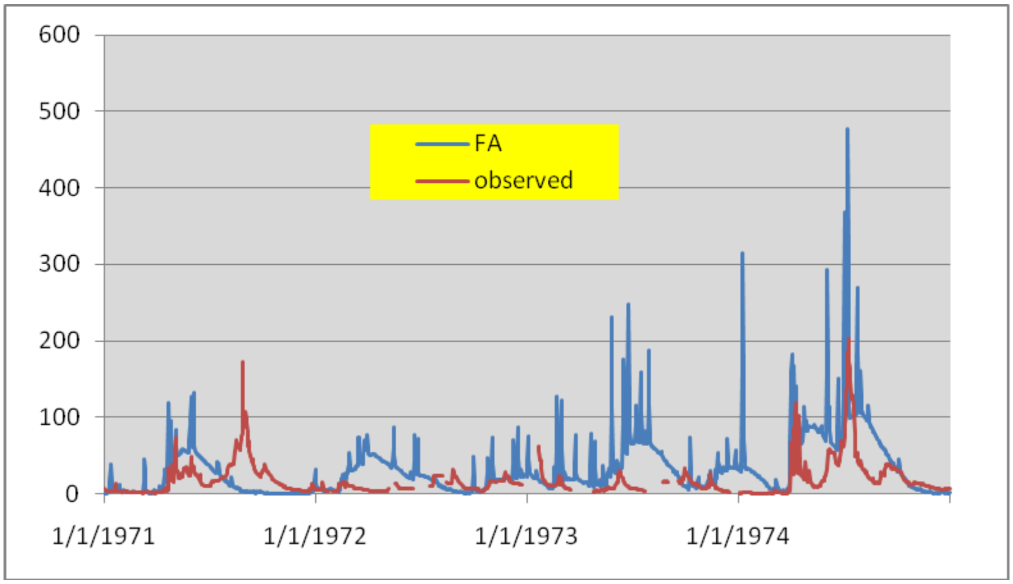


Figure 6.6: Comparison of the simulated flow using the flow averaging method and observed flow

The profile of the graphs from the rainfall based simulation was generally in agreement with that of the observed flow, although some they did not provide a good march to the observed flows hydrograph. The curves resulting from the Cluster Averaging (CA), and the Inverse distance weighting (IDW) showed a better fit than the rest of the curves, Fig 6.7.

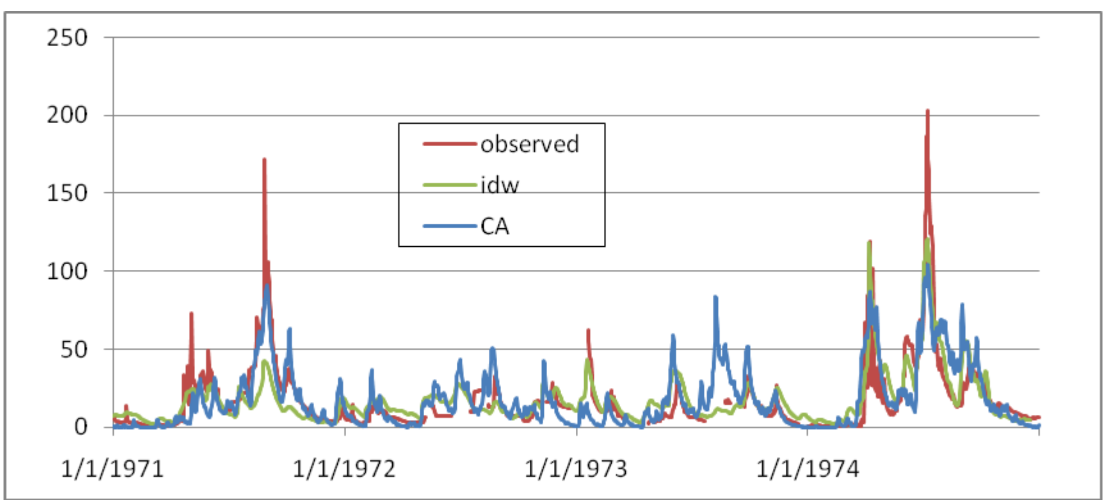


Figure 6.7. The different simulated flows resulting from different precipitation and flow inputs

6.5. Conclusions

Faced with a problem of high missing gaps, short term time series and non-availability of or inability to manipulate remote sensed data, the interpolation of rainfall from the available rainfall stations within and in the vicinity of the study area may serve to circumvent the challenge and produce credible results which render the model simulation usable for further catchment studies and analysis. Although geostatistical tools are available, the challenge of computation limitation due to the lack of skills and free availability of the software makes their application often impossible in developing countries. However using simple spreadsheet and open source software, it is possible to manipulate the data, and get reasonably good results. With a NSE of 0.62 with interpolated data, as opposed to 0.29 from original station data, the model calibration was deemed to be satisfactory and capable of being used for hydrological processes simulation.

6.6 References

Arnold, J.G., Williams, J.R., Maidment, D.R., 1995. Continuous-time water and sediment-routing model for large basins. Journal of Hydraulic Engineering 121 (2), 171–183.

Chang, J. C., and S. R. Hanna, 2004. Air quality model performance evaluation, Meteorology and Atmospheric Physics, 87: 167-196.

Cho, J., Bosch, D.D., Lowrance, R.R., StriCAland, T.C., Vellidis, G. 2009. Effect of Spatial Distribution of Rainfall on Temporal and Spatial Uncertainty of SWAT Output, Transactions of the ASABE, 52(5):1545-1555.

Creutin, J. C., and C. Obled. 1982. Objective Analysis and Mapping Techniques for Rainfall Fields: An Objective Comparison, Water Resources Research 18(2), 413–31.

Di Luzio, M., Srinivasan R., Arnold J.G. 2004. A GIS-Coupled Hydrological Model System for the Watershed Assessment of Agricultural Nonpoint and Point Sources of Pollution. Transactions in GIS, 8(1): 113-136.

Ehret. U., and E. Zehe, 2010. Series distance - an intuitive metric for hydrograph comparison, Hydrological Earth system sciences Discussion paper, 7, 8387-8425.

Gann. D., 2006. Rainfall Estimation Raster Conversion, Data Preparation for Hydrological Modeling with SWAT Hydrological Modeling with SWAT Mara Basin (Kenya / Tanzania).

Goovaerts, P. 2000. Geostatistical Approaches for Incorporating Elevation into the Spatial Interpolation of Rainfall. Journal of Hydrology 228, 113–29.

Green.I.R.A., and D.Stephenson, 1986. Criteria for comparison of single event models, Hydrological Sciences Journal, 31(3), 395 — 411.

Grimes D. I. F, and E. Pardo-Igúzquiza, 2010. Geostatistical Analysis of Rainfall, Geographical Analysis, Volume 42(2), 136–160.

Jain A.K., M.N.Murty, and P.J.Flynn, 1999. Data Clustering: A Review, ACM Computing Surveys, 31(3); 264-323.

Jayakrishnan, R., R. Srinivasan, C. Santhi, and J.G. Arnold, 2005. Advances in the Application of the SWAT model for water resources management,. Hydrological Processes 19, 749-762.

Lebel, T., G. Bastin, C. Obled, and J. D. Creutin, 1987. On the Accuracy of Areal Rainfall Interpolation of Precipitation, Water Resources Bulletin 21(3), 365–80.

Legates, D. R., and G. J. McCabe. 1999. Evaluating the use of "goodness-of-fit" measures in hydrologic and hydroclimatic model validation. Water Resources Research 35(1): 233-241.

Moriasi D. N., J. G. Arnold, M. W. Van Liew, R. L. Bingner, R. D. Harmel, and T. L. Veith, 2007. Model evaluation guidelines for systematic quantification of accuracy in watershed simulations , Transactions of the ASABE Vol. 50(3): 885−900.

Mulungu, D.M.M., Munishi, S.E. 2007. Simiyu River Catchment Parameterization using SWAT model. Journal of Science Direct. Physics and Chemistry of the Earth 32(2007) 1032-1039.

Ndomba, P.M., and B.Z. Birhanu, 2008. Problems and Prospects of SWAT Model Applications in NILOTIC Catchments: A Review, Nile Basin Water Engineering Scientific Magazine, Vol.1, 2008

Ndomba, P.M.,Mtalo, F.W. and Killingtveit, A. 2008. SWAT model application in a data scarce tropical complex catchment in Tanzania. Journal of Physics and Chemistry of the Earth. 33, 626-632.

Ndomba, P.M.,Mtalo, F.W. and Killingtveit, A. 2005. The Suitability of SWAT model in sediment yield modeling for ungauged catchments. A case of Simiyu subcatchment, Tanzania. In: Proceedings of the 3rd International SWAT conference, 11th-15th July, EAWAG-Zurich, Switzerland, pp. 61 – 69.

Santhi,C., J.G.Arnold, J.R.Williams, W.A.Dugas, R.Srinivasan, and L.M. Hauck 2001.Validation of the SWAT Model on a Large River Basin With Point and Non point Sources.Journal of The American Water ResourcesAssociation 37:1169-1188.

Schuol J. and K.C.Abbaspour, 2007. Using monthly weather statistics to generate daily data in a SWAT model application to West Africa, Ecological modeling, 201, 301–311.

Sevat, E., and A. Dezetter. 1991. Selection of calibration objective functions in the context of rainfall-runoff modeling in a Sudanese savannah area. Hydrological Sciences. Journal 36(4): 307-330.

Tabios, G. Q., and J. D. Salas. 1985. A Comparative Analysis of Techniques for Spatial estimation: A Case Study. Water Resources Research, 23, 2123–2134.

Van der Heijden, and U. S.Haberlandt, 2010. Influence of spatial interpolation methods for climate variables on the simulation of discharge and nitrate fate with SWAT, Advanced Geosciences, 27, 91–98.

Van Griensven. A., and T .Meixner, 2006. Methods to quantify and identify the sources of uncertainty for river basin water quality models. Water Science and Technology 53(1): 51-59.

Van Griensven A., M.K. Akhtar, D.Haguma, R. Sintayehu, J.Schuol, K.C Abbaspour, S.J Van Andel, and R.K Price, 2007. Catchment modeling using internet based global data: 4th SWAT international conference.

Zhang X., and R. Srinivasan, 2009. GIS-based spatial precipitation estimation: a comparison of geostatistical approaches. Journal of the American Water resources Association, 45(4), 894-906.

7 The Influence of Socio-economic Factors on Trees outside Forests in Sio River Basin, Kenya

Kweyu, R.[1]

Murimi, S.[1]

Obando, J.[1]

[1] Department of Geography Kenyatta University.

Email: rkweyu@yahoo.com

7.1 Abstract

Trees outside the Forest (TOF) are vital resources with functions similar to those of forest trees such as environmental, economic and social services. They also help to reduce pressure on natural forests as alternative sources of tree products. Therefore, if well managed, TOF can contribute to wealth creation by local communities. However, these trees have been threatened by different forms of human disturbances. This paper presents an analysis of the influence of socio-economic factors on the patterns and distribution of TOF in the Sio River Basin. The findings may serve as a pointer towards sustainable utilization of the resources in Sio River Basin as well as other river basins with similar situations.

Information concerning disturbance on trees was obtained using a tree stumps index denoted as number of trees per hectare (NS/ha). A Socio-economic survey was carried out by use of an informal interview with farmers to establish factors influencing the management of TOF. Data analysis involved testing the relationship between TOF and socio-economic factors. Results from the study reveal that the competitive nature of trees with food crops is the main reason refraining farmers from planting trees on their fields. Other factors include lack of enough land and tree seedlings. The survey on tree products depicts that farmers rely on TOF mainly for building followed by fuel. Further, some income generating and crop-friendly trees were grown in croplands. Majority of TOF are indigenous species that are either spared or have sprout.

This study demonstrates that TOF are purposely grown and maintained. It is important to supply farmers with seedlings of tree species having the potential of providing services and functions such as improved soil fertility, building materials and fuel wood.

Key words: *Trees Outside Forests, Socio-economic factors*

7.2 Introduction

Trees outside the forest (TOF) have been defined as trees and tree environments on land not defined as forest or other wooded land (FAO, 2000). TOF are often but not always domesticated and they include trees in cities, on farms along roads and other locations that are not part of a forest. As a renewable resource, TOF play an important ecological role. The forest patch, isolated trees, and windbreaks are important for conserving local and regional biodiversity because they provide food sources and nesting sites for a variety of animal species. They also serve as stepping-stones or corridors that facilitate animal movement across the agricultural landscape (Hugget, 2004; Tews et al., 2004). TOF also preserve the organic matter contained in the soil, boosting its fertility (Kiyiapi, 2002; UNEP, 2002), facilitate the percolation of rainfall and stability of stream water regimes (Allan, 2004), contributing to great extent in controlling soil erosion by flowing water and wind. This enhances agricultural production and increased yields in the long run. By providing many products such as fruits, fodder, fuel, timber and medicine, TOF play an important economic role.

In Kenya, extensive tree planting on farmlands promoted in 1970's and 80's with land tenure security resulted in an increased trend of tree cover and species diversification on privately owned farms (Kiyiapi, 2002). The Kenya Forests Master Plan notes that farm forestry has been very successful in increasing the growing stock of trees and in the production of wood and proposes to close the country's demand and supply gap by encouraging farmers to plant more trees (GOK, 2000).

7.3 Methodology

7.3.1 Study Area

The Sio River originates from Mount Elgon region which is located on the Western Kenya - Uganda border at an altitude of 2000m. The river flows into Berkeley Bay of Lake Victoria in Uganda. The transboundary river basin lies between latitude 0° 36' 42'' N and 0° 0' 34''S and longitude 34° 25' 24'' E and 34° 55' 52'' E. The basin has a fairly flat terrain with some areas having undulating slope. The basin has a medium elevation from 1100m to 1600m above sea level. The soils are moderately deep, and consist of well drained clay loams and sandy loams (see Figure 7.1).

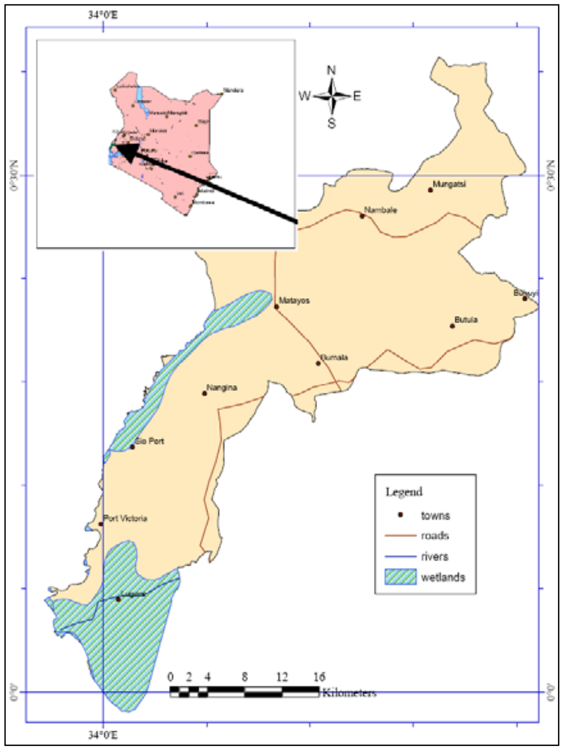


Figure 7.1: The study area: (Fieldwork, 2008)

7.3.2 Methods

Sample plots were laid out along existing boundaries of the farmer's field. The approximate size of a farmer's field in the study area varied from 0.1 hectares (for annual crops) to a hectare (for sugarcane fields). The variables collected during fieldwork were Land Use Categories (LUC) and number of tree stumps per hectare (NS/ha). The number of stumps was used to determine the human disturbance indicator in data analysis. Inside the plot, dominant LUC was identified and visually documented through direct observation. The number of stumps were recorded and computed during fieldwork sessions. Socio-economic survey involved the participation of 50 farmers in informal interview sessions. Data analysis was carried out using Microsoft Excel and SPSS software version 11.0.

7.4 Results and Discussion

7.4.1 Human disturbance on Trees Outside the Forest

Based on information obtained from Landsat images and pilot survey, land cover/land use in the study area was categorized as: Annual subsistence crops such as maize, cassava and potatoes, Perennial crops such as sugarcane, Bush, Pasture/fallow land, Settlement and Swamps. Since exploitation of trees is associated with partial or complete damage to trees, the presence of stumps can be used as an indicator of human disturbance (Chidumayo, 2005). Results from Figure 7.2 indicate a higher human disturbance index within the annual crops LUC of 6.5 stumps per hectare. This could be explained by the fact that farmers have to cut trees down especially when clearing a fallow or a bush to grow annual crops (Bewket, 2003).

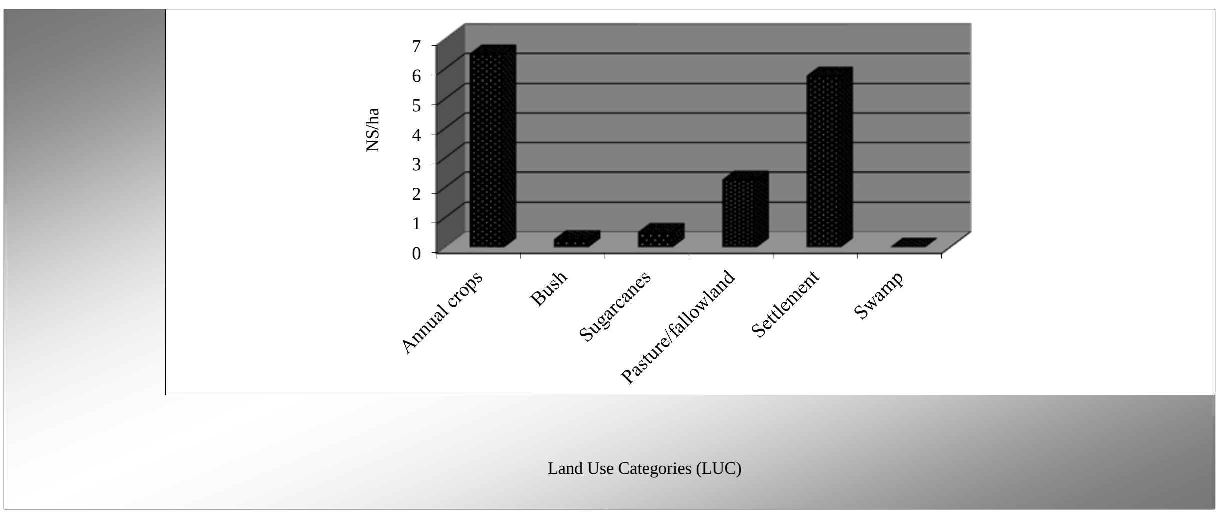


Figure 7.2: Number of stumps distribution in different LUC

Kruskal-Wallis test was performed to test whether there is significant difference of Number of Stumps per hectare (NS/ha) in different LUC. The results are: Test statistic for NS/ha, Kruskal-Wallis test, $\alpha=0.05$, $p<0.05$. (Kruskal-Wallis test: $x^2=14.706$, df=5, p=0.018). Therefore, the Null hypothesis is rejected and the study concludes that the number of stumps is significantly different in different LUC.

7.4.2 Socio-economic survey on tree products

The collected information about the most important tree products and services for rural livelihood was ranked according to priority given by the interviewees. As indicated in Figure 7.3, the most important tree product for the farmers in the area is building. Farmers who indicated building as the most important tree service were 47.5% while 35.0% recognized fuel wood as the most important tree product in their livelihood. Only 10% of farmers recognized shade as the most important tree service. When questioned about the second priority of importance, it was revealed that among 32.5% of the farmers, fuel wood was second important tree product for their livelihood. TOF are used directly as firewood by rural dwellers or burned to produce charcoal (Plate 1). Tree species used for fuel wood are also suitable for charcoal production (Bewket, 2003; Wamukoya, 1995). The shade provided by trees was second choice for 17.5% of the farmers. Poles for building were a second priority for 20% of the farmers. When questioned about the third priority of importance of tree products, 27.5% of the farmers recognized fruit, 23.0% shade and 15.0% fuel.

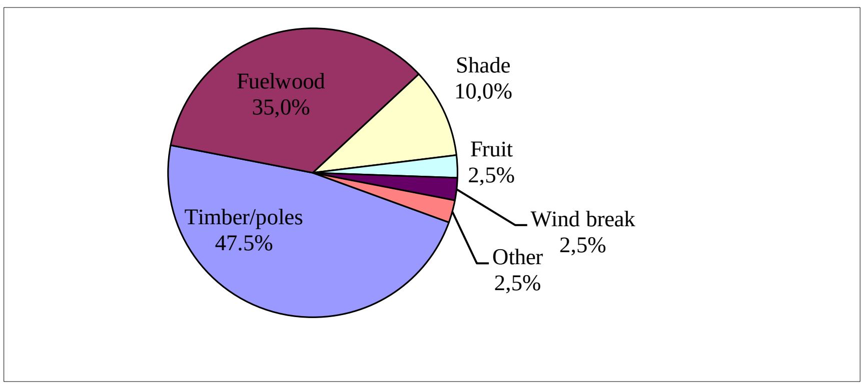


Figure 7.3: Tree products ranked first according to farmer's perception

Figure 7.4: Charcoal burning in the study area (17/08/2007)

According to the farmers, the main problem that hinders tree planting is that they compete with both annual and sugarcane crops for nutrients and space. Out of those interviewed, 35% noted that this discouraged them from planting trees on their lands. Thirty percent (30%) of farmers reckoned that lack of enough space (sufficient land) is the reason for not planting or maintaining trees in their fields. Sufficient land to farmers meant at least one hectare of land per three people. The Economic Recovery Strategy (ERS) for wealth creation and employment stipulates that Eleven million Kenyans live in absolute poverty and that majority have either insufficient or no land for farming (GOK, 2003). This scenario confirms that farmers in rural areas lack sufficient land to diversify their management options, including TOF maintenance. The other reasons for not planting trees according to farmers include lack of tree seedlings. Figure 7.5 shows the existing constraints that affect tree planting and management according to the farmers' perception.

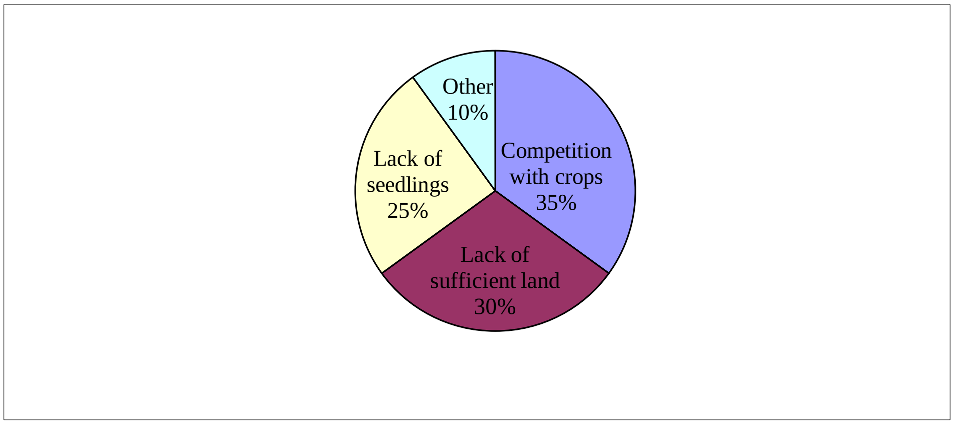


Figure 7.5: Constraints on tree planting and management

7.5 Conclusion and Recommendation

The research concludes that the distribution and density of trees outside the forest (TOF) are influenced by socio-economic factors in the Sio River basin. The research study also revealed that the main benefit of TOF products to farmers is building materials followed by fuel wood. Whereas the main constraint to maintaining TOF on farmers' field is the competitive nature of trees with crops followed by lack of sufficient land to support tree planting.

The study recommends that farmers need to practice collective participation in TOF management. This is in line with the forest bill 2005 (GOK, 2005) that calls for community participation in natural resource management. Fast growing tree species should be planted by farmers so that they can generate income by selling tree products. Indigenous tree species should be preserved on the landscape as they conserve the soil. The study specifically recommends to farmers coppicing tree species (one that grows back when its stem is cut) such as *Gliricidia sepium* (Jacq.) *Kunth. ex Walp* as permanent intercrop with sugarcane crop. Farmers should avoid planting of exotic evergreen species such as *Pinus patula Schiede ex Schitdl. & cham* within watersheds as they drain away water from the soil. To reduce competition between trees and crops, farmers should practice shoot and root pruning particularly during the early crop cycle.

7.6 References

Allan, D. J., 2004. Stream Ecology: Structure and function of running water. Kluwer Academic Publishers, The Netherlands.

Bewket, W., 2003. Household level tree planting and its implications for environmental management in the northwestern highlands of Ethiopia: a case study in the Chemoga watershed, Blue Nile Basin. Land degradation and development, 14: 377–388.

Chidumayo, E. N., 2005. Changes in Miombo woodland structure under different land tenure and use systems in central Zambia. Journal of Biogeography, 29: 1619–1626.

FAO, 2000. Forest resources assessment 2000: terms and definitions, FAO. Rome http://www.fao.org/forestry/fo/fra/docs/FRA_Wpleng.pdf. (accessed on 9/10/06).

GOK, 2000. Kenya Forestry Master plan. Ministry of Environment and Natural Resources, Nairobi

GOK, 2003. Kenya Economic Recovery Strategy for Wealth and Employment Creation 2003-2007. Ministry of Planning and National Development, Nairobi.

GOK, 2005. Kenya Forest Act 2005. Ministry of Environment and Natural Resources, Nairobi.

Hugget, R. J., 2004. Fundamentals of biogeography. Routledge, Oxfordshire.

Kiyiapi, J. L., 2002. Trees outside forests: Kenya. FAO. Rome

www.fao.org/DOCREP/005/Y2328E/Y2328e19.htm (accessed on 17/10/06).

Tews, J., Brose, U., Grimm, V., Tielbo¨rger, K., Wichmann, M. C., Schwager, M. and Jeltsch, F. , 2004. Animal species diversity driven by habitat heterogeneity: the importance of keystone structures. Journal of Biogeography, 31: 79–92.

UNEP. 2002. Africa Environment Outlook:Past present and future perspectives. Earthprint. UK.

Wamukoya, C., 1995. Energy consumption in 3 rural Kenya households. Journal of Biomass and Bioenergy, 8:44-51.

7.7 Acknowledgements

The authors are grateful to the Association of African Universities (AAU) for providing funds for this research. Sincere gratitude goes to Messers Michael Wandera, Benard, Jeremiah Akoma, Zebedeus Nyamari and the village heads for their support during the field research activities. Without their help it would have been difficult to accomplish the work in this study.

8 Hydro-economic Inventory for Sustainable Livelihood in Kenyan ASALs: The case of Muooni Dam

Luwesi, C.N.[1]

Obando, J.A.[1]

Shisanya, C.[1]

[1] Kenyatta University
P.O. Box 43844, Nairobi

Email: cushngonzo@gmail.com

8.1 Abstract

South-East Kenya is vulnerable to increased siltation and pollution of drainage channels and dams as well as to high risk of crop failure due to rainfall fluctuation. The latter increases the cost of water for the food production and energy supply. "Hydro-economic inventory" (HEI) is suggested to be the prerequisite for implementation of an "Integrated watershed management" (IWM) to ensure sustainable food production and energy supply in "Arid and semi-arid tropics" (ASATs). This study aimed to apply HEI to assess the impact of the Kenya water sector reforms on farmers and their environment. Specifically, it intended to: (i) investigate significant changes recorded in Muooni Dam Catchment due to inefficient use of agricultural water and land; (ii) analyze farm management practices and farmers' behaviour change in the selected catchment as a result of environmental changes; and (iii) determine the extent to which both social and environmental impacts have contributed to the variations of farming water costs and the economic efficiency of agricultural water use in the catchment. Results of this study show that both anthropogenic factors and environmental externalities perturb efficient use of water by farmers in the dam site. These factors have affected water availability in Muooni Dam at a decreasing rate of 6.2% per annum. The reduced water storage thwarts any prospect of high yields and good incomes among smallholder farms, and hampers sustainable supply of bio-energy and hydro-electricity. For efficiency, farmers are urged to adopt an "Economic order quantity (EOQ) or a "Limit average cost" (LAC) or at least a "Minimum efficient scale" (MES) of their water demand under the "Above normal" (NOR), "Normal" (NOR) and "Below normal" (BNOR) rainfall regimes, respectively, using efficient farming technologies and hydro-political strategies.

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

8.2 Introduction

Water stress and land degradation constitute major causes of losses of yields and incomes in the agricultural and energy sectors of Kenya, particularly in "arid and semi-arid tropics" (ASATs) (Jaetzold *et al.*, 2007). Most homesteads in these areas often rely on existing natural resources including crops, water and firewood supply, sand harvesting and quarrying as their main sources of livelihood (Shisanya &

Khayesi, 2007). Due to the degradation of most catchment areas, water crises arouse, not as a result of rainfall depletion but as an outcome of mismanagement of the available water resources such that billions of people and the environment suffer badly. To curb the trend of water stress and scarcity, John Howard, former Australian prime minister, suggested a “complete overhaul of how water is managed” so as to restore rivers to health after many years of over-exploitation of water and droughts (Ngurari, 2009). Therefore, many governments have embarked in the process of reforming the management of their natural resources with the aim of managing sustainably their water resource. The water sector reforms usually culminate with the enactment of comprehensive water legislations, policies, and strategies. As usual, most governments in developing countries rely on the funding and technical assistance from their bilateral and multilateral partners to implement their national agendas. Yet, a discreet observer would ask: (i) what significant changes have been recorded in different catchments since the implementation of these reforms? (ii) How have these interventions improved the life and behaviour of different categories of water users in the catchments? (iii) To what extent have they contributed to the economic efficiency of water and land uses?

This paper discusses hydro-economic issues leading to crop failure and energy disruption in Kenyan “Arid and semi-arid tropics” (ASATs). It introduces the concept of “Hydro-economic inventory” (HEI) and illustrates it with findings from the Hydro-geomorphologic impact assessment, the social impact assessment and the economic inventory conducted in Muooni Dam Catchment.

8.2.1 Concept of Hydro-Economic Inventory

“Hydro-Economic Inventory” (HEI) is defined as “an assessment of the impact of water use on the hydrology and the geomorphology of a catchment area, the social welfare of local stakeholders, and the economic efficiency of water and land use in a changing environment” (Luwesi, 2010). In a nutshell, HEI integrates three major techniques used to assess impact in a watershed and shed light on the final outcome of the water sector reforms. These techniques encompass an “Hydro-geomorphologic impact assessment”, a “social impact assessment” and an “Economic inventory” of the efficiency of water and land use.

Hydro-geomorphologic impact assessment uses the technique of "Environmental impact assessment" (EIA) to ensure that "the likely effects of new development on the environment are fully understood and taken into account before the development is allowed to go ahead" (Hacking & Guthrie, 2006). Figure 8.1 provides the sequence of repeatable steps followed during hydro-geomorphologic impact assessments. The Social impact assessment (SIA) entails a similar process as EIA but overlaps both planning and Monitoring and Evaluation (M&E). SIA focuses on the effects of a project or public policies on stakeholders' cultural heritage and archaeological sites, food security (production, preservation and distribution), health and education, environmental health (protection and conservation of the natural resources), and disaster adaptation and mitigation (the impact of environmental changes on economic activities) (Burdge, 2008).

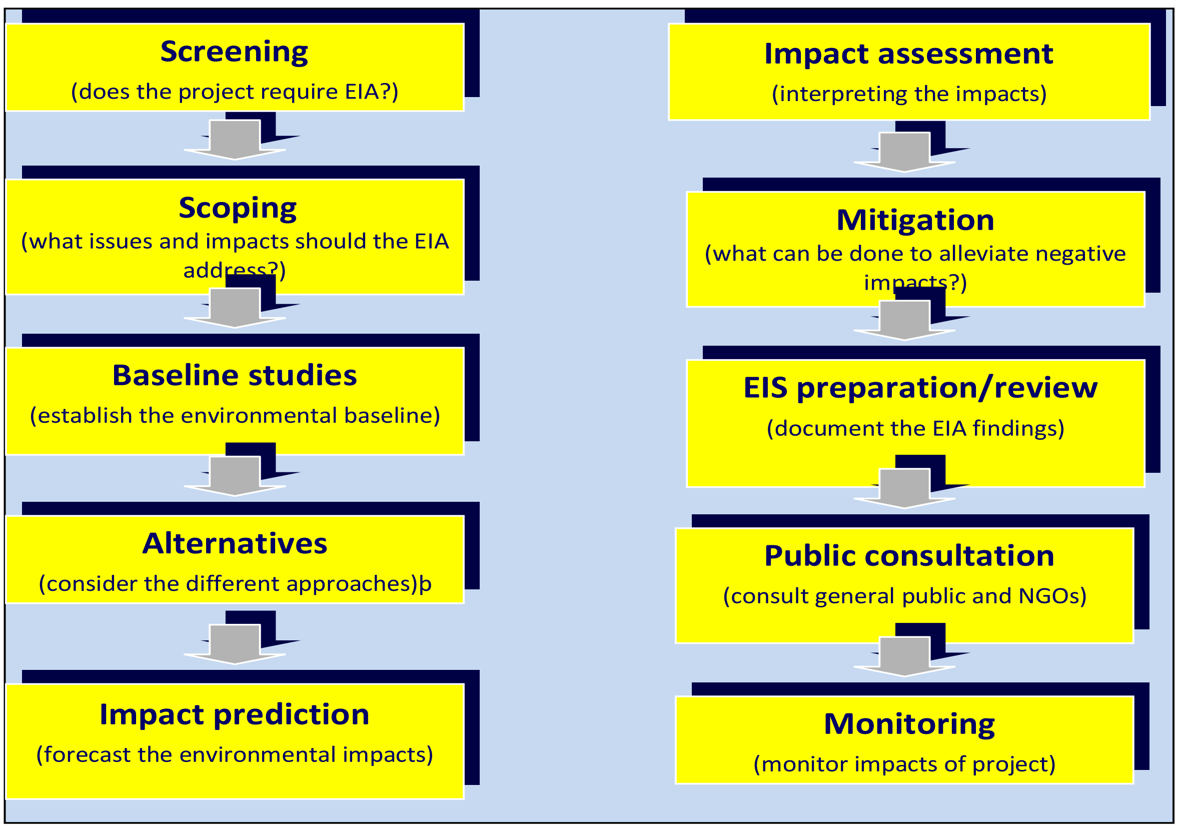


Figure 8.1: Environmental Assessment Framework (Hacking & Guthrie, 2006)

Finally, "Economic inventory" assesses the effects of an economic environment on the productivity of financial and physical resources. Thus, "hydro-economic inventory" uses hybrid inventory models to determine efficient levels of water use under "above normal" (ANOR), "normal" (NOR), and "below normal" (BNOR) rainfall regimes. Three key efficiency indicators are derived from this analysis, namely the "Economic order quantity" (EOQ) computed under the ANOR, the "Limit average cost" (LAC) determined under NOR, and the "Minimum efficient scale" (MES) calculated under the BNOR, respectively (Figure 8.2). These models combine both internal and external costs incurred in the management of water resources. To simulate efficient levels of water use under fluctuating rainfall regimes the model integrates both the cost of transaction and opportunity cost (internal costs), along with external costs such as the cost of water saving under ANOR, and the water shortage cost under BNOR. Finally, the analytical process assesses the variations of incomes vis-à-vis costs under different hypotheses of the management efficiency (EOQ, LAC and MES) to design strategic guidelines for the management or the reform of the water sector.

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

Figure 8.2: Economic Inventory Outputs (Luwesi, 2010)

Notes:

$\bar{r}_{an}$ *hereby represents the optimum water demand turnover ratio under the above normal rainfall regime scenario*

$\bar{r}_{no}$ *stands for the optimum water demand turnover ratio under the scenario of normal rainfall regime*

$\bar{r}_{bn}$ *is hypothesized to be the optimum water demand turnover ratio under the below normal rainfall regime*

Q refers to a normalized farming output quantity

q stands for a normalized water input quantity

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

8.3 Materials and Methods

8.3.1 Physiography of the Study Area

Muooni is a small catchment of 25 km^2 located in the Machakos District of the Eastern Province of Kenya. Geographically it is bound by latitudes 1□14' 24" S and 1□□□□ ' 48" S, and longitudes 37□9' 36" E and 37□□□ 2' 00" E in the 37th Meridian. It is a dry and hilly area rising between 1434 and 2005 m, within the upper midland agro-ecological zone 4 (UM4-AEZ), which is mainly a maize-sunflower zone. Average annual temperature range between 10 and 30 ^{0} C, with average annual rainfall of 626 to 783 mm. The catchment's climate ranges from arid to semi-arid with Muooni being the only perennial river. During the 2009 census, its population was estimated to 14,390 persons with a density of 535 persons /km2 (GoK, 2010). They are mainly Akamba people, agriculturalists from a Bantu tribe.

8.3.2 Research Methodology

Gonzalez *et al.* (1995) hydro-geomorphologic impacts sampling technique was used alongside Zeiller (2000) on-farm stratified random sampling. The impact sampling technique aimed to record significant land-use activities and impacts randomly occurring on farmlands, while the on-farm sampling technique involved the selection of some 66 farms at Muooni Dam site and 60 key informants outside the dam site.

This method provided equal chances of selection for all the respondents, both the most accessible ones and those far away from Muooni Dam site.

Data collected was analyzed using descriptive statistics, non-parametric tests, and time series analysis. This enabled the valuation of impacts assessed, the establishment of their relationship with land-use activities observed, and the prediction of Muooni Dam's active water storage capacity. Spatial data were processed using ArcView 3.3 GIS software to map land-use activities and impacts assessed. The analysis proceeded later on to the assessment of social impacts using mainly descriptive statistics, pattern and trend analyses, and a triangulation of both quantitative and qualitative methods. This led to the economic inventory, which totally relied on the computation of farmers' water demand and related costs using hybrid inventory models (see Table 8.1). It also helped to simulate the optimum levels (EOQ, LAC and MES) of farming water demand and cost under three respective scenarios of rainfall fluctuation: the ANOR, NOR and BNOR rainfall regimes. Efficiency indicators of water use were computed for three different categories of farmers, notably "Large-scale farmers" (LSF), "Medium-scale farmers" (MSF) and "Small-scale farmers" (SSF). The following sections present these analytical components of the HEI conducted in Muooni Dam Catchment.

8.4 Results and Discussion

8.4.1 The Hydro-Geomorphologic Impact Assessment

Hydro-geomorphologic impacts consisted therein of soil erosion problems, sedimentation of Muooni Dam and water over-abstraction in the catchment. After screening and scoping these issues, the analysis provided six hydro-geomorphologic indicators of water and land use and their impact on Muooni Dam Catchment (Table 8.2).

Table 8.2: Land-Use Activities and Impacts Assessed at Muooni Dam (Luwesi, 2010)

Weight	*Land-use activities*	*Weight*	*Environmental Impacts*
1	Tree planting	1	Sheet/ rill erosion in the farm area
2	Intensive cultivation using water	2	Encroachment on wetland

	pumps/ tanks		
3	Subsistence cultivation with limited irrigation	3	Sand harvesting/ quarrying impacts on farms
4	Subsistence cultivation without irrigation	4	Gully erosion on farmland
5	Livestock keeping with some cultivation	5	Landslide on farmland
6	Livestock keeping without cultivation	6	Eucalyptus water over-abstraction

This table indicates that land-use activities assessed and their likely hydro-geomorphologic impacts were assigned meaningful figures (1, 2, 3, 4, 5 and 6), according to the significance of their contribution to the degradation of Muooni Dam environment. This environmental degradation referred to the soil erosion problems leading to soil loss on farmlands, the sedimentation of Muooni Dam, and to excess water loss from its reservoir and the whole catchment. Land-use activities assessed and their likely environmental impacts are shown in Figure 8.2 and Figure 8.3, respectively.

Figure 8.2 reveals that subsistence cultivation without irrigation (46%) and sylvicultural activities (29%) are the dominant land-use activities. Thus, agro-forestry and rainfed cropping both represent two thirds of the total farming area estimated to 31.2 acres. Insignificant land-use practiced include livestock keeping with some cultivation (12.1%), intensive cultivation using water pumps and storing devices (10.6%), and subsistence cultivation with limited irrigation (3%). None among farmers surveyed was practising livestock keeping without cultivation. Figure 8.3 displays sheet and rill erosions along with eucalyptus water over-abstraction among the most significant environmental impacts observed in the catchment. This is a result of the depleting forest cover. It is followed by the planting of eucalyptus trees elsewhere in the catchment, including farms located in the wetlands, which represent 18% of the total number of farms surveyed. Under these wooden areas, sheets and rills occurred in more than 63% of farms assessed, while gully erosion, landslides and encroachment of agricultural fields on wetlands accounted for 8%, 3% and 8% of farms surveyed.

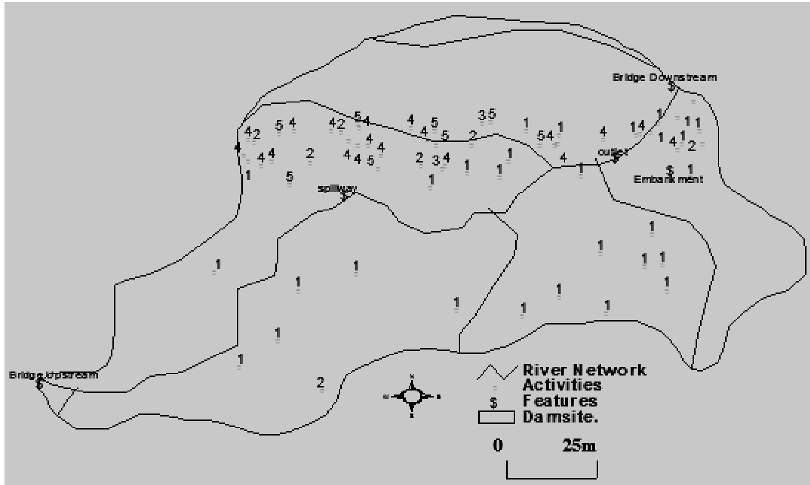


Figure 8.2: Spatial Distribution of Land-Use Activities in Muooni Dam Catchment (Luwesi, 2010)

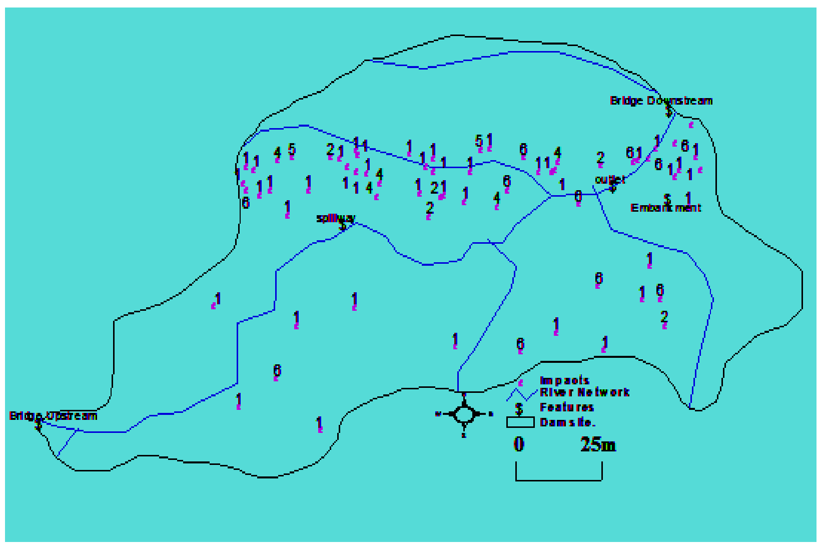


Figure 8.3: Spatial Distribution of Hydro-Geomorphologic Impacts in Muooni Dam (Luwesi, 2010)

Though hydro-geomorphologic impacts were likely widespread on farmlands, the analysis did not establish any significant association between the suspected impacts and land-use activities assessed. It is worthwhile to note that Mann-Whitney U-Test proved with 99.8% confidence level that the impacts observed on farmlands and land-use activities assessed were randomly drawn from independent populations ($Zu= 4.9562 > Z\rho = 3.99$, with $\alpha =0.002$, $U_1= 2,178$ and $n_1= n_2= 66$). This is corroborated by the Spearman's rank correlation which led to the acceptance of the null hypothesis ($Ho : \rho_s=0$) stating that there was no significant relationship between the populations from which the two samples were drawn ($Zu= -0.01081 > Z\rho = -3.99$ with $\alpha =0.002$ and $n-1=65$).

The analysis insinuated that drivers of environmental impacts might have included both anthropogenic and biophysical factors hastening the degradation of Muooni catchment area. The exponential decline in water storage capacity of the dam is an indication of the trend of soil erosion and eucalyptus water over-abstraction within the catchment (Kitissou, 2004). Figure 8.4 shows that the active water storage capacity of the dam reservoir was estimated to 208,791 m^3 (in the year 2010). Though its maximum capacity was established at 1,559,400 m^3 in 1987 it has decreased at an annual rate of 6.2%. In the absence of any intervention, it will reach out its threshold in the year 2019. Following such decrescendo, farmers are expected to experience more severe water stress in the coming future.

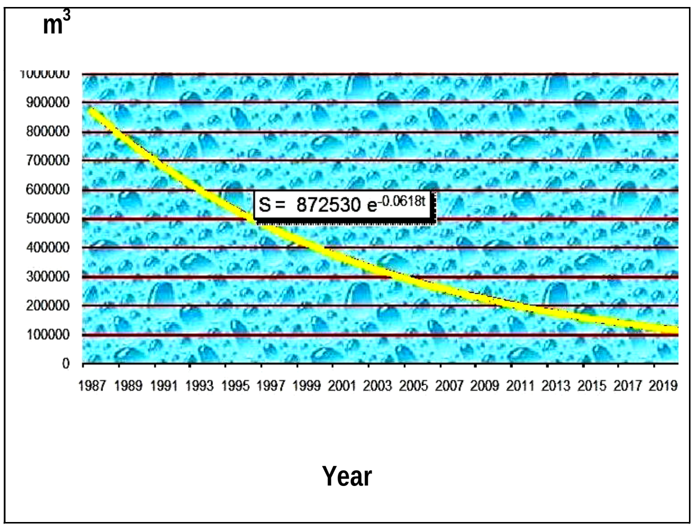


Figure 8.4: Trendline of Muooni Dam's Active Water Storage Capacity (Luwesi, 2010)

The trend of the dam storage capacity shows that its reservoir was cumulatively loaded by sediments from farms, just after the completion of the dam project. The siltation started with the 1987 El Niño drought which was accompanied by the 1988 La Niña flood (Shisanya, 1990; Shisanya *et al.*, 2011). Jaetzold et al. (2007) noticed that the lengths and intensities of agro-humid periods in south-eastern Kenya were mostly affected by the El Niño Southern Oscillation (ENSO), whereby the short rainy season could become extremely wet (Into-ENSO) or extremely dry (Anti-ENSO). For instance, the Into-ENSO of 1992-1993 was followed by an Anti-ENSO in 1993-1994. The resulting extreme moisture deficiencies led to plants desiccation and extreme water stress. When another Into-ENSO occurred in 1997-1998, gullies and landslides likely occurred in farmlands and elsewhere in the catchment (Wambongo, 2007). The latter were the drivers of excess loss of water and soil in farming that led to inefficiency of farming activities in Southeast Kenya in general, and Muooni Catchment in particular.

It is also important to note that about 34.35% of the variation of the dam storage capacity was likely due to other parameters including poor management, excessive evaporation and seepage from the bottom of the dam reservoir, owing to the obsolescence of the dam (Thompson & Scorging, 1995; Wikipedia, 2008). The decomposing wooden logistics may have produced some methane and carbon dioxide gases in the dam reservoir, thus contributing to the emission of greenhouse gases. The latter must have an impact on the variation of the temperature of water stored in the dam, and on the change of the catchment microclimate and the country climate as well as on the global climate. Reports by the World Commission on Dams highlight the fact that the decay of plant materials in anaerobic environments of flooded areas result in a change of climatic patterns of such environments (UNEP, 2002). The quality and safety of water as well as the sustainability of energy provided by such dams is thus questionable worldwide. The combined effect of these factors justifies the catchment microclimate change exhibited by the phenomena of drought recurrence, watercourses seasonality and relentless variations of rainfall regimes. Thus, water stress may have threatened farmers' social welfare and the economic viability of their activities under the variations of farming water costs with rainfall fluctuation. It may have resulted in the prevalence of food shortages, energy rationing or disruption, water borne diseases and other disasters to cite but a few.

Morgan (1995) observed that runoff could exceed a critical rate increasing its velocity or tractive force under changing climatic conditions resulting from excess land-uses. ENSO intense and deficient rainfalls were such tractive forces enhancing downstream and downwind sedimentation of Muooni River and its dam reservoir. Though farmers were enhancing soil protection using terraces, contours, cut-off drains, polyculture and agro-forestry, the on-site effects of soil erosion and eucalyptus water over-abstraction may be explained by inadequate soil conservation measures (Tiffen *et al.*, 1994; Mutisya, 1997; Luwesi, 2009). Off-site effects of soil erosion and high water evaporation from the dam reservoir may be elucidated by the effects of environmental changes, notably by El Niño floods and droughts, heavy wind pressures, footpaths and roadsides, sand harvesting and deforestation as well as others forces from outside Muooni Dam Catchment (Shisanya, 1996; Jaetzold *et al.*, 2007). Unskilled farmers could go blindly farming without expecting any early effect of soil erosion on land and water degradation. As a result, they would realize later that inter-rills have become gullies, just when they are "difficult to jump over" (Waswa, 2006). These geomorphologic impacts alongside water over-abstraction by alien trees (mainly eucalyptus) later hinder water availability in drainage systems and storages for agricultural use in Muooni dam reservoir. The “Social impact assessment” (SIA) and “Economic inventory” below focus on such issues.

8.4.2 Social Impact Assessment

It was observed that land management was highly correlated with the farmers’ level of education and poverty (Waswa, 2006). Their formal educational credits and professional status reflected the type on-farm management observed on the ground. Table 8.3 shows that a majority of farmers attained some levels of formal education, with primary (33.3%) and secondary (30.3%) educational credits, professional credentials (12.1%) and university degrees (6.1%). Only some 18.2% of the farmers interviewed had no formal education. An analysis of their professional status divulged that most farmers were self-employed, either in full-time farming (33.3%) or in off-farm activities (21.2%). Some others worked with private enterprises (36.4%) or in the Public Service (9.1%). None of them was a schoolteacher or a university lecturer.

Table 8.3: Farmers’ Categories and Education (Luwesi, 2009)

No	*Farmers' Category*	*Farmer Education Level*					*Total*
		None	*Primary*	*Secondary*	*Professional*	*Tertiary*	
1	Full Farmers	8	12	2	0	0	*22*
2	Public Servants	0	0	2	0	4	*6*
3	Private Employees	4	8	6	6	0	*24*
4	School teachers	0	0	0	0	0	*0*
5	Uncategorized	0	2	10	2	0	*14*
	Total	*12*	*22*	*20*	*8*	*4*	*66*

The distribution of farmers by level of income confirmed that poverty was a reality in the study area. Survey results disclosed that 30% of farmers in Muooni Dam Catchment had a daily average income of less than US $1, with an annual income averaging US$ 231 (for $1=KES 60). Accordingly, the distribution of farmers by class of income was dominated by small-scale (SSF) and Medium-scale farmers (MSF) earning a monthly income below KES 3,000, and between KES 3,000 and 5,999, respectively. Farmers' poverty in this area was likely due to lack of potential agricultural lands and population pressure on already degraded lands (Luwesi, 2010). Population pressure on land was characterized by increased settlement in marginal lands, the sub-division of ranches for sedentary small-scale farming, and further sub-division of land for settlement (Jaetzold *et al.,* 2007). Sedentary small-scale farming was portrayed by excessive multiple cropping and intercropping, while farmland subdivision depicted a strategic way of fighting extreme poverty in Muooni Dam Catchment. Farmers were subdividing their lands to allow new settlers undertake off-farm activities and/ or work part-time in farming. The risks of soil loss and water over-abstraction are to worsen in this catchment since farmland caretakers lack sufficient knowledge on soil conservation and efficient farming methods (Waswa, 2006). Moreover, poor yields and incomes lead a majority among farmers to substitute eucalyptus trees with subsistence crops, and monoculture with excessive multiple cropping and intercropping (of 6 to 15 species). Thus, exotic trees, crops, and weeds substitute the natural vegetation in most wetlands. These interlopers generally exacerbate the vital functions of the whole ecosystem, owing to the fact that they are not water friendly (Jansky *et al.,* 2005).

Farmers' recourse to excessive intercropping and multiple cropping of perennial indigenous and alien crop species on small farmlands cannot hold them back from poverty. The multiple cropping of about 6 seasonal crops and 9 perennial crops within a small plot area of 1.5 acres in such a hostile environment can only enhance the inefficiency of their farming activities (Luwesi *et al.*, 2011). With a declining rate of farming area of 40% in about 10 years, excessive intercropping and multiple cropping may have resulted in "land harassment" (Ngonzo *et al.*, 2010). Moreover, water over-abstraction by eucalyptus and other alien trees along with off-site effects of El Niño floods and droughts accelerate the risks of soil erosion and water excess loss (Kitissou, 2004; Ojwang; 2008; Ngurari, 2009). Farmers' strategy later rebound on the dam's active water storage capacity by spoiling its water reserves and loading important sediments in its reservoir, especially after tree harvesting. The negative trend of the active water storage capacity of the dam affects considerably the quantity and price of water in the catchment, resulting in a costly farming production. The following section develops an economic inventory to discuss issues related to the variations of the farming water demand and cost in Muooni Dam Catchment under rainfall fluctuation.

8.4.3 Economic Inventory

The decreasing water levels in Muooni Dam thwarts smallholder farms' yields and incomes. Table 8.4 suggests that most farmers surveyed are at the brink of poverty since they incur losses over years due to the decreasing productivity of their farming water and land resources. Therefore, the study needed to establish the levels of farming water efficiency under fluctuating rainfall regimes in Muooni Dam Catchment. To determine the optimum levels of farming water demand (EOQ, LAC and MES), the study needs first to assess the variations of actual farmers' water demand and their related costs.

Results show that increased shortage costs of farming water and the cost of fertile soil excess loss constrain farmers to order less farming water (W_f) than required by their crops (W_c). Large-scale (LSF), Medium-scale (MSF) and Small-scale farms (SSF) working in Muooni Dam Catchment could just afford 28.9%, 12.2% and 4.4% of their actual crop water requirements, respectively (Figure 8.5). In such conditions, their operational costs soared by 175%, 518% and 1,420% of the actual total costs of farming water under the ANOR, NOR and BNOR scenarios, respectively (Figure 8.6). This underscored a progressive accumulation of farming losses by a majority of farmers over years.

Table 8.4: Allocation of farmers' annual income (Luwesi, 2010)

N°	Operations	LSF (KES)	MSF (KES)	SSF (KES)
1	*Farming Income*	*428,400*	*273,600*	*55,800*
1.1	Total Income	428,400	273,600	55,800
1.2	Average Income/m^3	85.84	65.68	51.62
2	*Farming Expenditures*	*569,000*	*276,500*	*63,530*
2.1	Seeds	10,000	17,500	2,110
2.2	Fertilizers	23,000	0	1,900
2.3	Pesticides	8,000	16,000	0
2.4	Water	0	0	12,000
2.5	Water Pumps Fuel	360,000	135,000	0
2.6	Wages	108,000	81,000	0

2.7	Transport	60,000	27,000	11,520
2.8	Food	0	0	36,000
2.9	Total Cost	569,000	276,500	63,530
2.10	Average Cost /m^3	114.9065	66.3773	58.7648
3	*Farming Profit*	*-140,600*	*-8.111*	*-7,730*
3.1	Total Profit	-140,600	-8.111	-7,730
3.2	Average Profit/m^3	-28.1725	-0.701	-7.1502

An analysis of the optimum levels of farming water demand (EOQ, LAC and MES) revealed that farmers operating in Muooni Dam Catchment recorded high water productivities from 1987 to 2003, under ANOR rainfall regime. Their unit cost per m^3 averaged KES. 197, 188 and 159 for LSF, MSF and SSF, respectively. This water cost was assorted to an "Economic order quantity" (EOQ) of farming water demand in a very profitable economic conjuncture at Muooni Dam Catchment. From 2004 to date the loss of farming profitability under the NOR scenario is the most important economic incentive that leads to the subdivision of farmlands. As their average costs will become significantly high, older farmers are already limiting their water farming costs to a "Limit average cost" (LAC) of KES. 444, 415 and 361 for LSF, MSF and SSF, respectively. They do it by practicing sylviculture (mainly eucalyptus tree planting), and by leasing or even selling part of their farmlands to new comers. Some even leave their farmlands under fallow for years. By the year 2019, when the storage capacity of Muooni Dam will have gone under its threshold, a majority will be obliged to abandon their farming activities and adopt off-farm activities. Some would even embrace small-scale businesses, or jobs in the private and public sectors.

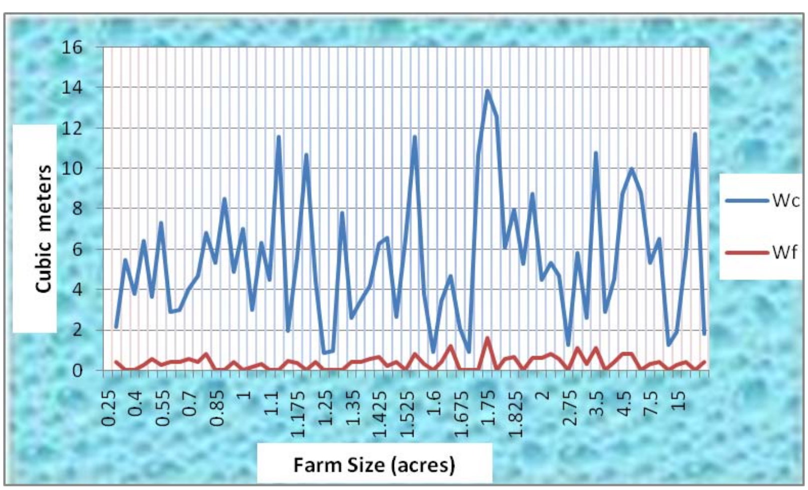


Figure 8.5: Farmers' water demand and crop water requirements (Luwesi, 2010)

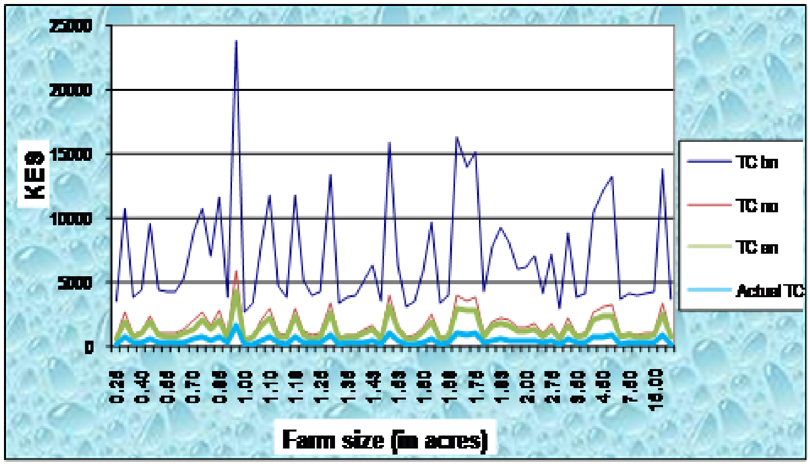


Figure 8.6: Farming water costs computed under fluctuating rainfall regimes (Luwesi, 2010)

The "survivors" will have to sacrifice their short-term benefits by adjusting their farming water demands to the "Minimum efficient scale" (MES) of KES. 831, 769 and 677 for LSF, MSF and SSF, respectively. Using this MES, farmers will be able to secure more water than their present actual water demand (Actual W_f) and crop water requirements (W_c) (Figure 8.7). This will allow them mitigate the high risk of crop failures under fluctuating rainfall regimes, especially under drought.

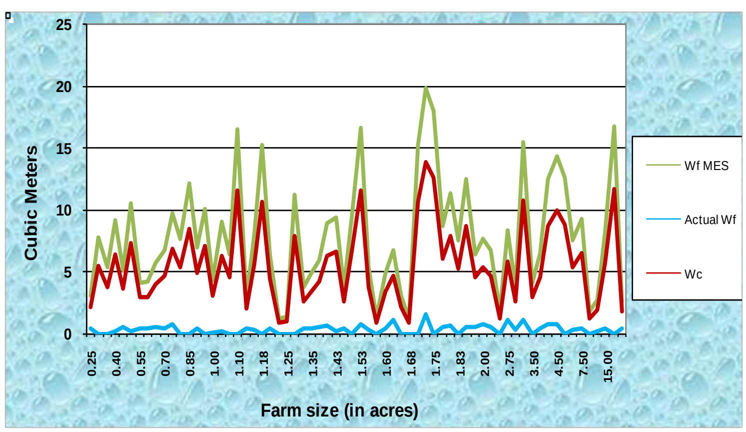


Figure 8.7: Minimum farming water demand under fluctuating rainfall regimes (Luwesi, 2010)

For efficiency, farmers need to increase their respective actual water demand by at least 42% to meet their optimal farming water levels under the scenario of an EOQ (ANOR rainfall regime), a LAC (NOR rainfall regime) and a MES (BNOR rainfall regime), respectively. By so doing, they would expect a fall of their farming water costs up to 36%, 78% and 232% under the three respective rainfall regimes. Such optimization of the farming water demand would result in a decrease of their operational average costs ranging from 30% to about 100%. This fall of operational costs would be accompanied by an increase of water productivities due to high farming yields and good incomes under the ANOR rainfall regime, if the EOQ was to be respected. Yet, farmers owe to apply a LAC or at least a MES to meet their crop water requirements under the NOR and BNOR scenarios. This would allow them ensure the economic viability of their farming activities in time of water stress and scarcity. If no prospect of farming efficiency is to be expected under changing climatic conditions, Lal (1993) firmly encourage farmers to make some tradeoffs between on-farm and off-farm income-generating activities. This would mean that they adopt off-farm activities if their farming water opportunity costs are higher than elsewhere to avoid running a deficient farming enterprise.

8.5 Conclusions and Recommendations

The Hydro-economic inventory conducted in Muooni Dam Catchment revealed that communities' livelihood is often disrupted by both endogenous on-farm management side effects and exogenous externalities from the environment affecting food production and energy supply. These factors enhance the rate of deforestation, soil erosion, fertile soil loss from farmlands and water stress in many catchment areas. Significance hydro-geomorphologic impacts occurring on farmlands have a precedence on water stress and scarcity in Muooni Dam Catchment, thus undermining the production of food and energy. Bad land management associated with low levels of education are propounded to be major causes of low agricultural yields and incomes, poverty and food insecurity. Put altogether, these factors affect at least 34% of the total variation of Muooni Dam's active water storage capacity, reducing it by 6.2% every year.

Consequently, there is no prospect of significant increase of farming yields and incomes in Muooni Dam Catchment, especially under the BNOR rainfall regime. Farmers are particularly expecting a significant decrease of their farming profitability under the BNOR rainfall regime due to farmland subdivisions and poor soil moisture. This soil moisture decrease is particularly attributed to both the change of the catchment microclimate and the global climate change. Farmers need to adjust their crop water requirements with soil moisture depletion. Otherwise, they would have to specialize to less than three water friendly crop species. They have also to minimize their costs of farming water by using other effective agronomic technologies and efficient on-farm management techniques such as rational crop treatments and selection, application of improved farming inputs (fertilizers, pesticides, fungicides, and rodenticides). They would have also to make use of hydro-political strategies such as water consumption metering, evapo-transpiration quotas, green water credits, virtual water import and rainwater harvesting in the context of "Integrated Watershed Management" (IWM). Therefore, the Government of Kenya needs to ensure that IWM is implemented at small scale catchments like Muooni Dam. It has to speed up the process of enforcement of key regulations of the water sector reforms, including water quality control, water use allocation and metering, and irrigation schemes and dams coordination.

8.6 References

Burdge RJ. (2008). "The focus of impact assessment (and IAIA) must now shift to global climate change". *Environmental Impact Assessment Review* 28: 618–622

GoK. (2007). Kenya Vision 2030. Available at: http:// www.investmentkenya.com/ Documents/Publications/vision_2030_BROCHURE_July_2007.pdf. Accessed on 28.04.2009.

GoK. (2010). *Kenya 2009 Population and Housing Census*. Central Bureau of Statistics, Government Print, Nairobi.

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

Hacking, T. & Guthrie P. (2006). "Sustainable development objectives in impact assessment: Why are they needed and where do they come from?" *Journal of environmental assessment policy and management*

(JEAPM) Vol. 08, issue 03: 341-371.

Jaetzold R., Schmidt H., Hornetz B. & Shisanya C. (2007) "Part C East Kenya, Subpart C1 Eastern Province". In: Ministry of Agriculture & GTZ (eds.), *Farm Management Handbooks of Kenya*, vol. 2. Nairobi, pp. 1-571.

Jansky, L., M. Haigh & H. Prasad. (eds.).(2005). *Sustainable Management of Headwater Resources: Researches from Africa and India*. Tokyo: United Nations University Press, 304 pp.

Kitissou, M. (2004). "Hydropolitics and Geopolitics: Transforming Conflict and Reshaping Cooperation in Africa", *Africa Notes*, Issue of November-December 2004.

Lal R. (1993). "Agricultural Sustainability and Soil Resilience". *Desertification Control Bulletin* No. 23: 26-43.

Luwesi, C. N. (2009). An Evaluation of Efficiency of Agricultural Watershed Resources under Fluctuating Rainfall Regimes at the Muooni Dam site, Machakos District, Kenya. Master Thesis. Nairobi: School of Pure and Applied Sciences, Kenyatta University, 160 p.

Luwesi CN. (2010). *Hydro-economic Inventory in Changing Environment – An assessment of the efficiency of farming water demand under fluctuating rainfall regimes in semi-arid lands of South-East Kenya*. Saarbrüken: Lambert Academic Publishing AG & CO.KG, 180 pp.

Luwesi CN, Shisanya CA & Obando JA (2011). "Toward a hydro-economic approach for risk assessment and mitigation planning for farming water disasters in semi-arid Kenya". In: M. Savino (ed), *Risk Management in Environment, Production and Economy*, InTech, 51000 Rijeka, Croatia, pp 27-46.

Morgan, R.P.C. (1995). *Soil Erosion and Conservation*. Essex: Longman Group, 198 p.

Mutisya, D. (1997). Socio-Economic and Agronomic Factors Influencing Soil Erosion in the Masinga Dam Catchment, PhD Thesis. Nairobi: Faculty of Arts, Kenyatta University, 286 p.

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: S.P. Saikia (eds.), *Climate Change*, International Book Distributors, Jorhat 785 006, Assam, India, pp. 117-140.

Ngurari P. (ed.)(2009). Water crisis: How safe is your water?. *Health Today,* Nov-Dec. 2009: 13-19.

Ojwang, J. (2008). Eucalyptus suspected to be causing water shortage in parts of Nile Basin. *Nile News* Jan-Mar 08, Issue 1, vol. 5: 6-7

Shisanya, C. A. (1990). The 1983-1984 Drought in Kenya. Journal of Eastern African Research & Development, Vol. 20: 127-148.

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. Trier: Faculty of Geosciences, Universität Trier, 417 p.

Shisanya, C. A., Recha, C. & Anyamba, A. (2011). Rainfall variability and its impact on normalized difference vegetation index in arid and semi-arid lands of Kenya. *International Journal of Geosciences*, 2: 36-47 (http://www.SciRP.org/journal/ijg).

Shisanya CA 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.

Tiffen M., Mortimore M. & Gichuki F. (1994). *More people less erosion: Environmental recovery in Kenya*. ACTS Press, Nairobi, 311 pp.

Thompson, D.A. and Scoging, H.M., (1995). "Agricultural Terrace Degradation in South-East Spain: Modelling and Management Strategies". In D.F. McGregor and D.A. Thompson (eds.), *Geomorphological and Land Management in a Changing Environment*. Chichester: John Wiley & Sons Ltd., pp. 153-175.

UNEP. (2002). *Global Environmental Outlook 3*. London: Earthscan Publications Ltd, 446 pp.

Wambongo, C.S. (2007). Seasonal Climate Forecast, Access and Use in Agricultural Production: A Case of Semi-Arid South-East Kenya, Masters' Thesis. Nairobi: School of Social Sciences and Humanities, Kenyatta University, 145 p.

Waswa PF. (2006). "Opportunities and challenges for sustainable agricultural land management in Kenya".

In: Waswa F., Otor S. & Mugendi D. (eds.), *Environment and sustainable development: A guide for higher education in Kenya*, Vol. 1. Nairobi: Kenyatta University, School of Environmental Studies and Human Sciences, p. 1-19.

Wikipedia. (2008). Environmental Impacts of Dams. http://en.wikipedia.org/wiki/environmental_impacts_of_dams. Accessed on 19.04.2008.

Zeiller (2000). *Methods of socio-economic analysis of rural development*. Göttingen: Universität Göttingen, Institute of Rural Development. Available at: http://www.childinfo.org/files/chap06.pdf. Accessed on 21.02. 2010.

9 Watershed Modeling and Calibration for poorly gauged Sigi River Basin in Tanzania Using the MWSWAT Modeling Tool

Mashingia, F. [1,2,3]
Bruen, M. [2]
Mtalo, F. [1]

[1] University of Dar es Salaam, Department of Water Resources Engineering, P.O. Box 35131, Dar es Salaam, Tanzania.
[2] University College Dublin, Department of Civil Engineering, Centre for Water Resources Research, Dublin 4, Ireland.

[3] Email of corresponding author*: fmashingia@yahoo.com

9.1 Abstract

Distributed hydrological watershed models are increasingly being used to support decisions about alternative management strategies in the areas of land use change, climate change, water allocation, and pollution control. But their application in developing countries is limited with skills and data availability. However, recent global developments in remote sensing, coupled with modeling and data assimilation, are providing new sources of information. The goal of this research is to provide an accurate modeling tool to simulate stream flow in Sigi River Basin and therefore to evaluate the impacts of land use/cover (LULC) and climate changes on stream flow contributing to integrated water resources management. We demonstrate the methods to set up, parameterize and calibrate MapWindow Soil and Water Assessment Tool (MWSWAT) model under data-sparse tropical environment. During model set-up, a reduction of the number of model parameters was obtained using an LH-OAT sensitivity analysis. The selected parameters were optimized by Sequential uncertainty fitting (SUFI-2). In general, a reasonably fair match can be observed in the shape of simulated and observed hydrographs for the 1977 – 1985 (long term) calibration periods. The model evaluation statistics were verified by coefficient of determination (R^2) and NS-coefficient values of 0.47 and 0.46 respectively. Generally, SWAT model can be set up for impacts of land use/cover, climate changes, erosion/sediment and pollutant transport studies in the Zigi River Basin and produce fairly good results. However, improvements of input datasets, optimization strategies and source codes to suit tropical climates are necessary.

Keywords: *Modeling, MWSWAT, East Usambara, SUFI-2, Hydrology*

9.2 Introduction

By the year 2025, it has been projected that Tanzania on the whole will be water-stressed (Mutayoba, 2003). Water scarcity threatens food crops production at large and subsistence level, energy production in case of hydropower and environmental integrity of the sub-catchments. At the same time, it is likely that climate change due to global warming will affect both the availability of supply and the demands for water, leading to further uncertainty and pressures. Population growth and increasing water demand in different sectors, in combination with high spatial and temporal variability of limited rainfall, underscore the need for sound interdisciplinary management of water distribution and allocation (Mashingia *et al.*, 2009).

Hydrological models are common tools for water resources planning and management. The distributed hydrological modeling will provide scientific data on reserved water allocation to humans and the environment and quantify the possibilities of equitable sharing of water with agriculture, industry, inter-catchment transfers, conservation and mining, accounting for impacts of land use and population dynamics (Mashingia *et al.,* 2009). One of the comprehensive hydrological models for this purpose is the Soil and Water Assessment Tool (SWAT) model (Arnold *et al.*, 1998). However, application of SWAT model in developing countries is plagued with a number of related problems such as: lack of data, lack of money (very few institutions can afford ESRI's ArcView/ArcGIS commercial softwares), inadequate training capacity, and dependence on experts from other countries.).

The Idaho State University Geospatial Software Lab has developed an interface to SWAT using MapWindow GIS which is a free and open source product that can be used by modelers, developers, and end-users. It is expected that this new GIS interface will support the continued distribution and use of SWAT around the world, and that it will also be included in a future release of EPA's Better Assessment Integrating Point and Nonpoint Sources (BASINS) watershed modeling system, which is also built on the MapWindow GIS platform.

The goal of this research is to provide an accurate modeling tool to simulate stream flow in Sigi River Basin while considering economic and ungauged disadvantages in the region. We demonstrate the methods to set up and calibrate MapWindow Soil and Water Assessment Tool (MWSWAT) model and since MWSWAT application in Tanzania is new, a step-by-step model application (in terms of data inputs and assessment of model suitability) was recommended.We therefore discuss the process of data collection, model development, sensitivity analysis and calibration for the study area.

9.3 Study area

The Sigi River basin (Fig.9.1) is a part of the Pangani river basin, one of nine major river basins in the country, located in northern Tanzania. The study area, which covers an area of 670.5 km^2, is also a northern zone Eastern Arc Mountain (EAM) sub-basin covering the East Usambara mountain forests. The East Usambara Mountains (EUM) serves several important ecological functions, which include water catchments. The EUM rise sharply to over 1000m and peak at 1500m above sea level. Being adjacent to the Indian Ocean, considerable orographic rainfall occurs in this area. The rainfall distribution is bi-modal, peaking between March and May and between September and December. The dry seasons are from June to August and January to March. However, precipitation occurs in all months. Rainfall is greatest at higher altitudes and in the south-east of the mountains, increasing from 1,200 mm annually in the foothills to over 2,200 mm at the higher altitudes.

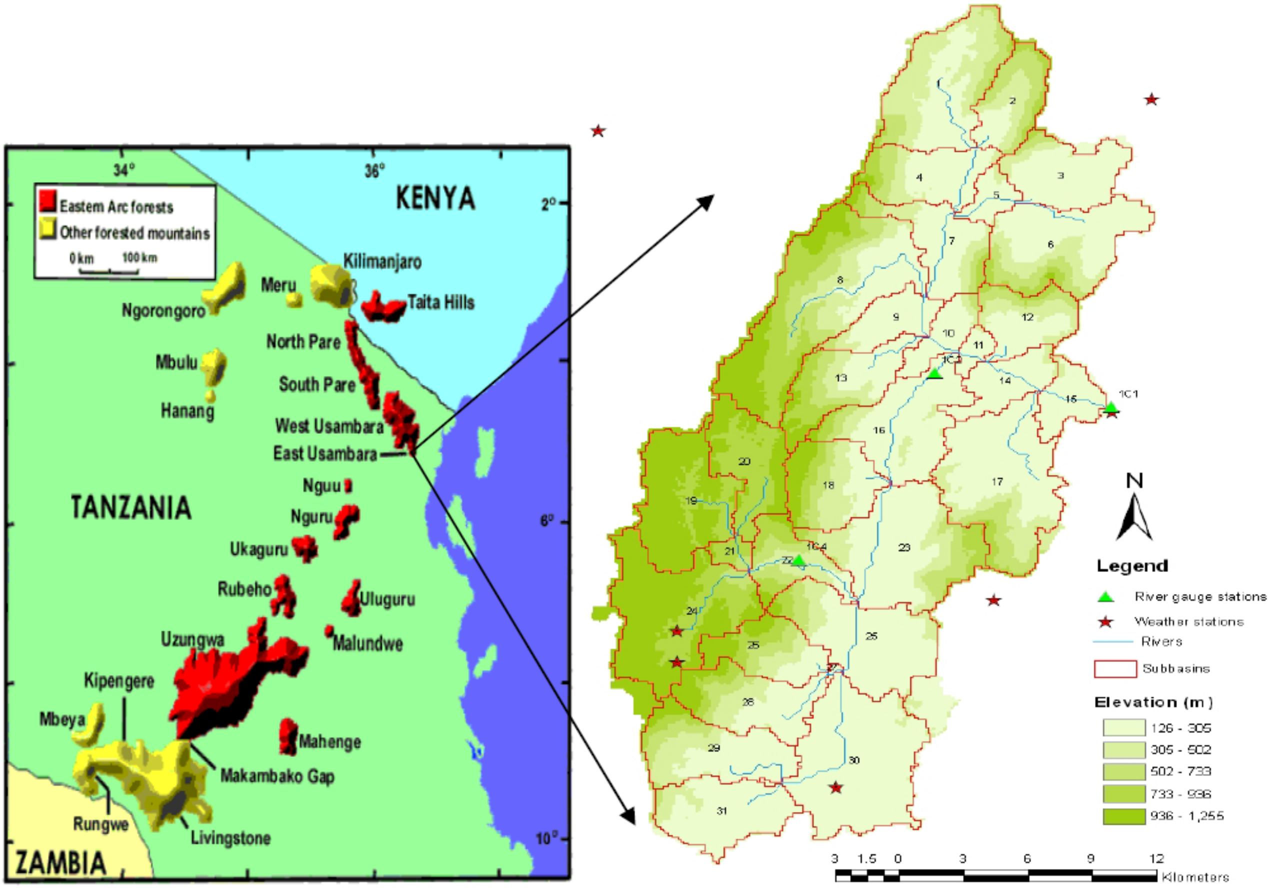


Figure 9.1: Location map and the hydro-meteorological network of the study area

9.4 Data and methods

9.4.1 SWAT model description

The Soil and Water Assessment Tool (SWAT) is a continuous time, physically based hydrological model developed by the USDA to predict the impact of land management practices on water, sediment and amount of chemicals originating from agriculture, in large complex river basins with varying soils, land use and management conditions over a long period of time. It uses hydrologic response units (HRUs) that consist of specific land use, soil and slope characteristics. The HRUs are used to describe spatial heterogeneity in terms of land cover, soil type and slope class within a watershed. The hydrologic routines within SWAT account for snow fall and melt, vadose zone processes (i.e., infiltration, evaporation, plant uptake, lateral flows, and percolation), and ground water flows. The hydrologic cycle as simulated by SWAT is based on the water balance equation:

$$SW_t = SW_o + \sum_{i=1}^{t} (R_{day} - Q_{surf} - Ea\,T - W_{seep} - Q_{gw})_i \quad [1.0]$$

In which SWt is the final soil water content (mm), SW_0 is the initial soil water content on day i (mm), t is the time (days), R_{day} is the amount of precipitation on day i (mm), Q_{surf} is the amount of surface runoff on day i (mm), Ea is the amount of evapotranspiration on day i (mm), W_{seep} is the amount of water entering the vadose zone from the soil profile on day i (mm), and Q_{gw} is the amount of return flow on day i (mm).

Surface runoff is calculated using the modified Soil Conservation Service (SCS) curve number CN2 (USDA-SCS, 1972) technique when a daily time step is used or the Green and Ampt (1911) infiltration equation when an hourly or subdaily time step is used. For evapotranspiration (PET) estimation, three options are available in SWAT: the Penman–Monteith method (Monteith, 1965), the Priestley–Taylor method (Priestley and Taylor, 1972) and the Hargreaves method (Hargreaves *et al.*, 1985). In SWAT, water is routed though the channels network using either the variable storage routing or Muskingum River routing method. More detailed descriptions of the different model components are listed in Arnold *et al.* (1998) and Neitsch *et al.* (2005).

9.4.2 MWSWAT model input

The preprocessing of the SWAT model input was performed within MapWindow GIS 4.7. The spatially distributed data needed for the MWSWAT interface include the Digital Elevation Model (DEM), soil data, land use and stream network layers. The required spatial datasets were projected to the same projection, WGS 1984 UTM Zone 37S. Data on weather and river discharge were also used for prediction of streamflow and calibration purposes.

Digital elevation model (DEM): Shuttle Radar Topographic Mission (SRTM) Processed 90m Digital Elevation Data (http://srtm.csi.cgiar.org/) was used to delineate the watershed and to analyze the drainage patterns of the land surface terrain. International Centre for Tropical Agriculture (CIAT) have processed this data to provide seamless continuous topography surfaces. Areas with regions of no data in the original SRTM data have been filled in using interpolation methods (SRTM, 2004). Subbasin parameters such as slope gradient, slope length of the terrain, and the stream network characteristics such as channel slope, length, and width were derived from the DEM.

Land use data: Land use is one of the most important factors that affect surface erosion, runoff, and evapotranspiration in a watershed. The 1km resolution land use data from the Global Land Cover Facility (Hansen *et al.*, 2000) was used to determine the types of land use and cover of Sigi River Basin. The land use map was generated from AVHRR satellites imagery acquired between 1981 and 1994. Fig.2 and shows the main land cover types of the area Dryland cropland and pasture, Cropland/woodland mosaic, Shrubland, Deciduous broadleaf forest, Evergreen broadleaf forest and Mixed forest. Table 9.1 defines the SWAT land use codes and their distribution.

Table 9.1 Land use distribution within the modelled basin

SWAT code	Land use	% Area
CRDY	Dryland cropland and pasture	76.96
CRWO	Cropland/woodland mosaic	0.86
SHRB	Shrubland	0.93
SAVA	Savanna	0.24
FODB	Deciduous broadleaf forest	5.25
FOEB	Evergreen broadleaf forest	5.54
FOMI	Mixed forest	10.22

Soil Data: SWAT requires different soil textural and physicochemical properties such as soil texture, available water content, hydraulic conductivity, bulk density and organic carbon content for different layers of each soil type. The soil data used in this study was from FAO/UNESCO 1:5 million scale soil maps (FAO/UNESCO, 2003). Major soil types in the basin are sandy loam and clay loam (Fig.9.2).

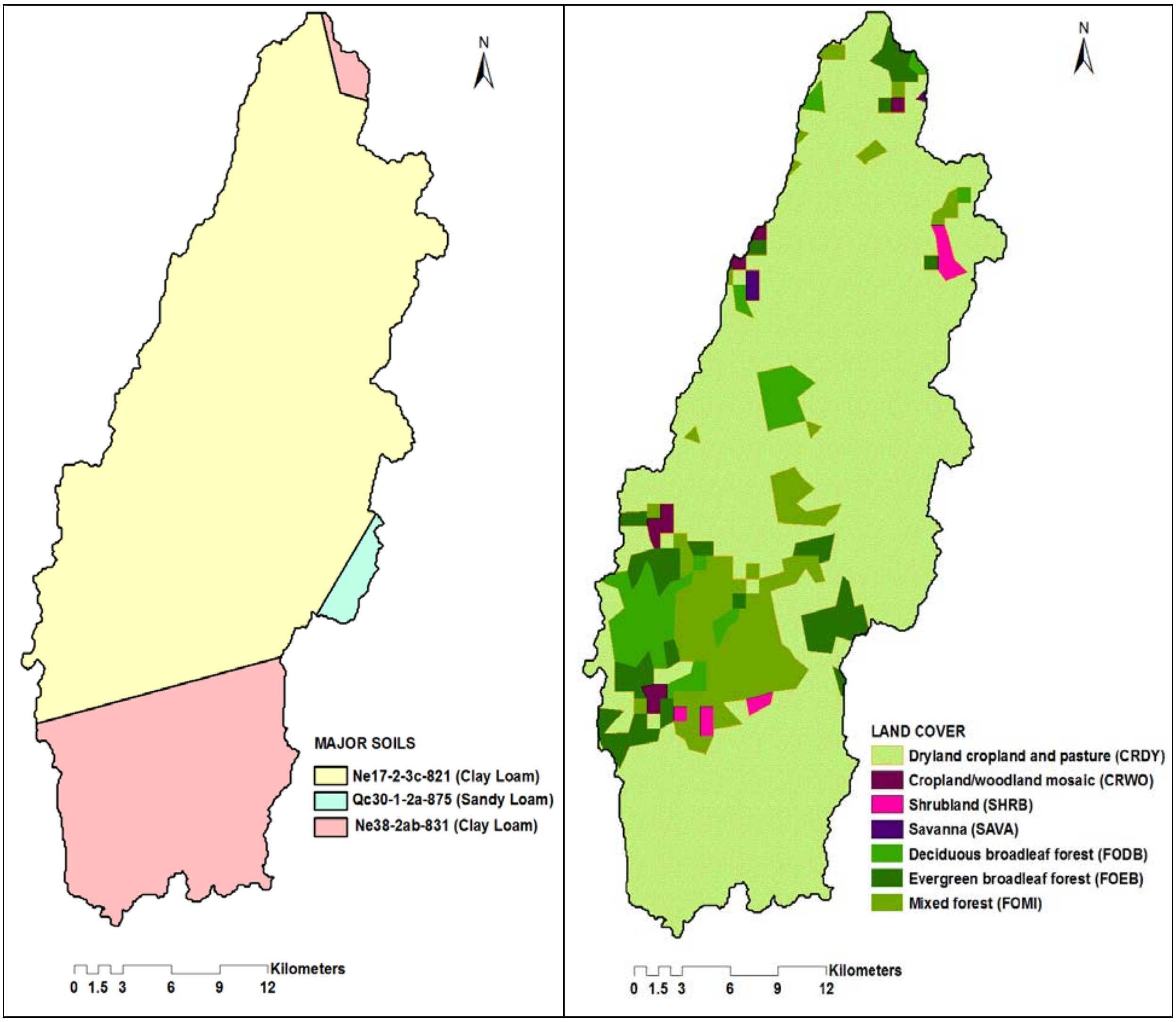


Figure 9.2 Soil and Land use/land cover map of Sigi River Basin

Weather Data: SWAT requires daily meteorological data that can either be read from a measured data set or be generated by the WXGEN weather generator (Sharpley and Williams, 1990). These data are daily rainfall, maximum and minimum air temperature, solar radiation, wind speed, and relative humidity. In this study, daily precipitation, minimum and maximum air temperature for the period 1973 – 1989 were used for driving the hydrological balance. The data is obtained from Department of Water Resource Engineering of the University of Dar es Salaam for stations located within and around Sigi river basin (Fig. 1). Monthly weather statistics for one station close to the catchment were calculated from available daily weather records to parameterize the WXGEN weather generator. WXGEN was used to fill missing data and generation of climatic data.

River Discharge: The daily time series river discharge values for Sigi-Lanconi (1C1) gauging station were obtained from Department of Water Resource Engineering of the University of Dar es Salaam. These daily river discharges data were used for model calibration. Missing discharge records were filled with seasonal mean. The baseflow alpha factor for 1C1 gauging station was calculated by the web-based SWAT baseflow filter (http://www.EnvSys.co.kr/~swatbflow) (Fig.9.3).

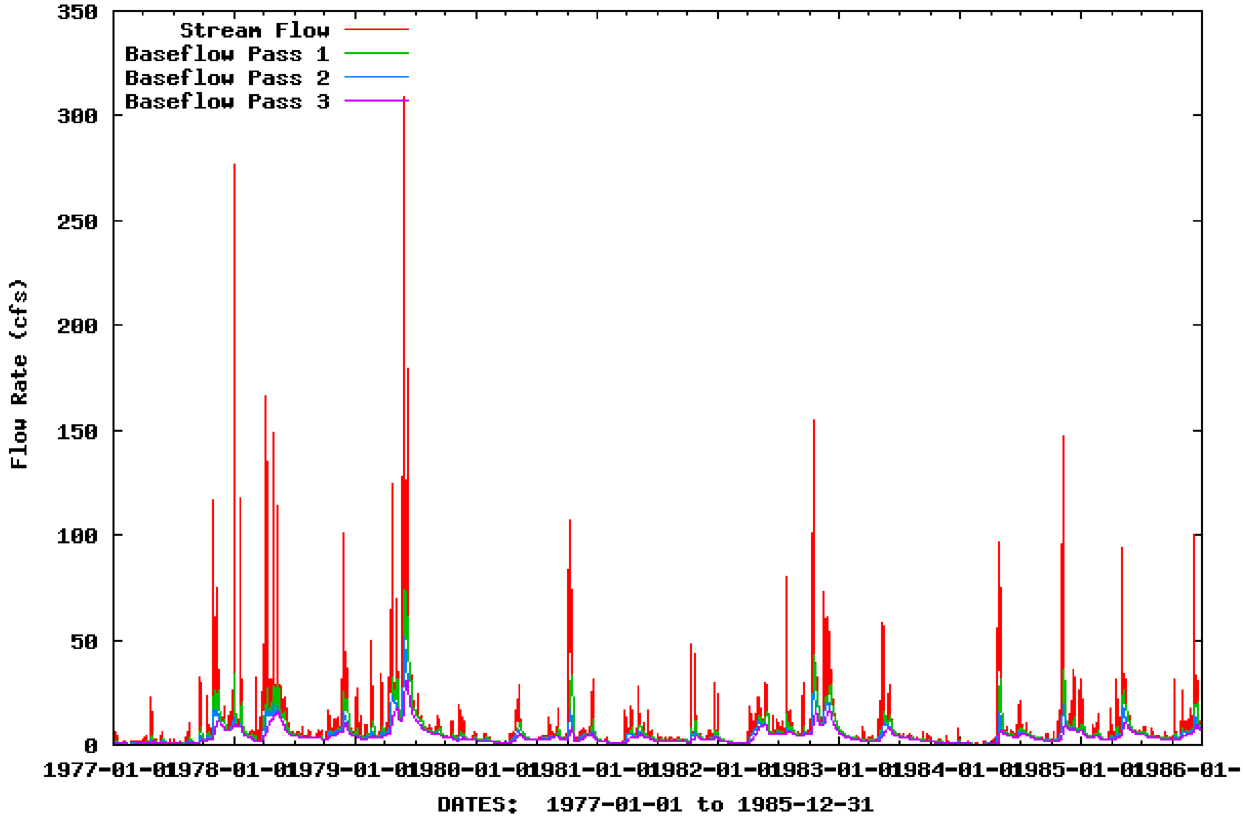


Figure 9.3 Baseflow filtering for 1C1 gauging station

9.4.3 MWSWAT model setup

The MapWindow interface to SWAT (MWSWAT) was used for the setup and parameterization of the model. The model setup involved five steps: (1) Watershed delineation (2) Creation of HRUs and (3) SWAT setup and Run. The watershed delineation processes include three major steps, DEM set-up, choosing the threshold (minimum area to be designated as drainage for a stream) and outlet and inlet definition.Creating HRUs includes selecting the landuse and soil maps, together with database tables (lookup tables), selection of intermediate slope percentages so as to form bands of slopes, and choosing singe HRUs (i.e. one per subbasin) or multiple HRUs. Subdividing the sub watershed into hydrological response units (HRU's), which are areas having unique land use, soil and slope combinations makes it possible to study the differences in evapotranspiration and other hydrological conditions for different land covers, soils and slopes. SWAT setup and Run includes meteorological data definition, hydrological processes selection and writing the SWAT files in the proper format. In this study, the SCS curve number method was used to estimate surface runoff. Potential evapotranspiration (PET) is estimated from Penman-Monteith method. And a variable storage method is used for channel flood routing.

9.4.4 Parameter sensitivity analysis

The parameter sensitivity analysis was done using the SWAT Editor interface. Twenty six hydrological parameters were tested for sensitivity analysis for the simulation of the stream flow in the study area. Sensitivity analysis is important for parameters monitoring and for assessing the model over parameterisation. The sensitivity analysis method implemented in SWAT 2005 is called the Latin Hypercube One-factor-At-a-Time (LH-OAT) (Morris, 1991). The LH-OAT sensitivity analysis combines the strength of global and local sensitivity analysis methods (Van Griensven and Srinivasan, 2005). The LH-OAT method performs LH sampling followed by OAT sampling. LH sampling (McKay et al., 1979) uses a stratified sampling approach that better covers the sampling hypercube with fewer samples. This method identifies parameters that do or do not have a significant influence on model simulations of real world observations for specific catchments (Van Griensven, 2006).

9.4.5 Model calibration and evaluation

Model calibration involves adjustment of parameter values of models to reproduce the observed response of the Sigi river basin within the range of accuracy specified in the performance criteria. The data for period 1977–1985 were used for model calibration at Sigi-Lanconi (1C1) gauging station. Periods 1973–1976 were used as 'warm-up' periods for calibration. The warm-up period allows the model to get the hydrological cycle fully operational. The calibration and uncertainty analysis were done using the Sequential Uncertainty Fitting, ver. 2 (SUFI-2) which is incorporated in an independent program called SWAT Calibration and Uncertainty Program (SWAT-CUP) (Abbaspour, 2007). SUFI-2 is developed for a combined calibration and uncertainty analysis. In SUFI-2, parameter uncertainty accounts for all sources of uncertainties such as uncertainty in driving variables (e.g. rainfall), parameters, conceptual model and measured data (e.g. observed flow). The degree to which all uncertainties are accounted for is quantified by a measure referred to as the *p*-factor, which is the percentage of measured data bracketed by the 95% prediction uncertainty (95PPU). The 95PPU is calculated at the 2.5% and 97.5% levels of the cumulative distribution of an output variable obtained through Latin hypercube sampling (Schuol and Abbaspour 2006). Another measure quantifying the strength of a calibration/ uncertainty analysis is the so called R-factor, which is the average thickness of the 95PPU band divided by the standard deviation of the measured data. SUFI-2, hence seeks to bracket most of the measured data (large P-factor, maximum 100%) with the smallest possible value of R-factor (minimum 0).

The goodness of calibration and prediction uncertainty is judged on the basis of the closeness of the *p*-factor to 100% (i.e. all observations bracketed by the prediction uncertainty), and the *r*-factor to 1 (i.e. achievement of rather small uncertainty band). Further goodness of fit can be quantified by the R^2 and/or Nash–Sutcliff (NS) coefficient between the observations and the final best simulation.

9.5 Results and discussion

9.5.1 Parameter sensitivity analysis

The analysis was carried out based on the objective function of the SSQ for all the 26 models parameters and 10 intervals of LH sampling. Table 9.2 describes the most sensitive parameters in determining the streamflow at the study area. The greater the mean sensitivity, the more sensitive a model output variable is to that particular parameter. Those with mean sensitivity≥1 were consider ed as high sensitive parameters, whereas those with 0.1≤ mean sensitivity < 1 are considered as normally sensitive ones. CN2 was found to be very crucial than other parameters. All the ten parameters generally govern the surface and subsurface hydrological processes and stream routing. It is important to note that each of these parameters was treated in an identical manner across different sub-watersheds or HRU‘s during the calibration process. This result illustrates how parameter sensitivity is site specific and depends on land use, topography and soil types, as compared to other studies elsewhere.

Table 9.2 Sensitivity ranking, and category of the most sensitive parameters

Parameters	Sensitivity rank	Category	Description
CN2	1	High	SCS runoff curve number for moisture condition II
CH_K2	2	Normal	Chanel effective hydraulic conductivity (mm/hr)
ALPH_BF	3	Normal	Baseflow alpha factor (days)
SURLAG	4	Normal	Surface runoff lag coefficient
ESCO	5	Normal	Soil evaporation compensation factor
BLAI	6	Normal	Maximum potential leaf area index
SOL_AWC	7	Normal	Available water capacity of the soil layer (mm/mm soil)
CANMX	8	Normal	Maximum canopy index
CH_N2	9	Normal	Manning's n value for main channel
SOL_Z	10	Normal	Soil depth (mm)

9.5.2 Model calibration and uncertainty measures

The simulated hydrographs were compared to the observed hydrographs at gauging site. Initial results from a first simulation of the model are shown in Figure 9.4 and Figure 9.5, which clearly indicates that parameters must be further optimized to have a better depiction of the different components of the hydrological cycle. Therefore parameters (CN2, CH_K2, ALPH_BF, SURLAG, ESCO, SOL_AWC, CANMX, CH_N2 and SOL_Z) identified during sensitivity analysis were used in SUFI-2 calibration. Table 9.3 SWAT model parameters included in the SUFI-2 final calibration, their initial ranges and fitted values. The SUFI-2 results (Fig.6) indicated that the *p*-factor which is the percentage of observations bracketed by the 95% prediction uncertainty (95PPU), brackets 71% of the observation and *r*-factor equals 0.68 for Sigi river at Lanconi station. The comparison between the observed and simulated streamflow indicated that there is a fairly good agreement between the observed and simulated discharge which was verified by coefficient of determination (R^2) and NS-coefficient values. The R^2 of 0.47 and NS of 0.46 was obtained for the calibration period (Fig. 9.7).

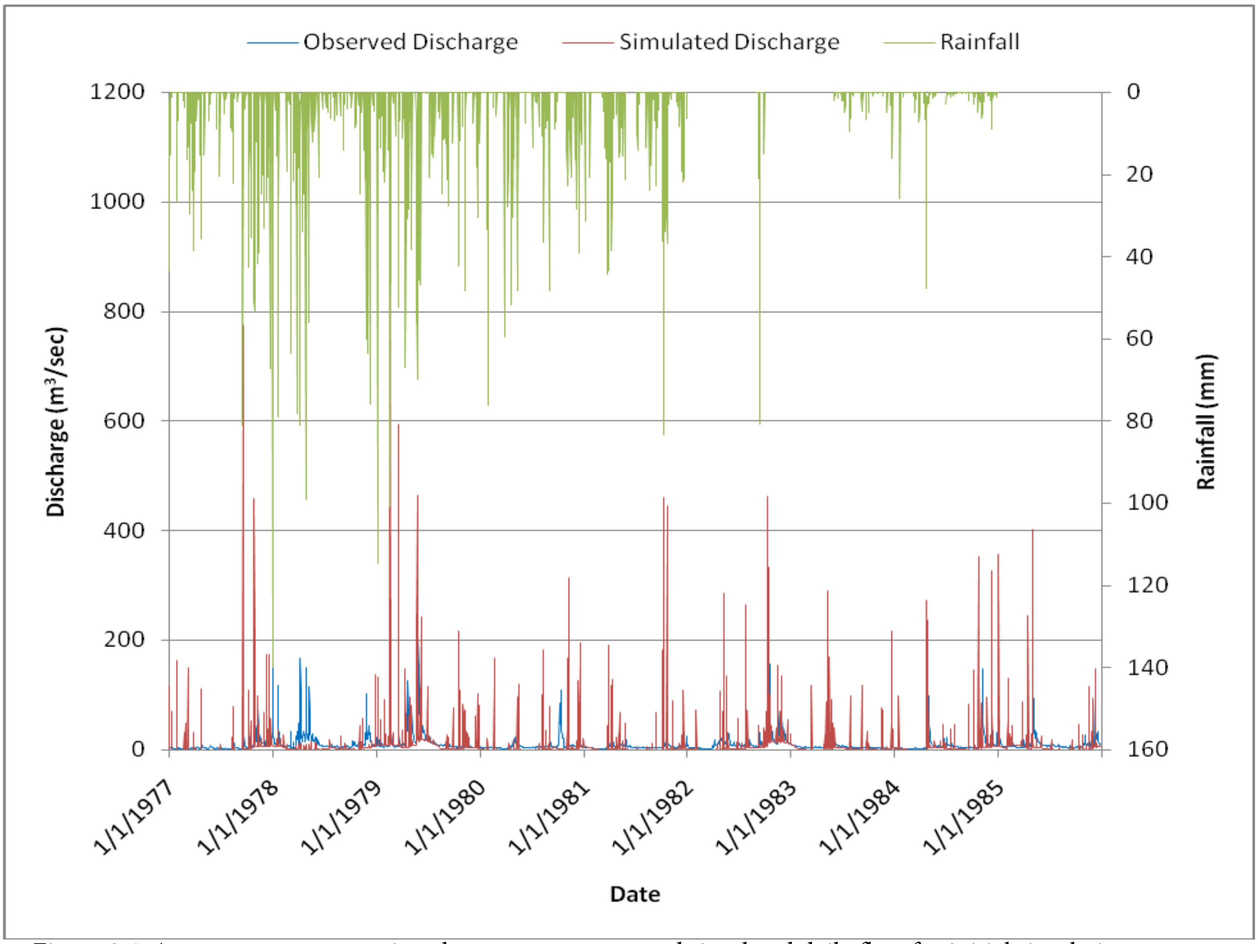


Figure 9.4: A scattergram comparison between measures and simulated daily flow for initial simulation

Table 9.3: SWAT model parameters included in the SUFI-2 final calibration, their initial ranges and fitted values

Parameter name	Initial range	Fitted value
r__CN2.mgt	-0.38 - 0.04	-0.22439
v__ALPHA_BF.gw	0.24 - 0.75	0.666105
v__ESCO.hru	0.01 - 0.64	0.519985
v__CH_N2.rte	0 - 0.3	0.06225
v__CH_K2.rte	65 - 150	133.8075
v__CANMX.hru	0 - 6.1	3.90705
r__SOL_AWC(1).sol	-0.195 - 0.1	-0.01579
r__SOL_Z(1).sol	-0.185 - 0.1	-0.14382
v__SURLAG.bsn	1 - 6.7	4.76485

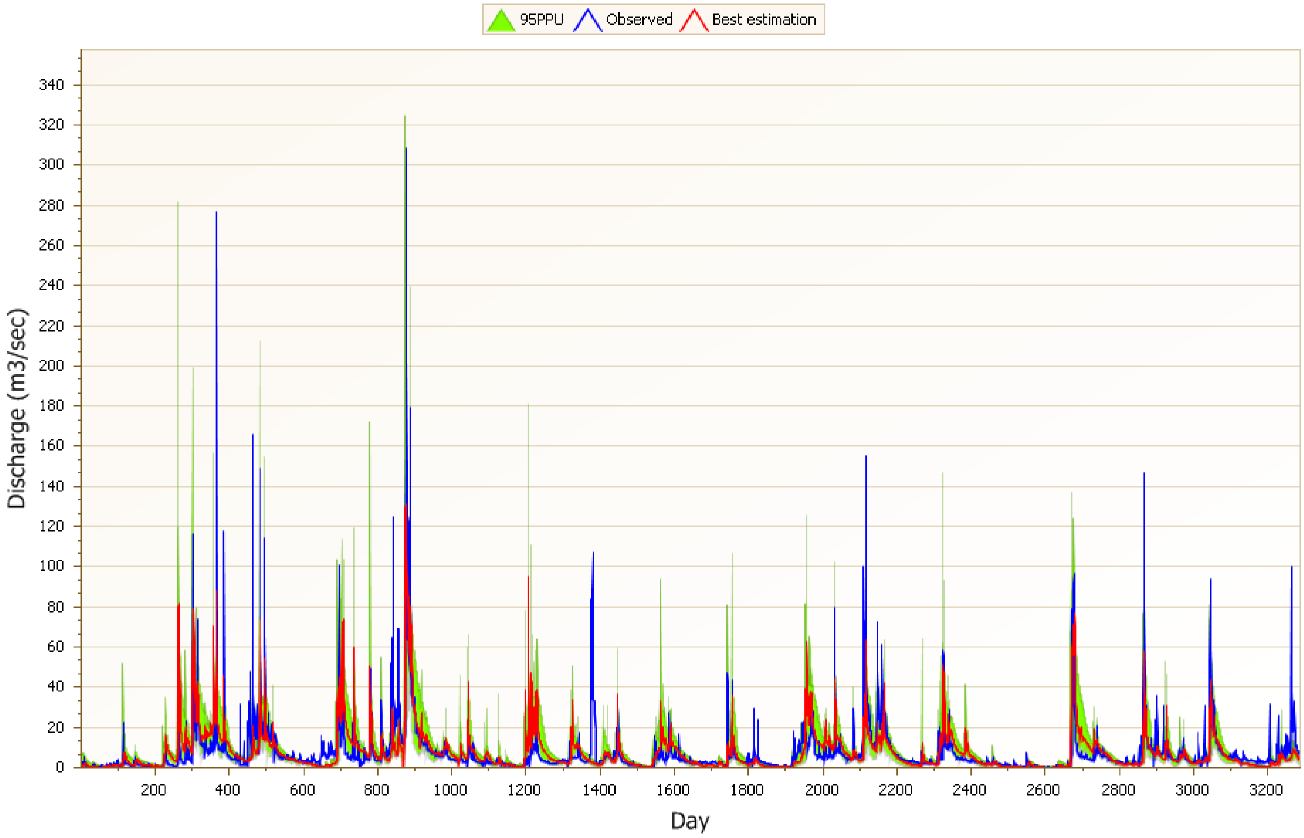


Figure 9.6: Daily calibration result showing the 95% prediction uncertainty interval along with the measured discharge

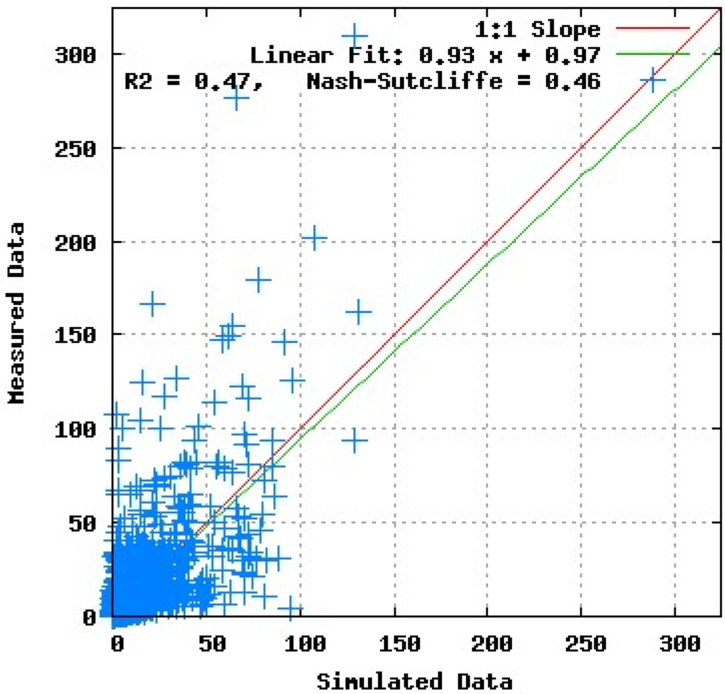


Figure 9.7: A scattergram comparison between measures and simulated daily discharge for calibration period

9.5.3 Implications for water resource management

The changes in flow regimes will have significant implications for water resource management in the Zigi river basin. From our analysis, the model behavior can easily be distinguished between two types in each year, one having abrupt peaks during rainy season and other smooth recession during the dry season. The peak flows are not adequately reproduced due to lack of precipitation and climate (temperature, humidity, wind speed and sun hours) data. The spatial and temporal variability of runoff may increase in the future and the implicated challenges to water resources management include: 1) Provision for dynamic nature of flow regime in water allocations for various uses and 2) Provision for dynamic nature of flow regime in reservoir inflow estimations. Among the various hydrologic processes that take place in a catchment, surface runoff, groundwater flow and evapotranspiration (ET) are most essential. With a proper description of these processes, changes in land use and climate can be studied, and different scenarios can be presented on the basis of various management schemes.

9.6 Conclusion

With recent advancement in GIS and RS, we parameterize a semi- distributed SWAT hydrological model for the study area. The model procedure included data collection, model set-up, sensitivity analysis, parameter calibration. An LH-OAT sensitivity analysis allowed for the screening of the large set of input parameters. The selected subset of parameters was then used for SUFI-2 model calibration. SUFI-2 algorithms gave good results in minimizing the differences between observed and simulated Streamflows. The p-factor and r-factor computed using SUFI-2 gave good results by bracketing more 71% of the observed data. A SUFI-2 algorithm is an effective method, but it requires additional iterations as well as the need for the adjustment of the parameter ranges. In general, a reasonably fair match can be observed in the shape of simulated and observed hydrographs for the 1977 – 1985 (long term) calibration periods. The model evaluation statistics were verified by coefficient of determination (R^2) and NS-coefficient values of 0.47 and 0.46 respectively. The calibrated SWAT model can be used for further analysis for operation and water/land management studies (e.g. impacts of land use/cover, climate changes, rain-fed agriculture and erosion/sediment and pollutant transport) in data sparse tropical Sigi river basin.

9.7 Acknowledgement

We gratefully acknowledge the Higher Education Authority (HEA)/Irish Aid and the IWMNet for providing partial financial support to the main author to carry out his doctoral study which has resulted in this paper. This project is undertaken as a joint venture between the University of Dar es Salaam (UDSM) and the National University of Ireland, University College Dublin (UCD)

9.8 References

Abbaspour, K.C., (2007). SWAT-CUP, SWAT Calibration and Uncertainty Programs. A user manual, Swiss Federal Institute for Aquatic Science and Technology, Zurich, Switzerland, 84p.

Arnold, J.G., Srinivasan, R., Muttiah, R.S., Williams, J.R., 1998. Large-area hydrologic modeling and assessment: Part I. Model development. Journal of the American Water Resources Association 34(1): 73-89.

FAO/UNESCO (2003). Digital Soil Map of the World and Derived Soil Properties. Rev. 1. (CD Rom), 2003. Available from http://www.fao.org/catalog/what_new-e.htm.

Google Map-based SWAT BFlow system Ver. 0.1 (2011), GIS Enviromental System Lab., Kangwon National University, Korea.

Green, W.H. and G.A. Ampt, 1911. Studies on Soil Physics, 1. The Flow of Air and Water Through Soils. J. Agric. Sciences 4:11-24.

Hansen, M., R. DeFries, J.R.G. Townshend, and R. Sohlberg (2000), Global land cover classification at 1km resolution using a decision tree classifier, International Journal of Remote Sensing. 21: 1331-1365. http://glcf.umiacs.umd.edu/data/landcover.

Hargreaves GL, Hargreaves GH, Riley JP. 1985. Agricultural benefits for Senegal River basin. Journal of Irrigation and Drainage Engineering 111(2): 113–124.

Mashingia, F. , Bruen, M., Mtalo, F. (2009) "GIS-based distributed hydrological modelling: a review of application for disaster management in sub saharan africa", Road Map Towards a Flood

Resilient Urban Environment, Proceedings Final conference of the COST action C22 Urban Flood Management in cooperation with UNESCO-IHP, Paris, France.

McKay,M.D., Beckman,R.J.,and Conover,W.J.(1979). A comparison of three methods for selecting values of input variables in the Analysis of output from a computer code. Technometrics, 21(2),pp 239-245.

Monteith JL. 1965. Evaporation and the environment. In The State and Movement of Water in Living Organisims, XIXth Symposium on the Society of Experimental Biology. Cambridge University Press: Swansea; 205–234.

Morris M.D.(1991). Factorial sampling plans for preliminary computational experiments. Technometrics, 33(2), 161-174.

Neitsch, S.L., Arnold, J.G., Kiniry, J.R., King, K.W., Williams, J.R., 2005a. Soil and Water Assessment Tool (SWAT) theoretical documentation. Blackland Research Center, Texas Agricultural Experiment Station, Temple, Texas, BRC Report 02-05.

Priestley CHB, Taylor RJ. 1972. On the assessment of surface heat flux and evaporation using large-scale parameters. Monthly Weather Review 100: 81–92.

Schuol, J., Abbaspour, K. C., (2006). Calibration and uncertainty issues of a hydrological model (SWAT) applied to West Africa. Adv. Geosci., 9, 137–143.

Sharpley, A.N.,Williams J.R. (Eds.), 1990. EPIC-Erosion Productivity Impact Calculator, 1. Model documentation. U.S. Department of Agriculture, Agricultural Research Service, Tech. Bull., 1768.

SRTM (2004). DEM data from International Centre for Tropical Agriculture (CIAT), available from the CGIAR-CSI SRTM 90m Database: (http://srtm.csi.cgiar.org).

USDA-SCS (U.S. Department of Agriculture-Soil Conservation Service), 1972. Hydrology, Section 4, Chapters 4-10. In: National Engineering Handbook. USDA Soil Conservation Service, Washington D.C.

Van Griensven, A., and Srinivasan, R., (2005). AVSWATX SWAT-2005 Advanced Workshop workbook. SWAT2005 3rd international conference, July 11-15, 2005, Zurich, Switzerland.

10 Improving Livestock Water Productivity on Degraded Bare Surfaces in Semi-arid Ecosystems

Mugerwa, S. [1]

Mpairwe, D. *[2]

Peden, D. [3]

Zziwa, E. [2]

[1] National Livestock Resources Research Institute, P. O. Box 96, Tororo, Uganda

[2] Department of Agricultural Production, Makerere University, Uganda

[3] International Livestock Research Institute, P.O. Box 5689, Addis Ababa, Ethiopia

* Corresponding author: Email: dmpairwe@agric.mak.ac.ug; Tel: +256772439372

10.1 Abstract

Rangeland degradation attributed to overgrazing, termite activity and deforestation resulted in the development of extensive large bare surfaces in the rangelands of Nakasongola District in Uganda. Devoid of adequate vegetation cover, the rangelands are associated with reduced water infiltration, accelerated runoff causing severe erosion, silting of down-steam water reservoirs and hence reduced livestock water productivity. This research was therefore aimed at improving livestock water productivity in the rain-fed pastoral production systems through restoring vegetation on degraded bare surfaces. The effect of reseeding and cattle manure application on pasture productivity and the resultant impact of these interventions on livestock water productivity were investigated. Six treatments were studied- Fencing plus manuring (FM), Fencing only (FO), Fencing plus reseeding (FR), Fencing + manure left on soil surface + reseeding (FMSR), Fencing + Manure incorporated in to the soil + reseeding (FMIR) and control (C) (no manuring, fencing and reseeding). Data on soil nutrient status and pasture productivity was collected covering three dry and three wet seasons. The dry matter yield varied significantly ($p < 0.05$) with treatments with highest mean dry matter yield (3820kg/ha) occurring in FMSR treatment plots and lowest in the control and fenced only plots. Mean dry matter production (3300kg/ha) recorded for manured plots was 125% higher than that (1470kg/ha) from non-manured plots. Increase in dry matter production led to improvement in livestock water productivity. Highest increment (31% increase) in livestock water productivity was recorded in FMSR plots with dry matter yield of 7644kg/ha/yr. Inclusion of cattle manure during reseeding operations improves pasture and livestock water productivity on degraded bare surfaces. The intervention is particularly important in termite infested degraded rangelands where pasture establishment is usually limited by termite damage.

Keywords: *cattle manure, reseeding, pasture*

10.2 Introduction

Uganda's rangeland ecosystem, also known as the "cattle corridor" cover approximately 84,000 km^2 (43%) of the total land area stretching from the north-east, through the central to the south-east of the country (NEMA, 2007). The cattle corridor is of immense social, ecological and economic importance as it supports over 40% of the human population, 55% and 42% of the indigenous and exotic cattle respectively, 42% of small ruminants, 36% of the pigs and about 38% of the national poultry flock.

Approximately 60% of the households in the rangeland ecosystem derive their livelihoods from livestock production signifying the importance of enterprise on both food and livelihood security to pastoralists and agro-pastoralist. Further, about 85% of the total national milk and beef output are derived from livestock, which thrive on natural pastures in the cattle corridor (Mpairwe, 1999).

Despite their gigantic importance in sustaining livelihoods of many pastoral and agro-pastoral communities, the rangelands' productivity for grazing and eventually ability to support livestock production is steadily dwindling owing to overgrazing, indiscriminate tree cutting (NEMA, 2007) and surges in termite activity (Mugerwa *et al.,* 2011a). The extent of ecosystem deterioration across the corridor is largely dependent on the intensity of anthropogenic and severity of natural factors driving the degradation process as well as the intricate interactions between the two factors. The semi-arid ecological zones (largely non-equilibrium systems) that support majority of the livestock population inhabiting the cattle corridor are more degraded than the dry sub-humid zones with relatively equilibrium ecosystem dynamics. The rangelands of Nakasongola fall within the semi-arid ecological zones facing severe desertification. The sparse vegetation alternates with large portions of bare surfaces that range between 75 to 100% of total grazing land (Mugerwa *et al.,* 2011b, c). These extensive bare surfaces eventually facilitate high rates of surface evaporation, surface run-off and sedimentation of downstream water reservoirs (Zziwa *et al*., 2008). There is thus inefficient utilisation of rain water for production of livestock feeds, livestock products and services as most of the water is lost from the system through run-off and surface evaporation (Snyman, 1999). This inefficient utilisation of water is despite the increased frequency of severe droughts attributed partly to climate change and variability in arid and semi-arid ecosystems.

The challenge currently faced by researchers and other stakeholders in the livestock sector is how to make livestock production a more water efficient and sustainable livelihood option in dryland ecosystems where water scarcity is an inherent feature (Peden *et al*., 2007). In order to overcome this challenge, improvement in livestock water productivity (LWP) will provide means both to ease water scarcity and to leave more water for other human and eco-system uses. Peden *et al*. (2005) defined LWP as the ratio of products and services to the amount of water depleted in producing these goods and services. Water is depleted or lost through transpiration, evaporation, and downstream discharge and cannot be readily used again and yet agricultural output depends primarily on transpiration. Similarly, animal production depends on the use of feed produced by transpiration.

One of the basic strategies to increase livestock water productivity in agricultural systems is to conserve water (Peden *et al*., 2007). This implies that, a maximum proportion of available water should be used for transpiration with minimum losses to evaporation and run-off. This therefore calls for restoration of the lost vegetation on degraded bare surfaces. Once vegetation is restored, runoff and surface evaporation will reduce while water infiltration and transpiration will increase (Mugerwa *et al*., 2008 and Zziwa *et al*., 2008). This study intended to improve livestock water productivity through restoration of vegetation on bare surfaces in the degraded rangelands of Nakasongola District in Uganda.

10.3 Materials and method

10.3.1 Study site

This study was conducted in the semi-arid ecosystem of Nakasongola (01^0 54'N, 32^0 54'E), which forms part of Uganda's cattle corridor. The corridor stretches diagonally from the Uganda-Tanzania border in the South through the plains of Lake Kyoga region, to Karamoja in the North East. Nakasongola is located in the central region of Uganda on Bombo – Gulu road 114 Km north of capital Kampala (Figure 10.1).

The mean daily temperature is 30^0C. Night heat surges are very common. The average humidity ranges from 80% in the morning to 56% in the afternoon. Rainfall range between 500mm-1000mm per annum and there are two rain seasons. The main rain season occurs from March-April to June-July while the second rain season follows from August to October-November. A long dry season occurs from December to February while a short spell comes around July-August. Very often the second rain season in the district is unreliable and at times the dry season extends from August to February. The minimum and maximum evaporation rates range from 1500mm to 1700mm during wet and dry seasons respectively.

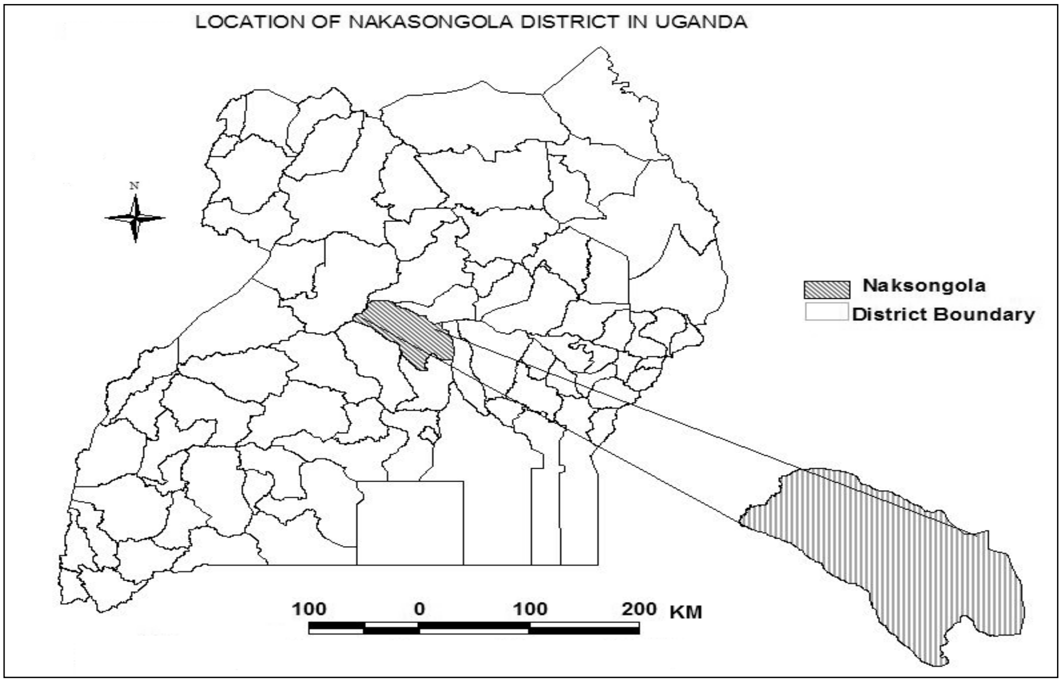


Figure 10.1: Map of Uganda showing the location of Nakasongola District

The natural vegetation in Nakasongola is dominantly open savannah woodland with tall grasses. *Combretum* and *Terminalia* tree species generally form the dominant portion of the woody vegetation while *Hyparrhenia, Andropogon, Panicum, Brachiaria, Loudetia, Chloris* and *Setaria* are among the dominant grass species. Various forest remnants and other ever green elements also occur. Deciduous broad leaved trees of the *Combretaceae* make up the bulk of the woody cover which is light to moderate, 10-40 ft high, with abundant *Combretum molle*, *Terminalia glaucescens* and *Albizia zygia*. The grass layer is 5-7 ft high at maturity and many of the grasses are of the same species found in the forest Savannah mosaic (Langdale-Brown, 1970).

The soils of Nakasongola are relatively homogeneous and strongly weathered with high sesquioxide content (FAO, 1998). It is frequently indicated that these soils are not suitable for permanent cultivation unless combined with the traditional fallowing techniques to restore basic cations and reduce acidity (FAO, 1998).

10.3.2 Experimental layout and design

Eighteen plots of 20 x 20m were established on the degraded bare surface following a completely randomised design with three replications. Six vegetation restoration treatments were evaluated and these included: (1) Fencing only (FO), (2) Fencing + manure (FM), (3) Fencing + reseeding (FR), (4) Fencing + manure left on soil surface + reseeding (FMSR), (5) Fencing + Manure incorporated in to the soil + reseeding (FMIR) and (6) control (C) (no manuring, fencing and reseeding). The treatments were randomly allocated to the experimental plots and data collection lasted for $1^1/_2$ years covering three wet and three dry seasons.

Cattle manure was added to experimental plots by night kraaling a herd of cattle for a period of two weeks in each plot allocated to manure treatment based on manure application rates recommended by Brady (1990). After the two weeks of manure deposition, the manure accumulated in FMSR treatment plots was left on the surface while that accumulated in FMIR plots was incorporated into the soil using hand hoes. During reseeding operations, a mixture of two grasses and two legume species was broadcasted in the experimental plots allocated to reseeding treatments. The legume species comprised of *Centrocema pubescens* (Centro) and *Macroptilium atropurpureum* (Siratro) which were sown at a seed rate of 4kg/ha. The grasses comprised of Panicum species (*Panicum coloratum var. Makarikariense and Panicum maximum)* and Brachiaria species (*Brachiaria ruziziensis* and *Brachiaria brizantha)* which were sown at a seed rate of 10 kg/ha.

10.4 Data Collection

10.4.1 Soil sampling and soil measurements

Two sets of soil samples were taken from each plot before treatments were allocated and after two growing seasons. Four soil samples were taken randomly from each plot to a depth of 0-15cm with an auger. The samples were thoroughly mixed and bulked to form one composite sample per plot. The samples were analyzed for nitrogen, organic matter, available phosphorus, potassium and soil pH according to methods of Anderson and Ingram (1989).

10.4.2 Dung measurements

The amount of manure deposited in plots was quantified at the end of the two weeks. The plot was partitioned into four equal small portions and a $1m^2$ square quadrat was placed randomly at two locations within each small portion. Manure samples were taken during dry conditions to reduce contamination of dung with mud (soil). Manure enclosed in each quadrat was collected, air dried to a constant weight and weighed. The average weight from the eight locations was used to estimate the total amount of manure deposited per plot. The same samples were analyzed for P, N_2, K, Mg, Ca and ash according to methods of Anderson and Ingram (1989) and this constituted the quality of manure added in each plot.

10.4.3 Vegetation measurements

Data was collected on dry matter yield, ground cover and seedling emergence. A 1-m margin was left in each plot to avoid edge effects during sampling. Seedling emergence was determined by counting the number of seedlings after 7, 14 and 21 days of sowing in reseeded treatments. Vegetation cover was determined using the point frame according to methods of Tothill (1978). The above ground pasture vegetation within each quadrat was cut at ground level, put in polythene bags and weighed. The samples from each plot were then dried at 60^0c to a constant dry weight after 72 hours in an air-circulating electric oven and then weighed to determine the dry matter yield for each plot according to methods L.'tMannetje (1978).

10.4.4 Estimation of LWP

The LWP model developed by Haileslassie *et al.* (2006; 2008) was used to estimate the contribution of the various treatments on LWP. The model consists of two excel worksheets which include the "depleted water" worksheet that estimates the amount of water depleted to produce livestock products and services and the "beneficial output" worksheet which estimates the amount the amount of livestock products and services produced per unit of depleted water. Upon estimation of both depleted water and livestock products/services, LWP was estimated according to the following equation. LWP = Livestock products and services/Depleted water. In the current study, the dry matter values for the respective treatments were fed into the "depleted water" worksheet to estimate the amount of water depleted to produce the amount of dry matter in consideration and the resulting amount of livestock products attributable the amount of dry matter in question was obtained from the "beneficial output" worksheet of the model.

10.4.5 Statistical Analysis

The data on vegetation parameters was subjected to analysis of variance using the GLM procedures of SAS (1989) for randomized experimental design.

10.5 Results

10.5.1 Soil Properties

The physic-chemical properties of the soils in the experimental plots before and after one year of treatment allocation are summarised in Table 10.1. Amendment of soil with manure increased soil pH by 71% and the highest increment (77%) was produced by FMIR treatment. The soils were originally moderately acidic but changed to near neutral soils after addition of manure. The soil pH for non-manured and/or reseeded plots was noted to decline tending to strongly acidic conditions. Deposition of cattle manure on degraded bare surfaces also improved soil organic matter (OM) by 167%. The average OM of experimental plots before addition of manure was 1.24%, far below the critical OM value (2%) required for optimum plant growth and establishment. After manure amendment, OM improved to 3.3%, above the critical level. Generally, manures improved soil nitrogen (N) by 171% and the highest increment (178%) was noted in plots subjected to FMIR treatment. The average soil N (0.08%) before addition of manures was below the N critical value (0.2%) for efficient plant establishment.

Table 10.1: Soil (0-15 cm) properties for the different pasture restoration treatments

Parameter	**Treatments (before manure application)**					
	FM	FMSR	FMIR	FR	FO	C
pH	3.5	3.4	3.6	3.7	4.3	4.3
SOM (%)	1.04	1.33	1.34	1.22	1.38	1.38
% N	0.08	0.07	0.09	0.09	0.04	0.04
Av.P(mg/kg)	1.38	1.5	1.64	1.33	1.9	1.38
K (Cmoles/kg)	0.3	0.4	0.87	0.3	0.3	0.25
	Treatments (after manure application)					
pH	5.8	5.8	6.4	3.3	3.9	4.0
SOM (%)	3.3	3.1	3.5	1.3	1.18	1.08
% N	0.2	0.2	0.25	0.09	0.04	0.04
Av.P(mg/kg)	5.38	5.42	5.5	4.34	1.7	1.28
K (Cmoles/kg)	2.5	2.1	2.7	0.25	0.25	0.25

10.5.2 Seedling Emergence

The highest number of emerged seedlings (51 m^2) was recorded in plots subjected to FMIR treatment (Figure 10.1). The number of seeds that emerged approximately doubled for FMSR, FMIR and FR treatments 14 days post sowing. After 21 days, the number of emerged seedlings increased by 12% and 6% for treatments FMSR and FMIR respectively. However, that of treatment FR decreased by 75% after 21 days.

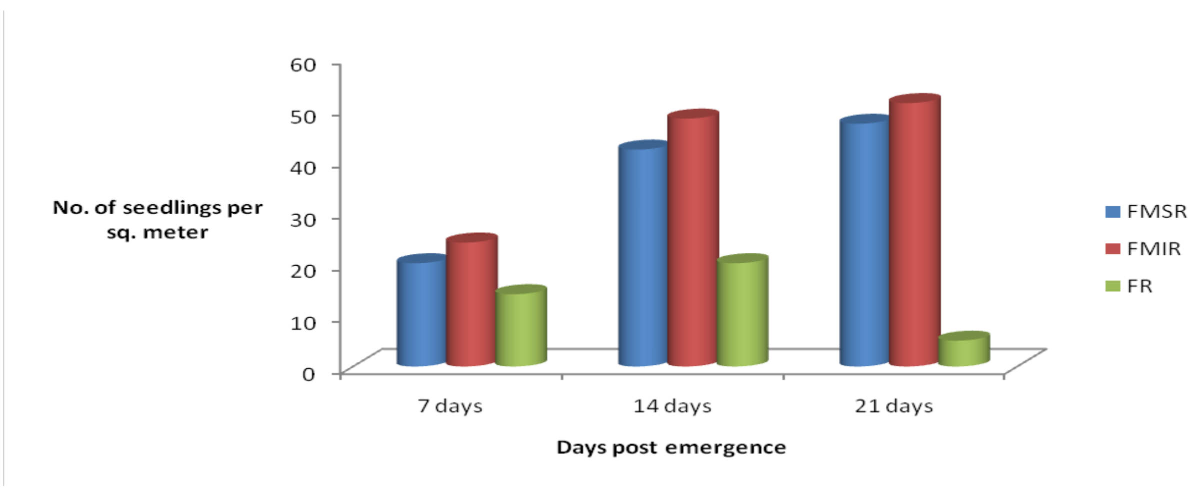


Figure 10.1: Cumulative Seedling emergence of pasture seeds after 7, 14 and 21 days of planting

10.5.3 Dry matter production

Results of dry matter yield and basal cover for different treatments in the different seasons are presented in Table 10.2. Irrespective of the seasons, the dry matter yield significantly ($p < 0.05$) differed among restoration treatments. Highest dry matter yield (3820kg/ha) was produced by FMSR treatment followed by treatment FM (3480kg/ha). The lowest yields were obtained in the control and FO treatment plots. Generally, mean dry matter yield (3300kg/ha) from manured plots was 125% higher than that (1470kg/ha) from non-manured plots. The mean dry matter yield also differed ($p < 0.01$) among seasons with mean yield (2895kg/ha) in the wet season being 23% higher than that (2349kg/ha) in the dry season.

10.5.4 Basal cover

The amount of ground covered by vegetation was significantly ($p < 0.05$) affected by restoration treatments. The control plots consistently remained bare thought the duration of the experiment. Generally, the amount of bare ground for manured plots was 5 and 2 times less than that for non-manured plots in the wet and dry seasons respectively. The highest proportion of ground covered with vegetation was caused by FMSR followed by FM treatments. The lowest proportion of ground covered with vegetation was obtained in the control plots.

Table 10.2: Mean Dry matter yield, percentage ground cover and species richness for different restoration treatments under different seasons

Season	Treatment	% Cover			DM (kg/ha)
		Bare ground	Forbs	Grass	
Wet	FMSR	2.4	40.7	56	4500
	FM	11.5	14.5	74	3700
	FMIR	22.8	33.7	43	2710
	FR	50.4	18	31	1940
	FO	70.8	0	29.2	1600

	C	100	0	0	0
Dry	FMSR	29.1	16.3	54.5	3130
	FM	28.7	3.4	68.2	3200
	FMIR	49.1	10.9	42.7	2500
	FR	72	8.4	2.1	1680
	FO	86.1	0	13.6	1160
	C	100	0	0	0
	SE	5.3	3.9	5	396
	Significance				
	Season	***	***	*	***
	Treatment	***	***	***	*
	Season*Treatment	*	***	ns	Ns

*** Significant at $p < 0.001$, ** Significant at $p < 0.01$, * Significant at $p < 0.05$ and ns- Non significant. FMSR (fencing+ manure left on surface+ reseeding), FMIR (fencing + manure incorporated in the soil + reseeding), FR (fencing + reseeding), FM (fencing + manure), FO (fencing only), C (control).

10.5.5 Livestock water productivity as influenced by different treatments

Changes in dry matter production as a result of different restoration treatments caused noticeable changes in LWP (Table 10.3). Improvement in dry matter production led to improvement in the LWP. Dry matter yields from plots subjected to FMSR, FM and FMIR improved LWP by 31, 25 and 13% respectively. The magnitude of LWP was noted to increase with a reduction in the amount of water depleted to produce beneficial outputs. LWP was therefore highest for treatment FMSR where the amount of water depleted was lowest (3,622,528 M^3).

Table 10.3: Effect of restoration treatments on livestock water productivity (LWP) values

Treatment	DM (kg/ha/yr)	Depleted water (M^3)	Beneficial output($)	LWP ($/m^3)
Current situation	4300	4,754,570	760,731	0.16
FMSR	7644	3,622,528	760,731	0.21
FMIR	5212	4,226,283	760,731	0.18
FM	6959	3,803,655	760,731	0.20
FR	3637	5,071,540	760,731	0.15
FO	2770	5,851,776	760,731	0.13

FMSR (fencing+ manure left on surface+ reseeding), FMIR (fencing + manure incorporated in the soil + reseeding), FR (fencing + reseeding), FM (fencing + manure), FO (fencing only). The current situation represents the current average situation on most grazing lands in Nakasongola upon which the suitability of various restoration techniques is assessed.

10.6 Discussion

10.6.1 Soil properties

Neutralization of soil pH was attributed to the reduction in concentration of acid forming ions in the soil solution. Ano and Ubochi (2007) also reported that when cattle manures are added to soils, the manures get mineralized leading to release Ca^{2+} ions into the soil solution which quickly get hydrolysed to form Calcium hydroxide. The Calcium hydroxides then react with soluble aluminum ions in the soil solution to give insoluble $Al(OH)_3$. The hydroxide of the calcium hydroxide also reacts with hydrogen ions to form water and reducing the concentration of acid forming ions. The high increment in soil pH caused by FMIR treatment was therefore attributed to the increased organic matter content which resulted into increased release of Ca ions whose hydroxides withdrew hydrogen ions from the soil. The increase in soil N was due to the decomposition of manures by micro-organisms to release N into the soil while the high increment in soil N produced by FMIR treatment was attributed to the limited loss of N via volatilization as the manures where incorporated into the soil.

10.6.2 Seedling Emergence

The act of mixing manures with soil resulted into a fine seed bed with improved soil physical properties including improved water infiltration to avail seeds with adequate water for establishment. Also, the close contact between seeds and the fine soil particles produced through incorporation of manures into soils stimulated imbibition processes and eventually seedling development and emergence in plots subjected to FMIR treatment as compared to other treatments. The decrease in the number of emerged seedlings after 21 days was partly due to severe destruction of seedlings by termites of the subfamily *Macrotermitinae* in the FR treatment plots. The termites were observed to attack the seedlings and cut them at ground level, reducing the number of standing seedlings. The possible cause of this destructive behaviour by termites was associated with the limited availability of feed resources (in form of organic materials) in non-manured plots (Mugerwa *et al*., 2008).

10.6.3 Dry matter production

In uniform pasture swards dominated by grasses, a positive relationship occurs between proportion of bare patches and biomass yield. Mugerwa (2009) also demonstrated the occurrence of this relationship in the rangeland ecosystem of Nakasongola in Uganda. This relationship possibly explains why dry matter yield was highest and lowest in FMSR and C treatment plots with lowest and highest proportions of bare surfaces respectively. On the other hand, the generally high dry matter yield on manured plots as compared to non-manured plots was attributed to the improved soil pH, soil organic matter and elevated concentrations of available nutrients (Naramabuye *et al*., 2007) as well as a reduction in destruction of seedlings by termites, particularly, members of the genus *Macrotermes*. *Macrotermes* species are generalist feeders that feed on dung, wood, litter and grass (Wood, 1991). Deposition of dung could have availed the species with adequate feed resources to deter them from destroying vegetation. Organic matter also enhances multiplication and survival of termite enemies particularly entomo-pathogenic fungi, entomo-pathogenic nematodes and predatory ants (*Odontomachus haematoda* and *Paltothyrus* sp) in soils (Sekamatte *et al*., 2003). Ants usually attach and prey on termites hence reducing the number and activity of termites which subsequently relieves the crops from termite damage (Sekamatte *et al*., 2003). It is therefore possible that cattle manure promoted the activity of termite enemies which in turn limited and reduced the destructive effect of termites. The low biomass yield in the dry season as compared to the wet season was mainly due to the limited availability of soil moisture. In this regard, Crowder and Chheda (1982) noted that rainfall is the greatest single factor affecting plant growth and herbage dry matter production in tropical countries. Its seasonal nature, variability and erratic incidence, and the high evaporation potential in many areas result in periods of water stress and prolonged droughts. During dry periods, biomass production is thus limited by low availability of water (Snyman, 1999).

10.6.4 Basal cover

The high proportion of ground covered by vegetation in manured plots was attributed the improved soil physic-chemical properties and the growth characteristics of the dominant species in plots amended with cattle manure. *Cynodon dactylon* constituted the major component of the herbaceous vegetation in manured plots. The perennial grass spreads quickly by stolons and rhizomes to cover large areas in a short time (Skerman and Riveros, 1990). Further, the grass is highly responsive to manure application and thus grows aggressively to cover large areas. Incorporation of manure into the soil possibly buried grass seeds (such *Cynodon dactylon*) contained in cattle manure deeper than the appropriate depth required for optimum establishment. The limited establishment of the grass probably resulted into less ground covered by vegetation as compared to plots where manure was left on the surface.

10.6.5 Livestock water productivity as influenced by different treatments

FMSR treatment led to the highest improvement in LWP and this was attributed to the high DM yield and amount of ground covered by vegetation in FMSR treatment plots. The high proportion of ground covered by vegetation was associated with reduced run-off and surface evaporation, improved water infiltration and hence more water was channelled into evapo-transpiration to produce livestock feeds and subsequently, livestock products and services. As noted earlier, LWP is defined as the ratio of products and services to the amount of water depleted, degraded and devalued in producing these goods and services (Peden *et al.*, 2007). $LWP = (P_L + S_L)/(W_{DP} + W_{DG} + W_{DV})$, Where; $P_L + S_L$ are livestock products and services & W_{DP}, W_{DG} and W_{DV} are quantities or value of depleted, degraded and devalued water respectively. If we assume the denominator to be similar for any two given systems, the system with more livestock products and services (numerator) will have a higher LWP than that with less livestock products and services. Since water is used more efficiently to produce more livestock feed on vegetated surfaces than on bare or less vegetated surfaces, more livestock products and services will be produced by animals grazing vegetated surfaces than those grazing less vegetated or bare surfaces. It is therefore not surprising that the model estimated high LWP values for treatments that contributed to high values of basal cover and biomass production. The results of the study reviled that rangeland management techniques that enhance adequate basal cover and sufficient production of biomass are critical in ensuring high LWP. Further, dry matter yields from plots subjected to FR and FO treatments reduced LWP by 7% and 19% respectively. This was attributed to the fact that the experimental plots were established on a completely bare area with zero dry matter yields. The contribution of treatments FR and FO was not sufficient to improve the dry matter production to 4300kg/ha which is the average dry matter production on most of the grazing lands in Nakasongola. As a result, these treatments led to reductions in the LWP values in relation to the average existing situation.

10.7 Conclusion

Night kraaling cattle in temporarily fenced plots established on degraded bare resulted in deposition of adequate quantities of cattle manure. The manure improved the soil properties on the bare surfaces and also reduced the susceptibility of seedlings to termite damage leading to high biomass yield, reduced amount bare and consequently improved LWP. FMSR lead to the highest production of biomass and eventually highest increment in LWP on degraded bare patches. In order to sustain productivity and profitability of animal production systems in water stressed areas, management of dryland ecosystems need to focus on enhancing water use efficiency in livestock production systems. Some of the interventions that ensure efficient utilization of rain water in rain-fed livestock systems include maintenance of adequate vegetation cover and production sufficient biomass.

10.8 Acknowledgements

This work was funded by the under the CGIAR “Challenge Program on Water and Food” through Nile Basin Livestock Water Productivity Project (PN 37).

10.9 References

Anderson, J. M., Ingram, J. S. I., 1989. TSBF: A Handbook of Methods of Analysis. CAB International, p. 39.

Ano, A. O. and Ubochi C. I., 2007. Neutralization of soil acidity by animal manures: mechanism of reaction. African Journal of Biotechnology, 6: 364-368.

Brady, C. N., 1990. The nature and properties of Soils. Tenth Edition. Collier Macmillan Publishers, London. 621p.

Crowder, L. V., Chheda, H.R., 1982. Tropical Grassland Husbandry. Longman Group Limited, Long Man House, Burnt Mill, Harlow, Essex, UK. 562pp.

FAO, 1998. The digital soil and terrain database of north eastern Africa. FAO .Rome.

Haileslassie, A., Mpairwe, D., Peden, D., 2008, Unpublished. Livestock Water Productivity in Agropastoral Systems of the White Nile Basin: Example from the "Cattle Corridor" in Uganda. 32pp.

Haileslassie, A., Peden, D., Negash, F., Gidyelew, T., 2006. Sediment sources and sinks in the Gumera watershed, Ethiopia: implications for livestock water productivity in the Nile River Basin. Proceeding of international conference on the role of the River Nile in poverty reduction and economic development in the region. November 30- December 2 2006. Addis Ababa, Ethiopia. pp 156-164.

Langdale-Brown, I., 1970. Vegetation. In: Jameson, J.D. (Ed) Agriculture in Uganda. Oxford University Press. pp 90-97.

Mpairwe, R.D., 1999. Improving feed resources in agro-pastoral systems for rangeland development in Uganda. In: Sabiiti, N. E., Tizikara, C and Nampala, M. P., (Eds) Sustainable Utilization of Dry land Ecosystems for Livestock Development. Proceedings of the First National Dry land Husbandry Project Workshop. Kazo, Mbarara District, Uganda (31 May-2 June 1999). pp 32-47.

Mugerwa, S., 2009. Effect of reseeding and cattle manure application on pasture and livestock water productivity on degraded rangelands of Nakasongola. MSc thesis. Kampala: Makerere University.

Mugerwa, S., Mpairwe, D., Mutetikka, D., Kiwuwa, G., Zziwa E., Owoyesigire B., Peden, D., 2008. Effect of cattle manure and reseeding on pasture productivity. In Fighting Poverty Through Sustainable Water Use: Volumes II, Proceedings of the CGIAR Challenge Program on Water and Food 2nd International Forum on Water and Food, Addis Ababa, Ethiopia, November 10—14, 2008.

Mugerwa, S., Nyangito, M., Mpairwe, D., Bakuneeta, C., Nderitu, J and Zziwa, E., (2011a). Farmers' Ethno-ecological Knowledge of the Termite Problem in Semi-arid Nakasongola. African Journal of Agricultural Research, 6:3183-3191.

Mugerwa, S., Nyangito, M., Mpairwe, D., Bakuneeta, C., Nderitu, J and Zziwa, E., (2011b). Termite assemblage structure on grazing lands iin semi-arid Nakasongola. Agric. Biol. J. N. Am, 2: 848-859.

Mugerwa, S., Nyangito, M., Mpairwe, D and Nderitu, J., (2011c). Effect of biotic and abiotic factors on composition and foraging intensity of subterranean termites. African Journal of Environmental Science and Technology, 5: 579-588.

Naramabuye, F.X., Haynes, R.J., Modi, A.T., 2007. Cattle manure and grass residues as liming materials in a subsistence farming system. Agriculture, Ecosystems and Environment 124, 136-141.

National Environment Management Authority (NEMA), 2007. State of the Environment Report for Uganda. NEMA, Kampala. 357pp.

Peden, D., Tadesse, G., A.K., Misra., 2007. Water and livestock for human development. In: Molden, D (ed), Water for food, water for life: A Comprehensive Assessment of Water Management in Agriculture, London: Earthscane and Colombo: International Water Management Institute. pp 485-514.

Peden, D., Ayalneh, W., Astatke, A., Sonder, K., Puskur, R., Taddese, G., 2005. Livestock water productivity of four community based small scale irrigation schemes in the upper Awash River basin of Ethiopia.

SAS.1989. SAS User's Guide: Statistics (4th Ed) SAS Inst., Inc., Cary, NC.

Sekamatte, B. M., Ogenga-Latigo, M., Russell-Smith, A., 2003. Effects of maize-legume intercrops on termite damage to maize, activity of predatory ants and maize yields in Uganda. Crop Protection 22, 87-93.

Skerman, P. J., Riveros, F., 1990. Tropical Grasses. FAO Plant Production and Protection Series, No. 23. 832pp.

Snyman, H. A., 1999. Short term effects of soil water, defoliation and rangeland condition on productivity of semi-arid rangeland in South Africa. Arid Environments 43: 47-62.

Tadasse, G., Peden, D., Astatke, A., Ayaleneh, W., 2003. Effect of manure on grazing lands in Ethiopia; East African highlands. Mountain Research and Development 23, 156-160.

't Mannetje, L., 1978. Measurement of Grassland Vegetation and Animal Production. CSIRO Division of Tropical Agronomy. Cunningham Laboratory. Brisbane, Queensland, Australia.

Tothhill, C. J., 1978. Measuring Botanical Composition of Grasslands. In 't Mannetje, L (ed) Measurement of Grassland Vegetation and Animal Production. CSIRO Division of Tropical Agronomy. Cunningham Laboratory. Brisbane, Queensland, Australia. pp 230-290.

Wood, G. T. 1991. Termites in Ethiopia: The Environmental Impact of Their Damage and Resultant Control Measures. Ambio Vol. 20: No. 3-4.

Zziwa, E., Mpairwe, D., Kyambande, J., Iwadra, M., Mutetika, D., Kiwuwa, G., **Mugerwa, S** and Peden, D., 2008. Upper catchment management and water cover plants effects on the quality and quantity of water in surface reservoirs. In Fighting Poverty Through Sustainable Water Use: Volumes II, Proceedings of the CGIAR Challenge Program on Water and Food 2nd International Forum on Water and Food, Addis Ababa, Ethiopia, November 10—14, 2008.

11. Detection of Mau Forest Cover and Lake Nakuru, using Multi-Temporal Remote Sensing and GIS

Murimi, S.K.

Obando, J

Prasad, H

Kenyatta University
P.O Box 43844 Nairobi

skmurimi@yahoo.com

11.1 Abstract

Remote sensing technology in combination with Geographic Information System (GIS) can render reliable information on spatial-temporal changes in land cover. The analysis of the spatial extent and temporal change of vegetation cover using remotely sensed data is of critical importance in monitoring encroachment of farming activities into natural forest areas. Remotely-sensed images can be processed to produce important basic data sets that can be combined with other types of spatially referenced data within an integrated GIS to generate information relevant to temporal changes in land cover/use. The current study investigates the Spatial-Temporal changes in landcover/use within Mau East Forest and its surrounding areas by use of remotely sensed data. The Forest is located in the Western Escarpment of Central Rift Valley System in Kenya and forms the main watershed of Lake Nakuru. Supervised classification was done and maximum likelihood operation performed to compute landcover maps. For recognition of landcover reflectance, Ground Control Points (GCP) were recorded with a Global Positioning System (GPS) device in strategic locations to establish cover categories during the training phase. The ground truth data georeferenced by GPS were used to validate classification. In addition, multi-band calculation of Vegetation indices, namely Normalized Difference Vegetation Index (NDVI) and Leaf Area Index (LAI) were applied to detect spatial extent of vegetation, as well as vegetation stress. Results from the study indicate that vegetation cover as well as areas under the Lake, farms and settlements has significantly changed during the 1973 – 2006 period. The spatial extent of natural vegetation, that is, forests, grasslands and bushland and that under the Lake's surface area has decreased remarkably while that under farmland and built-up areas is increasing towards present. It means that decrease in vegetation has been as a result of anthropogenic activities in the study area. It can hence be concluded that detecting changes in land cover/use, for example, vegetation, settlement, etc, by use of remote sensing and GIS techniques over a period of years, is a very useful tool for watershed studies.

Key words: *Remote sensing, GIS, NDVI, LAI, Supervised classification*

11.2 Introduction

Rural-rural migration resulting in growth in population has been a major factor which has altered natural vegetation cover, due to anthropogenic activities. In the Lake Nakuru watershed, accelerated land cover change (LCC) has been experienced during the last four decades. Former large-scale farms have been transformed into small-holder farms and plots while plantation forests are gradually being lost. These changes have negatively impacted on the hydrologic regime of water resources within the watershed. Some of the negative effects include the drying up of rivers during the dry season and the increased surface runoff during the wet seasons. Thus, there is need to quantify spatial-temporal land cover dynamics for hydrologic response assessment. This study derived LCC maps using remote sensing and Geographic Information System tools. The use of remote sensing data in recent times has been of immense help in monitoring the changing pattern of vegetation. Meijerink (2007) described change detection as a process that observes the differences of an object or phenomenon at different times. Drury (2001) defines change detection as variation in spectral response and involves situations where the spectral characteristics of vegetation or other cover types in a given location change overtime.

Multi-band and Multi-spectral classifications were performed to establish vegetation changes in the study area. Normalized Difference Vegetation Index (NDVI) was used because vegetation differential absorbs visible incident solar radiant energy and reflects much in the near infrared (NIR). It means that data on vegetation biophysical characteristics can be derived from visible and NIR portions of the electromagnetic spectrum (EMS). The NDVI approach is based on the fact that healthy vegetation has low reflectance in the visible portion of the EMS due to chlorophyll and other pigment absorption and has high reflectance in the NIR because of the internal reflectance by the Mesophyll spongy tissue of green leaf (Campbell, 1987). NDVI can be calculated as a ratio of Red (Visible band 3) and the NIR (band 4) spectral bands of a sensor system. NDVI values range from –I to +1. Because of a high reflectance in the NIR portion of the EMS, healthy vegetation is represented by high NDVI values that range between 0.1 and 1. This means that, NDVI values are sensitive for a range of poor vegetation cover to just a full cover respectively (Lillesand and Kiefer, 1994*).* NDVI values can be expressed in terms of the Leaf Area Index (LAI). LAI represents the proportion of total leave area per unit ground surface area. NDVI is sensitive for LAI values of up to about 3. For LAI values >4 the NDVI does not change much as it is saturated. It should be noted that the internal shadows of the canopy influences NDVI and hence LAI, for example, the NDVI of a tropical rainforest with its irregular canopy structure has LAI of >15 values. On the other hand, exotic pine plantations have LAI of <15, since they are made up of a more even canopy surface. Irregular canopy (LAI>15) introduces undefined pixels where no NDVI values and hence no land cover information is available. Appropriate Filters are used to remove the undefined pixels in the classified maps. Remote sensing has shown great potential in agricultural mapping and monitoring due to its advantages over traditional procedures in terms of cost effectiveness and timeliness in the availability of information over larger areas. The aim of this study was to incorporate the temporal dependence of multi- temporal image data to identify the changing pattern of vegetation cover and consequently enhance the interpretation capabilities. Moreover integration of multi- sensor and multi- temporal satellite data effectively improves the temporal attribute and the reliability of multi- data. Therefore, this paper discusses methods of the detection of vegetation cover utilizing multi-temporal and multi-sensor remotely sensed data incorporated in a GIS environment.

11.3 Study Area

The study area is located in the Eastern Mau forest and forms part of Lake Nakuru watershed in Kenya with spatial extent between 0°18’09.03” to 0°40’18.41” S latitude and 35°50’37.53” to 36°09’38.31” E longitude. Figure 11.1 shows the location of Eastern Mau forest and various settlement schemes in the Lake Nakuru watershed. The area has attracted farming communities from various rural areas of Kenya due to its favourable climate, drainage and fertile soils (Murimi and Prasad, 2005).

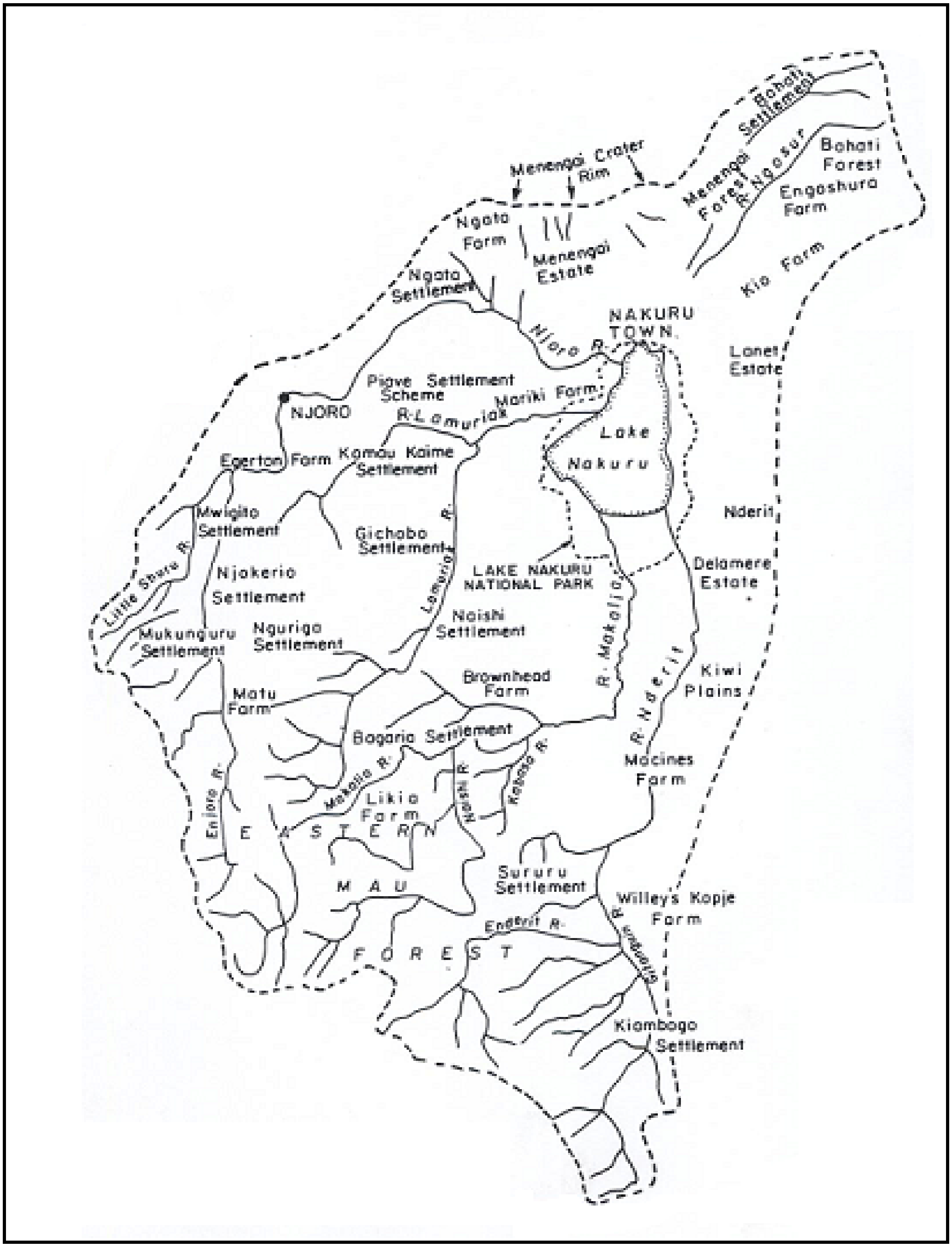


Figure 11.1. Lake Nakuru watershed showing Mau forest, the Lake and various settlements (various sources)

11.4 Methodology

The main goal of this study is to reveal vegetation change using multi- temporal satellite data, in order to extract changes. Figure 11.2 is a flow diagram of the methodology. Digital image-processing software ENVI 4.0 and ILWIS 3.6 were used for the processing, analysis and integration of spatial data to reach the objectives of the study. ILWIS 3.6 was used to generate colour composites of various Landsat images (Table 11.1), by stacking Bands 4, 3, 2 and 5, 4, 2 for false colour composite (FCC) and pseudo natural colour composite respectively. For image classification, seven classes were defined as Water bodies, Built-up areas, Bushland and shrubs, Grassland and trees, Forests, Bare surfaces and Large farms (Table 11.2). Ground control points obtained using a Global Positioning System (GPS) device for locations in relation to the classes of the study area was plotted on Landsat ETM+ (2000) image. This was done in order to verify the training sites (defined classes) as regards the spectral signature (Figure 11.3). Supervised classification (maximum likelihood) for the various classes was performed using ILWIS 3.6 for TM and ETM+ images. Finally post-classification using Undef Majority Filter type and Filter name Majundef (x4) was used to remove unclassified pixels in the classified raster images. Multi-band Calculation of Vegetation indices NDVI and LAI for the period 1973 – 2006 was performed (Equation I and II).

NDVI= [(near infrared band- red band)/ (near infrared band+ red band)]

NDVI values between -1.0 and 0 represent non-vegetative features such as bare surface, built- up area and water body. Conversely, greater than 0 display vegetation covers.

To find out the changing pattern of vegetation during 1986- 2000, Histograms for both images were crossed and visually examined.

In addition LAI image maps were computed using the following red and infrared ratios.

LAI= [near infrared band/red band]

Afterwards, vegetation cover map of 1973; 1986; 2000 and 2006, were crossed to generate the map of change of vegetation cover for the respective dates and to find out the changing pattern of vegetation cover. The False Colour Composite (FCC) images and the spectral vegetation indices images were draped over SRTM 3D Digital Elevation Model (DEM) of the computed SRTM image mosaic.

Table 11.1. Data source and Types

A. **Remotely Sensed Data**				
	Satellite (Sensor)	**Band**	**Micrometer (µn)**	**Resolution**
1.	Landsat Multi Spectral Scanner (mss) p181r60_1m19730131:-nn01 – nn04	1	0.5 – 0.6	80m
		2	0.6 – 0.7	80m
		3	0.7 – 0.8	80m
		4	0.8 – 1.1	80m
2.	Landsat Thematic Mapper (TM) p169r60_5t860128:-nn1 – nn7	1	0.45 – 0.53	30m
		2	0.52 – 0.60	30m
		3	0.63 – 0.69	30m
		4	0.76 – 0.90	30m
		5	1.55 – 1.75	30m
		6	10.40 – 12.50	120m
		7	2.08 – 2.35	30m
3.	Landsat Enhanced Thematic Mapper (ETm+) p169r060_7t2000127_z36:-nn10 – nn70	1	0.45 – 0.515	30m
		2	0.525 – 0.605	30m
		3	0.63 – 0.690	30m
		4	0.75 – 0.90	30m
		5	1.55 – 1.75	30m
		6	10.40 – 12.5	60m
		7	2.09 – 2.35	30m
		Pan	0.52 – 0.90	15m
4.	Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) AST_LIB_00305052006183929_06022006.hdf	1 Visible	0.52 – 0.60	15m
		2 Visible	0.63 – 0.69	15m
		3N (Nadir looking)	0.76 – 0.86	15m
5.	Shuttle Radar Topographic Mission (SRTM)	Geocoded Terrain Corrected (GTC) product, 3arc-sec DEM, 30m -SRTM_fB03_s001e035.tif -SRTM_fB03_s001e036.tif		

(Meijerink, 2007)

Table 11.2. Landcover classification categories for the Mau-Lake Nakuru area

	Land cover Category	**Symbol**	**Description**
1	Water bodies	WB	Open water bodies
2	Built-up areas	BA	Built-up areas, towns, homestead, small gardens, plots
3	Bushland and shrubs	BL	Bushland and shrubs

4	Grassland and trees	GT	Grasses mixed with scattered trees
5	Forests	FT	Forests, indigenous, exotic plantations
6	Bare surfaces	BS	Bare surfaces and saline mudflats
7	Large farms	LF	Large farms (wheat, maize, pasture)

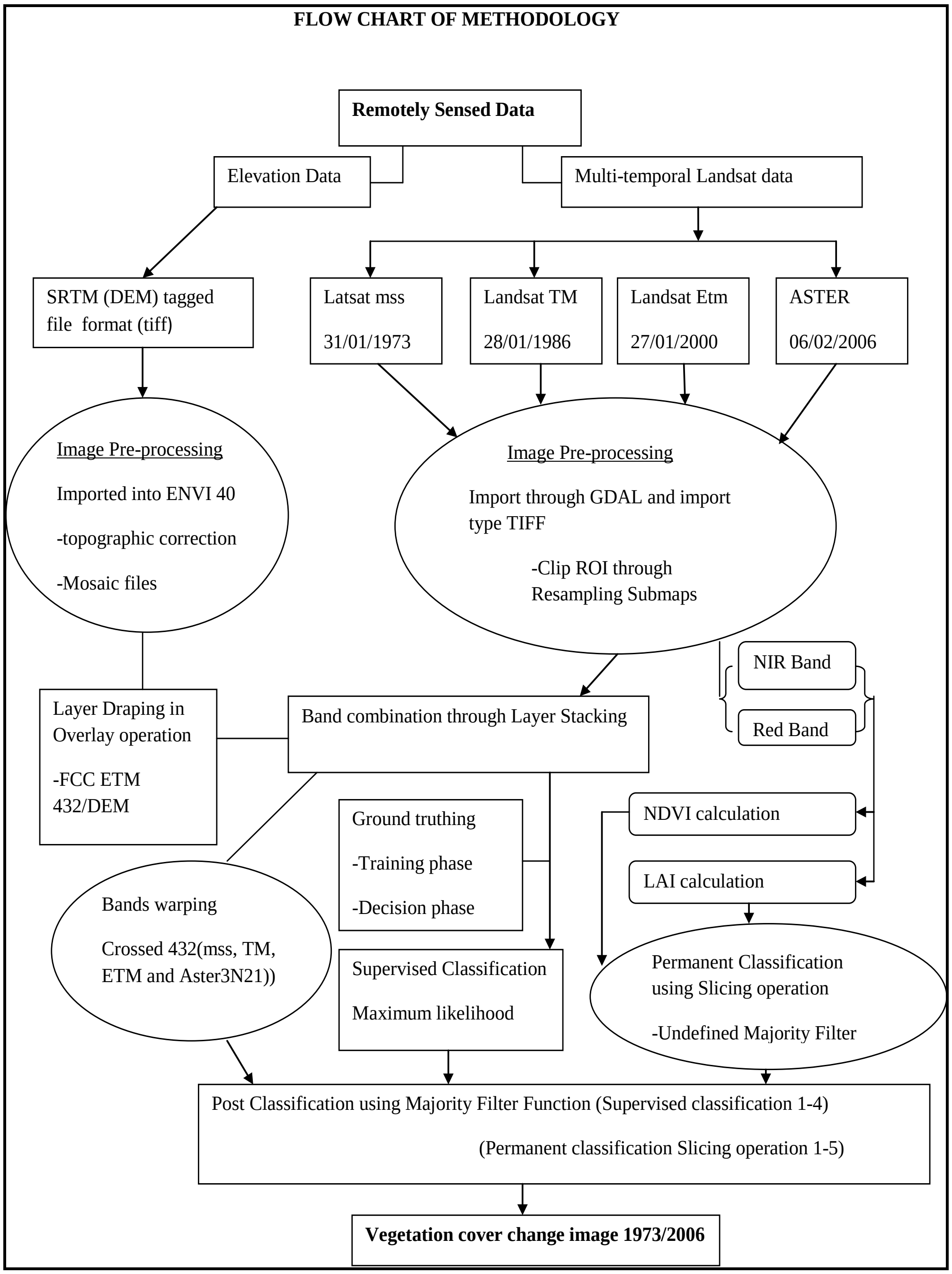


Figure 11.2. Flow Chart of Methodology

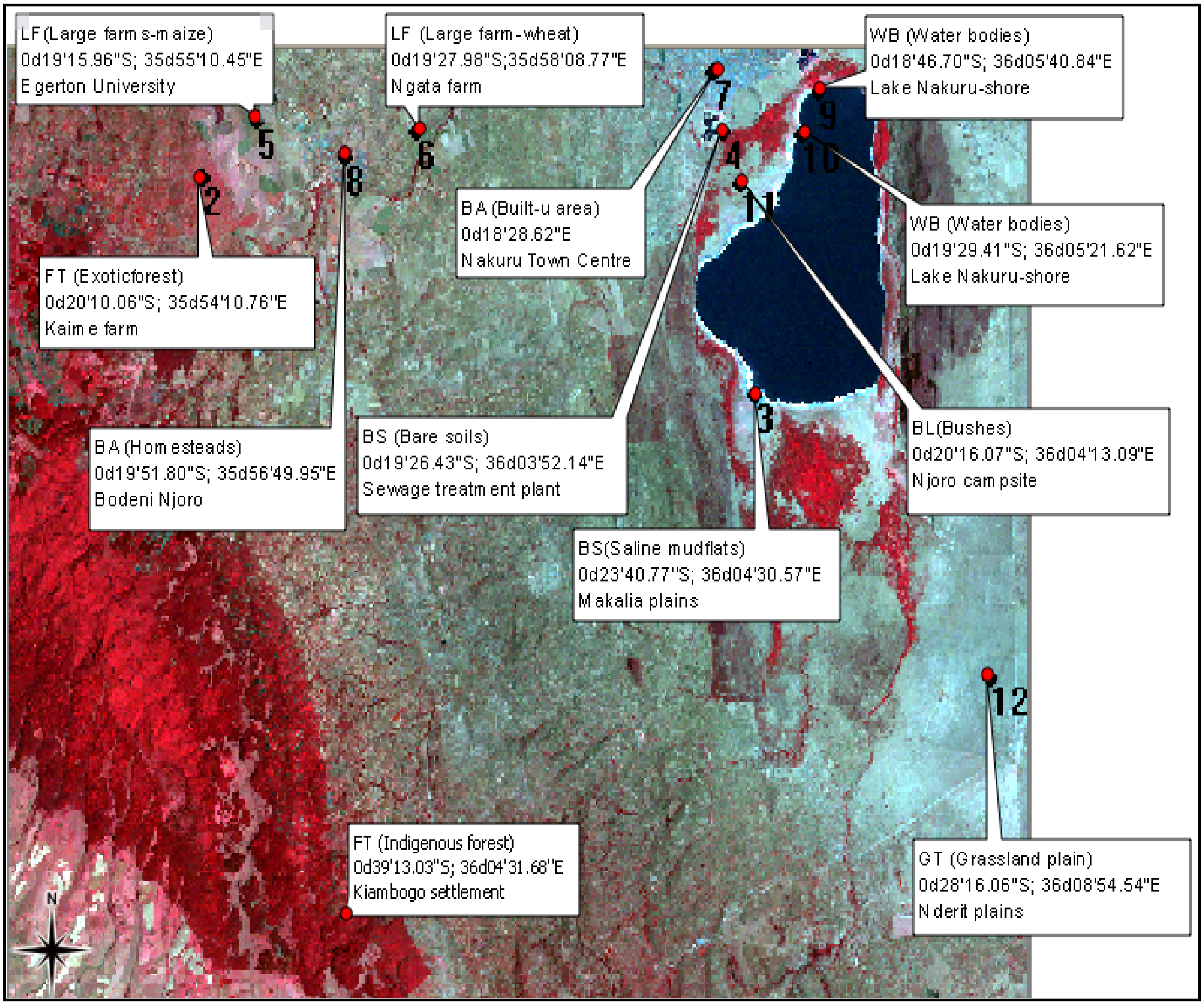


Figure 11.3. GPS points for Ground truth Training sites

11.5 Data Analysis

Three methods of data analysis were adopted in this study: -

i). Maximum likelihood supervised classification and Post classification using majority filters were performed to compute change in land cover for TM (1986) and ETM+ (2000).

ii). NDVI and LAI Calculation and permanent classification using slicing and majority filters iii). GIS Cross-overlay operations.

11.6 Results and Discussion

Post classification procedure using majority spatial filters was carried out in order to remove spectral overlaps and undefined pixels in sample sets (Figure 11.4 and 11.5).

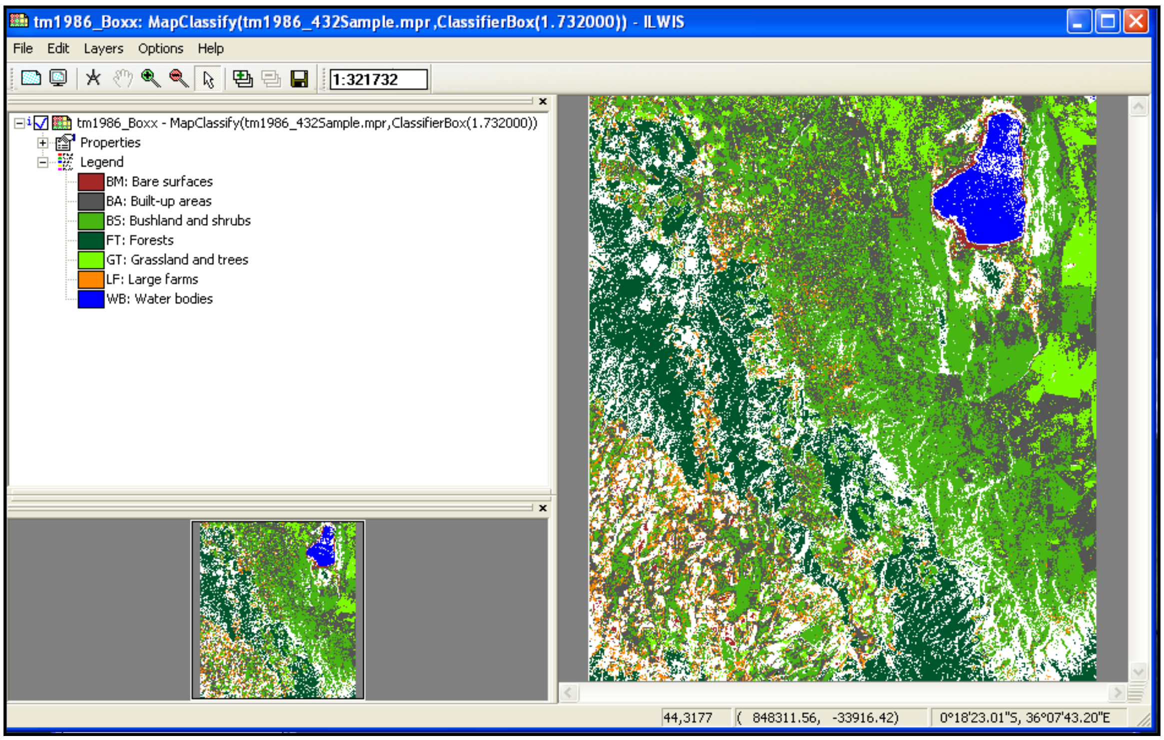


Figure 11.4. Post classification of classified TM (1986) image.

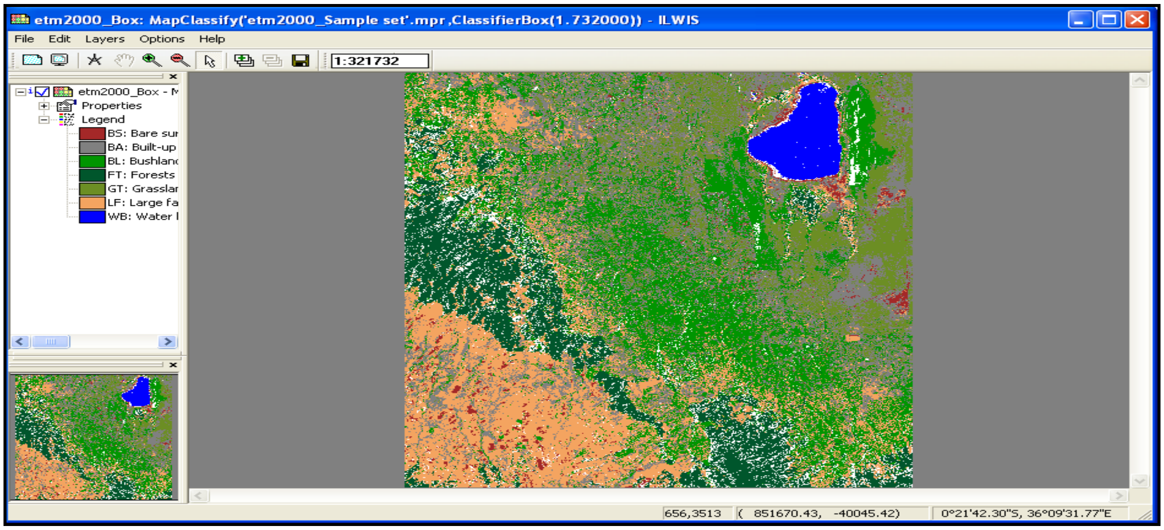


Figure 11.5. Post classification of classified ETM+ (2000) image.

Histograms computed from the classified images (TM1986 and ETM+2000) indicates that spatial extent of the cover type categories (Figure 11.6 and 11.7) within the study area has changed towards present (Table 11.3).

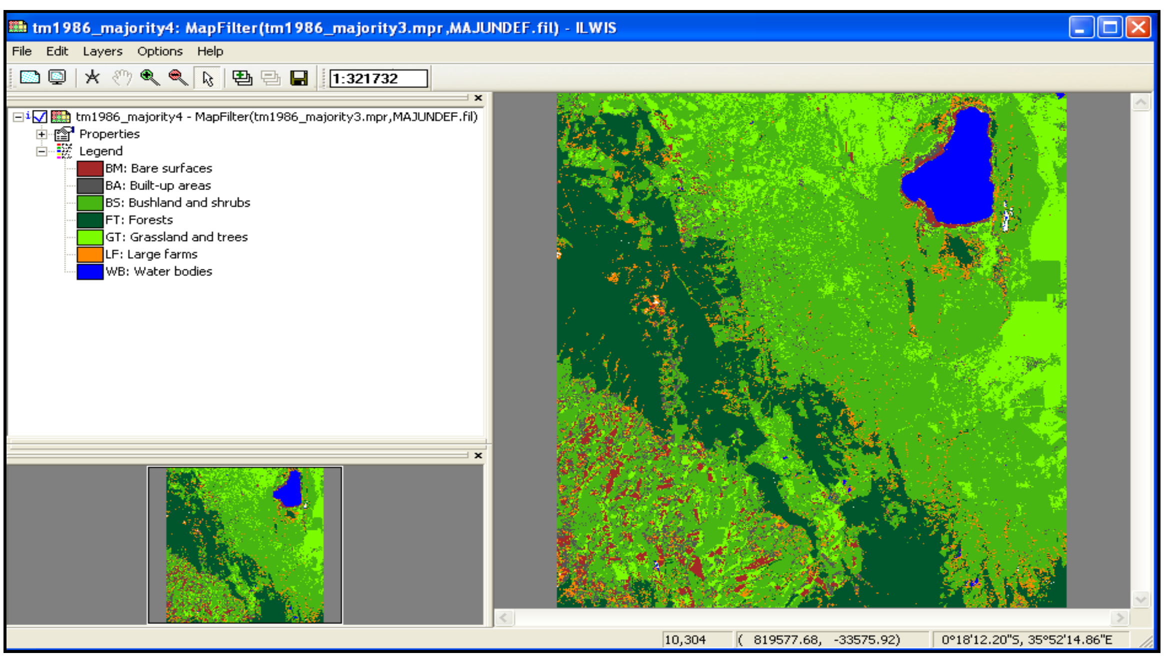


Figure 11.6. Map calculation and Histogram results for TM (1986) classification.

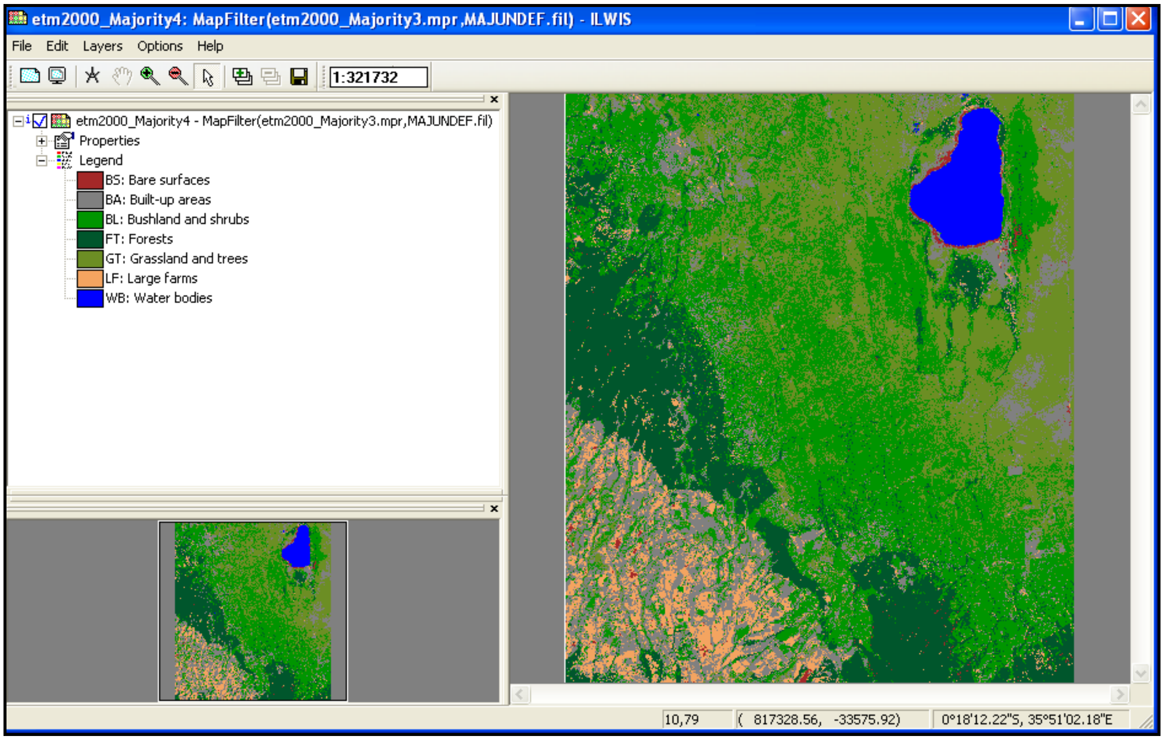


Figure 11.7. Map calculation and Histogram results for ETM+ (2000) classification.

Table 11.3. Comparison of spatial extent of land covers after Post-classification

Land cover types	**TM (1986) Area in Km²**	**% of the Area**	**ETM+ (2000) Area in Km²**	**% of the Area**	**% change between 1986 – 2000 period**
Bare surfaces	32.9	2.28	7.47	0.52	1.76 Decrease
Built-up areas	61.58	4.27	209.91	14.54	10.27 Increase
Bushland and shrubs	699.7	48.47	510.76	35.38	13.09 Decrease
Forests	340.6	23.60	248.68	17.23	6.37 Decrease
Grassland and trees	214.67	14.87	346.25	23.99	9.12 Increase

Large farms	55.89	3.67	80.5	5.58	1.91 Increase
Water bodies	37.28	2.58	39.99	2.27	0.31 Decrease

The above results (Table 11.3), reflects the decrease in vegetation for Bushland and shrubs, Forests, Bare surfaces and the Lake's surface area from 1986 to 2000, but an increase in large farms and Built-up areas. The study area has been receiving immigrants from the densely populated rural areas since independence. The study indicates that increase in area under built-up areas, that is, the towns, homesteads, small gardens and plots is experienced. In addition, the area under large farms is also increasing at the expense of forests, bushlands and grasslands. Encroachment into forests and bushland is taking place on the steep slopes and scarps hence (Figure 11.8) exposing the area to a lot of erosion during the rainy season. Figure 11.8 is a DEM of the study area draped with ETM+432 FCC where vegetation is shown in red shades. Earlier study in the Lake Nakuru watershed (Murimi and Prasad, 2002) found out that some of the sediments are transported down and deposited on the wetland region before reaching the Lake, whereas some gets into the Lake. Such an effect reduces the capacity of the Lake to hold water.

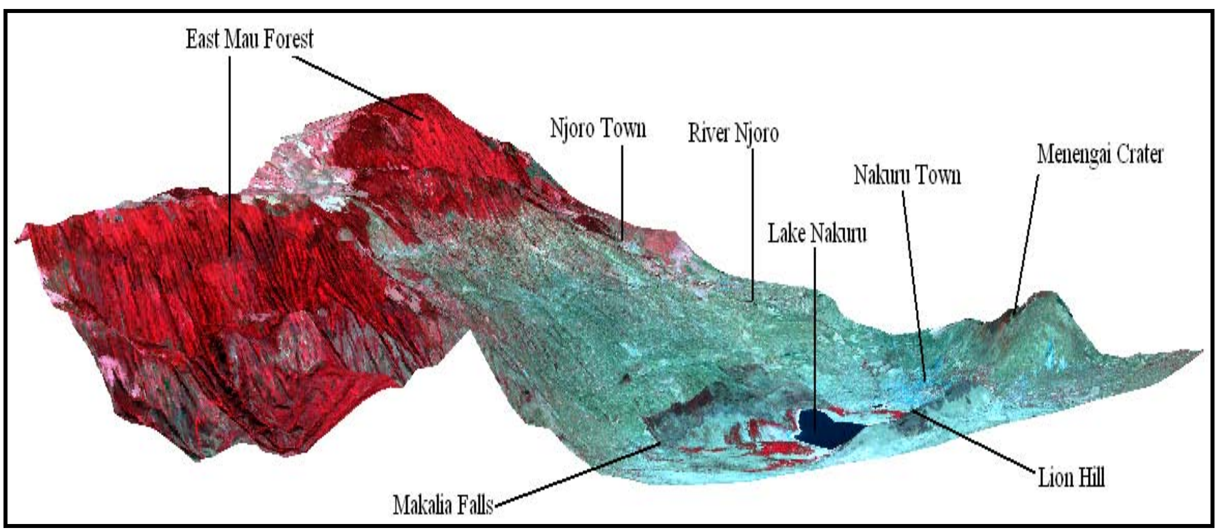


Figure 11.8. FCC (ETM+2000) draped over SRTM DEM of the Lake Nakuru Watershed

NDVI and LAI computations were performed by ILWIS 3.6 slicing operation to produce vegetation indices for the various Landsat images. Results of vegetation reflectance and values reveal a decrease towards present. MSS (1973) had high values for both NDVI and LAI but both decrease systematically for 1986, 2000 and 2006 images. The very high intensities of white tones in figure 11.9 is an indication of high NDVI values corresponding with high vegetation cover for the MSS (1986) image, while very low values in figure 11.10 (ASTER(2006)) indicates low vegetation cover. This means that there is a changing pattern of vegetation cover for the study period under consideration.

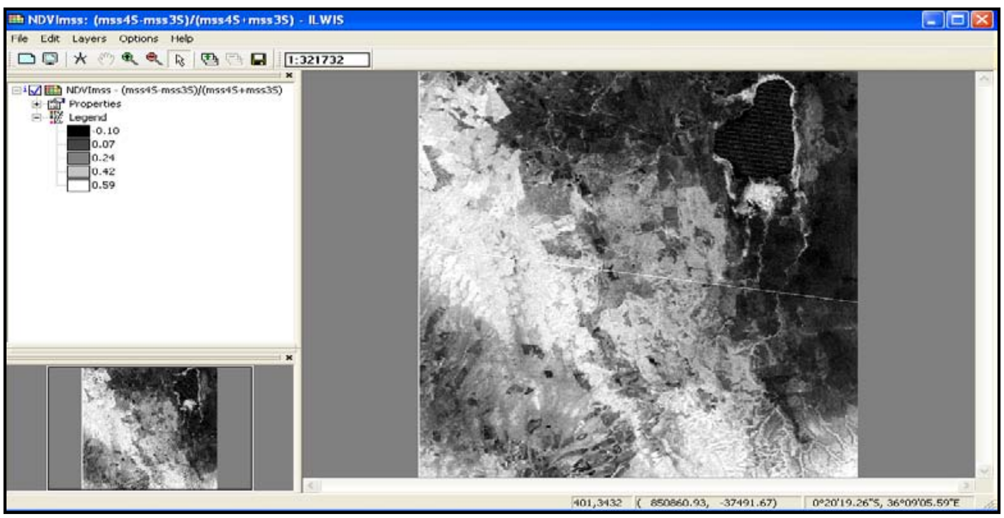


Figure 11.9. NDVI for MSS (1973) 4:3 image

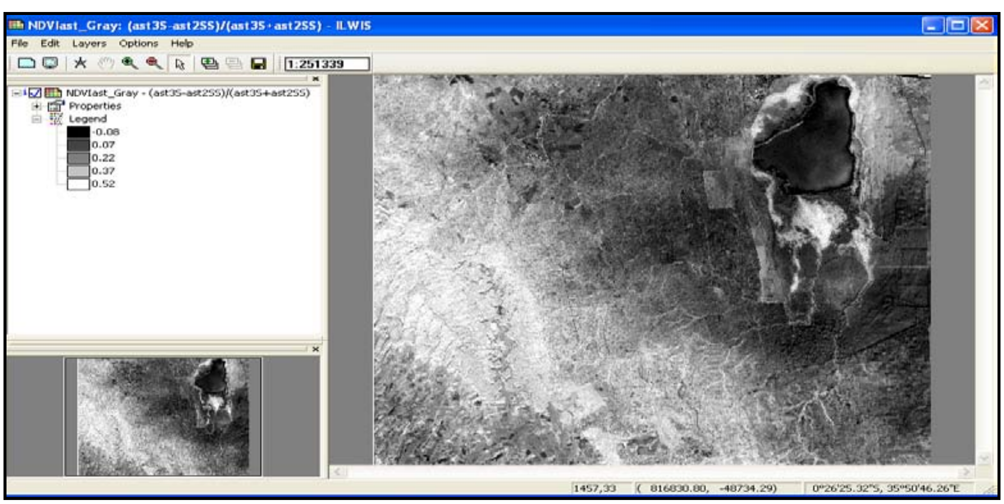


Figure 11.10. NDVI for ASTER (2006) 4:3 image

GIS cross-overlay operation between classified NDVI values and calculated histograms for the TM(1986), ETM+(2000) and ASTER(2006) images (Figure 11.11) was done to establish changes in five (5) categories of vegetation cover extent grouped as Very high, High, Moderate, Low and Very low vegetation covers. Table 11.5 summarizes the spatial-temporal changing characteristics of the various vegetation cover extents in the Lake Nakuru watershed.

Table 11.5. Comparison of spatial extent of various categories of vegetation cover

Vegetation cover categories		**TM (1986) Area in Km2**	**% of the area**	**ETM (2000) Area in Km2**	**% of the area**	**% change between 1986-2000**	**ASTER (2006) Area in Km2**	**% of the area**	**% change between 2000-2006**
A	Very high vegetation cover	263.6	18.26	195.0	13.51	4.55-Ve	213.75	19.09	5.58+ Ve
B	High vegetation cover	154.96	10.73	227.45	15.76	5.03+Ve	299.3	26.74	10.98 +Ve
C	Moderate vegetation cover	556.68	38.56	499.28	34.59	3.97-Ve	350.6	31.32	3.27- Ve
D	Low vegetation cover	439.4	30.44	508.07	35.20	4.76+Ve	244.93	21.88	13.32- Ve
E	Very low vegetation cover	17.57	1.22	13.65	0.95	0.27-Ve	10.8	0.97	9.83- Ve

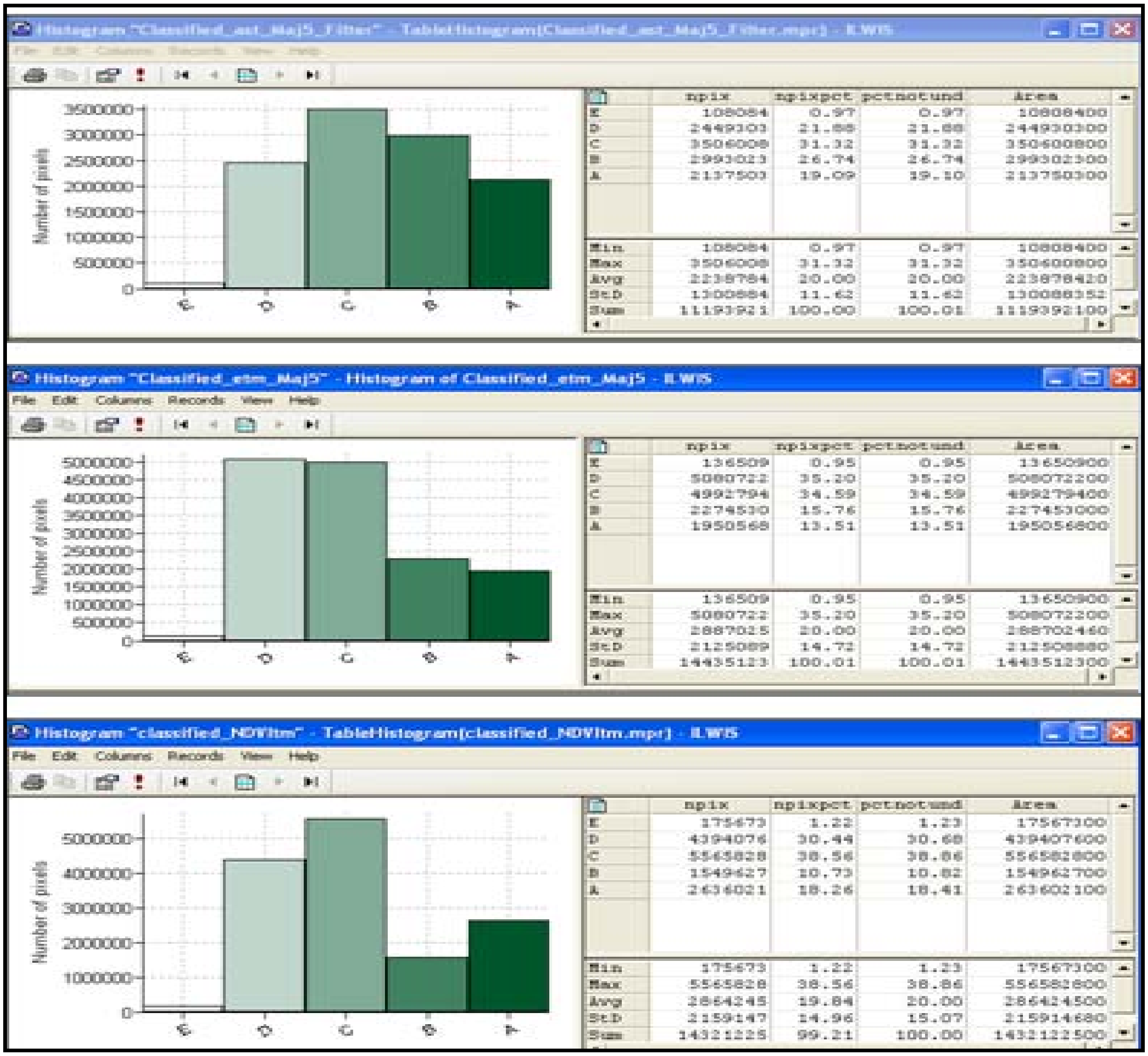


Figure 11.11 Comparison of classified NDVI (TM (1986), ETM+ (2000), ASTER (2006) histograms.

11.7 Conclusion

Capabilities of remote sensing and GIS to extract and compute land cover changes in watersheds have been documented by the current study. Remote sensing and GIS techniques integrated in this study indicate that the methodology is well suited for spatial-temporal analysis of land cover/use. In this study LANDSAT images were used satisfactorily for the identification of vegetation. Results from the study show that vegetation cover as well as area under farms and settlements has significantly changed during the 1973 – 2006 period. The area under vegetation, that is, forests, grasslands and bushland has decreased remarkably while that under farmland and built-up areas is increasing towards present. It means that decrease in vegetation has been as a result of anthropogenic activities in the study area.

11.8 References

Campbell JB, (1987). '*Introduction to Remote Sensing*'. The Guilford Press, New York.

Drury, S. (2001). *Image Interpretation in Geology*. Blackwell science, London.

Lillesand TM and Keifer W (1994); *'Remote Sensing and Image Interpretation'*. John Wiley, New York.

Meijerink, A.M.J. (2007). *Remote sensing Applications to Groundwater*. UNESCO, Paris.

Murimi, S.K. and H. Prasad. (2002). Modelling Potential Soil Erosion in Lake Nakuru Drainage Basin; In, *Ecohydrology Journal, Vol 3.* PP 65-74.

Murimi, S.K. and Prasad, H. (2005). Land use changes and hydrological responses in the Lake Nakuru basin. In, *Sustainable Management of Headwater Resources*. PP 155-164. United Nations University Press, New York.

12 Assessment of the Contribution of Water Resources to Improve Livelihoods in Semi-Arid Lands: A Case of Rural Women in Tanzania

Mwalyagile,

12.1 Abstract

Water resource is a fundamental resource in socio-economic development. This resource is even more crucial for social and economic empowerment of women through its contribution to various production activities and improvement of health that enhances their sustainable livelihoods. The study conducted in semi-arid area (Tanzania) provides evidence on how a water resource enhances women's livelihoods particularly on their income, decision making and household expenditure. The study adopted cross-sectional research design where structured questionnaire was used to collect primary information from 120 respondents. Purposive and simple random sampling techniques were employed to obtain the desired sample. Focus Group Discussions (FGDs) and key informants interviews also conducted in order to obtain as much important information as possible. Statistical Package for Social Sciences (SPSS) computer software was used to analyse the data collected. Descriptive statistics such means, frequencies and percentages were computed. Chi-square and t-test statistics were applied to find out relationships between variables. Findings from this study confirm that water resources have its contribution in women's livelihoods particularly in their income. The study shows that 72% of total income earned by women annually came from water-related activities. Whereas 43% of this annual income generated from non-agriculture-based water-related activities, 29% was from agriculture-based water-related activities. Likewise, the majority of women (89.2%) have access, control over and decision on incomes earned from non-agriculture-based water-related activities. Water-related cash income earned by women is important in meeting household expenditure through home consumption and development issues. Furthermore, the study found that rural women adopted best practices in water uses, management and conservation, they are aware of constraints those facing water resources. Generally, the study helps to identify development strategies for enhancing sustainable livelihoods of rural women using water resources.

Key words: *water resources, management, rural women, sustainable livelihoods, semi-arid.*

12.2 Introduction

12.2.1 Background

Water resources are amongst of the resources that provide people with the capability to build sustainable livelihood. Livelihood as a term refers to attempts to capture not just what people make a living, but the resources that provide them with the capability to build a satisfactory living (Ellis and Freeman 2005). A livelihood also comprises incomes in cash and in kind, the social relations institutions that facilitate or constrain individual or family standards of living and access to social services that contribute to the well being of the individual or family (Ellis 1998). Therefore, water resource is a fundamental resource to socio-economic development. Indirect or direct, water provides employment and it counts much in ensuring good economic development especially for poor countries such as Tanzania. For instance, poor men and women in urban, rural and peri-urban settings base their livelihoods on informal activities, which are small-scale cropping, livestock keeping, agro-processing and other micro-enterprises. In many of these activities, an adequate water supply is a crucial, as it is use in or necessary for the activity itself (Butterworth and Moriarty, 2004). Water is also a key element in improved health that enables people to work. Likewise, in the context of mass poverty in most developing countries, the critical role of water resources are strongly needed in improving productivity, incomes and survival of human.

Studies conducted worldwide indicate that women's poor is directly related to the absence of economic opportunities and autonomy, lack of access to economic resources, including water, credit, land ownership and inheritance, lack of access to education and support services and their minimal participation in the decision making process (Women watch, 2005; UNESCO, 2005). Meanwhile rural women are architects of the rural economy; they are vital to agricultural production, food security and other related development issues (Nanavaty, 2000). In many of these activities, water is an important resource. Limited access to water is an insuperable obstacle to escaping poverty. Rural women spend hours each day fetching water instead of using that time to start market gardens and other income generating activities thereby improving their incomes and diets (FAO, 2003). In addition, poor quality or unavailability of water affects the health, productivity and at the same time increases workload of the poor, and especially the women who assume the primary burden for the provision of water and its many domestic uses (Soussan, 1998). For the world's poor, their relationship with natural resources base is a key to their survival, which includes the available water resources (Soussan, 1998). Water is at the heart of many livelihood activities and is an important source of food and income (FAO, 2004). Freshwater is an essential input in food preparation, livestock and crop production. It is also an indispensable household resource for health and sanitation purposes. Water also used to generate income from beer brewing and teashops for women (Sandys, 2005). Despite its importance in human livelihoods, the relationships between women and water resources for women's sustainable livelihoods have been little addressed. Therefore, the paper presents the contribution of water resources in improving rural women's livelihoods in semi-arid area particularly in women's incomes to bring about good understanding for targeting interventions for women's development. Findings can be useful to development agencies, planners and policy makers in planning and designing realistic strategies for women's livelihoods particularly in semi-arid areas.

12.2.2 Description of the study area

The study was conducted in Chunya district, a semi arid area in Tanzania. The district has a total area of 29 219 square kilometres (29 219 000 ha.) of which 28 114 square kilometres (28 114 000 ha.) is land and 1105 square kilometres (1 105 000 ha.) is covered with water (including rivers Songwe, Lupa, Zira and part of inland lake Rukwa). Mean annual rainfall ranges between 600 mm and 1 000 mm with the peak period of heavy rains recorded during the months of December and March. Water resources available in this district include inland lake, rivers, wet lands and spring water. These resources are important in supplementing the shortage of rainfalls if properly utilized. Main economic activities in the district include agriculture, which characterized by growing of maize, beans, millet, cassava, potatoes, sorghum, groundnuts, and sunflower. Other activities are livestock keeping, small-scale mining (Gold), fishing and forest products (URT, 2003).

12.3 Methodology

12.3.1 Research design

The study adopted cross-sectional research design that allows data to be collected at one point in time. The study relied on two main sources of data, which are primary and secondary data. The structured questionnaire and checklist used to collect primary data whereby structured questionnaire used as the main instrument. Checklist used to gather information from key informants and to guide Focus Group Discussions (FGDs). The questionnaire contained both close-ended and open-ended questions.

12.3.2 Data collection procedures

The study was conducted in 2006 and 2007. The study involved two phases of primary data collection. Phase one involved preliminary surveys of the study area while the second phase based mainly on administering the questionnaire. The preliminary surveys were conducted to provide the general picture of the study area. During this time, data collection instruments pre-tested under field conditions in order to establish the reliability of the instrument. Structured interview used to obtain primary data whereby face-to-face interviews were administered to the selected respondents. More information was also obtained from key informants and Focus Group Discussions (FGDs). Discussions at the FGD and key informants aimed to obtain as much important information as possible on contribution of water resources to women livelihoods, socio-economic challenges facing women, best practices on water resources adopted by women, types of water available in their area and its uses. The secondary data obtained from research papers, journals, books and bulletin were used to enrich the primary data.

12.3.3 Sampling procedure

12.3.3.1 Study population and Sample size

The study sample was drawn from population of women who were performing water related income generating activities. The sample included married, widows, divorced, single and separated women. The sample size involved 120 respondents.

12.3.3.2 Sampling technique

Both purposive and simple random sampling techniques were employed. Purposive sampling technique was used to obtain four wards in Chunya district basing on type of water resources availability such as lake, rivers, and good rainfall pattern, wet lands and dry area. The method also used to select four villages, one from each ward where actual data collection was done. The selection of these villages based on characteristics of respondents required for the study. These included women with water related activities and villages with suitable required number of the respondents. Simple random sampling technique was used to select 30 respondents from each village.

12.3.4 Data processing and analysis

Statistical Package for Social Sciences (SPSS) version 11.5 computer software was employed in data analysis. Descriptive statistics such as mean, frequencies and percentages were computed. The results were presented in tables and pie charts. Microsoft Office Excel 2003 was used in creating the pie charts. Chi-square statistics was used to measure relationships between selected variables. Other statistical techniques included t-test which was employed to test relationships among various variables of interest. The Gross Margin (GM) analysis was done to estimate income generated from IGAs of the respondents (water related and non-water related water income generating activities). Gross Margins were obtained using the following formulae:

GM = ATR - ATVC

Where: GM = Gross margin of IGAs

ATR = average total revenue of IGAs in USD

ATVC = average total variable costs in USD

FGDs and key informants data were analyzed using non-statistical methods (Content Analysis). Content analysis is a set of methods for analysing the symbolic content of any communication with an intention to reduce the total content of communication to some set of categories that represent some characteristics of research interests (Kajembe, 1994).

12.4 Results and discussion

12.4.1 Demographic and socio-economic characteristics of respondents and its influences in their livelihoods

The survey revealed various backgrounds of respondents basing demographic and socio-economic characteristics. This aimed at determining the level of relationship between a selected demographic and socio-economic factors and women's welfare and their incomes generated from water-related activities. These included age, marital status, education, head of household and main occupation. It was found that the age of all the respondents ranged between 19 and 70 years old but the majority (70.8%) were between 20 – 40 years old. About one quarter (26.7%) were between 41-60 years old, while 1.7% and 0.8% were below 20 years and above 60 years old respectively. Majority of the respondents (85%) have attained difference levels of formal education whereby 80% have attended primary school education while 5% attended primary school with other qualification. Meanwhile, 15% of the respondents have not been to school (formal education).This implies that the literacy level among the respondents was good for them to understand the basic needs for their sustainable livelihoods. It was observed that 74.1% of the respondents were married while 10% of the respondents were divorced, 9.2% were widow, 4.2% were separated and only 2.5% were single.

The main occupation for women in the study varied by including off- farm activities. The results showed that 44.2% of the respondents were engaged in agriculture as their main occupation, while 44.1% did farming together with other activities such as local brewing, food vending, and small business. Other 11.6% of the respondents were completely not engaged in agriculture at all. Moreover, the study revealed that 23.3% of the respondent's households were female-headed while 76.7 % were male-headed. Therefore, the relationship between woman occupation and the household head occupation should not be overlooked because occupational status affects women's welfare, like income, decision making and control of resources, education, and health. For instance, in this study, it reported that in male-headed household 75% of their heads who were men mostly controlled income earned within the household. Meanwhile, 23.3% reported that women controlled and decided with what to do with income earned. Notwithstanding, it was observed that the households in which women controlled income were female headed.

Chi-square statistical test used to determine the level of relationship between a certain selected socio-economic and demographic factors and income generated from WRAs[1] in the study area as summarises in Table 12.1 below.

[1] Water-Related Activities

Table 12.1: Relationship between socio-economic and demographic factors and WRA's incomes

Category of the respondents	Income earned from WRAs (USD)			Chi-square value	P-Value
		1 - 255	> 255		
Age (years old)					
< 36	F	61	10	3.803	0.051
	%	50.8	8.3		
36 and above	F	35	14		
	%	29.2	11.7		
Marital status					
Married	F	71	18	0.011	0.917
	%	59.2	15.0		
Not married	F	25	6		
	%	20.8	5.0		
Education attained					
Formal	F	78	24	5.294	0.021
	%	65.0	20.0		
Non formal	F	18	0		
	%	15.0	0.00		

NB: F = Frequency; % = Percentage

Basing on the chi-square test there was no statistical significant (P>0.05) between age of the respondents and water-related income. This is probably due to most of the respondents were between 20 – 60 years old, under normal circumstances this is the most economically active age for Tanzania. Moreover, the chi-square test shows no statistical significant relationship between marital status of the respondents and income earned from water-related activities (P>0.05). Being married or not does not affect income earned by rural women. This may attributed to the fact that the majority of women either their married or not in rural areas lack access to, and control over productive resources. Patriarchal system strengthened by other culture and traditions prevent women from accessing and controlling productive resources in Chunya district. Analysis of the chi-square test shows significant association between level of education and income earned from water-related (P<0.05). This indicates that there is a minimum level of education necessary for respondents for better understands the basic needs for sustainable livelihood and poverty reduction. According to Rodgers (1989), education is one of strongest determinants of poverty. It improves access to economic and welfare and stands as an important dimension of poverty and livelihood. Indeed, high rate of literacy is an important input that enables rural women to know, understand and adopt new technologies more easily thus develops strategies for avoiding and fighting poverty in their localities.

12.4.2 Water-related activities performed by rural women in semi-arid areas

Six water-related activities (WRAs) were identified namely crop and horticulture production, local beer brewing, food vending, fishing, water selling and brick making. Table 12.2 summarizes the findings.

Table 12.2: Women water-related income generating activities (n=120)

Types of activities	**Frequency**	**Per cent (%)**
Fishing	2	1.7
Water selling	2	1.7
Food vending	39	32.5
Brick making	1	0.8
Crop/horticulture production (irrigated)	89	74.2
Local beer brewing	49	40.8

NB: percentages do not add to 100 because of multiple answers/responses

The findings show that the interviewed women were engaged in more than one water-related activity as their income generation activities. However, the activities they had done the most included crop and horticulture production (74.2%), local beer brewing (40.8%) and food vending (32.5%). From FGDs, it revealed that there were specific water-related activities for women and men, and some that performed by both. For example, local beer brewing and food vending were women water-related activities in the study area while agriculture activities considered as both men and women water-related activities. Experience from FGDs and key informants showed that women were mostly water users in both productive activities and domestic activities. From the study area, it revealed that there was no single source of water for women's daily activities, albeit, the mostly uses water sources were rivers, spring and wet area (77.5%), followed by tape water (27.5%) and natural well (25.8%). Meanwhile only six (6) respondents (5%) reported to use lake as their water sources for some of their IGAs.

Generally, this study revealed that water-related activities for rural women in semi arid are more than agriculture. There are several activities, which required water resources and which enabled women to earn income in their daily, weekly or monthly bases. The rural women from the study area were engaged in the above mentioned activities as their employment activities and their income generating activities (IGAs) through which they earned income that enables them to sustain their livelihoods. The study further showed that rural women were engaged in more than one water-related activity as their income generating activities (IGAs) to supplement low income earned for agriculture. This finding concurs with Makombe *et al.* (1999) who reported that since the 1980s and 1990s women are increasingly getting more involved in income generating activities than in agriculture. This may be due to the fact that women especially in rural areas did not control the income gained from agricultural production, therefore this made them turn to other economic activities to enable them earn independent incomes in order to fulfil their obligations.

12.4.3 Roles of water resources in women's livelihoods

The roles of water resources in women's livelihoods were determined through its contribution that based on income generated by the respondent from water-related activities and its characteristics, expenditure of those incomes, and women's empowerment particularly in access and control of income earns from water-related activities.

12.4.3.1 The income generated from the water related activities

Income is one of important component of livelihood; therefore, to determine and characterize the income generated from water related activities is very important in explaining the contribution of water resource towards improving of their livelihood. Women's IGAs categorized into three groups, namely:- agriculture-based water-related activities (direct water-related activities), non-agriculture-based water-related activities (indirect water-related activities) and non-water-related activities. The finding from this study revealed that water-related activities have contributed 72% to the total income earned by women while non-water-related contributed only 28% (Figure 12.1 and Table 12.3).

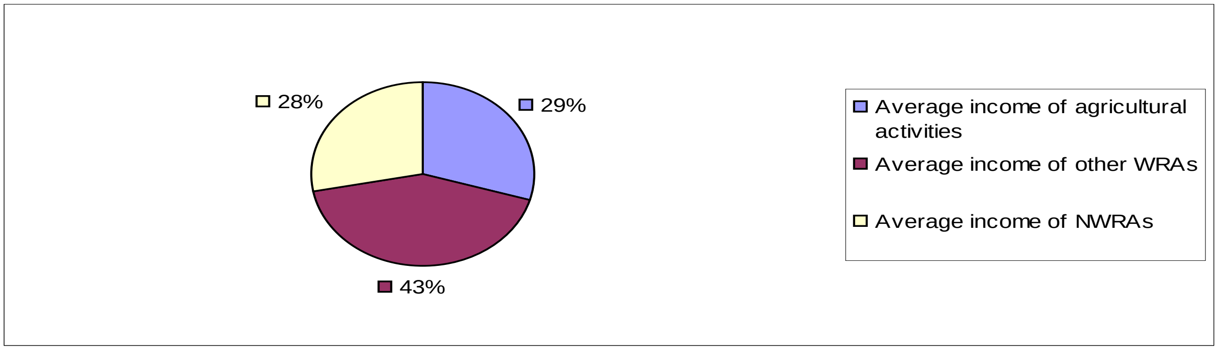


Figure 12.1: Contribution of WRAs in total income earned by women (2005 – 06)

Table 12.3: Annual mean income earned by rural women in 2005 – 06

Category of income	**Mean in USD**	**T-Value**	**P-Value**
Income from agriculture-based WRAs	70.96	-2.098	0.037
Income non-agriculture-based WRAs	102.24		
Total income from water-related activities (WRAs)	173.20	5.648	0.000
Income from non-water-related activities	67.66		

Furthermore, the findings revealed that, among the water-related activities performed by respondents the local beer brewing, food vending, fishing, water selling and brick making together contributed 43% of women's total income. Agricultural-based water-related activities contributed 29%, while non-water-related activities contributed only 28%. Therefore, the study noted that non-agriculture-based water-related activities contributed more in women's income compared to others activities. Basing on statistical T-test results (Table 12.3), the study shows significant difference between mean income of agriculture-based water-related activities and those from non-agriculture-water-related activities ($P<0.05$). This also confirms that non-agriculture-based water-related activities contributed more towards women's income. Further T-test analysis noted significant difference between women's mean income of water-related and non-water- related activities ($P<0.05$). Therefore, it is clear that water-related activities play greater role in generating incomes for rural women, particularly the non-agriculture-based water-related activities.

12.4.3.2 Access and Control of women's income earned from their IGAs

Table 12.4 below summarizes the finding that shows women's access and control of income earned from IGAs.

Table 12.4: Distribution of surveyed women according to who access, controls and decides upon income earned from their IGAs

Category	Frequency	Per cent
Agriculture-based water-related cash income(n=81)		
Woman herself	29	35.8
Husband	52	64.2
Non-agriculture-based water-related cash income (n=83)		
Woman herself	74	89.2
Husband	9	10.8
Non-water-related cash income (n=57)		
Woman herself	48	84.2
Husband	9	15.8

The majority of women had control on income earned from non-agriculture-based water-related activities and non-water related activities by 89.2% and 84.2%, respectively. Most women had no direct control over income earned from irrigated agriculture (only 35.8% reported to control such income). This attributed to lack or little access to irrigated land. Traditionally, married women allowed to access land for use with permission from husbands. Thus, even the income earned from this land is normally under control of the husband. Sometimes women receive labour support from other members of household, such as husbands who assist them in cultivation of land. Under this situation, husbands considered income earned from this piece of land as part of their own income. On the contrary, incomes earned from non-agriculture-based water-related activities such as local beer brewing and food vending were under women control because these activities were considered as female activities in the study area. This was also reflected during the FGDs. Therefore, water-related activities undertaken by rural women particularly the non-agricultural water- related activities were more likely to have positive effect on their livelihood because the income earned was controlled by the women themselves to a large extent. This agrees with UDEC (2002) who noted that IGAs undertaken by women may provide more opportunity for women to become empowered socially and economically.

12.4.3.3 Expenditure of income earned by women form IGAs

The expenditure of the income earned from water-related activities considered in order to determine the importance of these activities in sustaining human life. The study revealed that rural women spend their water-related cash income in sustaining household expenditures through home consumption and development issues. Most of women spent their income on family clothes, family food, paying for health services and children education expenses. It further revealed that women's incomes from non-water-related activities also used to support some household expenditure and development issues. However, most of their incomes spent on education expenses for children and family clothes. These findings concurs with Ellis (2000) and Commission for Africa (2005). Ellis (2000) reported that women spent cash income that came into their hands wholly on family needs in India. It was also noted in Kenya that the share of total income controlled by women has positive and significant influence on the calorie consumption in households Ellis (ibid). Furthermore, the Commission for Africa (2005) reported that women tend to spend greater proportion of earnings they control on household needs, particularly for the children. Therefore, it is evident that women incomes have great role in sustaining human life particularly at household levels. As a matter of fact, water resource has greater potential to reduce poverty levels among poor rural women communities and to improve their livelihood standard.

12.4.4 Water resources availability and its contribution on women's income

The availability of sustainable water resources has an important role to play in women's income. In this study, it noted that the more water resources were available and accessible, the higher the income earned. The distribution of annual income of the respondents in survey villages confirms it and the findings summarizes in Table 12.5.

Table 12.5: Distribution of women annual income in four surveyed villages (USD)

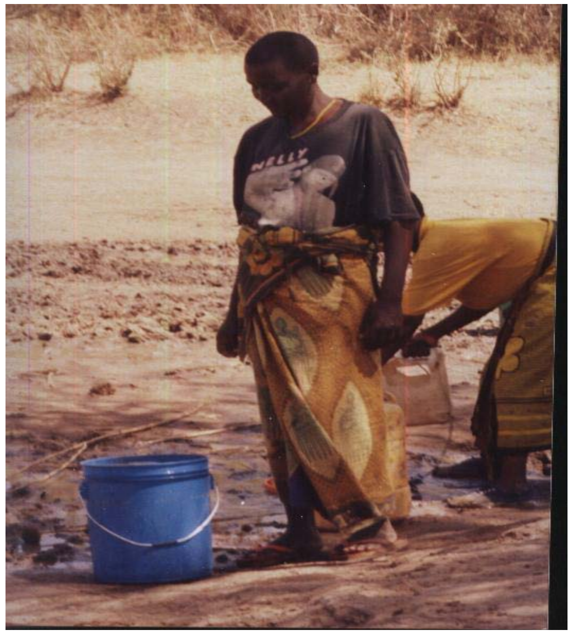
	Ifumbo		**Ifwenkenya**		**Mbuyuni**		**Totowe**	
Category of income	**No**	**%**	**No**	**%**	**No**	**%**	**No**	**%**
WRA (n=120)								
1 – 85	6	5.0	6	5.0	10	8.3	16	13.3
86 – 255	14	11.7	17	14.2	13	10.8	14	11.7
256 – 425	4	3.3	5	4.2	5	4.2	0	0.0

426 – 596	6	5.0	2	1.7	1	0.8	0	0.0
> 596	0	0.0	0	0.0	1	0.8	0	0.0
NWRA[2] (n= 57)								
1 – 85	4	7.0	8	14.0	9	15.8	5	8.8
86 – 255	7	12.3	7	12.3	5	8.8	3	5.3
256 – 425	4	7.0	2	3.5	0	0.0	0	0.0
426 – 596	1	1.8	1	1.8	0	0.0	0	0.0
> 596	0	0.0	1	1.8	0	0.0	0	0.0

NB: No = number of the respondents; % = percent

The findings also reveal that, the respondents from Ifumbo and Ifwenkenya villages earned more than in than other two villages due to availability of water and easily accessible as reported by key informants and FGDs. Furthermore, the overall income from both water-related and non-water related activities, shows that women from Totowe village earned less. This may be due to severe water scarcity in Totowe village as reported in FGDs. It was revealed that women in Totowe village walk long distance every day to fetch water whereby two to three hours are used for single trip. During the dry seasons the water shortage situation is made worse as natural wells, river and springs dry up, this worsens the situation to women who are now forced to spend more time looking for water for domestic and productive use. In sometimes forces women to obtain water from wells dug along dried water streams, and temporary rivers as shown in Figures 12.2 and 12.3. This action not only brings insufficient water but also such water is not safe for human consumption. Consequently, incidents of water-borne diseases such as cholera are highly reported in this area, this leads women to close of their water-related businesses such as food vending and local beer brewing as reported in FGDs.

[2] Non-Water Related Activity



October 2006

Figure 12.2: Women of Totowe village fetching water along the water streams

October 2006

Figure 12.3: Women of Totowe village fetching water in the dug hole along dried Temporary River

A statistical T-test was computed to compare the relationships between mean incomes earned in four villages surveyed as shown in Table 12.6. The results showed that there was highly significant difference (P<0.05) between water-related mean income of Totowe village and the remaining three villages. Annual average income of woman from Totowe village was 83.3 USD, while that of women from Ifumbo, Ifwenkenya and Mbuyuni villages, were more than 169.8 USD each. This implies that, women in Totowe village have lower incomes compared to other three villages. T-test for non-water-related mean income showed a significant difference (P<0.05) between two villages namely Totowe and Mbuyuni and the rest of the villages. More water resource available in these villages is probably one of the key reasons for higher incomes. Unlike in other villages, respondents from Ifumbo and Ifwenkenya reported on water scarcity as being not a big limiting factor to their welfare because time lost in search of water in these villages now saved for use on income generating activities.

Table 12.6: Mean annual income earned in surveyed villages

Category	N	Mean income (USD)
Water related activities (WRAs)		
Ifumbo village	30	238.6
Ifwenkenya village	30	184.8
Mbuyuni village	30	169.9
Totowe village	30	83.3*
Non water related activities (NWRAs)		
Ifumbo village	16	103.7
Ifwenkenya village	19	113.1
Mbuyuni village	14	33.6*
Totowe village	8	19.3*

*NB: * significant different from the rest of the villages at P < 0.05; N= number of respondents*

12.4.5 Hindering factors for contribution of water resources to sustainable livelihood

Although women have actively adopted various strategies to improve their livelihoods and their household member livelihoods through water resources, they are faced with a number of constraining factors. Most of these factors included water scarcity, cultural attributes, land constraint and ownership, poor equipment, high price of input, low price paid for their products and unreliable markets for their products. Others were lack of technical knowledge/skills, time constraints due to other household responsibilities, lack of labour, poor and lack of working capital, poor roads/transport, water borne diseases or/ outbreak of diseases (cholera) and frequent conflict over land and water between farmer and livestock keepers. These reported factors are important in constraining strategies for improving and ensuring sustainable livelihoods since they have a major role to play in economic water resource utilization. The presence of one factor may give raise to other factor(s). For instance, lack of land ownership prevents women from accessing loans in the micro-finance market. Global fund for women (2003) reported that across 70% of Africa, women lack the right to inherit land. Without such collaterals, banks are unwilling to finance for women's income-generating activities. This study for example, noted that only 6.7% of 120 interviewed women have received loans as working capital for their water related IGAs. Therefore, respondents in the study area suggested several issues in order to improve their income for better living condition. These include improvement of sustainable source of clean and safe water for economic and domestic uses and its accessibility (73.3%), availability of credit facilities to rural women so that they can be able to access credit (65.8%). Also, gender relationship at household and community level should be improved through sensitization so as to reduce women harassment in all aspects of social and development issues.

12.4.6 Best practices on water conservation

Women play a greater role in water use and conservation. Nanavaty (2000) proclaimed that women used water as artisans, producers, laboured and traders. This is due to the fact that women are major water collectors, water users within households and farmers in rainfed agriculture. It was clear from the study that, best practice on water use and conservation adopted by women were mostly concerned with agricultural activities. These practices included mulching, zero tillage, tie ridges, use of organic manure, cover crops and contour farming. This implies that rural women tend to practice water conservation practices while performing their agriculture-base water-related activities. Likewise, they are knowledgeable and aware of important water conservation techniques. Despite their importance in water conservation, these practices have also other important roles. Rocheleau, *et al.* (1988) pointed out that mulching and cover crops which include leguminous trees, improves soil fertility through nitrogen fixation thus improved crop yield. The leguminous trees have additional benefit of reducing soil erosion

(Rosecrance *et al.,* 1992; Jama *et al.,* 1998). Contour farming is also important in controlling soil erosion and soil conservation (ICRAF, 1993). Use of groundcover and tillage techniques can be used to increase the amount of water stored within the soil and in surface catchments. Ground cover is crucial for the maintenance of soil structure in wet-and-dry climates. It was evident from the study that women were aware of environmental conservation that is very crucial for water conservation such as deforestation.

12.5 Conclusion

Water resources have a greater role to play in women's sustainable livelihood by providing informal employment through the water-related activities either directly or indirectly. These resources have also a large contribution in women's income through it contribution towards their daily or annually income. This study has noted that up to 72% of annual total income earned by women in the study area comes from water-related activities. T-test results also indicated that, the variation between water-related and non-water-related activities was significantly different ($p< 0.05$). It also found that these resources have important role in women's empowerment socially and economically. For instance, 89.2% of rural women in the study area reported to have full access and control over t income earned from non-agriculture-based water-related activities. Water-related cash income earned by women is also important in sustaining household expenditure through home consumption and development issues. Therefore finding of the study imply that water resources are heart of rural women's livelihoods, thus water studies should look women as a core water users and should be not bypassed in any strategies concern water studies. Meanwhile water resources should be considered as among of cross-cutting issues in any development strategies undertaken by development agencies, planners and policy makers.

12.6 References

Butterworth, J., Moriarty, P**.,** 2004). Water, Poverty and Productive uses of water at the household level. IRC International Water and Sanitation Centre. [http://www.wca-infonet.org/cds_upload/1060849235354_WDWP80.pdf] visited on 10th June, 2007

Commission for Africa, 2005. Our Common Interest: Report of Commission for Africa. May, 2005. 461pp

Ellis, F. (2000). Rural Livelihoods and Diversity in Developing Countries. OxfordUniversity press, Oxford, UK. 241pp

Ellis, F., Freeman, H. A., 2005. Rural Livelihoods and Poverty Reduction Policies.Routledge, USA and Canada.

FAO, 2003. Agriculture, food and water. The World Water Development Report, 2003.

FAO, 2004. Rural Households and Resources: A pocket guide for extension worker. Viale delle Terme di Caracalla 00100 Rome Italy. 37pp

Global fund for Women, 2003. More Than Money: Strategies to Build Women's Economic Power, Impact Report No. 1 [*www.globalfundforwomen.org*] visited 12/07/2006

ICRAF,1993. International Centre for Research in Agroforestry: Annual Report 1993. Nairobi, Kenya. 208pp

Jama., B., Buresh, R.J., Ndufa, J.K. and Shepherd, K.D., 1998. Vertical distribution of roots and soil nitrate; tree species and phosphorus effects. *Soil Sci. Soc. Am. J*. 62(1): 280-286.

Kajembe, G.C.,1994. Indigenous management systems as a base for community forestry Tanzania*: A case study of Dodoma Urban and Lushoto Districts*. Tropical resource management paper no.6. Wageningen Agricultural University. The Nertherlands framework for integrating biodiversity conservation and sustainable development. Maryland. pp15

Makombe, I. A.M., Temba, E. I and Kihombo, A.R., 1999. Credit Schemes and Women's Empowerment for Poverty Alleviation: Case of Tanga Region, Tanzania. Research Report on Poverty alleviation No. 99.1 REPOA, Dar es Salaam. 67 pp

Nanavaty, R., 2000. Women, Water and Work: SEWA's (Self Employed Women's Association) Millennium Campaign. Opp. Lok Manya Titak Baug Bhadra, Ahdmedabad-380 001. "World Water Forum" – 17-22 March 2000.

Rocheleau, D., Weber, F. and Field-Juma, A., 1988. Agroforestry in dryland Africa. Nairobi: ICRAF 18-19 pp.

Rogers, B.,1991. The Domestication of Women. Routledge, Chapman and Hall, Inc. New York. pp200

Rosecrance, R.C., Brewbaker, J.L. and Fownes, J.H. (1992) Alley cropping of maize with nine leguminous trees. *Agroforestry systems* 17: 159 –168.

Sandys, E.,2005. Women2000 and beyond: Women and water. United Nations Division for the Advancement of Women Department of Economic and Social Affairs. New York, NY 10017.[http://www.un.org/womenwatch/daw/public/w2000] site visited on 20th June, 2007

Soussan, J., 1998. Water/Irrigation and Sustainable Rural Livelihoods. In: Sustainable Rural Livelihoods: What contribution can we make? Paper presented at the Department for International Development's Natural Resources Adviser's Conference, July 1998 (Edited by Carney, D) Russell Press Ltd., Nottingham. 181-190 pp

UDEC, 2002. Women Entrepreneurs in Tanzania

[http://216.239.59.104/search?q=cache:dZI14H_G2tYJ:www.ilo.org/dyn/empent/docs/F745439070/ILO%2520WED%2520study%2520Tanzania]. Site visited on 15 / 06 /2006

UNESCO, 2005. The Role of Informal Sector in Poverty Reduction [http://www.unescap.org/pdd/CPR/CPR2006/English/CPR3_1E.pdf] site visited on 20/11/2006

URT, 2003. Mbeya Region Socio-economic Profile. National Bureau of Statistics and Mbeya Regional Commission's office. Dar es Salaam, Tanzania. 2nd Edition 176pp

Women Watch, 2005. Women and Poverty [http://www.un.org/womenwatch/daw/Beijing/platform/poverty.htm] site visited on 1/12/2005

13 Evaluation of the Potential for a Reward for Environmental Services (RES) Scheme in Sasumua Watershed, Kenya

Mwangi, J. K. [1*]
Mwangi H. [1]
Gathenya J. M. [1]
Shisanya, C. A. [2]

[1] Jomo Kenyatta University of Agriculture and Technology, Kenya
[2] Kenyatta University Kenya

13.1 Abstract

Human exploitation of ecosystems for the production of consumptive goods is placing increasing pressure on ecosystem functions such as sediment retention and flow regulation. As the demand for water grows, enhanced quantity and quality have become tradable environmental services. The study was in Sasumua watershed which is source to 20% of Nairobi's water supply. Intensification of human activity has placed pressure on rivers supplying Sasumua reservoir resulting in reduced flows and increased sediment load with implications on water treatment costs for Nairobi Water Company. The objective was to evaluate the potential for developing a reward mechanism to regulate flow and mitigate pollution loading. The Soil and Water Assessment Tool (SWAT), a distributed hydrological model was used to biophysically identify areas where interventions would have maximum impact on environmental services delivery. An economic analysis of interventions determined the most cost effective one while a socio-economic study evaluated willingness to accept (WTA) of land owners. Flat lowly areas and the steeply sloping cultivated areas were the major sediment sources. Simulation of terraces, filter strips and grassed waterways reduced sediment yield at reservoir inlet by 85%, 49%, and 40%, respectively while marginally increasing water yield. Terraces were the most expensive to implement while grass strips were cheaper and popular with farmers. WTA the scheme was 91% with environmental conservation and financial rewards as motivations. Gender, income and education levels influenced WTA. A reward scheme is feasible in the watershed and can operate under the existing legal and institutional framework. The results can be used to devise sound watershed management plans and to understand the implications of current land uses.

Key words*: BMPs, Environmental services, Hydrological model, Pollution, RES*

13.2 Introduction

Ecosystems provide important and beneficial services to human beings ranging from provision of products such as food, timber, fuel wood and fresh water to no-tangible benefits such as flood regulation, water purification and aesthetics. Human livelihoods form an integral part of the ecosystem and hence are linked to the sustainability of human life (Millennium Ecosystem Services, MA, 2003). With increasing world population and growing commodity demand, pressure is being placed on ecosystem functions, such as sediment retention and stream flow regulation (Kremen, 2005). With this increasing pressure, proper management of watersheds is required for continued enjoyment of these services. One option is ecosystem conservation through rewards for environmental services (RES) (Asquith *and* Wunder, 2008), which are cash transfers made to landowners in exchange for providing environmental services (ES) to downstream users. RES is a new market-based approach to conservation where the beneficiaries and stewards of environmental services work together in order to maintain or restore natural ecosystems. RES has increased the appeal of conservation practices to land owners and is likely to be successful once fully embraced (WWF, 2006).

Although a lot of information exists on ecosystem services threats and valuation (Daily, 1997), the relation between incremental area conserved and ecosystem service gains has not received attention (Dasgupta *et al.*, 2000), making it difficult to know how much, and where in the landscapes, land use needs to be changed, to deliver the desired ecosystem services.

Distributed hydrological models establish specific parameter values for the different spatial subunits of a watershed (Beven, 1985) and can thus identify where ES are generated. They are suitable under conditions of high spatial heterogeneity within watersheds although lack of data often hinders their applicability. The Soil and Water Assessment Tool (SWAT) model has less complexity, yet is powerful in data generation (Arnold *et al.*, 1998). It is a continuous-time model where modelled catchments are subdivided into sub-basins and hydrologic response units (HRU), which are spatially explicitly parameterized to capture the impacts from different topography, soils, and land covers (Di Luzio *et al.*, 2005). HRUs contribute to the sub-watershed with specific stream flow and sediment yields (Haverkamp *et al.*, 2005). SWAT thus spatially identifies units crucial for the delivery of watershed services (water production and sediment retention) information crucial in the design of RES schemes.

Sasumua watershed which provides 20% of Nairobi's water needs is crucial for the production of ecosystem services i.e. flow regulation and water filtration. Land use changes, driven by agricultural production have led to degradation which has impacted negatively on the production of these ES and livelihood of the community. Intensified farming has resulted in increased use of inorganic fertilizers and pesticides posing a water pollution threat. The upland catchments, necessary for maintaining regular and quality water flow, have been transformed through inappropriate land use resulting in reduced dry weather flows, increased incidences of floods, soil erosion and water quality deterioration. The life span of Sasumua reservoir and abstraction infrastructures e.g. Chania and Kiburu intakes is also threatened by siltation. These have caused increased siltation and high drinking-water treatment costs for Nairobi Water Company (NWC). With this increasing pressure on ES, proper land management is crucial to ensure continued production and enjoyment of these services. To reduce sediment and agro-chemical load to Sasumua reservoir requires sensitization of upstream landowners on the need for sustainable farming practices and creation of incentive mechanisms such as RES. The Premise of RES is that the economic value of ES and goods should be recognized by society and the stewards of these ecosystem services compensated.

By rewarding landowners for the ES they generate, RES acts as a motivating tool for their continued provision through land use changes and adoption of best management practices (BMPs) (Landell-Mills and Porras, 2002). These payments are in addition expected to improved rural incomes. RES has attracted increasing interest as a mechanism for translating external, non-market values of ES into incentives for local actors to provide the required ES (Engel *et al.* 2008). However, design of RES schemes should also address issues such as: the amount of ES provided, payments required; and avoid perverse incentives. Monitoring effectiveness of RES in stimulating adoption of proposed measures, impact on ES and on household welfare is also vital. To provide a platform for negotiations in supply and demand of ES, it is necessary to identify and understand landowner's preferences for various land use options that enhance their provision, and their willingness to accept (WTA) rewards. The willingness of land owners to participate in a RES scheme is an indicator of whether they perceive it will improve their livelihoods (Pagiola *et al.,* 2005). An important factor in the extent to which RES can affect poverty levels is the payment made, which lies between the minimum willingness to accept (WTA) of land owners to change land use and the maximum willingness to pay (WTP) of beneficiaries for the services they obtain. Although in practice, payment levels have tended to be set closer to the minimum WTA (Pagiola *et al.,* 2005) the beneficiary's willingness and ability to pay must be higher than the providers' opportunity costs for RES to be attractive. Successful RES schemes require identification of beneficiaries for whom payments are more cost-effective than high water treatment costs, regular de-silting of intakes or development of alternative water supplies. RES schemes should be realistic and affordable by the sellers and buyers while set targets should be real and achievable (Laxman *et al.,* 2009). Many types of RES schemes exist but the final choice depends on whether market forces are at work or state regulations are driving watershed management approaches. RES schemes are more efficient than command-and-control approaches (Landell-Mills *and* Porras, 2002) because they are flexible and concentrate their efforts in areas of high benefits and low costs. Since farmers invest time, labour, money and land in watershed conservation and beneficiaries require assurance of returns on their investment in conservation stakeholders entering into these schemes need to do so willingly. One limitation of RES schemes however, is high transaction costs.

13.3 Materials and Methods

Sasumua watershed (107 km^2) lies between longitudes 36.58°E and 36.68°E and latitudes 0.65°S and 0.78°S with an altitude of between 2200m and 3850m. The watershed has a reservoir (Sasumua) which receives water from Sasumua, Chania, and Kiburu sub-watersheds (Figure 13.2). The stream network in the Sasumua sub-watershed (67.44 km^2) is intermittent providing water to the reservoir only during the rainy season which is highly polluted. The stream network in the Chania (20.23 km^2) and Kiburu (19.30 km^2) sub-watersheds are perennial and connected to the reservoir via tunnel and pipe diversions respectively thus providing water of comparatively higher quality throughout the year. Surface water distribution in the watershed is not even in time and space which creates water use conflicts between the residents and NWC. Apart from Njabini Township and other market centres where there are commercial activities; farming is the main socio-economic activity in the watershed with potatoes, cabbages, garden peas and carrots being grown for the Nairobi urban market. The steep slopes and heavy rainfall makes much of the watershed vulnerable to land degradation- a problem exacerbated by high population density (242 persons per km^2). This has increased demand for natural resources, such as land, water and energy, heightening risks of ecosystem degradation.

Rainfall increases with increasing elevation while temperature decreases with increasing elevation. Mean annual rainfall varies from 1000-1600 mm, is binomial in pattern with long rains occurring from March to May and short rains from October to December, Gathenya *et al.,* (2009). Mean monthly temperature is 12°C while mean potential evaporation is 1250mm. Daily rainfall records for ***three*** stations Njabini ATC (9036152), South Kinangop Forest station (9036164) and Sasumua dam (9036188) with records spanning (1970-2008) was used. Daily rainfall records for ***three*** stations Njabini ATC (9036152), South Kinangop Forest station (9036164) and Sasumua dam (9036188) with records spanning (1970-2008) was used

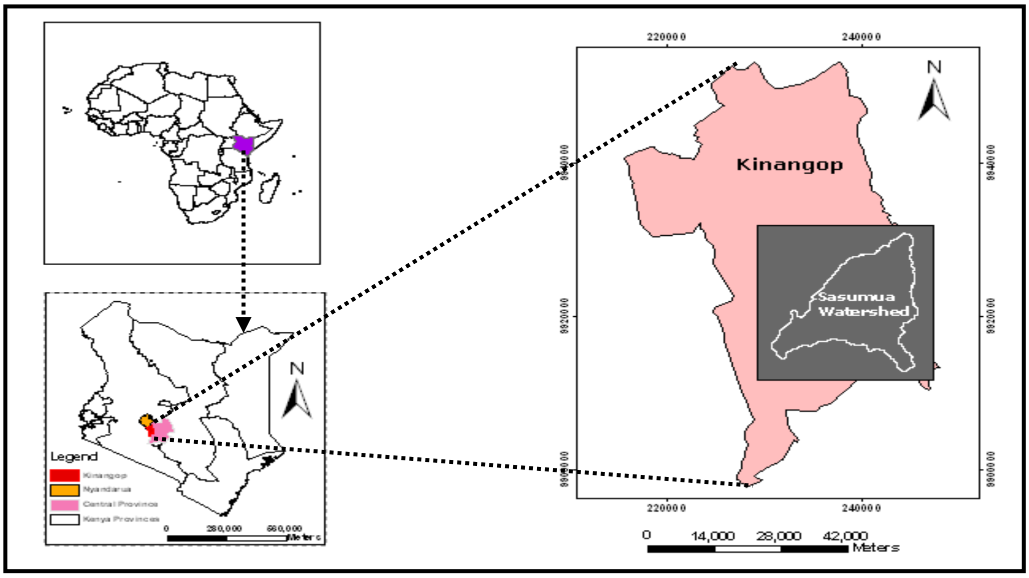


Figure 13.1: Location of study area

Due to lack of streamflow data, reservoir inflow was deduced from reservoir water balance equation (1) which was possible because Sasumua, Chania and Kiburu sub-watersheds drain to the reservoir which has relatively good volume storage and abstraction data. This entailed installing a 'hypothetical gauge' at the junction of sub-basins **35** and **36** and computing inflow at that point as follows;

$$V_{\inf low} = (V_{end} - V_{beginning}) + V_{flowout} + V_{evap} + V_{seep} - V_{pcp} \quad (1)$$

Where V_{inflow} is the volume of water entering the reservoir during the day (m^3), V_{end} is volume of the water at the end of the day (m^3), $V_{beginning}$ is volume of water in the reservoir at the beginning of the day (m^3), $V_{flowout}$ is the volume of water leaving the reservoir during the day (m^3), V_{pcp} is volume of rainfall falling on the reservoir during the day (m^3), V_{evap} is volume of water lost from the reservoir through evaporation during the day (m^3) while V_{seep} is volume of water lost from the reservoir through seepage (m^3). The volume of water lost through seepage and through overspill during high inflows was input as flow over a weir downstream of the reservoir. No record of sediment data was available but measurements of total suspended solids (TSS) were made for three months for comparison with simulated values.

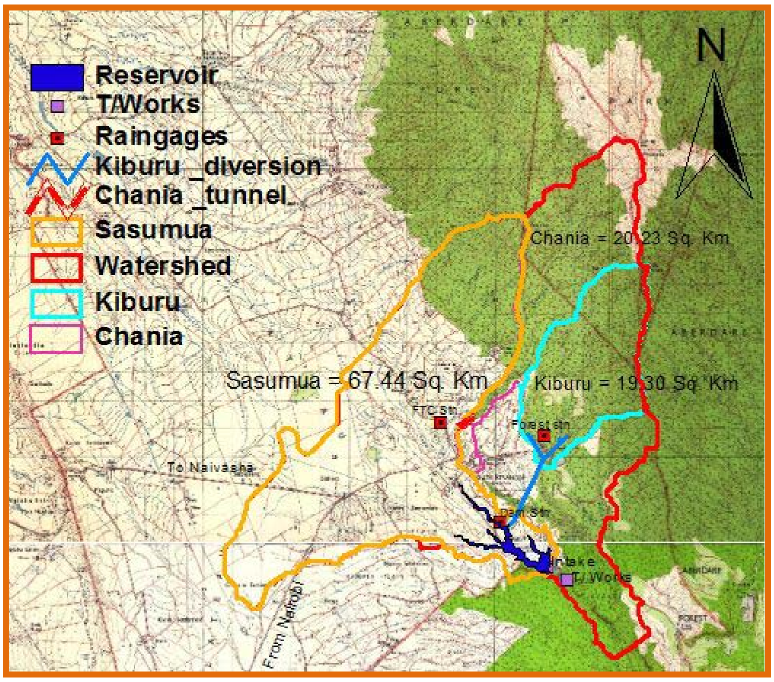


Figure 13.2: Contributing sub-catchments of Sasumua watershed

13.3.1 The SWAT Model

SWAT is a physically based distributed parameter, continuous-time model that operates on a daily time step designed to predict the impact of land management practices on water, sediment and agricultural chemical yields in large watersheds with varying soils, land use and management conditions (Arnold et al., 1998). Weather, hydrology, soil temperature and properties, plant growth, nutrients, pesticides, bacteria and pathogens, and land management are the major components in the model (Gassman *et al.*, 2007). The model partitions the watershed into a number of sub-basins depending on the critical source area specified by the user. The critical source area is required to initiate a channel flow (Arabi *et al.*, 2008). The sub-basins are further partitioned into hydrologic response units (HRUs) which are the product of a distinct combination of soils and land use. Detailed description of the model is given by Arnold *et al.* (1998), Neitsch *et al.* (2005), and Gassman *et al.* (2007).

To accurately predict sediments, nutrients, and pesticides hydrological processes should be well simulated. Watershed hydrological cycle is divided into land phase and the routing phase. The land phase controls the amount of water, sediments, nutrients and pesticides entering the main channel while the routing phase deals with their movement through the channel network of the watershed to the outlet (Neitsch *et al.*, 2005). The land phase of hydrological cycle in SWAT is given by:

$$SW_t = SW_o + \sum_{t=1}^{t}(R - Q_s - E_a - W_{seep} - Q_{gw}) \tag{2}$$

Where, SW_t is the final soil water content (mm), SW_o is the initial water content on day i (mm), t is time in days, R is amount of precipitation on day i (mm), Q_s is the amount of surface runoff on day i (mm), E_a is the amount of evapotranspiration on day i (mm), W_{seep} is the amount of water entering the vadose zone from the soil profile on day i (mm) and Q_{gw} is the amount of return flow on day i (mm)
Erosion and sediment yield in SWAT are calculated using Modified Universal Soil Loss Equation (MUSLE) (Williams, 1975). The difference between MUSLE and Universal Soil Loss Equation (USLE) is that USLE uses rainfall as indicator of erosive energy while MUSLE uses the amount of runoff to simulate erosion and sediment yield. The advantages of using MUSLE over USLE are; prediction accuracy of the model is increased, the need of a sediment delivery ratio is eliminated and estimates of sediment yields for a single storm can be computed (Neitsch *et al.*, 2005). The MUSLE equation is;

$$Sed = 11.8.(Q_s.q_{peak}.A)^{0.56} \times K_{USLE} \times C_{USLE} \times P_{USLE} \times LS_{USLE} \times CFRG \tag{3}$$

Where Sed is the sediment yield on a given day (tons/ha), Q_s is the surface runoff (mm/ha), q_{peak} is peak runoff rate (m^3/s), A is area of HRU (ha), K_{USLE} is the USLE soil erodibility factor, C_{USLE} is the USLE cover management factor, P_{USLE} is the USLE support factor, LS_{USLE} is the USLE topographic factor and $CFRG$ is course fragmentation factor.

A key strength of SWAT is its flexible framework that allows simulation of a wide range of conservation practices (Gassman *et al.* (2007) with straightforward parameter changes. The partitioning of the watershed into sub-basins is useful when different areas of the watershed are dominated by different land uses/soils that impact on watershed hydrology (Neitsch *et al.,* 2005). This subdivision enables the model to reflect differences in evapotranspiration (ET) for various soils and crops. Runoff for each HRU is predicted separately and then routed to obtain the total watershed runoff. SWAT was selected for this study because it is physically based, simulates actual land management processes in large watersheds, has good user support and integrates both water and sediment yields. The model provides outputs at the watershed, sub-basin, and HRU level on a daily, monthly or annual basis.

13.3.2 DEM-Generation and watershed delineation

A 10m resolution digital elevation model (DEM) was generated using digitized contours from 1:50,000 Survey of Kenya topographic maps (UTM, WGS84 zone 37S) using ArcGIS 9.3 (figure 13.3). The watershed was delineated from the larger DEM using SWAT. Use of a fine resolution DEM was necessary because of its effect on topographic parameters, runoff and sediment yields. The geographical information system (GIS) interface of the model (AvSWAT; Di Luzio *et al*., 2002) was used to specify a critical source area (CSA) that controlled the number of sub-basins and channel network density. A threshold CSA of 200Ha was adopted in this study as it provided a balance between sufficient detail and the number of sub-basins that could be handled. The resultant watershed had an area of 13,456 Ha, 41 sub-basins and a mean sub-basin area of 328.8Ha. Each sub-watershed was further sub-divided into one or more HRUs representing unique combinations of land use and soil types.

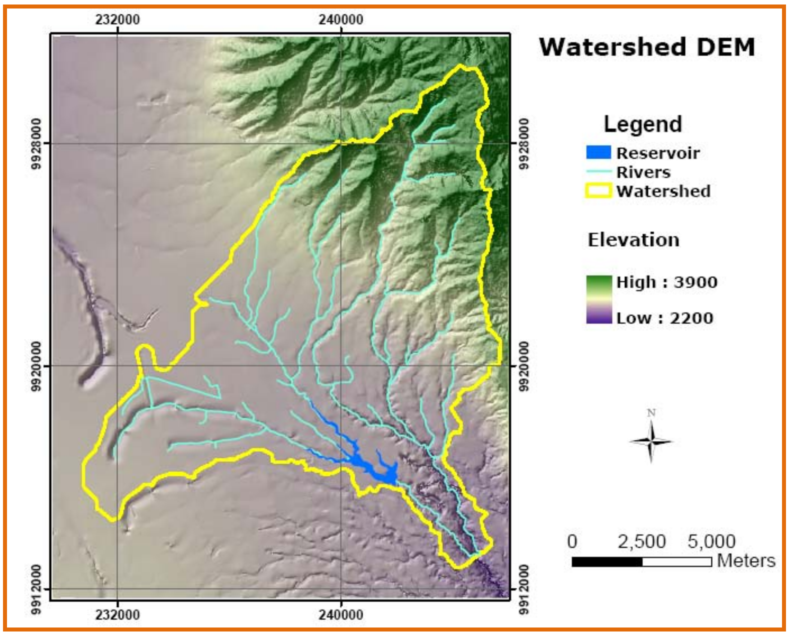


Figure 13.3: A 10m DEM of the watershed

HRUs are treated as a fraction of sub-basin area and so are not assigned a spatial location. Implicit in the concept of HRUs is the assumption that there is no interaction between HRUs in a sub-basin, loadings from each HRU being calculated separately and summed up to determine the total sub-basin loadings. Flow generation, sediment yield and pollutant loadings are then summed up across all HRUs and routed through channels, ponds and/or reservoirs to the watershed outlet (Neitsch *et al.,* 2002). HRUs are defined based on user specified land use and soil area distribution thresholds (Arnold *et al.,* 1998). Multiple HRUs option was used in this study with thresholds of 20% for land cover and soils respectively resulting in 66 HRUs. Key factors that affect stream flow simulations are characteristics of HRUs since surface and sub-surface runoff are generated at HRU level (Jha *et al.*2004). Sensitivity analysis was done to identify important parameters for model calibration. Ndomba *et al.,* (2008) has indicated that the same set of parameters can be identified from SWAT model runs without the use of observed data.

Model calibration was done manually due to lack of measured data for auto-calibration. Parameters modified during simulations were obtained from sensitivity analysis results and published literature. Calibration and validation procedure presented in the SWAT user manual (Neitsch *et al.,* 2002), was followed with calibration for water balance and stream flow being done initially for average annual conditions and parameters later fine-tuned using monthly data. The first two years (1987-1988) were used as a *"warm-up"* and were not included in the analysis. Model calibration was done for the period (1989-1992) while validation was done for the period (1993-1996). The Calibration parameter adjusted for surface runoff was mainly the curve number (CN) and Soil evaporation compensation factor (ESCO) while the parameters adjusted for base flow proportioning were threshold depth of water in the shallow aquifer required for return flow to occur (GWQMN), plant uptake compensation factor (EPCO) and ground water delay (GW_DELAY). The calibration process consisted of ensuring that: (a) the simulated flow matched the observed flow and that (b) there was proper proportioning of the simulated flow between surface runoff and base flow. Calibration was intended to reduce parameter uncertainty and increase robustness of results.

Model validation was done to test whether the model could estimate outputs for locations, time periods or conditions other than those that the parameters were adjusted to fit. It was done only for hydrology simulations as there was no measured sediment data. The coefficient of determination (R^2) and Nash-Sutcliffe efficiency (E_{NS}) were used to evaluate model performance. R^2 indicates the strength of the relationship between observed and simulated values while Nash-Sutcliffe efficiency measures how well the simulated and observed flows correspond. The validated model was used to simulate annual sediment yields in agricultural areas of the watershed for the period (1970-2010) based on coincident period of available data. This formed the base scenario for simulation of BMPs. Due to the agricultural focus of SWAT, urban areas in the watershed were not adequately simulated but this was understandable considering that the focus of the study was on quantifying the effectiveness of agricultural BMPs. Urban loadings in the watershed are also comparatively smaller although they can be damaging to receiving streams due high pollutant contents.

13.3.3 Evaluation of BMPs

Impact of BMPs simulations on water and sediment yield was quantified using the model. Pre and Post-BMPs scenarios were evaluated to determine changes in flow and sediment yield due BMPs implementation. The results are presented as percentage increase/decrease in flow and sediment loadings at reservoir inlet. The BMPs simulated were indentified from literature (Arabi *et al.,* 2008) and included filter strips, parallel terraces, contour farming and a grassed waterway. Filter strips were simulated by adjusting parameter (FILTERW) in agricultural HRUs in SWAT and excluded the riparian buffer strip managed by NWC. A sensitivity analysis was carried out to determine the effect of filter strip width on surface runoff and sediment yield. Upon each adjustment sediment loading was determined at the reservoir entrance (sub-basins **35+36**). The trapping efficiency of sediments in SWAT is given by equation 4 (Neistch *et al.*, 2005).

$$Trap_{eff\_sed} = 0.367 \times FILTERW^{0.2967} \tag{4}$$

Where $Trap_{eff\_sed}$ is the trapping efficiency of sediments and *FILTERW* is filter strip width (m). The effectiveness of filter strips in abating Non-Point Source pollution (NPS) is based on its trapping efficiency and is affected by width (Yuan *et al.,* 2009; Abu-Zreig, 2001) and land slope (Gilley *et al.*, 2000). It can be enhanced by varying the vegetation type.

Parallel terraces were implemented by varying SCS curve number (CN), USLE support Practice factor (USLE_*P)* and hillside slope length (SLSUBBSN) Arabi *et al.* (2008), Gassman *et al*. (2006) in their study found terraces to be effective in sediment reduction. When implemented on steeply sloping areas they reduce land slope, surface runoff and increase infiltration. By reducing land slope and slope length they reduce peak runoff rates and hence erosive action of surface runoff. They are ideal where erosion by water, slope length and runoff is a problem.

Channel width (CH_W2), channel depth (*CH_D*), channel Manning's roughness coefficient (*CH_N2*) and channel cover factor (*CH_COV)* were adjusted in channel segments to represent installation of grassed waterways. The effectiveness of grassed waterways in sediment trapping depends on soil characteristics, land slope, vegetation type and the maintenance provided. A wide waterway with well established vegetation is effective in sediment trapping. Grassed waterways were simulated in sub-basins that feed Ming'utio stream where flooding is a problem. Secondary data on monthly chemical usage at Sasumua water works was collected together with gross margins of major enterprises in the watershed. Information on land rents, labour costs and data on production and livelihoods systems was obtained through a poverty assessment study and was used in socio-economic assessment of land-use alternatives. To assess the feasibility of a RES scheme, demand and supply of ES was evaluated and an economic assessment of technological changes needed to provide ES done. A willingness to accept (WTA) study was carried out targeting 77 riverine households using a combination of random and purposive sampling. To estimate ES demand, a study was carried in the western corridor of Nairobi served by Sasumua reservoir the aim being to assess the willingness to pay (WTP) of water consumers for increased and reliable supply of water via watershed conservation. A contingent valuation method (CVM) was used that targeted 200 randomly selected and spatially distributed households encompassing low, medium and high income areas. The respondents were presented with a hypothetical but realistic situation and asked through a bidding procedure the maximum they were willing to pay above their monthly water bills to fund watershed conservation. The results were evaluated using SPSS. A cost-benefit analysis was carried out to identify the most cost-effective intervention. A business case for NWC was evaluated with the base scenario adopted as no intervention leading to worsening of watershed degradation with consequential increase in water treatment and de-siltation costs for NWC. The major benefit considered was reduction in water turbidity with resultant reduction in annual water treatment costs. A review of existing legal and institutional frame work was carried out to determine whether a PES scheme would be illegal under Kenyan law.

13.4 Results and discussions

Calibration results (1989-1992) gave an R^2 of 0.80 and E_{NS} of 0.74 while validation results (1993-1996) gave R^2 = 0.85 and E_{NS} = 0.81. Comparison of observed and simulated time series show that observed flow was systematically underestimated in months of high rainfall. This can be explained by possible inaccuracies in the method used to compute reservoir inflow. For example both Chania and Kiburu diversions are regulated and no data was available to indicate when their maximum carrying capacities were exceeded and extra water led back to the rivers. Low and intermediate flows were however better predicted and in general the simulated time series fitted the observed one well which necessary for accurate sediment simulation and in identifying HRUs with the highest sediment yield.

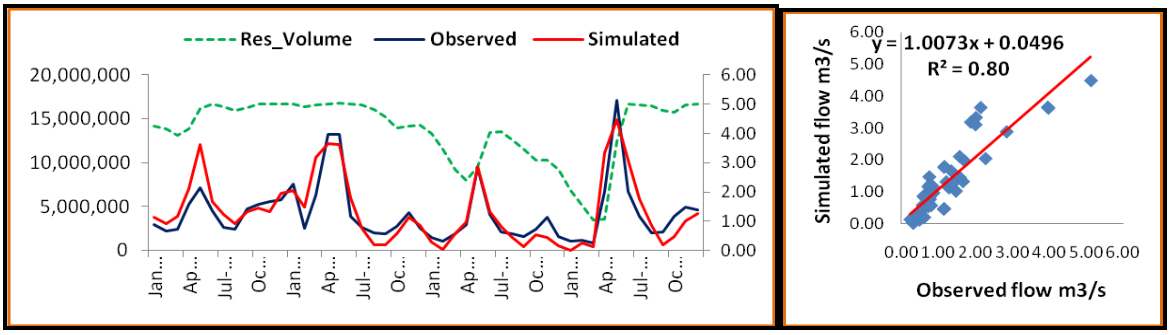


Figure 13.4: Calibration hydrograph and scatter plot at reservoir inlet

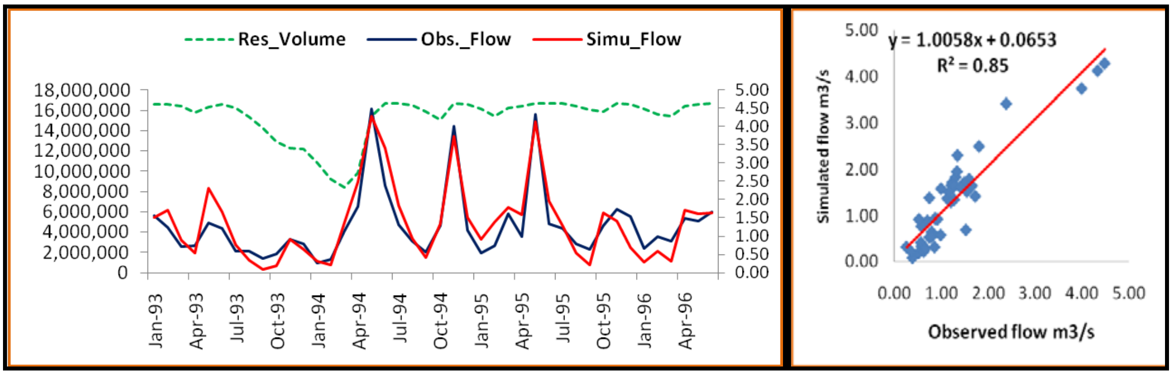


Figure 13.5: Validation hydrograph and scatter plot at reservoir inlet

13.4.1 Identification of hot spots

These were identified and prioritized on the basis of average annual sediment yields simulated using SWAT. Annual sediment yields simulated for each sub-watershed were ranked according soil erosion classes described by Singh *et al.,* (1992) and arranged in a descending order (table 13.2). From model simulations the major sediment producing areas are the flat poorly drained areas of Githioro and

Kwa-Haraka to the southwest of the watershed (Figure 13.6) and the intensively cultivated slopes of little Sasumua and its tributaries. These few areas are responsible for high amounts of sediment yield (table 13.2) and implementation of BMPs is required to control soil loss. Impacts of simulated conservation practices on water quality were evaluated as impacts on sediment yield at reservoir inlet. In general, these practices were classified into two groups: (*a*) practices installed on upland areas, such as contour farming, parallel terraces and vegetative filter strips; (*b*) practices installed within channel network, such as grassed waterways. The upland practices were implemented in steep cultivated areas of the sub-watershed covering about 52% while impacts of within-channel practices were evaluated when installed within drainage ditches/streams with different geomorphologic characteristics in the flat areas of the sub-watershed covering about 37% of the sub-watershed area. Hot spots had the highest potential to provide ES to downstream users if BMPs are implemented and by spatially identifying these units the model provided data for the design of a possible RES scheme.

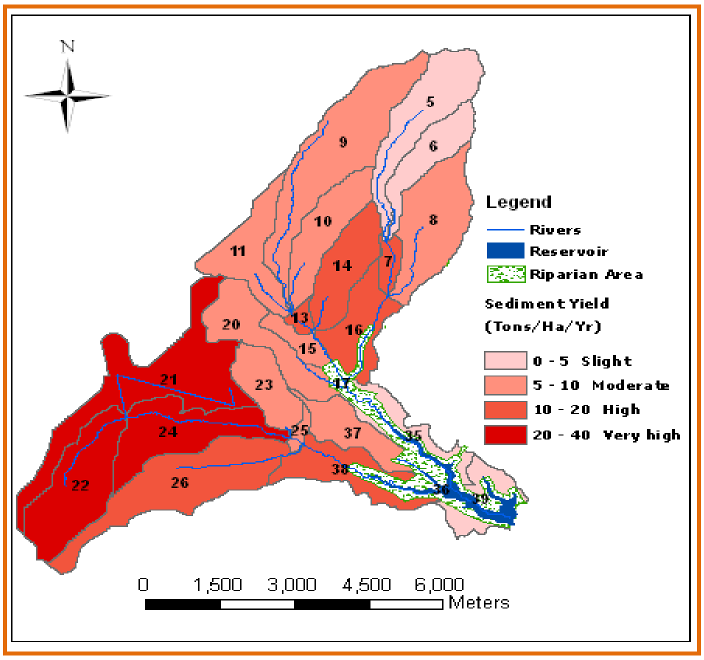


Figure 13.6: Major Sediment producing areas in the watershed

13.4.2 BMPs simulations

Filter width parameter (FILTERW) in SWAT was adjusted to simulate this conservation practice and sediment loading at the outlet of sub-basins 35 and 36 for various widths of the filter strip determined. Results show that reduction in sediment loading as a function of filter strip width is not linear (figure

13.6) which is consistent with other studies (Arabi *et al.*, 2008; Yuan *et al.,* 2009; Abu-Zreig, 2001). It also shows that the optimum width for a filter strip is about 30 meters. According to the trapping efficiency equation used in SWAT (4), a filter width of 30 m has a trapping efficiency of 1 (Parajuli *et al.*, 2008) indicating a sediment yield reduction of 100% in target sub-basins. However, this is only applicable if the filter strips are implemented in the entire watershed which was not the case in this study as BMPs were implemented only in the agricultural areas of the watershed excluding forests and the riparian area under NWC.

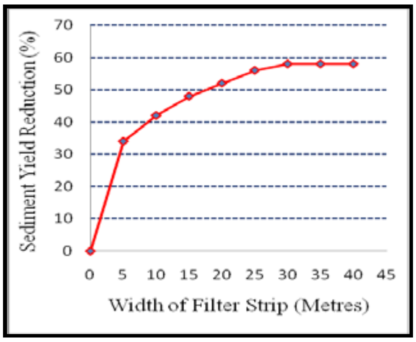


Figure 13.7: Variation of sediment yield reduction with filter strip width

Due to high demand for land and the small land holdings (average 1 ha) interventions that minimize land taken out of production should be encouraged and a filter strip width of 10m was adopted with a sediment yield reduction of 42%. Implementation of terraces in the watershed would reduce sediment loading to the reservoir by about 85% and increase infiltration to the soil by enhancing ponding. The enhanced infiltration by terraces recharges the shallow water table, reduces surface runoff there-by releasing the water stored in the shallow aquifer to the streams as base flow. This reduces flooding incidences, creates more regulated stream flows as base flow takes a longer time to reach streams than surface runoff. Terraces also reduce slope length and peak runoff rates (Arabi *et al.*, 2008) which is directly proportional to soil erosion rate. Simulations of grassed waterways in the flood prone areas of the watershed showed a sediment reduction of 54% at reservoir inlet while a combination of 10m wide filter strips and a grassed waterway achieved a 73% reduction (table 13.1). Filter strips have added benefits of being fodder for livestock.

Table 13.1: Sediment yield reductions at reservoir inlet (tons/year) by interventions

Rank	Intervention	% Removal
1	30m wide filter strips and grassed waterway	80
2	Parallel terraces, 10m VFS and grassed waterway	75
3	10m wide filter strips and grassed waterway	73
4	Contour farming and grassed waterway	66
5	Grassed waterway only	54

Table 13.2: High sediment yielding sub-basins

Sub-Basin No.	Sediment yield ton/ha/year	Rank	Remarks
17	***29.21***	***1***	Very high
24	***27.82***	***2***	
22	***26.07***	***3***	
21	***20.70***	***4***	
38	14.71	5	High
16	11.77	6	
07	11.04	7	
13	11.02	8	
26	10.14	**9**	
14	9.98	10	Moderate

Classification based on Singh *et al.,* (1992)

Grassed waterways occupy large tracts of land and hence are not popular with farmers unless they are compensated for their land. The effectiveness of this conservation practice also depends on the maintenance provided in the form of frequent removal of accumulated sediments to maintain waterway capacity and retention of vegetation cover at all times. The grass harvested from a grassed waterway can be used as fodder and creating an added benefit.

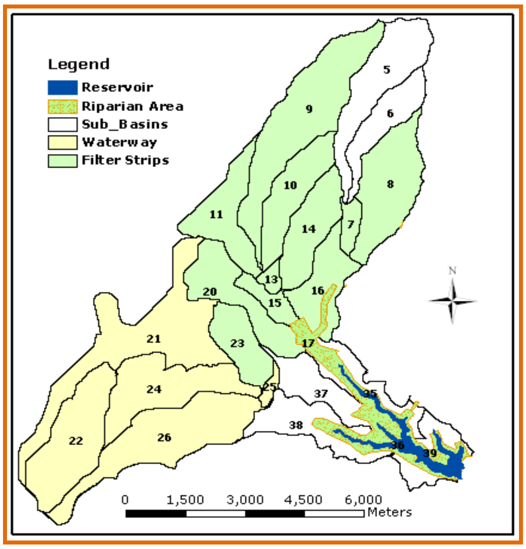


Figure 13.8: Areas for implementation with filter strips and grassed waterway

The cost of treating water at Sasumua plant is high (US$ 0.0178/m^3) but this could be lowered by improving the quality of incoming raw water through adoption of sustainable land management practices. The savings can then be used to incentivize upstream landowners to adopt sustainable land management practices which will also improve their household income. A business case therefore exists for NWC and although not explicitly mentioned in law contracts between environmental stewards and beneficiaries would not be illegal

Results show WTA was 91% at US$250 with gender, income and education levels tending to influence WTA. To reduce transaction costs existing local institutions such as water resource users associations (WRUAs) should be used including the financial and technical capacity of NWSC and the legal mandate of Water Resources Management Authority (WRMA) to manage watersheds given by the Water Act, 2002. Vegetative filter strips were the cheapest to install and maintain as they are less labour intensive. They also provide additional benefits as livestock fodder if palatable varieties of grass are used. Terraces have high establishment and maintenance costs due to their labour intensive nature but in the long term their internal rate of return is higher compared to other interventions.

13.5 Conclusions and recommendations

SWAT model can be used to quantify sediment loading within watersheds, and to highlight potential 'hot spots' for intervention. Implementation of parallel terraces, grass strips and grassed waterways reduced sediment loadings at reservoir inlet substantially. Parallel terraces were the most effective in reducing sediment yield and increasing base flow. However, filter strips were popular with farmers because of their added value as livestock feed. There are tradable ES in the watershed in the form of regular flow and improved water quality but a critical mass of buyers is required to make a RES reality. There is sufficient organizational structure in place and an operational WRUA that can act as a seller vehicle. Improved drainage in eutric Planosols areas, which are prone to flooding and increased woody cover through planting of suitable tree species as buffer strips along rivers should be promoted in the landscape to protect the soil from erosion. A RES Green Certificate should be introduced as a motivation to landowners providing ES. A watershed management plan should be developed and used as a basis for implementing appropriate land management practices that should include proper waste disposal, safe use and disposal of agricultural chemicals and establishment of soil and water conservation measures in "*hot spots* areas" of the watershed. Priority should be given to marginal cropped lands degraded hillsides and common lands. Existing legislations relating to utilization and management of watershed areas should also be enforced and PES embedded in natural resource management policies as a watershed management tool through land use transformation, a recognition that will facilitate dissemination and implementation of PES systems.

13.6 Acknowledgements

This research was supported by Jomo Kenyatta University of Agriculture and Technology, the PRESA project of the World Agro- Forestry Centre (ICRAF) and the European Union Water Project (IWMnet). I am grateful to all.

13.7 References

Abu-Zreig M., (2001): Factors affecting sediment trapping in vegetated filter strips: simulation study using VFSMOD. *Hydrological Processes.* 15, 1477–1488

Arabi, M., J. Frankenberger, B. Engel, and J. Arnold. (2008): Representation of agricultural management practices with SWAT. *Hydrological Processes 22: 3042-3055*

Arnold, J.G., Srinivasan, R., Muttiah, R.S., Williams, J.R., (1998): Large area hydrologic modelling and assessment Part I: model development. *Journal of the American Water Resources Association* 34 (1), 73-89.

Arnold, J.G., Williams, J.R., Srinivasan, R., King, K.W., (1999): Soil and water assessment Tool. USDA, Temple TX, P. 92

Asquith, N., Wunder, S. (Eds), (2008): Payments for Watershed Services. The Bellagio Conversations. Fundacion Natura Bolivia and CIFOR, Santa Cruz, P 29

Beven, K.J., (1985): Distributed Models. In: Anderson, M.G., Burt, T.P. (Eds), Hydrological Forecasting. John Wiley and Sons, New York, pp 405-435

Daily, G., (Eds.) (1997): Nature's Services: Societal Dependence on Natural Ecosystems. Island Press, Washington.

Dasgupta, P., Levin S., Lubchenco J. (2000): Economic pathways to ecological sustainability. Bioscience 50,339-345

DiLuzio, M.D., R. Srinivasan, and J.G Arnold (2002): Integration of watershed tools and SWAT model into BASINS. *Journal of American Water Resources Association (3894): 1127-1141*

Di Luzio, M., Arnold, J.G., Srinivasan, R. (2005): Effect of GIS data quality on small watershed stream flow and sediment simulations. *Hydrological Processes 19,629-650*

Engel, S., S. Pagiola and S. Wunder (2008): 'Designing payments for environmental services in theory and practice: An overview of the issues', *Ecological Economics 65(4): 663–74. Elsevier, Amsterdam.*

Gassman P.W., E. Osei, A. Saleh, and J. Rodecap, (2006): Alternative practices for sediment and nutrient loss control on livestock farms in northeast Iowa. *Agriculture, Ecosystems and Environment* 117:135–144

Gassman P.W., M.R. Reyes, C.H. Green and J.G. Arnold, (2007): The Soil and Water Assessment Tool: Historical Developments, Applications and Future Research Directions. *Transactions of ASABE, 50 (4): 1211-1250.*

Gathenya J.M, Thiong'o G.T., and Mwangi J.K. (2009): Hydrologic and water quality assessment report for Sasumua watershed. Technical Report. Word Agro-forestry Centre.

Gilley J.E., B. Enghball, L.A. Kramer and T.B. Moorman, (2000): Narrow grass hedge effects on runoff and soil loss. *Journal of soil and water conservation.* 55 (2): 190-196.

Haverkamp, S., Fohrer, N., Frede, H.-G., (2005): Assessment of the effect of land use patterns on hydrologic landscape functions: a comprehensive GIS-based tool to minimize model uncertainty resulting from spatial aggregation. *Hydrological Processes 19, 715–727*

Jha M., Gassman P.W., Secchi S., Gu R., and Jeff Arnold (2004): Effect of watershed sub-division on SWAT flow sediment and Nutrient predictions. *Journal of the American Water Resources Association 40(3):811-825*

Kremen, C., (2005): Managing ecosystem services: What do we need to know about their ecology? Ecology letters 8, 468-479

Landell-Mills, N., and Porras, I., (2002) Silver bullet or fools gold? A global review of markets for forest environmental services and their impact on the poor. *International Institute for Environment and Development (IIED). London, UK*

Laxman J., B. Leimona, D. Catacutan, T. Yatich, J. Dietz, H. Mwangi, F. Sinclair, S. Bhattarai, L. Onyango, S. A. Kalinganire, Q. Noordin, J. Bayala, K. Tscherning and C. Pinon (2009): Supporting landscape multifunctionality for reduced vulnerability to climate change. In Trees and livelihoods co-adapt to climate change: support for landscape multi-functionality to reduce vulnerability. ICRAF, Unpublished

Millennium Ecosystem Assessment (MA), (2003): *Ecosystems and Human Wellbeing: A Framework for Assessment*. Washington, DC: Island Press. http://www.millenniumassessment.org/en/Framework.aspx

Monteith, J.L. 1965: Evaporation and the Environment. *In:* The state and movement of water in living organisms. 19thSymposia of the Society for Experimental Biology. Cambridge University Press, London, U.K pp 205-234

Ndomba P., F. Mtalo and A. Killingtveit, (2008): SWAT model application in a data scarce tropical complex catchment in Tanzania. *Physics and Chemistry of the Earth 33: 626–632* Elsevier B.V.

Neitsch, S.L., Arnold, J.G., Williams, J.R., Kiniry, and K.W.King (2002): Soil and Water Assessment Tool (Version 2000) Model Documentation. GSRWRL02-01, BREC 02-05, TR-191,Texas Water Research Institute, Texas A&M University, College Station, TX. Available at: http://www.brc.tamus.edu/swat.

Neitsch, S.L., Arnold, J.R., Kiniry and J.G. Williams (2005): Soil and Water Assessment Tool (Version 2005) Model Documentation. Temple Tex.: USDA-ARS Grassland, Soil and water research laboratory. Available at: http://www.brc.tamus.edu/swat/doc.html.

Pagiola, S., N. Landell-Mills, and J. Bishop (2002): "Making Market-based Mechanisms Work for Forests and People." In S. Pagiola, J. Bishop, and N. Landell-Mills (eds.), *Selling Forest Environmental Services: Market-based Mechanisms for Conservation and Development*. London: Earth scan.

Pagiola S, Arcenas A., Platais G. (2005: Can payments for Environmental services help reduce poverty? An exploration of issues and the evidence to date from Latin America. World Development 33(2): 237-253

SCS.1972: Hydrology. Section 4 in National Engineering Handbook. Washington D.C. USDA Soil Conservation Service

Van Liew, M.W., Arnold, J.G., Bosch, D.D., (2005): Problems and potential of Autocalibrating a hydrologic model. Soil & Water Division of ASAE 48 (3), 1025–1040.

Williams J.R. (1975): Sediment routing for agricultural watersheds. *Journal of the American Water Resources Association, No. 75065* of the Water Resources Bulletin 11(5): 965-974

WWF (2006): Payment for environmental services: An equitable approach for reducing poverty and conserving nature

Yuan Y. R.L.Bingner and M.A. Locke, (2009): A review of effectiveness of vegetative buffers on sediment trapping in agricultural areas. *Ecohydrology (2): 321-336.*Wiley interscience.

14 Hydrological response of Watershed Systems to Land Use / Cover Change: A Case of Wami River Basin

Nobert J.,

Jeremiah J.,

Mtalo F.,

Mkhandi S.H.

University Of Dar es Salaam
P.O Box 35131 Dar es Salaam

nobert@udsm.ac.tz

14.1 Abstract

Wami river basin experiences a lot of human disturbances due to agricultural expansion, and increasing urban demand for charcoal, fuel wood and timber; resulting in forest and land degradation. Comparatively little is known about factors that affect runoff behaviour and their relation to land use in data poor catchments like Wami. This study was conducted to assess the hydrological response of land use/cover change on Wami River flows. In data poor catchments, a promising way to include land use change is by integrating Remote Sensing and semi-distributed rainfall-runoff models. Therefore in this study SWAT model was selected because it applies semi-distributed model domain. Spatial data (land use, soil and DEM-90m) and Climatic data used were obtained from Water Resources Engineering Department, government offices and from the global data set. SWAT model was used to simulate stream flow for land use/land cover for the year 1987 and 2000 to determine the impact of land use/cover change on Wami stream flow after calibrating and validating with the observed flows. Land use maps of 1987 and 2000 were derived from satellite images using ERDAS Imagine 9.1 software and verified by using 1995 land use which was obtained from Institute of Resource Assessment (IRA). Findings show that there is a decrease of Forest area by 1.4%, a 3.2% increase in Agricultural area, 2.2% increase in Urban and 0.48% decrease in Water body area between 1987 and 2000. The results from SWAT model simulation showed that the average river flow has decreased from 166.3 mm in 1987 to 165.3 mm in 2000. The surface runoff has increased from 59.4mm (35.7%) in 1987 to 65.9mm (39.9%) in 2000 and the base flow decreased from 106.8mm (64.3%) to 99.4mm (60.1%) in 1987 and 2000 respectively. This entails that the increase of surface runoff and decrease of base flows are associated with the land use change.

Keywords: *Landuse/Landcover change, Hydrological response, Data poor catchments*

14.2 Introduction

During recent decades, concerns about the impacts of changing patterns of landuse associated with deforestation and agricultural transformation on water resources have created social and political tensions from local to national levels. This shift towards an increasingly urbanized landscape has generated a number of changes in ecosystem structure and function, resulting in an overall degradation of the ecological services provided by the natural system in Wami river basin. Ecosystem services are defined as the multiple benefits available to humans, animals and plants that are derived from environmental processes and natural resources (Costanza *et al.* 1997). Ecosystem services provided by surface water systems are vital to the health and success of human development. For example, many urban areas depend heavily on streams to provide water for municipal, agricultural and commercial uses (Meyer *et al.* 2005).

Threats to the Ukaguru Mountain forest in Wami river basin include encroachment from farmers and the plantation forest, fuel-wood collection and fires spreading from lowland areas. There is a high level of destruction of the forests in the Nguru Mountains, which have more than 40 endemic species. The threats to the Nguru forests are agricultural encroachment and under planting of forest with cardamom and banana, pit sawing of timber and fires. Other disturbances include timber harvesting; livestock grazing; pole cutting; firewood collection and charcoal production (Doggart and Loserian 2007).

Identifying and quantifying the hydrological consequences of land-use change are not trivial exercises, and are complicated by: (1) the relatively short lengths of hydrological records; (2) the relatively high natural variability of most hydrological systems; (3) the difficulties in 'controlling' land-use changes in real catchments within which changes are occurring; (4) the relatively small number of controlled small-scale experimental studies that have been performed; and (5) the challenges involved in extrapolating or generalizing results from such studies to other systems. Much of our present understanding of land-use effects on hydrology is derived from controlled, experimental manipulations of the land surface, coupled with pre- and post-manipulation observations of hydrological processes, commonly precipitation inputs and stream discharge outputs.

In order to account for the natural heterogeneity within watersheds as well as anthropogenic activities, hydrologic simulation models are often employed as watershed management tools. Simulation models have proven useful for planning managers as a form of decision support for evaluating urbanized watersheds. While conservation efforts have often focused on maximizing the quantity of land conserved, research efforts in landscape ecology have shown that the spatial pattern of land conversion can have a significant effect on the function of ecological processes, particularly when examining watershed networks. Recently, many research efforts have been launched to predict the hydrologic response of varying scenarios of land use modification through the development and application of multiple models

(Im *et al.* 2009). Current models vary tremendously in their degree of complexity and can range from statistical simulations, such as a regression analysis or the Spatially Referenced Regressions on Watershed Attributes (SPARROW; Schwarz *et al.* 2006) model, to more process-based models, such as the Soil and Water Assessment Tool (SWAT; Neitsch *et al.* 2005*a*) or the Hydrologic Simulation Program Fortran (HSPF; U.S. EPA 1997). In data poor basins, a promising way to include land use change is by integrating Remote Sensing and semi-distributed rainfall-runoff models. Therefore in this study SWAT model was selected because it applies semi-distributed model domain.

14.3 Description of the Study Area

From its source in the Eastern Arc Mountain ranges of Tanzania, the Wami River flows in a south-eastwardly direction from dense forests, across fertile agricultural plains and through grassland savannahs along its course to the Indian Ocean. Located between 5°–7°S and 36°–39°E, the Wami River Sub-Basin extends from the semi-arid Dodoma region to the humid inland swamps in the Morogoro region to Saadani Village in the coastal Bagamoyo district. It encompasses an area of approximately 43,000 km^2 and spans an altitudinal gradient of approximately 2260 meters (Figure 14.1). According to a 2002 census, the sub-basin is home to 1.8 million people in 12 districts: Kondoa, Dodoma-urban, Bahi, Chamwino, Kongwa, Mpwapwa, (Dodoma Region) Kiteto, Simanjiro (Manyara Region), Mvomero, Kilosa (Morogoro Region), Handeni, Kilindi, (Tanga Region) and Bagamoyo (Coast Region). It also comprises one of the world's most important hotspots of biological diversity: the Eastern Arc Mountains and coastal forests (WRBWO, 2008a).

Average annual rainfall across the Wami sub-basin is estimated to be 550–750 mm in the highlands near Dodoma, 900–1000 mm in the middle areas near Dakawa and 900–1000 mm at the river's estuary. Most areas of the Wami sub-basin experience marked differences in rainfall between wet and dry seasons. Although there is some inter-annual variation in timing of rainfall, dry periods typically occur from July to October and wet periods from November to December (*vuli* rains) and from March to June (*masika* rains) (WRBWO, 2007b). The river network in the Wami sub-basin drains mainly the arid tract of Dodoma, the central mountains of Rubeho and Nguu and the northern Nguru Mountains. The Wami sub-basin river network (WRBWO, 2008a) comprises the main Wami River and its five major tributaries—Lukigura, Diwale, Tami, Mvumi/Kisangata and Mkata (Figure 14.2). The Mkata tributary is the largest and includes two major sub tributaries, the Miyombo and the large Mkondoa. The Mkondoa River includes the major Kinyasungwe tributary with the Great and Little Kinyasungwe draining the dry upper catchments in Dodoma.

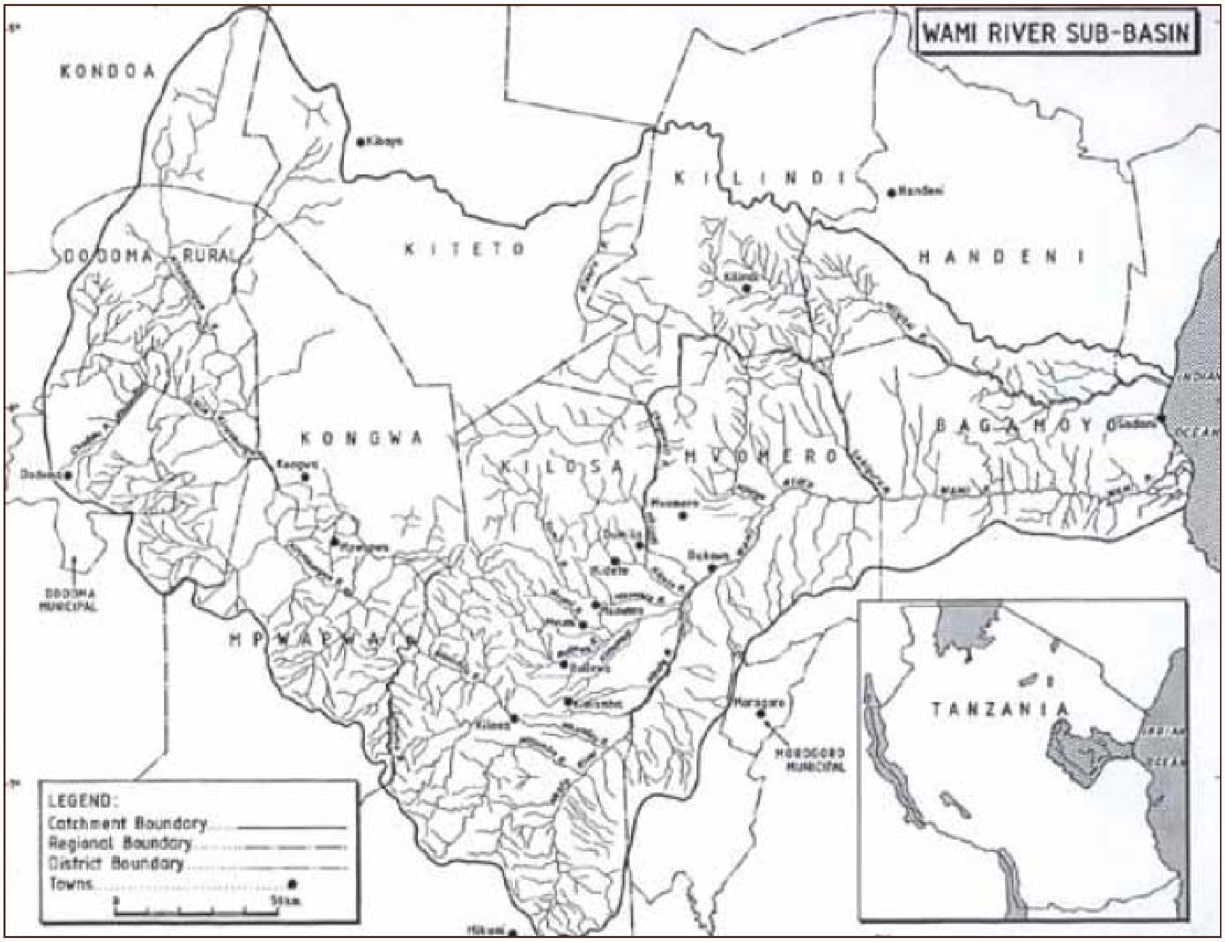


Figure 14.1 Wami Sub-basin (Source: WRBWO, 2007a)

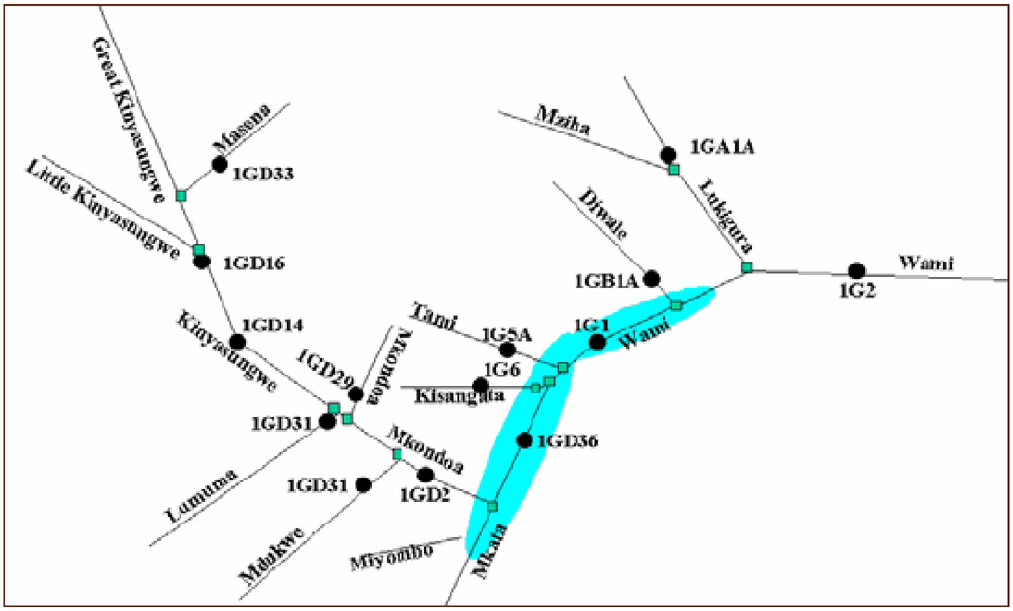


Figure 14.2 Schematic representation of the river network (Source: WRBWO, 2007d)

14.4 Methodology

14.4.1 SWAT model

The Soil and Water Assessment Tool (SWAT) is a basin-scale model that operates on a daily time step to predict the impact of land use and management practices on water quality within complex catchments (Arnold and Fohrer, 2005). Originally developed by Dr. Jeff Arnold for the USDA Agricultural Research Service, SWAT was chosen for this study for its focus on modeling the hydrological impacts of land use change, while specifically accounting for the interactions between regional soil, land use and slope characteristics (Arnold *et al.* 1998).

In SWAT, watersheds are delineated into sub-basins, which are further divided into hydrologic response units (HRUs), each of which represents a unique combination of land use, management and soil characteristics. Sub-basins are calculated based on topographical data and both temperature and precipitation values are considered homogeneous within a sub-basin. HRUs are calculated as the area within each sub-basin that reflect a unique combination of land cover, soil type and slope characteristics. It should be noted that HRUs are not synonymous to a field, but rather represent the total area in the sub-basin with a particular land use, soil and slope type. Runoff is calculated for each HRU and routed to the sub-basin level to obtain total watershed flows.

The data required to run SWAT was collected and included elevation, land use, soil, climatic data and stream flow information. After model set-up was completed, the simulation was run and calibration procedures were used to improve model accuracy. Next, a future land use scenario was created based on previous land use change for the area and the output from the future scenario was compared to the current baseline results, in order to assess the variance in stream flow.

14.4.2 Data preparation

Data is the crucial input for the model in hydrological modelling. Data preparation, analysis and formatting to suit the required model input is important and has influences on the model output. The relevant time series data used for this study included daily rainfall data, stream flows, temperature (minimum and maximum), relative humidity, wind speed and solar radiation. Data was collected from the University of Dar es Salaam (UDSM), Water Resources Engineering Department (WRED) data base, Ministry of Water at Ubungo, Wami Ruvu Basin office at Morogoro and Tanzania Meteorological Authority office (TMA). These data records differ in length from the starting and ending dates (Table 14.1). The selection of the time series data was on basis of availability and quality of data.

Table 14.1: Rainfall data used

S/N	NAME	Start Year	End Year	Length of years	Elevation (a.m.s.l)	%Missing
1	9635001	1/1/1932	31/12/1995	64	1120	26.05
2	9536004	1/1/1962	31/12/1991	30	1524	11.00
3	9636029	1/1/1972	31/12/1990	19	914	8.02
4	9635012	1/1/1961	31/12/1990	30	1133	18.03
5	9636008	1/1/1947	31/12/1995	49	1067	27.03
6	9636018	1/1/1956	31/12/1995	40	1676	34.03

7	9635014	1/1/1962	31/12/1995	34	1067	20.07
8	9636013	1/1/1953	31/12/1995	43	914	41.10
9	9736006	1/1/1960	31/12/1989	30	1783	10.17
10	9636027	1/1/1970	31/12/1993	24	1880	12.53
11	9636026	1/1/1970	31/12/1989	20	1786	15.57
12	9536000	1/1/1925	31/12/1961	37	1037	21.97
13	9537009	1/1/1976	31/12/1994	19	1150	52.12

The climatic data used for the study included daily (maximum and minimum) temperature, daily relative humidity, solar radiation and wind speed. Flow data at the outlet of sub-basin (1G2) was used for calibration purpose. Table 14.2 shows the climatic data and flow data used for this study.

Spatial data used included land use data from 30m Landsat TM Satellite, Digital Elevation Model (DEM) with 90-m resolution and Soil data from Soil and Terrain Database for Southern Africa (SOTERSAF).

Table 14.2: Climatic and flow data

STATION CODE	VARIABLES	Start year	End year	Number of years
9635001	Relative humidity	1974	1984	10
	Wind speed	1974	1984	10
	Solar radiation	1974	1984	10
	Max and Min temperature	1974	1984	10
1G2	Flow	1974	1984	10

14.4.3 Model set-up

14.4.3.1 Watershed delineation

The watershed delineation interface in ArcView (AVSWAT) is separated into five sections including DEM Set Up, Stream Definition, Outlet and Inlet Definition, Watershed Outlet(s) Selection and

Definition and Calculation of Sub-basin parameters. In order to delineate the networks sub-basins, a critical threshold value is required to define the minimum drainage area required to form the origin of a stream.

After the initial sub-basin delineation, the generated stream network can be edited and refined by the inclusion of additional sub-basin inlet or outlets. Adding an outlet at the location of established monitoring stations is useful for the comparison of flow concentrations between the predicted and observed data. Therefore, one sub-basin outlet was manually edited into the watershed based on known stream gauge location that had sufficient stream flow data available from 1974-1984. The delineated catchment is shown in Figure 14.3.

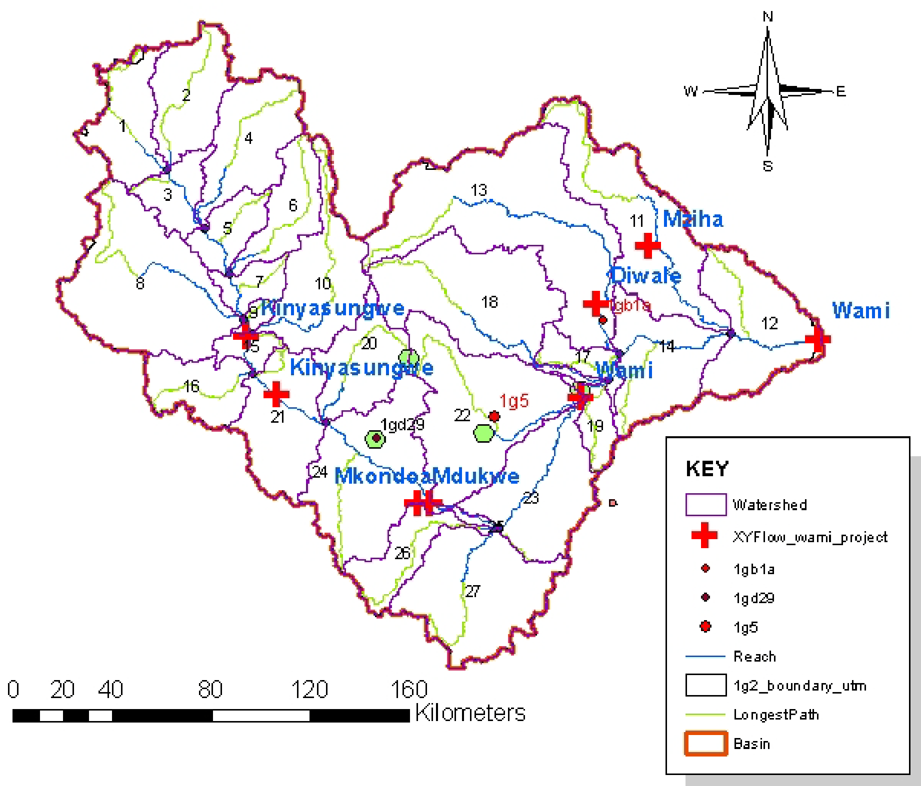


Figure 14.3 Delineated Wami catchment

14.4.3.2 HRU definition

The SWAT (ArcView version) model requires the creation of Hydrologic Response Units (HRUs), which are the unique combinations of land use and soil type within each sub-basin. The land use and soil classifications for the model are slightly different than those used in many readily available datasets and therefore the land-use and soil data were reclassified into SWAT land use and soil classes prior to running the simulation.

14.4.4 Land use change analysis

Land use/cover classification was derived from Landsat satellite images of two different years 1987 and 2000. Supervised classification using ERDAS Imagine software was used and the final classification resulted into four land cover classes namely forest, agriculture, water bodies, and urban areas. The procedure used for the classification of the satellite images and the classified maps are shown in Figures 14.4 & 14.5, respectively. These images were verified by using the existing landuse/ landcover map of 1995 which was prepared by Institute of Resource Assessment (IRA) through ground truthing.

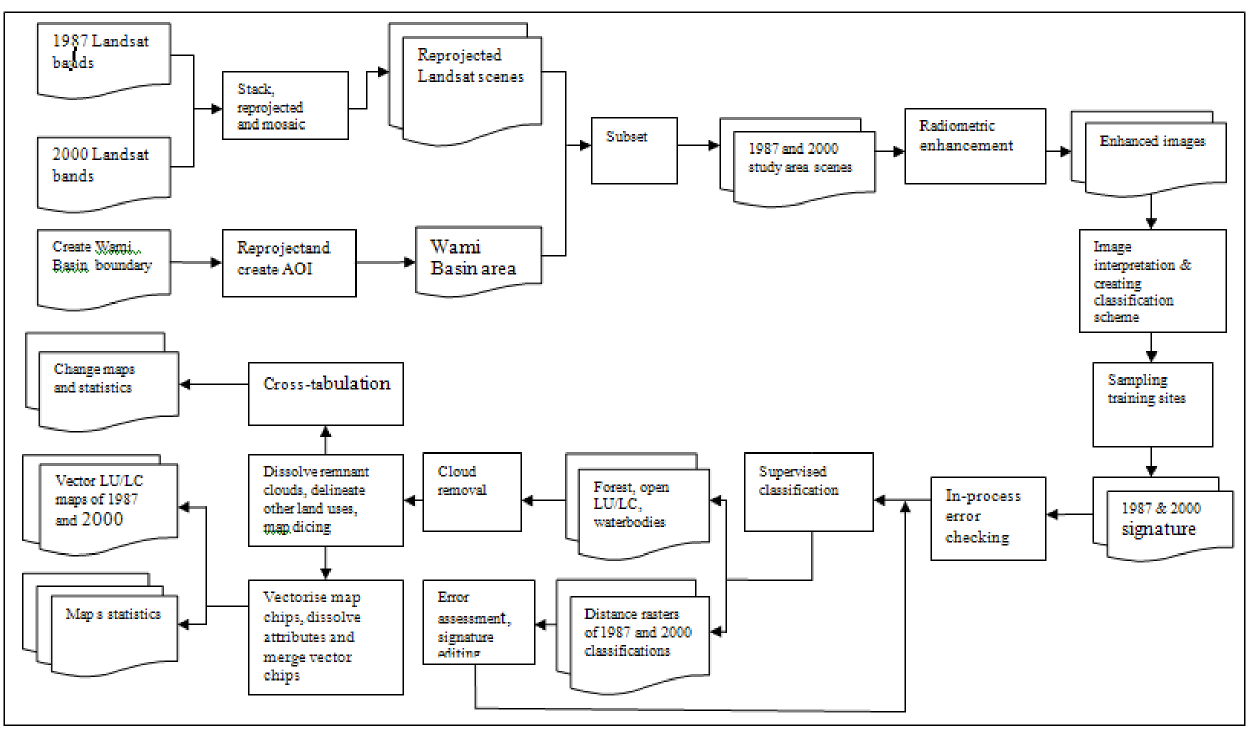


Figure 14.4 Flowchart for the classification of the satellite images

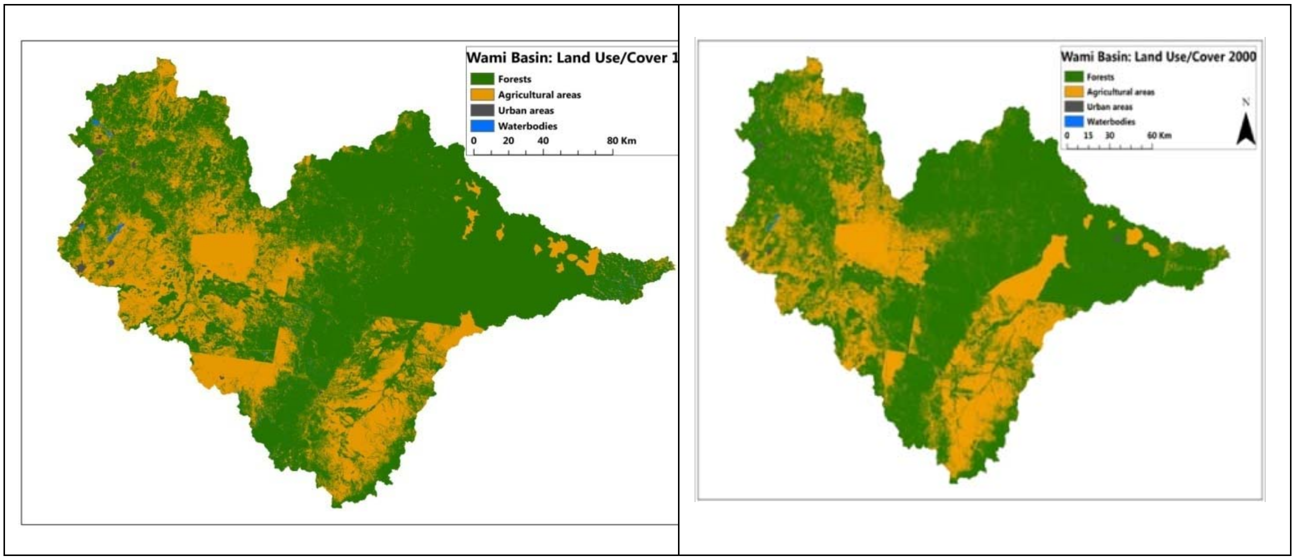


Figure 5 Landuse/landcover classifications for the year 1987 and 2000

14.4.5 Calibration/Sensitivity analysis

The time series of discharge at the outlet of the catchment (1G2) was used as data for calibration and validation for SWAT model, the model was calibrated using the measurements from 1974 to 1980 and first the sensitive parameters which govern the watershed were obtained and ranked according to their sensitivity. The parameters were optimized first using auto calibration tool then calibration was done by adjusting parameters until the simulated and observed value showed good agreement.

14.4.6 Analysis of impact of land-use/cover change on stream flows

Three scenarios were used for the analysis of impact of land use/cover change on stream flows. In the first scenario the land use/cover for 1995 was used for calibration and validation of the model. In the second and third scenarios land use maps for the year 1987 and 2000, respectively, were used to simulate the impact of land-use change on stream flows. Hydrological characteristics that were studied and compared were surface runoff and ground water (base flow) components.

14.5 Results and Discussions

14.5.1 Land use/cover change analysis

The results for land use/cover change analysis (Table 14.3 & Figure 14.6) shows that between 1987 and 2000 there was increase of 3.17% in agricultural land, 1.36% decrease of forest, 0.48% decrease of water bodies, and 2.23% increase in urban areas. The area change between 1987 and 2000 shows a decrease of forest area and an increase in agricultural area. The decrease in forest area and increase of agriculture are interdependent in Wami basin. The activities which caused forest decrease in the basin include the increase in farmland in order to ensure food security and hence clearing of trees for farm preparation, expanding settlements to meet population growth and other activities including cutting the forest for timber, construction materials and charcoal. In some areas of Wami, wetlands have changed into agricultural areas for rice and maize.

Table 14.3 Land use change summary

Land cover	Land Cover Area (km^2)			Area change (km^2)		Percentage Area Change (%)
	Year 1987	**Year 1995**	**Year 2000**	**1987_1995**	**1987_2000**	**1987_2000**
Agricultural area	16527.58	16815.33	16916.68	287.75	389.12	3.17
Forest area	19092.57	18799.33	18655.62	-293.25	-459.77	-1.36
Water Bodies	1020.23	1019.01	994.91	-1.22	-2.53	- 0.48
Urban Area	3359.62	3366.33	3432.79	6.72	73.18	2.23
Total	40000	40000	40000	0	0	

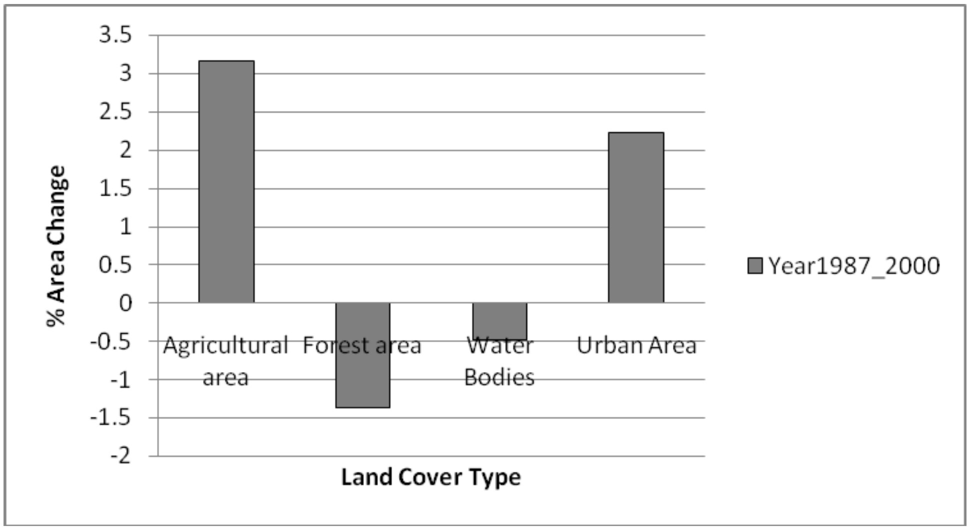


Figure 14.6 Percentage of land use/cover change between 1987 and 2000

14.5.2 Model calibration

The model was first calibrated for water balance and stream flow for average annual condition. Long-term simulation period from 1974 to 1981 was chosen to simulate the water balance for 1G2 which is considered the catchment outlet. The calibration results for the water balance for both surface and base flow components are shown in Table 14.4. Calibration and verification was performed for the periods from 1977 to 1980 and 1975 to 1976, respectively. Nash and Sutcliff efficiency criteria (NS), and the Index of Volumetric Fit (IVF) functions were used to test the model performance. The Nash and Sutcliff coefficient after calibration was 52.2% and Index of Volumetric Fit (IVF) was 99%.

Table 14.4 Long Term Water Balance Simulation Results

	Total water yield (mm)	Base flow (mm)	Surface flow (mm)
Actual	169.5	107.2	62.2
SWAT	165.4	102.7	62.6

The Simulated hydrograph (Figure 14.7) shows the trend between observed and simulated flow during calibration, it can be observed that low flows are well simulated in most periods than high flows in other periods.

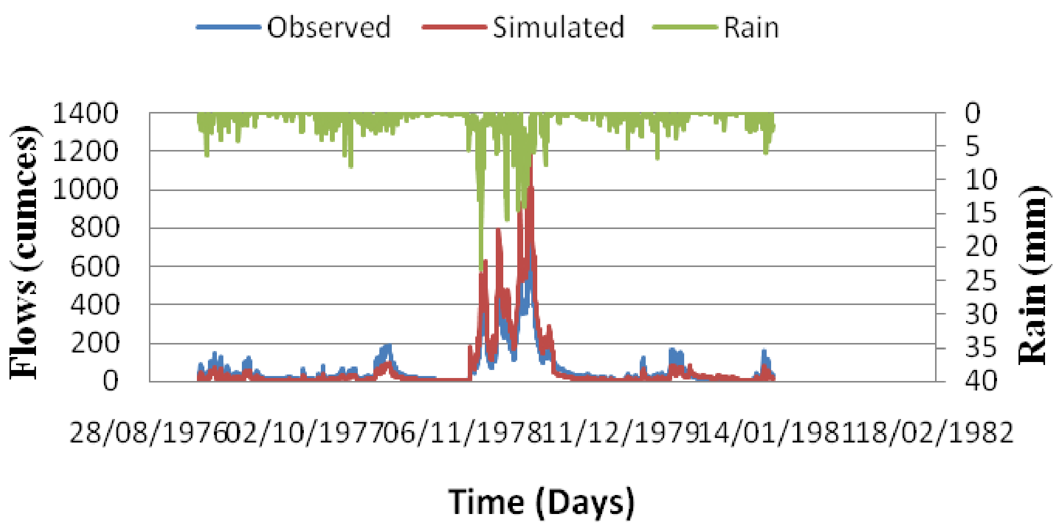


Figure 14.7 Calibration Results at the subbasin outlet 1G2 for the year 1995

14.5.3 Land use/cover change impact on stream flows

From the simulated hydrographs (Figures 14.8 & 14.9) it can be observed that the change in land use between the years 1987 and 2000 caused an increase in the peak flow because of the land cover change mainly from forest to agriculture and urban areas. Analyzing peak flows for the simulated hydrograph, on 24th of April 1979, the peak flows were 1069.5 m^3/s, 1193.8 m^3/s and 1324.6m^3/s for the land use data of 1987, 1995 and 2000, respectively. This trend shows that there is an increase in magnitude of surface flow which is directly associated with the change in land use cover type. The change in land use has affected the ability of the soil to retain more water (infiltration capacity) during the rain prior to direct runoff.

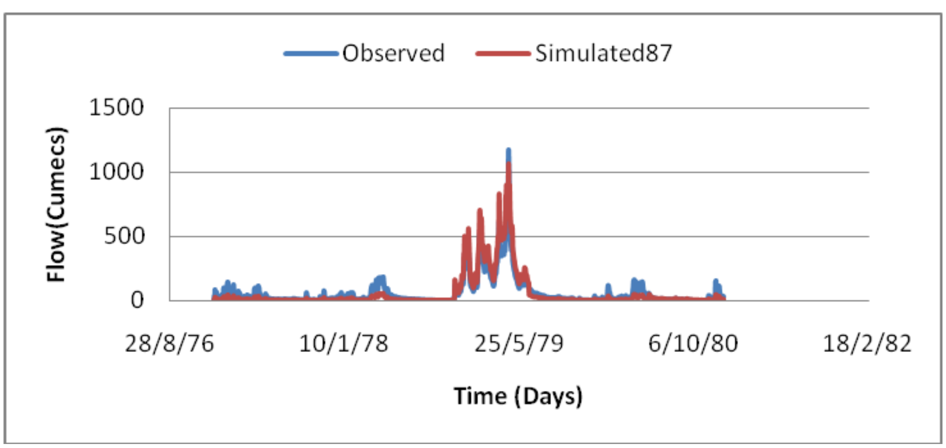


Figure 14.8 Scenario 2: Simulated Hydrograph (land use map 1987)

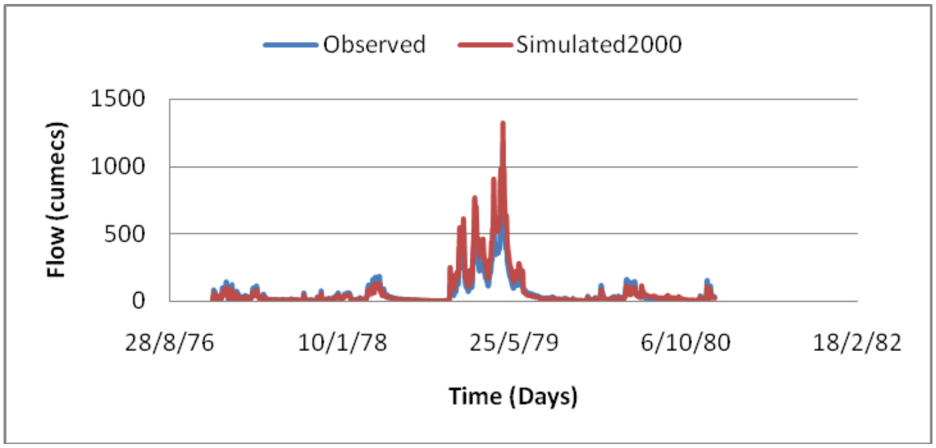


Figure 9 Scenario 3: Simulated Hydrograph (land use map 2000)

14.6 Conclusions

The study findings have revealed that the Land cover in Wami basin has changed significantly as a result of disturbances due to encroachment from farmers, fuel-wood collection and fires spreading from lowland areas. Degradation of the catchment has affected the flow characteristics in the basin as observed from increase in surface runoff and decreasing base-flow.

14.7 References

Arnold, J.G and N. Fohrer. 2005. SWAT2000: Current Capabilities and Research Opportunities in Applied Watershed Modeling. *Hydrological Processes* 19: 563 –572.

Arnold, J.G., R. Srinivasan, R.S. Muttioh, and J.R. Williams. 1998. Large Area Hydrologic Modeling and Assessment Part I: Model Development. *Journal of the American Water Resources Association* 34 (1): 73-89.

Costanza *et al*., 1997. The Value of the World's Ecosystem Services and National Capital. *Nature* 387: 253-260.

Doggart, N. and D. Loserian (eds.) 2007. South Nguru Mountains: A Description of the biophysical landscape. TFCG Technical Paper No 11. DSM Tz pp 1 – 71.

Im, Sangjun, Hyeonjun Kim, Chulgyum Kim and Cheolhee Jang. 2009. Assessing the Impacts of Land Use Changes on Watershed hydrology using MIKE SHE Environmental *Geology*. 57: 231-239. www.springer.com.

Meyer, Judy L., Michael J. Paul, and W. Keith Tulbee. 2005. Stream Ecosystem Function in Neitsch, S.L., J.G. Arnold, J.R. Kiniry and J.R. Williams. 2005*a*. *Soil and Water Assessment Tool Theoretical Documentation, Version 2005*. Blackland Research Center, USDA Agricultural Research Service. Temple, Texas 76502.

Schwarz, G.E., A.B. Hoos, R.B. Alexander and R.A. Smith. 2006. The SPARROW Surface Water-Quality Model: Theory, Application and User Documentation. Reston, Virginia: U.S. Geological Survey. http://pubs.usgs.gov/tm/2006/tm6b3/.

U.S. Environmental Protection Agency (U.S. EPA). 1997. Center for Exposure Assessment Modeling. The Hydrologic Simulation Program – FORTRAN (HSPF). http://www.epa.gov/ceampubl/swater/hspf/.

Wami/Ruvu Basin Water Office (WRBWO). 2007a. Environmental Flow Assessment (EFA),

Wami River Sub-Basin, Tanzania: Socio-economic component of the Wami River EFA Study. Literature Review for BBM Workshop. 2007. Wami/Ruvu Basin Water Office, Morogoro.

Wami/Ruvu Basin Water Office (WRBWO). 2007b. A Rapid Ecological Assessment of the Wami River Estuary, Tanzania. Prepared by Anderson, E.P. and McNally, C. Global Water for Sustainability Program, Florida International University.

Wami/Ruvu Basin Water Office (WRBWO). 2007d. Environmental Flow Assessment (EFA), Wami River Sub-Basin, Tanzania: The Wami Hydrology. Volume 1 – General Description. Prepared by Valimba, P. Wami/Ruvu Basin Water Office, Morogoro.

Wami/Ruvu Basin Water Office (WRBWO). 2008a. Business Plan. Wami/Ruvu Basin Water Office, Morogoro.

15 Implementing Environmental Flows in Kenya: A Case Study of Mara River Basin

Nyangena John,

Kenyatta University
P.O Box 43844 Nairobi

jmnyangena@yahoo.com

15.1 Abstract

The Mara River is a trans-boundary ecosystem between Kenya and Tanzania. It is located in a large and diverse catchment area with varying land uses. The headwaters comprise a protected forest which is undergoing rapid encroachment; small-scale subsistence agriculture is predominant in the upper reaches; while large-scale irrigated wheat farming and the world-famous Mara Game Reserve are found near the confluence. Rising water use in support of these activities poses great challenges. In 2007, an Environmental Flow Assessment was conducted to determine the initial estimates of the minimum water necessary to maintain the river's ecological functions. The findings triggered a public debate on how environmental flow could be implemented in the context of existing policy, legal and institutional frameworks. This paper explores the recognition of environmental water needs in relevant policies and identifies obstacles in implementing them in the Mara river basin. Study data was collected in a fieldwork undertaken in November, 2010 using a semi-structured questionnaire, observation, Focus Group Discussions and Key Informant Interviews, while secondary data was obtained through review of pertinent literature. According to the study, the Water Act adopts the term water reserve for environmental flow and defines it as the water needed to satisfy basic human needs for all people who are or may be supplied from the water resource, and protect aquatic ecosystems in order to secure ecologically sustainable development and use of the water resource. The National Water Strategy accords the reserve priority over all water uses and calls for its requirement to be met before water can be allocated for other uses. In circumstances where water is already allocated, the reserve may be met progressively over time using three main strategies; Market-based (water pricing- using user pays principle), Effluent charges (based on polluter pays principle), and Incentives (adjusted tariffs for water users adopting catchment measures). Institutions to supervise eflows implementation have been established at national, regional and basin level although there are challenges on collaboration at the three tiers. Additionally, five main factors were found to constrain eflows management in the Mara basin; Catchment degradation, Land use changes, Lack of a Water Allocation Plan, Resistance in re-allocating water to the environment from current users and low capacities of Water Resource Users Associations. It is recommended that a water allocation plan for the basin be developed to guide water allocation and an improvement on the collaboration of the various institutions in water resources management.

Key Words: *Mara, environment flow, environmental flow assessment, Reserve, Water Allocation Plan*

15.2 Introduction

Fresh water ecosystems provide vital goods and services that support development and livelihoods. These services are particularly important among the rural poor who disproportionately depend on agriculture for survival. Yet, these ecosystems are increasingly under threat (MEA, 2005). In the past century, global human population has quadrupled, land under irrigation increased six fold while withdrawals from freshwater water sources increased eightfold (Gleick, 2006; Richeter *et al.*, 2006). Concomitantly, water use conflicts driven by rapidly growing population are becoming prevalent (Gleick *et al.*, 2004; Poff *et al.*, 2003).

Kenya is already categorized as water scarce with fresh water per capita of 647 cubic meters and this is projected to fall to a paltry 235 cubic meters by 2025 (Kenya, Republic of 2008). Declining water availability is driven by several factors such as climate change and variability, population growth, competing water demand and pollution. Meeting the growing water demand while allowing adequate water for freshwater ecosystems to enable them continue providing essential services is a major challenge of the 21st century. As the demand for water rises, the need to balance water needs for social, economic and environmental needs is becoming urgent. The task for water managers and policy makers is thus to allow environmental water needs that balance demand and visions (Poff *et al.,* 2003).

Environmental flow (eflow) refers to the quality, quantity, and timing of water flows required to maintain the components, functions, processes and resilience of aquatic ecosystems which provide goods and services to people (Nature Conservancy, 2006). Globally, there is a growing recognition of goods and services obtained from the river ecosystem and rising threats from human development and climate change (Richer, 2003; Postel and Richer 2003; Reid *et al*., 2005; Arthington *et al.,* 2006; Dudgeon *et al.,* 2006). Reduced river flow impacts directly on the health and habitats of aquatic species. The natural flow variable is vital to aquatic ecosystem functioning; for example, flood flows trigger and enable spawning and migration patterns of fish and other aquatic animals and provide water to fill wetlands and flood plains. On the other hand, natural low flows are vital in sustaining crucial aquatic ecosystem life cycles. Thus, human modifications of the variations of river flow regimes often interfere with these key ecological processes. Despite government efforts, many rivers in Kenya are increasingly becoming seasonal, with some drying up completely during dry season leading to frequent and alarming water scarcity (Kenya, Republic of, 2009*).*

Determination of environmental flows is a highly scientific process guided by well defined tools. Several methodologies exist for eflow assessment (Thame, 2003; Dyson *et al*., 2003), with each having its own merits and demerits. In the Mara River, the assessment was based on the building block methodology with the objective of initial estimates of the reserve. The findings show that during maintenance years, majority of water available for abstraction is concentrated in a few months when flows are high. Far less water is available during the dry season period. During the drought years, a different scenario unfolds whereby the reserve is not met during several months of the year pointing to the possibilities of a process of alteration of the Mara river flow regime (LVBC& WWF-ESARPO, 2010). Taking into account the rapidly changing water demand in the basin coupled with climate change effects, implementing eflow in the Mara requires major shifts in the manner in which water is governed today and in the future. In countries where the eflow concept has been embraced for a longer period, experience show that procedures for implementation have been less well described and eflow implementation has been as challenging as determining them.

To address water use concerns in Kenya, the government, in 1992 embarked on a reform agenda which culminated in the development of a National Water Master Plan (NWMP). The plan proposed a national framework for orderly planning and development of water resources and recommended the formulation of a national water policy (Kenya, Republic of, 1992). Several policy instruments have since been developed and implemented aimed at achieving the water balance at the country's six catchments. Policies are critical in determining water allocation to the competing needs through application of diverse instruments. Three mechanisms for implementing environmental flows are identified namely: r*ule-based* which gives prior right to environment before water can be allocated to other consumptive uses, *market-based* entails purchasing access licenses and putting that water to the environment and *efficiency gains*-achieved by curbing losses arising from poor infrastructure and using the gains for environmental outcomes (Swainson *et al*., 2011). These mechanisms suggest a pivotal role of policies in eflow implementation. Since 1992, Kenya has pursued water sector reforms with an objective to establish a national framework for orderly planning and development of water resources in the country culminating in the development of several policy instruments of water resource management. However, limited work has been done to assess how the new policy regime has incorporated eflow and how this has actually been instituted at the basin level. The purpose of this paper therefore is to fill this gap by using data obtained from the Mara river basin.

15.3 Analytical framework

Securing eflow can be achieved through a number of factors defined within the water governance regime. These factors fall into three categories:- policies and laws, organizations and managements. Anderson (1997) defines public policy as a purposive course of action followed by government in dealing with some problem or matter of concern while Searle (2005) defines policies as positions taken and communicated by governments- 'avowal of intent' that recognize a problem and in general terms state what will be done about it. They define principles, actors and processes which are enforced through the law. Laws can broadly encompass both codified or written laws and unwritten laws. They lay a structure through which obligations are laid down, with rights which can be enforced and protected. Only codified laws on water resource management are considered in this study.

Institutions are predictable arrangements meant to undertake processes or customs serving to structure political, social, cultural and economic transactions and relations in a society. These need to be coordinated with a definite mandate, long- term strategy, and a clear organizational structure. In this paper, institutions analysed are those established by the water legislation. Management is 'on-ground' practical actions needed in translating policies into tangible physical outcomes. Policies set overall direction at the higher level while management takes action at local level toward achieving that direction.

Factors influencing eflow implementation can therefore be analysed across the three tiers of policy, institutions and managements and include aspects like recognition in policies, institutional mandates and coordination, allocating water, monitoring water resource, enforcing user rights, protecting ecology and water user participation. These factors are closely related to those used in a framework for analysing basin management regimes as discussed by Svendsen (2005). Figure 15.1 presents a framework used to investigate the factors influencing water allocation.

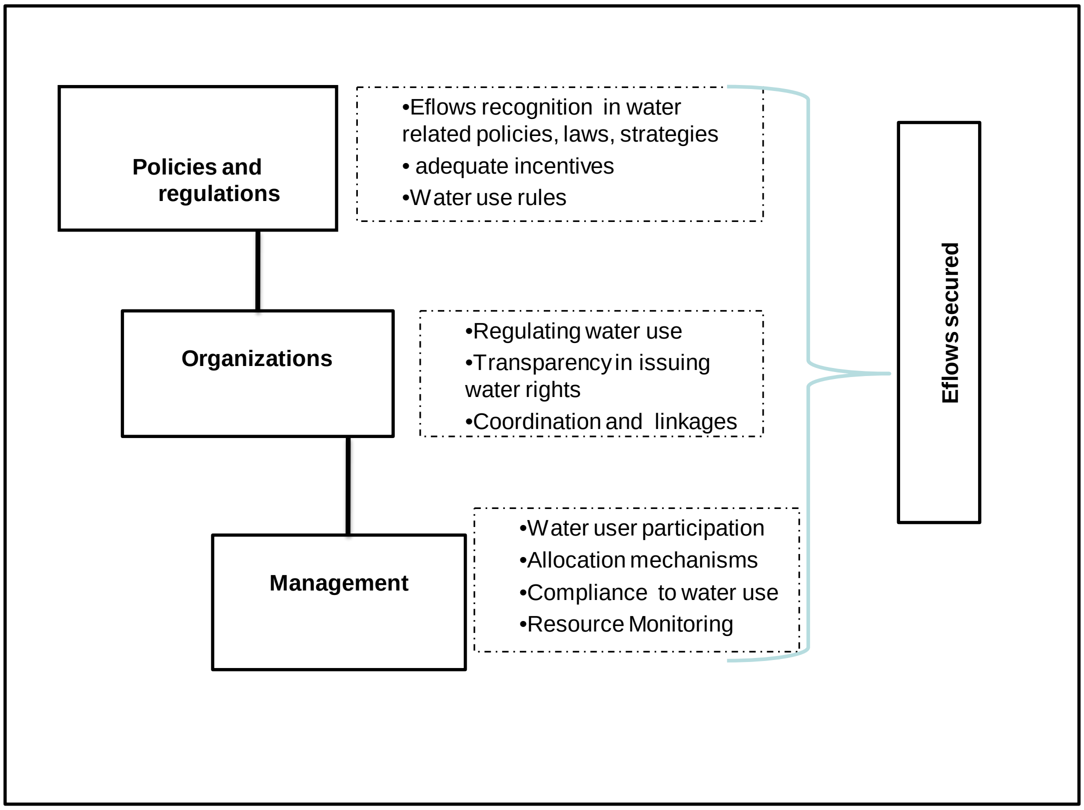


Figure 15.1: Framework for eflow implementation (Source: Author, 2011)

At the policy level, eflow implementation is determined by the extent to which water allocation to the environment is provided for in relevant laws. This is important in determining how the government prioritizes water allocation within growing demand and increased conflict between alternative uses.

Institutions are formal and informal mechanisms that define and shape social and individual expectations, interactions and behaviors (Ostrom, 1990). They are conduits through which policies and legislations are translated into actions at the local level. The Water Act creates water resource institutions at national, regional and local levels. Following the conclusion of the water reforms, at national level, the policy and legislation functions are assigned to the Ministry of Water and Irrigation (MWI) while the functions of planning, management, protection and conservation of water resources are the responsibilities of Water Resources Management Authority (WRMA). WRMA is also charged with issuance of water permits, enforcement of permit conditions, regulation of conservation and abstraction structures, catchment and water quality management, regulation and control of water use and coordination of the Integrated Water Resource Management Plan. These functions are devolved to six catchments created along the drainage patterns where WRMA operates with the Catchment Area Advisory Committees (CAACs) in the respective catchments. CAACs are responsible for advising WRMA on water allocation at the catchment, development of catchment management strategies and plans, conflict management and facilitation of development of Water Resources Users Association (WRUAs) at local level. WRUAs, therefore represent the lowest operational unit in water resource management and are charged with registration of water users, collaboration in water allocation and catchment management, monitoring and information sharing and cooperative management of water resources (MWI, 2007).

Eflow management is executed through the WRUAs comprised of water users at basin level. Eflows are implemented at local level and successful implementation is determined by the measures instituted by local institutions. There are a number of factors determining appropriateness of institutions in allocating water for the environment. These include local appreciation and consultations in forming them and agreed upon goals that integrate local environmental, economic, social and cultural outcomes from the river; and sufficient capacity (Swainson *et al.*, 2011).

15.4 Materials and Methods

15.4.1 Methodology

This study adopted a descriptive case study approach as described by Yin (1994) in understanding the role of policy in implementing eflows in the study area. Purposive sampling technique was employed to select the basin because it is the only one in Kenya where environmental flow assessment (EFA) has been carried out. The study was undertaken three years after the EFA and therefore there has not been sufficient time to fully institute a water allocation in the basin.

15.4.2 Study area

This study was carried out in Mara River Basin with the aim of understanding the extent to which eflows are operationalized. The basin is located roughly between longitudes 33° 47’ E and 35 ° 47’ E and latitudes 0 ° 28’ S and 1 ° 52’ S. Mara River originates from the Napuiyapui swamp in the Mau Escarpment (2932 m above sea level) and covers approximately 13,750 km^2 shared between Kenya and Tanzania, with the former hosting 65% of the basin. Kenya also holds a greater responsibility in determining the future of this basin, as the basin's headwaters primarily stem from Kenya's Mau Escarpment and Loita Hills.

The main perennial tributaries of the Mara River are the Amala and the Nyangores rivers, which drain from the western Mau Escarpment. Other tributaries include the Talek, which originates from the Loita plains and joins the Mara in the Masai Mara Game National Reserve (MMNR), the Engare Ngiro, originating from the Ilmotyookoit ridges, and the Sand River, which is the last main tributary, joining the Mara at the Kenya-Tanzanian Border in the Serengeti plains. The Mara then flows through Tanzania and into the Mara Swamp, finally draining through the Mara Bay into Lake Victoria at Musoma, Tanzania. As it flows downstream the river plays vital roles- supporting the largest wildebeest migration in the world, fisheries, and water to over a million people.

Rainfall varies with altitude in the basin. Mean annual rainfall ranges between 1,000-1,750 mm in the Mau Escarpment, 900-1,000 mm in the middle rangelands, and 700-850 mm in the lower Loita hills and around Musoma. Rainfall seasons are bi-modal, falling between April and September, and again between November and December.

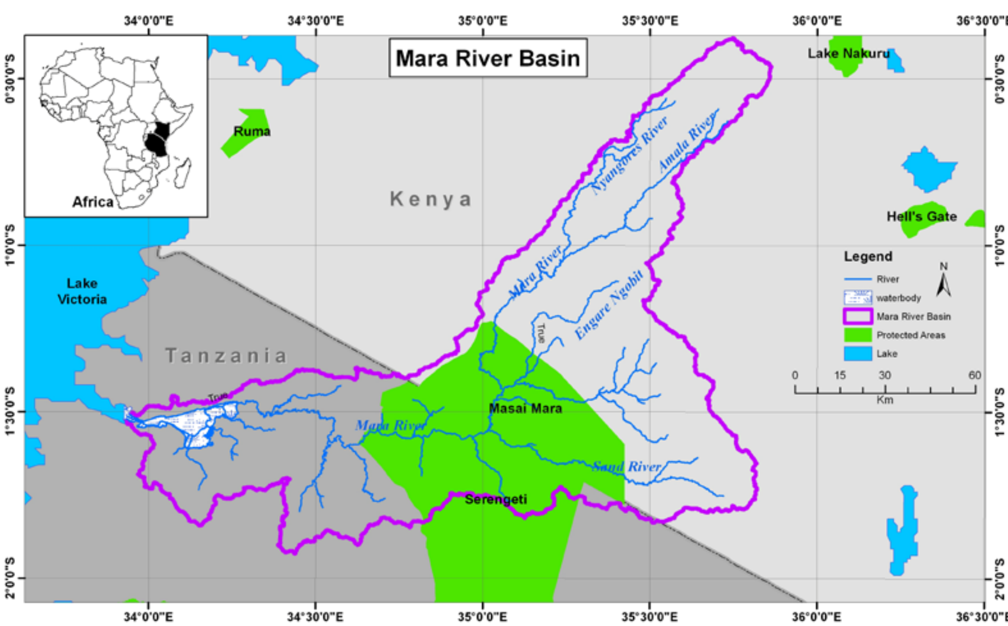


Figure 15.2: Location of Mara River Basin (Source: Author, 2011)

Mara River is functionally and ecologically related to the socio-economic activities in Lake Victoria and along the River Nile. The main challenges in the basin include high population growth rate, expansion of agricultural lands, decrease in forest cover and increasing abstraction for irrigation, industry and tourism. EFA was conducted in the Kenyan side on three sites along Nyangores and Amala rivers and at the boundary with Tanzania.

15.4.3 Data collection

Secondary data was obtained through review of relevant literature at national and basin level. The review was guided by the analytical framework and was based on relevant government policy documents and technical reports. The Primary data was obtained through observation and focus group discussions held during field work in the month of November, 2010. Interviews were conducted for twenty four Key informants comprising of MWI (1), WRMA (3), Civil Society (7), Lake Victoria South CAAC (4) and WRUA executive committee members (9). The key informants were selected based on their knowledge and experience in water resource management in the basin. Separate interviews for each category of informants were conducted and information was obtained using semi-structured questionnaires. Information gathered included extent of institutional capacity and linkages, community participation in water resource management, data collection, water allocation mechanism and compliance and enforcement of water permits. Observations were made on the Talek river to assess the effectiveness of community initiatives to protect eflows.

Data analysis involved coding guided by the factors identified in the analytical framework. Common factors were categorized and assessed against those identified in the framework. This enabled the researcher to make own opinion on the gap between various provisions in the policy documents and management at the study site.

15.5 Results and Discussions

15.5.1 Policy and legal aspects for eflows

Increasing water demand conflicts coupled with climate change effects are the main threats to eflows in Kenya. Eflows can best be achieved through a sound water governance system established through policies and legislations, institutions and management.

The Water Policy on Water Resources Management and Development was developed in 1999 and recognizes the adverse impacts of human activity on the water resources. The policy set broad guidelines to mitigate degradation of water resources in the country and proposed the enactment of appropriate water legislations. The Water Act was enacted in 2002 and outlines provisions to ensure access to safe water resources for all people, as well as sustaining the valuable ecosystems upon which people depend. The Act defines the water reserve as the water needed a) to satisfy basic human needs for all people who are or may be supplied from the water resource, and b) to protect aquatic ecosystems in order to secure ecologically sustainable development and use of the water resource. It contains important provisions for protecting the eflows such as declaration of protected areas and introduction of special measures to enable eflows and reallocation of water to ecosystems through variation of permits (Kenya, Republic of, 2002). The Water Resources Management (WRM) rules were enacted in 2007 to expound on the Act. The rules address issues of eflows pertaining to; Composition, Quantity computation/estimation, Channeling of complaints on violation, responses to complaints and display of public information regarding reserve water.

Other important instruments in water resource management are the strategy and the guidelines for water allocation. The water strategy was formulated to provide for the management, protection, use, development and conservation and control of water resources in Kenya. It accords the reserve priority over all water uses and calls for its requirement to be met before water can be allocated for other uses. In circumstances where water is already allocated, the reserve may be met progressively over time using three main strategies; Market-based (water pricing- using user pays principle), Effluent charges (based on polluter pays principle), and Incentives (adjusted tariffs for water users adopting catchment measures) (Kenya, Republic of, 2007). The guidelines for Water Allocation of 2010 spell out the finer details by which the requirements of eflow are taken into consideration and on how its provisions will be administered. The main elements of the guidelines include; water resource management underlying principles, inventory and information system on water balances, priority allocations and criteria for decision making, and methodology of quantification of the reserve water.

15.5.2 Institutional aspects

Both the policies and the Acts create a framework within which participatory sustainable management can be undertaken. Recent frameworks encourage community participation in water management. This is mainly through the Catchment Area Advisory Committees (CAACs) and Water Resource Users Associations (WRUAs). However, modalities for ensuring full operation of these institutions are still lacking. As far back as the 2nd year of operation of WRMA, it was noted that CAACs were not appreciated by WRMA and the Regional Offices were not accountable to CAACs.

WRMA head office oversees and coordinates water resource issues rather than regulating the regional offices and supporting them to enforce the rules. The public perception on WRMA is that it only collects water use charges without providing commensurate service. In the five years of its existence, WRMA has not shown tangible progress towards investing in water resources planning information.

Generally WRMA does not have any obligation to implement any advice emanating from CAAC; i.e., the Regional Office is not accountable to CAACs for the advice they receive. Weak mechanisms exist for close interaction between WRMA and WRUAs to enable WRUAs function effectively especially in circumstances where the use of water is not yet commercialized. Although WRUA development is viewed as the principal function of CAAC, they are constrained by WRMA's continued direct engagement in various basin activities.

The WRUA Development Cycle (WDC) gives guidelines for the formulation of WRUAs and also provides the criteria for assessing the level of maturing (Water Services Trust Fund, 2009). WRUAs are voluntary community groups registered with the Registrar of Societies as associations. The WDC envisages WRUAs to operate under a governance framework which promotes transparency and participation in water management. Assessed against the WDC criteria, the Mara WRUA is registered although its management committee shows that the members' participation in decision making processes is weak. The WRUA has low public presence and image, and lacks resources to undertake its activities.

15.5.3 Management aspects

The Mara River is not very large and continued increases in abstraction will greatly threaten its sustainability. From records, the river has never stopped flowing although it has come close to doing so during severe droughts. The river is unregulated and this presents immeasurable challenges in allocating water to the environment. This limits implementation to options as provided for in the Water Act. Yet, a number of obstacles need to be overcome. The Sub-catchment Management Plan (SCMP) and the water allocation plan are two vital instruments for implementing IWRM at the local level. The SCMP describes water resources management problems within the sub-catchment and priority activities to address them. In the study area, SCMPs have been developed for two sub-catchments; the Amala and Nyangores sub-catchment. Pending SCMPs are for the Main Mara, Talek and Sand River catchments.

The main water abstractors in Mara are large scale irrigators (which includes the expansive Olerai Farm), human populations (domestic use), and livestock. Attempts to allocate water to the environment have been met with great resistance from these users. This is compounded by the absence of incentives to encourage compliance in water use rights. Although provided for in the National Water Strategy, there are no mechanisms to design and implement appropriate incentives in the basin.

Further, the monitoring of flows in the basin is generally characterized by dilapidated infrastructure, lack of gauge readers and irregularity in data collection. These factors combined significantly compromise the quality of data necessary to undertake planning, implementing and monitoring of eflows.

The Mau forest forms the major catchment of the Mara River. The forest was encroached and severely degraded. This fact, coupled with other non-flow factors has compromised measures to implement eflows in the basin. There are however ongoing efforts to protect the forest within the Participatory Forest Management (PFM) initiatives. In line with the Forests Act (2005), three Community Forest Associations (CFAs) have been formed to operate in the three forest blocks of the Trans Mara forest block of the wider Mau forests complex. Already, the CFAs have been involved in practical forest management initiatives such as tree nursery establishment and tree planting. Management plans for the three forest blocks are almost complete. Once the Kenya Forest Service approves these plans, the CFAs can begin implementing the activities stipulated in the plan. It is anticipated that with the signing of the forest management agreements between the CFAs and KFS (after finalization of the management plan), co-management of forest resources between CFAs and KFS will officially begin. The plan will enable communities to improve their livelihoods while participating in forest management. The CFAs and WRUA in the upper catchment are also working together and have developed a joint work plan for activities aimed at managing the catchment focusing on both forest and water resources.

Unavailability of information on water abstraction constrains water use planning in the Mara. The main sources of information are estimates obtained from research documents which in many cases have great disparities. This information has recently been complemented with an abstraction survey undertaken by WRMA and the local WRUAs in 2009-2010. Regarding water permit data, informants reported many cases where permits do not exist, have expired or only have initial authorisation. This significantly underestimates abstraction levels in the basin and hinders development of a Water Allocation Plan.

Prior to the reforms, water was generally regarded as a public good without any value. As such water use was free. The notion has persisted and is responsible for low compliance to conditions on water permits. Additionally, WRMA lacks the capacity to enforce the water regulations at local level.

15.6 Conclusion

The Mara River currently has no major dams acting to significantly modify its flow regime. Thus, reserve flow prescriptions must be achieved by improving the management of the catchment, controlling permits for abstractions, and developing and implementing sustainable technologies for harvesting and storing wet season runoff for consumptive use during dry months. Because the Mara is a trans-boundary river, these efforts must be closely coordinated between responsible institutions in the two countries. The responsibility for implementing and enforcing environmental flows in the Mara River resides with the lead agencies in each country—Lake Victoria South Catchment Management Area of the Water Resources Management Authority in Kenya, and the Lake Victoria Basin Water Office of the Ministry of Water and Irrigation in Tanzania. However, local Water Resource Users' Associations may also play a critical role in grassroots monitoring and enforcement.

This paper has shown that eflow implementation is determined by three main factors. Sound policies and laws, well coordinated institutions and relevant basin level activities. An assessment of the water governance regime show sufficient recognition for eflow particularly in the Water Act, 2002 and in The National Water Resources Management Strategy (2007). The reserve water is accorded priority over other water uses and calls for various strategies to be used to ensure its protection. These include market-based approaches, technology based or mandatory mechanisms.

The process of allocating water for the environment in Kenya continues to receive scanty attention from policy makers and water resource managers. This is partly due to constrained understanding of the environmental water needs as compared to other economic needs (such as hydropower generation, food production and irrigation, industrial and urban water supply and flood and drought mitigation). The absence of a deliberate water allocation system to the aquatic environment through disruptions in volume, pattern and quality of flow can have severe ramifications to downstream ecosystems and communities. Eflows are linked to Kenya's national economy as the main economic sectors such as tourism and horticulture are highly dependent on eflow.

Monitoring of water resources in the Mara River is weak. There are no adequate hydrometric networks and most equipments are decrepit. At the same time, data is not gathered with regularity and is thus of poor quality for effective planning.

15.7 Recommendations

Implementing eflow in Mara river will require that water policies are translated into 'on-ground' actions supported by a flexible water allocation mechanism to allow for adjustments and reallocation in the water licenses. As a starting point, it is recommended that a SCMP and a water allocation plan for Mara basin be developed to guide water allocation. Meanwhile, precautionary measures should be introduced and these may include setting a ceiling on water abstraction to various sectors.

In tandem with policy implementation, there is need to improve on the collaboration of various institutions in water resource management. In particular, the relationship between WRUAs, WRMA and CAACs should be strengthened. This should entail strengthening the role of WRUAs to allow them supervise eflows including monitoring eflow breaches.

Investments are required to improve the quality data necessary for water resource planning. This means incorporating modern techniques such as installation of automatic gauges to replace the dilapidated hydrometric infrastructure.

15.8 References

Anderson ,J. 1997. *Public Policy Making,* 3rd ed: Hough Mifflin Co. Boston.

Arthington, A. H., Bunn, S. E., Poff L., Naiman R.J. 2006. *The challenges of providing environmental flow rules to sustain river ecosystems*. Ecological Application, 16(4), 1311-1318.

Dudgeon, D.; Arthington A.H.; Gessener M.O.; Kawabata.Z.;. Knowler. D.; Lévêque. C.; Naiman. R. J.; Prieur-Richard. A.H.; Soto, D and Stiassny, M.L. J. 2006. Freshwater Biodiversity: Importance, threats, status, and conservation challenges. Biological Reviews 81(2): 163-182.

Dyson, M.; Bergkamp, G. and Scanion ,J. 2003. *Flow: The essentials of environmental flow.* Gland, Switzerland: The World Conservation Union –IUCN.

Gleick, P.H., Cooley, H.; Katz.D. 2006. The World's Waters 2006-2007: the biennial report of freshwater resources. Island Press. Washington D.C., USA.

Gleick, P.H.; Cain. N.L.; Haasz, D.; Henges-Jeck ,C.; Hunt, C.; Kiparsky, M.; Moench, M.; Palaniappan, M.; Srinivasan, V, and Woff. G.20004. The World's Waters 2004-2005: the biennial report of freshwater resources. Island Press. Washington D.C., USA.

Kenya, Republic of. 1992. The Study on the National Water Master Plan, Ministry of Water and Irrigation.

Kenya, Republic of. 1999. Sessional Paper No. 1 of 1999 on National Policy on Water Resources Management and Development, Ministry of Water and Irrigation.

Kenya, Republic of. 2002. The Water Act (No. 8 of. 2002), Ministry of Water and Irrigation.

Kenya, Republic of. 2007: The Water resources Management Rules 2007. Ministry of Water and Irrigation.

Kenya, Republic of. 2008. Study on Harmonisation of Institutional Mandates and Legislation Related to Water Resources Management in Kenya. Ministry of Water and Irrigation.

Kenya, Republic of. 2009. Water Sector Strategic Plan 2009 – 2014. Ministry of Water and Irrigation.

Kenya, Republic of. 2010. Guidelines for water Allocation. Water Resources Management Authority.

LVBC and WWF-ESARPO. 2010. Assessing the Reserve Flows for the Mara River. Lake Victoria Basin Commission and World Wide Fund for Nature, Eastern and Southern Africa Regional Office, Kisumu and Nairobi.

Millennium Ecosystem Assessment. 2005. Ecosystems and human wellbeing: Biodiversity Synthesis, World Resource Institute, Washington, DC.

Ministry of Water and Irrigation. 2007. The National Water Resources Management Strategy (NWRMS) 2007-2009 1st Ed.

Nature Conservancy. 2006. Environmental Flows: Water for People, water for nature: TNC.MRCS01730. Boulder, CO. Nature Conservancy.

Ostrom, E. 1990. Governing the Commons: The Evolution of Institutions for collective action. Cambridge University Press. Cambridge.

Poff, N. L.; Allan, J.D.; Palmer, M.A. ; Hart, D.D.; Richer, B.D.; Arthington, A.H.; Rogers, K.H., Meyer, J.L and Stanford, J.A. 2003. River flows and water wars: emerging science for environmental decision making. Frontiers in Ecology and the Environment 1: 298-306.

Postel, S., and Richer, B. 2003. Rivers for Life: Managing water for People and Nature. Island Press. Washington D.C.

Reid, W.V., Mooney, H.A., Cropper, A., Capistrano, D., Carpenter, S.R., Chopra, K., Dasgupta, P., Dietz, T., Duraiappah, A.K., Hassan, R., Kasperson, R., Leemans, R., May R.M., McMichael A.J., Pingali, P., Samper, C., Scholes, R., Watson, R.T., Zakri, A.H., Shidong, Z., Ash, N.J., Bennett, E., Kumar P., Lee, M.J., Raudsepp-Hearne, C., Simons, H., Thonell ,J and Zurek, M.B. Eds., 2005: Ecosystems and Human Well-being: Synthesis. Island Press, Washington, DC.

Richer, B.D.; Warner, A.T.; Meyer, J.L and Lutz, K. 2006. A collaborative and adaptive process for developing environmental flow recommendations. River Research and Applications 22(3):297-318.

Searle, J.R, 2005. What is an institution? Journal on environmental economic (2005) 1: 1-22. UK

Stendsen, M., ed. 2005. Irrigation and river basin management: Options for governance and institutions. Wallingford U.K. CABI International.

Swainson, B.; Loë R.C. and Kreutzwiser R.D, 2011. Sharing water with Nature: Insights on Environmental Water Allocation from a Case Study of the Murrumdidgee Catchment, Australia. Water Alternatives 4 (1): 15-34.

Thame, R.E. 2003. A global perspective on environmental flow assessment: Emerging trends in the development and application of environmental flow methodologies. River Research and Applications 19(5-6): 397-441.

Water Services Trust Fund. 2009. Water Resource Users Association Development Cycle (WDC).

Yin, Robert. 1994. Case study research: Design and Methods (2nd edit). Sage Publishing. Thousand Oaks, CA.

16 Response of Rice Yields to the Quantity of Irrigation Water Used in Mwea Irrigation Scheme, Kenya

Owilla, Benedict Peter Obiero[1],

Makokha George Lukoye[2],

Shisanya Chris Allan[3]

16.1 Abstract

The increasing scarcity of usable water due to the expanding agricultural and non-agricultural uses threatens sustainable socio-economic development in the already water-stressed, agro-based economies like Kenya. Enhanced intra- and inter-sectoral water-use efficiency is therefore paramount for prolonged use of the finite resource in such regions. Since agriculture dominates Kenya's water use, the production elasticity of irrigation water use is critical in determining sustainable allocation of water within this vital sector. This study sought to determine the response of rice yields to the quantity of irrigation water as a rice production factor in Mwea Irrigation Scheme, the country's largest irrigation project. Cross-sectional data were used in an integrated approach to regress rice yield against irrigation water, land, labour and capital uses to derive the Cobb-Douglas production function for the Scheme. The sum of the input elasticities was found to be 0.903, implying decreasing returns to scale or use of irrigation water below its productive potential. Further, the quantity of water as used in the Scheme had insignificant effect while that if capital was significant on rice yields at 0.05 level of significance. This was attributed to structural social capital in the Scheme and irrigators' value for irrigation water as a social good that improved use of capital but not water. It is recommended that the performance of irrigation be improved through upscaling of the. Further, farmers' capacity building on irrigation water management, canal lining and partial mechanization of such operations as harvesting will improve water and labour productivity respectively. Finally, the Scheme water-use efficiency should be determined, and factors of water-use inefficiency identified to mitigate the current over-use of water.

Keywords: *Irrigation water use, Cobb-Douglas Production Function, Mwea Irrigation Scheme*

16.2 Introduction

Kenya's economic dependence on agriculture, the declining arable land (Oduol, 2006) and the increasing vulnerability of the sector have led to calls for irrigation expansion to boost the sector's productivity (GoK, 2011; Jaetzold *et al.*, 2007). Further, shifts in consumer preferences towards rice require increased rice production (Atera *et al.*, 2011; Awange et al., 2007). This calls for innovative distribution and use of the limited resources such as water that are available to agriculture (Todaro & Smith 2006; Rosegrant *et al.*, 2001).

Since the access to and use of irrigation water is associated with social, economic, and environmental costs (FAO, 2008), this finite resource should be exploited in such a way as to minimize these costs, especially in water-scarce countries like Kenya. The economic costs associated with irrigation water-use are a function of the irrigation technology (Shajari, Bakhshoodeh &, Soltani, 2008). Technological gaps can be indicated by how the quantity of water as used does add value to rice yields. Investigating the production elasticity of irrigation water use thus forms a critical step towards determining these gaps, and consequently the irrigation water-use efficiency. This study therefore sought to determine the rice yield response to the quantity of irrigation water as a rice production factor in Mwea Irrigation Scheme. It was hypothesized that there was no significant effect of the quantity of irrigation water, as used, on the rice yields in the Scheme. The parametric function approach which uses the production function to determine the relative contribution of the independent variables to the dependent variable was adopted.

16.3 Data

16.3.1 Study area

The study area is located in Mwea District of Kirinyaga County, Kenya. It is situated in the upper region of the Tana Catchment that is drained by the Thiba, Nyamindi, and Ruamuthambi Rivers and several streams. Its relief is gently undulating. The higher areas have shallow reddish-brown lateritic clay loams (red soils), while the low lands are impervious heavy montmorillonitic clays. Mwea has bi-modal rainfall with peaks in April and November, a mean annual precipitation of 944.1mm, and a temperature range of 22°C in July and 24°C in February (Chuaga, 1981). Although the precipitation compares favourably with the national mean of 630mm (FAO, 2007) and the global mean of 750mm (Nandalal & Semasinghe, 2006), it is insufficient to meet the crop water requirement owing to seasonal variability and distribution patterns. The predominant land-use activity in the area is commercial flood-irrigation of rice through open-earth gravity flow water abstraction and delivery systems. Horticultural crop cultivation is also significantly carried out using furrow irrigation.

16.3.2 Data collection

Primary data were collected using interview schedules. A sample of 121 out of the Scheme population of 4,189 irrigators was collected using the Valades and Bamberger (1994) method.

16.3.3 Data analysis

The quantities of inputs used (water, land, working capital, labour) and their log values as well as the quantity of rice harvested and its log value per farmer were computed, and the Cobb-Douglas production function for rice for the Scheme generated using SPSS-PC.

Two functional forms of regression models were used to determine the rice yield response to the production factors: the commonly used Cobb-Douglas production and the multiple linear regression functions. A generalized Cobb-Douglas production function is expressed as follows (Hájková & Hurník, 2007):

$$Y_i = AX_1^{\beta 1} * X_2^{\beta 2} * \ldots * X_n^{\beta n} \qquad (1)$$

The multiple linear regression function on the other hand is expressed thus:

$$Y_i = a + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_n X_n + \varepsilon \qquad (2)$$

In both Equations (1) and (2), Y_i is the dependent variable (regressand), X_1 through X_n are the independent variables (regressors), A and a are regression constants and β_1 through β_n are the regression coefficients for X_1 through X_n. ε is the error term that accounts for the residuals that arise from measurement errors in Y_i and errors in the specification of the relationship between the dependent and the independent variables.

Assuming that the elasticity of production is constant over the entire production surface such that equal increments of inputs add the same percentage to total output at all levels of input use, Equation (1) can be converted into the functional form of Equation (2) through a log-linear transformation (Badar *et al.*, 2007) to give Equation (3), thus:

$$InY = InA + \beta_1 InX_1 + \beta_2 InX_2 + \ldots + \beta_4 InX_4 + \varepsilon \qquad (3)$$

The log-linear transformation enables the use of ordinary least squares method to solve the Cobb-Douglas production function. The ordinary least squares method determines the line of best fit that minimizes the sum of squared errors. The regression coefficients in both models have different interpretations. In the multiple linear regression model, these coefficients refer to the change in *Y* due to a unit change in one regressor with all other regressors held constant. In the log-linear regression model, however, the coefficients refer to elasticities or the percent change in *Y* due to a unit-percent change in one regressor with all the other regressors held constant.

In this study, *Y* is the gross output (the quantity of rice harvested); X_1, X_2, X_3 and X_4 are the factors of production (representing irrigation water, labour, other operating costs termed collectively as working capital, and land respectively); *A* is a regression constant; ε is the error term accounting for the effects, on the dependent variable, of other variables not included in the model. It captures the variation above and below the regression line due to all other factors not included in the model. β_1, β_2, β_3 and β_4 are the partial regression coefficients (also termed elasticities of production).

The function allows for constant, increasing or decreasing returns to scale depending on whether the sum of the coefficients (β_1, β_2, β_3 and β_4) is one, more than one, or less than one respectively. The popularity of the use of the Cobb-Douglas production function is premised on the following advantages (Ogbonna *et al*., 2009):

a) The regression coefficients immediately give the elasticities of production which are independent of the units of measurements for the respective inputs;
b) Assuming that the errors are small and normally distributed, such a logarithmic transformation of the variables will presume, to a substantial degree, the function assumes normality in the distribution of errors in the data.

Data were collected on the quantities of irrigation water, labour, and capital used, as well as the rice output per farmer.

The explanatory power of the model revealing the apparent functional relationship between dependent and explanatory variables was determined by evaluation using the coefficient of multiple determination, R^2. This index measures the explanatory power of the regression model by measuring the proportion of the change in the dependent variable that is explained by all the independent variables in the model.

16.4 Results and Discussion

The SPSS outputs of the data analysis are summarized in Tables 16.1 and 16.2 below. Since the farm and irrigation canal designs as well as irrigation water supply schedules were similar, the irrigation water-use was assumed to be uniformly applied across the farms, and any variation in the quantity of water used per farmer was due to variation in the size of land irrigated. Similarly, the labour and working capital too were strongly correlated with the land size. The regression output, therefore, showed exclusion of land from the analysis results, since the effects of the land input could be explained by the effects of the other variables.

Table 16.1: Summary of coefficients for the regression model

Parameter	Unstandardized Coefficients		Standardized Coefficients: Beta	T	Sig. (α)
	β	Std Error			
Log Constant	0.481	1.017		0.473	0.637*
Log quantity of water	0.099	0.222	0.097	0.445	0.657*
Log total labour	0.294	0.209	0.286	1.409	0.162*
Log land	n/a	n/a	n/a	n/a	n/a
Log working capital	0.510	0.174	0.517	2.928	0.004**

a. Predictors: (Constant), log of working capital, log of quantity of water used, log of total labour, log of land under irrigated rice;

b. Dependent Variable: Log of total rice harvested;

c. ** significant values;

d. * insignificant values

(Source: Author, 2008)

From the regression results, the Cobb-Douglas function was fitted to the data in order to derive the production function for rice in the Scheme. The elasticity values obtained from the regression analysis were substituted into the logarithmic function (Equation 3) with X_1, X_2, X_3, and X_4 representing irrigation water, labour, working capital and land respectively as follows:

$$InY = 0.481 + 0.099InX_1 + 0.294InX_2 + 0.510InX_3 + \beta_4 InX_4 + \varepsilon \quad (4)$$

With the elimination of land from the function, Equation (4) was transformed into Equation (5):

$$InY = 0.481 + 0.099InX_1 + 0.294InX_2 + 0.510InX_3 + \varepsilon \quad (5)$$

Substituting the mean log values into Equation (5) gave -0.0036 as the value of ε, with the final function being:

$$InY = 0.477 + 0.099InX_1 + 0.294InX_2 + 0.510InX_3 \quad (6)$$

The output for the SPSS-PC run of the coefficient of multiple determination as well as the Standard Error of the Estimate is given in Table 2 below.

Table 16.2: Summary of statistics for the regression model

R	R^2	Adjusted R	Standard error of the Estimate
0.891(a)	0.793	0.788	0.28137

a.Predictors: (Constant), log of working capital, log of quantity of water used, log of total labour, log of land under irrigated rice;
b. Dependent Variable: Log of total rice harvested
(Source: Author, 2008)

The R^2 and Standard Error of the Estimate were 0.793 and 0.28137 respectively. This reveals that 79.3% of the change in the rice output is explained by the changes in the quantity of irrigation water used, labour, and working capital. This fact together with the low standard error of the estimate implied that the regression plane defined by the model fitted the data fairly well. It was therefore, concluded that there exists a relationship between the rice output and irrigation water, labour and working capital used in rice production process. The strength and direction of this relationship is given by the corresponding coefficients of correlation. The corresponding coefficients of correlation ranged from 0.876 to 1.000, indicating a strong and direct relationship.

From the result of this analysis, it can be observed that the quantity of irrigation water, labour and capital used have positive impact on rice output in the Scheme. The impacts, however, are insignificant for water and labour, but significant for capital at 0.05 significance level. Since the impact of the quantity of irrigation water used on rice yield was insignificant, there was no sufficient evidence to reject the null hypothesis.

On the basis of the data obtained from the sample of 121 Scheme irrigators, the production elasticities of inputs were 0.099, 0.294, and 0.510 for water, labour, and working capital respectively. Two principal inferences can be drawn from the production function depicted by Equation (6), both related to the regression coefficients. The first one is linked to the relative importance of the factor inputs used in Mwea Irrigation Scheme. A 0.51% change in output would be observed if working capital changed by 1% with labour and water held constant. Similarly, an equivalent change in labour would change rice output by 0.294% with all other inputs held constant; whereas, a 1% change in water would change the output of rice by only 0.099%, *ceteris paribus*. Considering the three inputs therefore, rice output in the Scheme is most responsive to capital, and least responsive to quantity of irrigation water under the current level of technology.

Statistically, there is no significant relationship between the quantity of irrigation water as used, and the rice output in the Scheme. At the 0.05 level of significance, α-value should be 0.05 or less to imply significant effect. The significance of capital can be explained by the concept of structural social capital (Fiorillo & Sabatini, 2011) observed in the Scheme. Farmers cultivate rice following a well-defined cropping programme dictated by a strict irrigation schedule. Non-compliance with this programme means forfeiting a whole season's crop to the farmer's detriment. Under such an arrangement, farmers act co-operatively in crop monitoring, and there is increased informal insurance as well as diffusion of innovations. Information on capital use flows freely among the farmers' groups. Therefore, even the least technically-informed farmers are driven by the lucrative returns from rice and the available pool of information within the groups. This argument was supported by the high allocative efficiency observed among the surveyed farms. This works in favour of efficient use of capital which is associated with high costs, but has the opposite effect on water that is still considered a social rather than economic good. Farmers pay an irrigation system maintenance fee charged at flat rate per acre irrespective of the quantity of water used, and no charge is levied on the water.

The low response of output to water suggests that irrigation water in the Scheme is used below its productive potential, possibly due to over-use. Alternatively, the irrigation water has probably attained its maximum productivity in the Scheme and, at the current technology, is in the third stage of the production function. In this stage, both the average and marginal productivity are positive but are declining. At this point, these productivity indices can only be increased by changing the technology of irrigation. The precise technological changes, however, requires determination of the Scheme water-use efficiency and identification of the factors of the observed efficiency.

The second inference regards the implication of the sum of the coefficients. The sum of β_1, β_2 and β_3 in the model is 0.903. The fact that this sum is less than unity indicates a situation of decreasing returns to scale. This means that production inputs are being used below their optimal productivity scale, and an increase in rice output has to be accompanied by more than proportionate increase in the inputs. Improving the input productivity through technical change could increase the sum to unity or more than unity.

The above analysis and inferences only refer to the functional relationship between the factors of production and the output. They do not, in any way, prove whether the water resources are optimally utilized or not. In order to address this limitation, an analysis of the efficiency of use of the water resources is necessary.

16.5 Conclusions and Recommendations

The quantity of irrigation water as used in the Scheme has insignificant effect on rice yields at 0.05 level of significance. The low response of rice output to water suggests that water-use in the Scheme is below its productive potential. There is need to improve the efficiency with which irrigation water is used in the Scheme. This will help increase rice yields without additional water abstraction, and hence assure sustainable use of the available irrigation water.

The sum of the input elasticities is 0.903. The fact that this sum is less than unity indicates a situation of decreasing returns to scale (Das, 2005). This means that an increase in rice output has to be accompanied by more than proportionate increase in the factors of production. The solution to improving the productive capacity of the water resources thus lies in technical change rather than physically expanding their use.

This study recommends that productivity of water, land, and labour be improved. Several approaches can be used to improve water productivity. The structural social capital enjoyed by the Scheme should be exploited to disseminate efficient use of irrigation water. The capacity of the new irrigation water-users' association should be built to help achieve this goal. Measuring gauges need to be installed along the conveyance system to monitor water distribution to match supply with the crop needs, and the irrigators sensitized to regard water as a resource with economic value. In addition, the irrigators need training on optimal on-farm irrigation water application and management. The performance of irrigation infrastructure too needs improvement through canal lining to enhance water conveyance efficiency. Soil fertility improvement rice with non-flood irrigated crops and partial mechanization of such operations as harvesting of rice will improve soil and labour productivity respectively.
Finally, a study of irrigation water use efficiency and identification of the factors of the efficiency should be determined to enable project-specific mitigation measures.

16.6 References

Atera, E. A., Onyango, J. C., Azuma, T., Asanuma, S. and Ito, K. (2011). "Field Evaluation of Selected Nerica Cultivars in Western Kenya". *African Journal of Agricultural Research* Vol. 6(1), pp.60-66, 4 January 2011. http://www.academicjournals.org/AJAR . Accessed on 14/09/2012

Awange1, J. L., Aluoch, J., Ogallo, L. A., Omulo, M. and Omondi, P. (2007). "Frequency and Severity of Drought in the LakeVictoria Region (Kenya) and its Effects on Food Security". *Climate Research*. Vol. 33: pp. 135–142.

Chuaga, F. M. (1981). "Water Balance Study of Thiba Section of Mwea Irrigation Settlement". M. Sc. Thesis, University of Nairobi. Unpublished.

Coeli, T. J., Rao, D. S. P., and Battese, G. E. (1998). *An Introduction to Efficiency and Productivity Analysis*. Kluwer Academic Publishers, Boston. pp 267

Das, S. (2005). "The Concept of Elasticity in Economics"
http://www.nvcc.edu/home/sdas/elasticity/broaderusage.htm. Accessed on 23/03/2010

FAO. (2007). "Water Profile of Kenya". http://www.eoearth.org/article/water profile_of _Kenya # Economy.2C_Agriculture.2C_and_Food _Security. Accessed on 06/6/2008

FAO. (2008). "The State of Food Insecurity in the World 2008- High Food Prices and Food Security, Threats and Opportunities" http://www.globalpolicy.org/socecon/hunger/general/2008/2008foodinsecurity.pdf . Accessed on 15/10/2008

Fiorillo, D. and Sabatini,F.(2011). "Structural Social Capital and Health in Italy". Health, Econometrics and Data Group, the University of York. WP 11/23, July 2011 http://www.york.ac.uk/res/herc/hedgwp Accessed on 15/09/2012

GoK. (2011). *Agricultural Sector Development Support Programme*. Ministry of Agriculture. www.kilimo.go.ke. Accessed on 14/09/2012

Hájková, D. and Hurník, J. "Cobb-Douglas Production Function: The Case of a Converging Economy". *Czech Journal of Economics and Finance*, 57, 2007, no. 9-10: 465-476

Jaetzold, R., Schmidt, H., Hornetz, B. and Shisanya, C. (2007). "Part C East Kenya, Subpart C1 Eastern Province". In Ministry of Agriculture and GTZ (eds.), *Farm Management Handbooks of Kenya, Vol. II: Natural Conditions and Farm Management Information*. Nairobi, 571 pp.

Malik, A, and Mahmood, K. (2009). "Web Search Behaviour of Students: A Case Study at University of Punjab". *Webology*, Vol. VI, 2, 2009. http://www.webology.ir/2009/v6n2/a70.html Accessed on 16/8/2008

Mohaddes, S.A. Mazhari, M. "Total and Input Factor Productivity Analysis of Poultry Production in Khorasan Province, Iran". *American-Eurasian J. Agric. & Environ. Sci.*, 2 (Supple 1): 151-154, 2008

Nandalal, K.D.W. and Semasinghe, S.B.A.D. (2006). "A System Dynamics Simulation Model for the Assessment of Water Resources in Sri Lanka". In *Sustainable Development of Water Resources, Water Supply and Environmental Sanitation*. 32nd WEDC International Conference, Colombo, Sri Lanka, 2006. p 259-262. http:wedc.lboro.ac.uk/conferences/pdfs/32/Nandalal.pdf. Accessed on 18/2/2008.

Oduol, J. B. A. (2006). “Resource Productivity and Resource Use Efficiency Under Land and Capital Constraints in Kenya: Evidence from Smallholder Farms in Embu District”. PhD. Thesis, Kyushu University. Unpublished.

Ogbonna, M. C., Anyaegbunam, H. N., Madu, T. U. and Ogbonna, R. A. (2009). “Income and Factor Analysis in Sweet Potato Landrace Production in Ikom Agricultural Zone of Cross River State, Nigeria”. Journal of Development and Agricultural Economics Vol.1(6), pp. 132-136, September 2009. http://www.academicjournal.org/JDAE Accessed on 14/09/2012

Phengphaengsy, F. and Hiroshi, O. (2006). “Improvement of Efficiency in Paddy Fields in the Lower Mekong Basin (IIEPF) ”. http:/wwwmrcmekong.org/download/Papers/full_paperimpr_of_irrigation.pdf. Accessed on 20/12/2009.

Rosegrant, M., W., Paisner, M. S., Meijer, S., and Witcover, J. (2001). “2020 Global Food Outlook: Trends, Alternatives, and Choices”. A Vision for Food, Agriculture, and the Environment Initiative. International Food Policy Research Institute. Washington D.C.

Shajari, S., Bakhshoodeh, M., and Soltani, G. R. (2008). “Enhancing Irrigation Water Use Efficiency under production risk: Evidence from Wheat Farms in Iran”. *American-Eurasian J. Agric. & Environ Sci.*, 2(Supple 1): 36-41, 2008

www.idosi.org/aejaes/jaes2(supple%25201)/6.pdf. Accessed on 27/12/2009

Todaro, M. P. and Smith, S. C. (2006). *Economic Development*. Ninth edition. Pearson Education Limited, UK. pp 851

Valades, J. and Bamberger, M. (1994). “Monitoring and Evaluating Social Programmes in Developing Countries: A Handbook for Policymakers, Managers, and Researchers”. The World Bank. Washington D.C. pp519

Waiyaki, N. (2007). “Sensitive and Special Products in Trade Negotiations: The Case of Kenya”. Kenya Institute for Public Policy Research and Analysis, http://www.uneca.org/eca_programmes/trade_and_regional_integration/documents/cotonu/Special%20Products%20Slides%20Cotonou.ppt#315,15,Slide15. Accessed on 30/3/2009.

17 Market Driven Natural Resource Management; a key to sustainable Agricultural Development: Case study of Bufundi sub-county, Kabale District, Uganda.

Tenywa,M.M., [1]

Rao, KPC.,

Majaliwa, J.GM.,

Foerch, G.,

Kizza, C.L.,

Tukahirwa, J.B.,

Fungo, B.,

Kuule, M.,

Musinguzi, P.,

Bamutaze, Y.,

Kamugisha, R.,

Gabiri, G.

Kaliisa, R.

----

[1]*Makerere University Agricultural Research Institute,*
Kabanyolo (MUARIK)
P.O. Box 7062 Kampala, Uganda.

17.1 Abstract

Most soil and water conservation approaches in Sub-Saharan Africa are supply-driven rather than demand-driven, and predominantly use the linear research-extension-farmer technology transfer model rather than demand led/informed systemic institutional innovation approach (Tenywa *et al.,* 2011). This paper highlights the successes and challenges in addressing the problem of soil erosion in Bufundi, Kabale district arising from the balance in directing efforts towards the environmental dynamics vis-a-vis institutional (Multi-stakeholder Innovation Platforms-IPs established under FARA-SSA-CP). A baseline survey and an outcome evaluation were conducted in the sub-county in 2008 and 2010, respectively. The outcome evaluation was based on the framework developed by Lopez (1987) that stipulates that if institutional dominate environmental dynamics, new institutions that protect the land emerge, and consequently livelihoods of farmers are improved. However, if environmental dynamics predominate institutional dynamics, conflicts arise and the soil erosion problem is exacerbated. Outcome evaluation of the efforts targeting institutional and environmental dynamics revealed mixed results. Initial institutional efforts to organize and empower farmers involved in formation of multi-stakeholder and multi-institutional IPs, and resulted in collective action focusing on protecting the water sources (e.g. springs). Consequently, conflicts over benefits arose in communal lands and efforts were fragmented. Institutional interventions on creation of awareness of local leaders about benefits of collective action through exposure visits resulted in positive change in attitudes. The IPs were only 2 years old. The turnaround in sustainable natural resource investment is envisaged from demand-driven efforts that will accrue from linking farmers to markets through substantial contractual arrangements. We argue that for sustainable investments in Natural Resource Management (NRM) to be realized, efforts should focus on market driven institutional and policy arrangements in preference to the supply driven environmental dynamics approach. .

Key words: *soil erosion, water quality, demand-driven, investment, institutional arrangements, policy*

17.2 Introduction

Past approaches to natural resource management (NRM) have largely been supply driven rather than demand driven (German *et al.,* 2005). SWC is a resource (labour, time input and fiscal) intensive investment and farmers are unlikely to adopt new technologies unless both productivity and profitability are assured (Glenn et al., 2005). Sub Saharan Africa (SSA) continues to experience degradation resulting from the destructive, extractive, over-exploitation and inadequate conservation practices (Tenywa and Bekunda, 2008). This has continued to threaten its agricultural productivity, biodiversity, climatic patterns, water quality and availability (Scherr and Yadav 1995) as well as the livelihoods of the poor, of whom 90% depend on the natural environment for their survival (World Bank, 2008).

On-going efforts in SSA to mitigate environmental degradation are yet to succeed in their approaches, organization, and choice of technologies as well adoption of policies for the diverse and complex problems in NRM (Nkonya, 2002). He further argues that addressing these complex and diverse linkages requires adoption of new approaches, institutions, policies, demand specific technologies as well as efforts that are demand-driven by economic-institutional markets, ecological and social cultural needs of the poor rather than the existing supply driven NRM approaches. Emergency of demand-driven NRM models is rooted in first, understanding the dynamic relationship that exists between NRM institutions and the environment under which they operate in the demand-economic chain (Marshall, 2008). Lopez (1987) highlights that in this model, when environmental dynamics dominate institutional dynamics; environmental problems will simply be exacerbated thus leading to more degradation of the environment. However, if institutional dynamics dominate environmental dynamics, then, new institutions emerge that protect the land and soil while improving the economic status of farmers. On the other hand, if the land is fragile and institutions are weak, then incredible damage to the natural resource base can occur and the result is a vicious cycle of demographic pressure-poverty-environmental degradation.

Lake Kivu region forms part of the fragile mountainous humid tropical areas of SSA characterized with high population density of up to 700 km^2 dependants on agricultural systems that deteriorate the existing natural resources (FARA, 2009). Agricultural production has continued to decline over the years in this region characterized by intensively cultivated steep degradation prone hill slopes, disorganized market supply chains as well weak institutional and policy arrangements (Nkonya et al., 2009). Over the years, farmers in this region have adopted unique indigenous soil conservation practices that apparently "conflict" with the conventional SWC practices and have attracted scholarly debates (Tenywa and Fungo, 2009). The farmers in most of the sub-watershed catchments use traditional SWC methods (stone lines) that are laid along the slopes rather than across the slopes. This is also seen in the way they plant crops and cultivate the land down the slope rather than along the contours as commonly recommended and thus contributing to tillage erosion.

In addition, efforts of tree-eucalyptus planting in the watershed have generated mixed reactions among researchers and farmers. Whereas in some areas of the Lake Kivu watershed overlain by volcanic Andosols eucalyptus planting does not seem to cause negative impacts, in other areas covered by more weathered tropical soils (Bufundi sub-catchment area) have been associated with exacerbated soil erosion as well as soil infertility and water quality degradation. The adage "eucalyptus spoils soils" cannot be taken for granted and under the diverse ecological niches it is evolution can be likened to "egg-chicken" phenomena.

According to FARA (2009), the problems of widespread land degradation, failed markets and poorly implemented policies that characterized the Lake Kivu watershed were diagnosed to engender an Integrated Agricultural Research for Development (IAR4D) approach that integrates emergence of new multi-stakeholder institutions commonly known as Innovation Platforms (IPs) that integrate economic-market demand production, SWC, as well as NRM collaborative research and networking under a new Integrated watershed management planning framework. This paper highlights a comprehensive analysis for a baseline survey that was conducted in 2008 and an outcome evaluative survey (2010) based on the framework developed by Lopez (1987) in one of the sub-catchment (Bufundi-Lake Bunyonyi). An integrated watershed planning framework was adopted to diagnose the complex problems that were identified during the baseline survey of which soil infertility, water resource degradation associated with soil erosion were ranked to be the major constraints to increased productivity in Bufundi water catchment area**.** The hypotheses were that when communities are incentivized by addressing socio-economic issues, institutional innovations (e.g. collective action) are generated to directly respond by increasing production and indirectly environmental degradation.

17.3 Methodology

17.3.1 Description of the study Area

Bufundi Watershed Catchment area is geographically located in South-western Uganda, it is located between 1.345 latitudes and 29.850 longitudes and it covers up to 20 km^2.

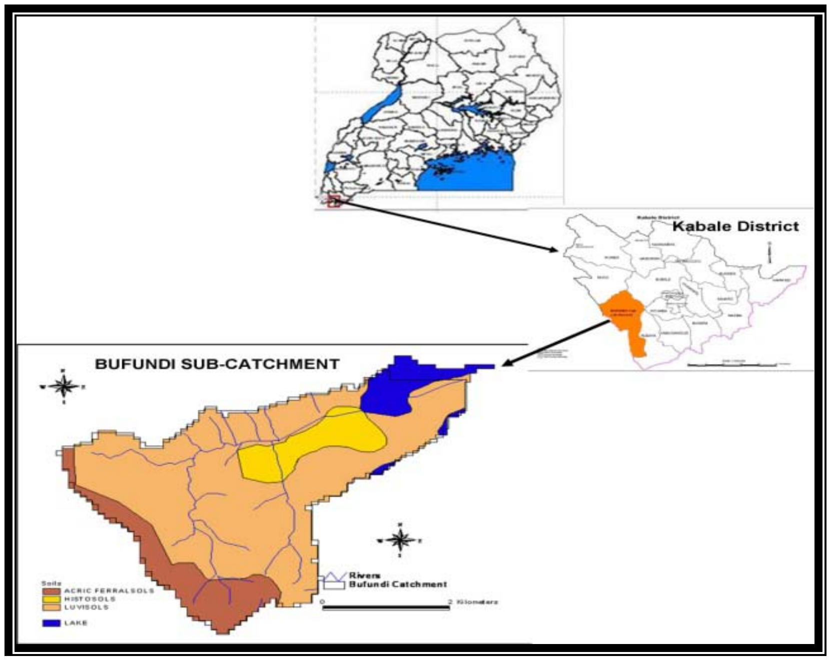


Figure 17.1: A map showing the study area

The terrain is dominated by hills and valleys with most slopes ranging between 12 to 50% but may go as high as 80% (LKPLS Survey report, 2008). Bufundi catchment has a bimodal rainfall pattern that provides opportunity for two cropping seasons in a year. The "long rains" occur from mid-February through early June while the "short rains" occur from mid-September to mid-December. The average annual rainfall in the catchment varies between 900 mm to 2200 mm with a mean annual temperature of 16.7°C.

The soils in the catchment are typically Andsols, Nitosols and Ferrasols with declining fertility due to continuous cultivation (Wortmann and Eledu, 1999). There are relatively fertile in nature but susceptible to extreme soil erosion from any drop of rainfall (NRM-SSA-CP baseline report, 2008). This catchment is drained by various means including small aquifers, various small streams and rivers in the valley bottom wetland which drain into Lake Bunyonyi. Land for cultivation in this catchment is scarce as a result of over population and land fragmentation.

Among the most land use practices is crop farming, livestock, pastures, woodlots under eucalyptus and limited agro forestry. Despite the small size holdings, farmers in the catchment tend to grow a number of crops which include; potatoes, beans, and sorghum, though grown on small areas. Other crops of high importance are sweet potatoes, maize and a number of vegetables like tomatoes, cabbages and carrots.

Nearly 60% of the land area is intensively cultivated and poverty in the catchment is directly linked to the low and deteriorating productivity and profitability of these enterprises. Smallholder farming in Bufundi Watershed Catchment area is characterized by unsustainable agricultural practices including; over cropping using inferior germplasm and very little or no inputs, poor control of diseases and pests and poor management and husbandry of land. The steep slopes give rise to high runoff rates and severe soil erosion (especially from the woodlots of eucalyptus trees) leading to limited benefits accruing from past NRM programs in the catchment. Other forms of land degradation in the catchment include off-site siltation and nutrient mining through crop removal, leaching and runoff water. The agro-ecosystem and biological resources in the Catchment are rapidly degrading, largely due to mismanagement of steep cultivated slopes and wetland valleys, related in part to inadequacy of old methods to cope with the new food demands of a growing population. Deforestation, soil erosion, nutrient depletion, and flooding of valley bottoms are the major processes of land degradation in the catchment that need IWM planning under a multi-stakeholder arrangement.

17.3.2 Research Design

A baseline survey and an outcome evaluative survey to identify institutions involved in NRM.SWC and status of the natural resources management were conducted in the IP that was established in the action sites in November 2008. At the time of selection, the IP site was similar to the no-action sites with little or no interaction between stakeholders. It was classified as poor market access based on cost distance algorithm ran in a GIS environment (friction surface) using the typology of roads and land use classes. The baseline survey was determined through informant interviews using a semi-structured questionnaire.

The outcome evaluated survey was based on the performance and evaluation of the newly formed institutional arrangements commonly referred to as Innovation platforms. As stipulated in the framework developed by Lopez (1987) that if institutional dynamics dominate environmental dynamics, new institutions that protect the land emerge, and consequently livelihoods of farmers improved.

17.3.3 Sampling frame

Purposive sampling of 60 households out of a total of 600 households in the catchment that are involved in IP activities were purposively selected from 5 villages in the catchment (12 households in each village) which were clustered into three clusters (i.e. up stream, middle, downstream). Up to 6 households out of the 60 households were purposively selected for the study to give a representation of the selected villages. The main objective of the sampling was to evaluate the success and challenges involved in addressing natural resources challenges/soil and water conservation practices. Data on Institutions that have been involved in NRM/SWC before the Innovation platforms, Perceptions of the farmers on NRM/SWC in the IP, reasons for participation in Instituional-economic derived SWC/NRM, Challenges identified to hinder collective action for SWC and reasons for changes on the status of natural resources management/soil and water conservation practices were collected from the survey.

17.3.4 Data analysis

Data was cleaned and entered into SPSS version 17.0 soft ware for analysis. A descriptive analysis was generated from the data. A chi-square test was used to test whether there was a significant relationship between the registered benefits of collective action and the reasons why farmers were participating in innovation platform activities.

17.4 Results and Discussion

Objective 1: Evaluation of successes in addressing natural resources management/soil and water conservation practices; Balance between institutional and environmental factors

17.4.1 Institutions that have been involved in NRM/SWC before the Innovation platforms

In an attempt to understand the previous institutions that have been involved in NRM/SWC in the sub-catchment, two major institutions were reported by respondents to be the most involved in NRM/SWC in the sub-catchment where Government institutions were reported more involved (Figure 17.2) as compared to NGOs. KULIKA and AFRI-CARE were the NGOs reported to be involved in SWC in the catchment

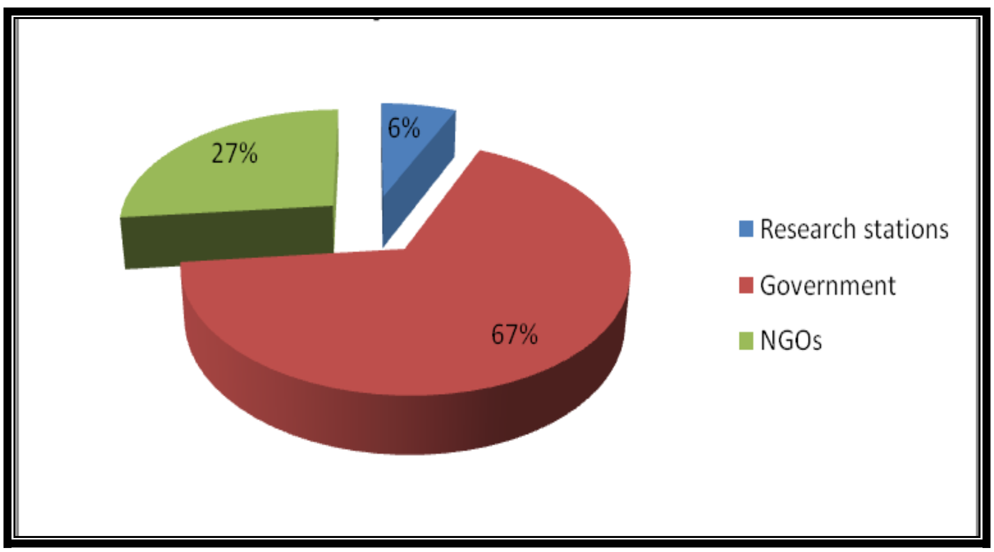


Figure 17.2: Institutions that have been involved in SWC/NRM before the IP

Boyd *et al.* (2000) reports that the changes in the wider political environment in Uganda at both national and local levels have affected investment in SWC through changes in the capacity and perceived authority of institutions that have been entrusted with SWC; Since the colonial period, responsibility for promoting SWC has been delegated to local leaders and administrations. The decentralization policy adopted in 1994 has reinforced this approach an indicator of the state's commitment for SWC. However, the notion of SWC is not necessarily high on the agenda of local administrations, as they have limited capacity and expertise to promote SWC. Support from agricultural extension staff is limited by retrenchment, low motivation and a shortage of resources. Noteworthy, from this kind of institutional arrangement is that it has remained supply driven in nature, therefore the need to test demand driven SWC practices that integrate planning tools of IWM and multi stakeholder institutional arrangements (innovation platforms) that have evolved in Bufundi sub-catchment under the SSA-CP. IP formation as a new institution that has emerged to protect the land was reported the most important reason for changes on management of natural resources in the sub-catchment

17.4.2 Perception on NRM/SWC in the IP

From the survey it was reported that IP formation had strongly encouraged people in the sub-catchment to get involved in Collective action for SWC as well as implementation of the proposed SWC measures. A lichet scale value, (strongly agree, Agree and do-not Agree) was used to understand the respondent' perceptions of Collective action (Table 17.1). Forty seven (47) respondents reported that they had observed some form of change in form of institutional-economic derived benefits arising from Collective action.

Table 17.1: Respondent's perceptions on collective action

Changes on SWC/NRM	**Perceptions on measure of change on NRM/SWC**			**Total**
	No change	Some form of change	Remarkable change	
Implementation of proposed SWC	2	27	7	36
Information on SWC	1	19	3	23
Formulation of by-laws	0	1	0	1
Total	**3**	**47**	**10**	**60**

Despite the fact that by-laws had been formulated and revised, it was reported that non IP members especially grazers were still not implementing them, however, the efforts of the IP to implement these by-laws should be supported by policy makers at all levels.

Further efforts were made to quantify the levels of change on four variables (use of fertilizer, land management, attitude change and marketing structures). Respondents appreciated the role IPs had performed on soil fertility and land management, attitude change and marketing structures (Figure 17.3).

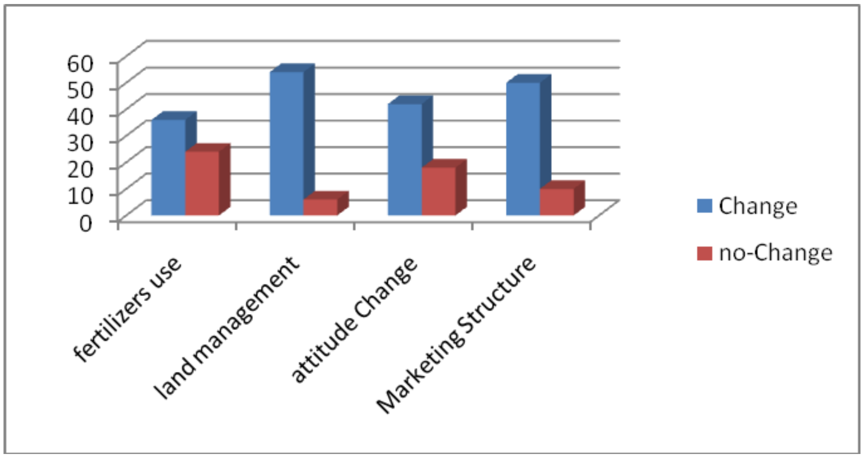


Figure 17.3: Response on soil fertility and land management, attitude change and marketing structures

17.4.3 Reasons for participation in Instituional-economic derived SWC/NRM

The main reason why people participate in collective NRM/SWC is to increase productivity of their land by reducing the rate of soil erosion and declining fertility of their soils. The chi-square test (x^2= 91.333, df= 4, p>0.000) proved that there was a significant relationship between the registered benefits of collective action and the reasons why farmers were participating in collective action. We note that tenure insecurity was reported in the baseline as not a hinderance if farmers are to invest in efforts to protect their land in Lake Kivu pilot Learning site. Water channels and collapsing terraces were reported the major areas of intervention on collective SWC by the members of the IPs.

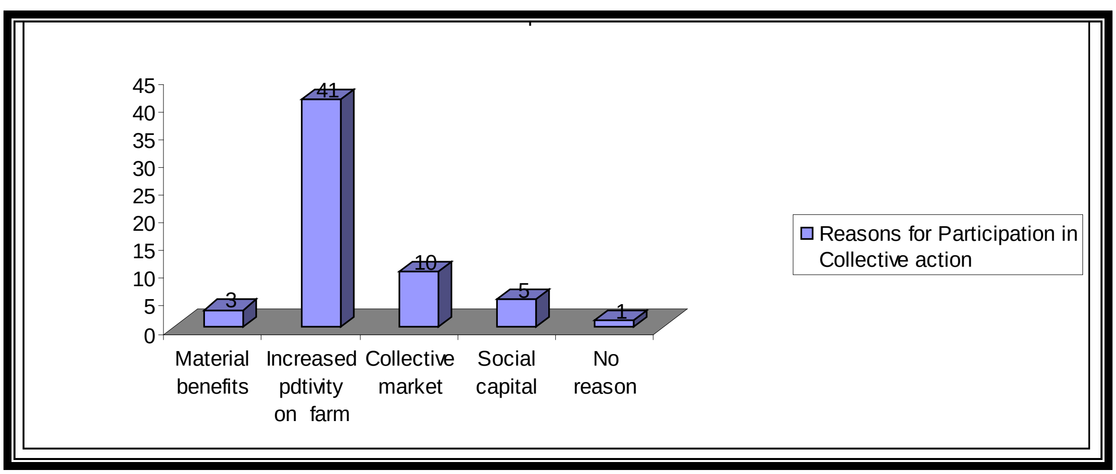


Figure 17.4: Response for participation in collective action

17.4.4 Why are there these changes?

Validation of the institutional-environmental dynamics model proposed in Lopez (1987) revealed that institutional-economic demand driven value chain interventions for NRM/SWC had occurred as a result of the emergency of Innovation Platform based on a value chain and multistakeholder consesus on NRM/SWC. (Table 17.2)

Table 17.2: Reasons for the changes in the catchment

Reasons for changes	Frequency	Percent	Valid Percent	Cumulative Percent
Formation of IPs	28	46.7	46.7	46.7
Collective action	5	8.3	8.3	55.0
Collective marketing	4	6.7	6.7	61.7
Attitude change of stakeholders	9	15.0	15.0	76.7
Good leadership of IPs	3	5.0	5.0	81.7
Formation of bylaws by IPs	8	13.3	13.3	95.0
Access to inputs by IPs	3	5.0	5.0	100.0
Total	60	100.0	100.0	

Objective 2: Challenges in addressing NRM/SWC practices; Balance between institutional and environmental dynamics

17.4.5 Challenges identified to hinder collective action for SWC

Livestock grazing was reported the most common type of conflict that hindered efforts of collective action in establishing Fanya Juu and Fanya chini (trenches) especially on communal grazing lands that are considered sources of degradation (soil erosion). Although bylaws on livestock grazing have existed even before the IPs, they have remained weak on communal grazing land.

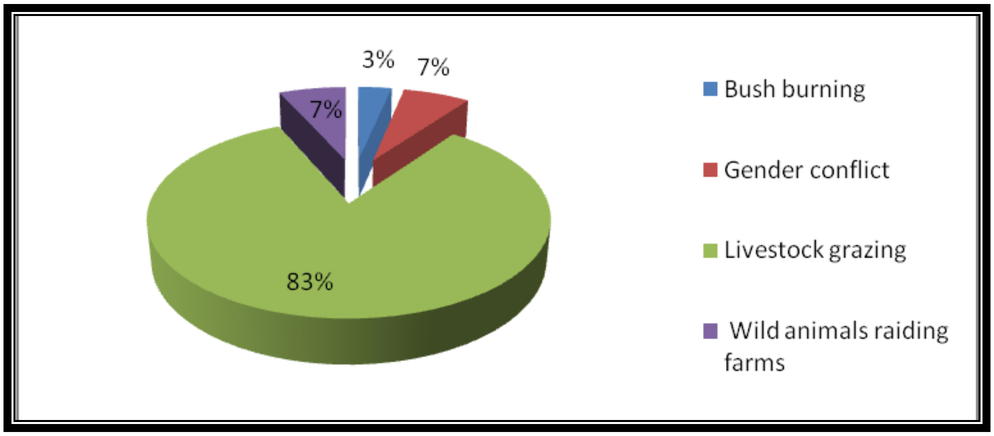


Figure 17.5: Conflicts cited to hinder collective action on communal land

17.5 Conclusion and recommendations

Early positive SWC outcomes associated with collective action based on newly formed Innovation Platforms were registered. The turnaround in sustainable natural resource investment is envisaged from demand-driven efforts that will accrue from linking farmers to markets through substantive flexible arrangements. We argue that for sustainable investments in NRM to be realized, efforts should focus on market demand-driven institutional and policy arrangements in preference to the supply driven environmental dynamics approach.

17.6 References

Boyd, C, Turton, C., Hatibu, N., Mahoo, H.F., Lazaro, E., Rwehumbiza, F.B., Okubal, A.P., and Makumbi, M.B., 2000. The Contribution of Soil and Water Conservation to Sustainable Livelihoods in Semi-arid Areas of Sub-Saharan Africa Agricultural Research and Extension Network Department for International Development (DFID) UK 5-10.

FARA., 2009. Status of social, financial, human and physical capital in Lake Kivu Pilot Learning Site, Sub-Saharan Challenge Programme, Accra Ghana

German, L., Kidane, B., and Mekonnen, K., 2005. Watershed Management to Counter Farming Systems Decline: Toward a Demand-Driven, Systems-Oriented Research Agenda. AgREN Network Paper 145. African Highlands Initiative (AHI), Working Papers # 16, 1- 8.

López, R.E., 1987. "Productivity Measurement: A Market Equilibrium Approach," in Developing a Framework for Assessing Future Changes in Agricultural Productivity, Resources for the Future, Washington, D.C

Marshall. R., 2008. Investment planning under regional NRM delivery; Current processes and issues in three NSW regions; Working Paper 1 from the project 'Improving economic accountability when using decentralized, collaborative approaches to environmental decisions' 20 – 40.

Nkonya, E., 2002. Soil Conservation Practices and Non-Agricultural Land Use in the South Western Highlands of Uganda. The International Food Policy Research Institute (IFPRI) 2033 K Street, N.W. Washington, D.C. 20006, 3- 10.

Nkonya, E., Pali, P., Oduol, J., Kwaw, S. A., and Kato., E., 2009. Lake Kivu Pilot Learning Site Baseline Socio-economic baseline study 4 – 10.

Scherr, S.J., and Yaday., 1995. Land Degradation in the Developing World: Implications for Food Agriculture and the Environment to 2020. 2020 Vision for Food, Agriculture and Environment Discussion Paper 14 Washington D.C. Science and Plant Analysis 27,365-386.

Tenywa, M.M., and Mateete, B., 2009. Managing soils in Sub-Saharan Africa: Challenges and Opportunities for Soil and Water conservation doi:10.2489/isw.64.1.44A. Journal of soil and water conservation society.

Tenywa, M.M., and Fungo, B., 2009. Lake Kivu Pilot learning site bulletin volume 1 Sub-saharan Challenge Programme, FARA Accra Ghana.

Tenywa, M.M., Rao, K.P.C., Buruchara, R., Kashaija, I., Majaliwa, J.D., Tukahirwa, J.B., Adekunle, A.A., Fatunbi, A.O., Mugabe, J., Wanjiku, C., Mutabazi, S., Pali, P., Mapatano, S., Lunze, L., Mugabo, J. and

Ngaboyisonga, C. 2011. Institutional innovations for building impact-oriented agricultural research, knowledge and development institutions; Journal of Agriculture and Environmental Studies 2(1):24-55 Word bank. 2008. World development report; Agriculture for Development 6 – 23.

Wortmann, C.S., and Eledu, C.A., 1999. Uganda's agro-ecological zones: A guide for planners and policy makers. Centre for International Tropical Agriculture (CIAT) Kampala, Uganda.

18 Farm Level Nutrient Balance for Chahi Sub-Catchment, Kisoro District in Uganda

Tenywa, M.M.,

Majaliwa, J.G.,

Gabiri, G.,

Kaliisa, R.,

Kizza, C.L.

----

[1]Corresponding author; Makerere University Department of Soil Science,
[2]Makerere University Institute of Environment and Natural Science,
[3, 4,5] Makerere University Department of Agricultural Production

Email: tenywamakooma@yahoo.com

18.1 Abstract

Negative farm level nutrient balances associated with food insecurity and environmental degradation widely reported for SSA are symptomatic of the problem of past technology driven approaches that neglected socio-economic factors. The purpose of this study was to improve our understanding of the importance of addressing socio-economic issues in improving the farm level nutrient balances. Nutrient balances were estimated in Chahi sub-catchment, SW. Uganda where Multi-stakeholder Innovation Platforms (IPs) based on the Integrated Agricultural Research for Development (IAR4D) concept of the SSA-CP was established and in the counterfactual sites. The nutrient flows were estimated using data from several sources including interviews with farmers belonging to IPs, literature and soil analyses. The data were analyzed using NUTMON software version 3.5. The farming systems in S.W. Uganda are characterized by low external input, inflows predominantly from organic manures (52-90 %) with biological nitrogen fixation (BNF) contributing to 22-27 % of the total N input across the action IAR4D and non IAR4D farms in study area. However, inorganic fertilizers are hardly used except by farmers belonging to IPs that were conducting experiments. The major avenues of nutrient losses were crops/produce sold and leaching. Soil erosion was not a major pathway for nutrient loss in this sub-catchment. The major crops grown include beans, sorghum, potatoes and maize. N balance for beans on IAR4D farms was more (0.9 Kg/ha) positive and more negative (-3.01Kg/ha) on non-IAR4D farms compared to the N balance for other crops on both categories of farms. The NPK stocks for IAR4D farms were higher (960 N Kg/ha, 808 P Kg/ha, 950 K Kg/ha) than those on non IAR4D farms (618 N Kg/ha, 315 P Kg/ha and 784 K Kg/ha). The high costs, non availability and other constraints related to input use especially mineral fertilizers and scarcity of ready markets for the outputs in this area constrain the farmers. The feasible option is increased use of other sources of N P K as indicators for sustainable fertility management especially if high yields are to be maintained. We recommend that forward–backward market linkages should be strengthened in order to contribute to more favorable balances through increased access to credit, increased investments in soil fertility management, tapping premium prices and increase enterprise profitability.

Key words: *Nutrient balance, N, P and K, Biological nitrogen fixation (BNF), IAR4D*

18.2 Introduction

Studies of soil nutrient balances across Africa are showing evidence of widespread mining of the soil resource within the smallholder farming sector (Stoorvogel and Smaling, 1990). In Uganda nutrient balance studies report that smallholder farmers have relatively low nutrient stocks and declining productivity with negative nutrient (Nitrogen-N, Phosphorus-P, Potassium-K) balances (Sanchez et al., 1996, Stoorvogel *et al*., 1993, Shephered *et al*., 1995 and 1996, Wortman 1999, Stoorvogel and Smailing, 1990, Henao and Neidert, 1999, Wortmann *et al*., 1998 and Walaga C, 1999, Nkonya and Kaizi, 2005., Ebanyat *et al*., 2010).

Essential elements NPK are usually required by plants in large amounts for normal growth and are reported as major nutrients limiting crop production in sub-Saharan Africa (SSA) farming systems (Vlek, 1990). In Uganda just like other African countries, smallholder farmers are unable to compensate for these soil nutrient losses using crop residue, animal manure as well as mineral fertilizers, thus resulting into a negative nutrient balance reported at the national level for sub-Saharan African countries (Stoorvogel and Smaling, 1990).

Soil nutrient depletion in SW. Uganda has been reported as one of the major biophysical constraints to food security and improved livelihood (FARA, 2009). Most of the soil fertility management techniques and practices used by smallholder farmers for this part of Uganda are reported in the overall FARA, report (2009) as poor and/or inappropriate thus resulting into soil mineral extraction, structural degradation and soil erosion hence leading to very low productivity of the area.

Studies of nutrient balance in SW. Uganda by Briggs and Twomlow (2002) concluded that soils on the hillsides of SW. Uganda are gradually becoming depleted of nutrients, as farmers give low priority to improving the nutrient status of hillside fields distant from homesteads. Similarly, Walaga *et al.,* 2002 and Ssali, 2000 in SW. Uganda also observes that declining fertility is worst on fields far from the homesteads where over half of the fields are suffering from declining fertility. Despite the fact that these studies have been done they do not capture integrated innovations for soil nutrient management under IAR4D interventions in agricultural research and development of the area.

According to De Jager *et al*. (1998), nutrient balances are computed as the difference between total nutrient inflows and total nutrient outflows and can be measured at various spatial scales ranging from plant, plot, field, farm, community, regional, national and continental. Wijnhond *et al*. (2003) also assert that combination of social-economic data, field and farm scale, nutrient balances can also help to identify factors important for sustainable soil fertility management. Whitbread *et al.,* 2003, Nambiar *et al.,* 2001 and Bouma, 2002 reported that nutrient balances have been used as indicators of sustainability with respect of soil fertility. Relating them with farm household characteristics can therefore help to identify factors that influence sustainability of farming systems in SW. Uganda.

The Multistakeholder Innovation Platforms (IPs) established in SW. Uganda of the Lake Kivu Pilot Learning Site (LKPLS) on the basis of value chains of common socio-economic interests when monitored in terms of nutrient balances and compared against counterfactuals presents a great opportunity in understanding the factor controls of sustainable farming systems.

The major objective for this study was to evaluate nutrient balances at farm and crop level of farmers that are market oriented (IAR4D interventions) vis-a-vis those under the conventional system in Chahi sub-catchment of the LKPLS.

18.3 Methodology

The study was carried out in Chahi sub-catchment that drains into Lake Muhehe in South Western Uganda. The catchment was selected because it was one of the pioneer sub-catchments where the IPs organized under the IAR4D concept were established but also for its proneness to land degradation. It is overlain by young volcanic (Andosols) soils that are highly permeable, with a low P and a high land use intensity a low input.

Field data collection was carried out using a NUTMON structured questionnaire tool (Vlaming *et al*., 2001) from 30 farmers using a purposive sampling technique. Fifteen (15) of these farmers were members of IPs and had been involved in the IAR4D research experiments and fertilizer trials on some of their farms while the other 15 had not been involved in any IAR4D research activities. These farmers were requested to draw sketches (resource maps) of their fields followed by a farm tour-transect walk in their fields. Nutrient balances were computed using the NUTMON software version 3.5 from the inflow and outflow data at both farm and crop level.

18.4 Results and Discussions

18.4.1 Crops grown

Cereals (maize and sorghum), grain legumes (climbing and bush beans), root and stem tubers (potatoes, sweet potatoes) are the major crops in the study area. The traditional food crops mainly maize, sorghum and potatoes are sold in large quantities.

18.4.2 Crop nutrient balances for the two categories of farms (IAR4D and non IAR4D farms)

Nutrient balances for different crops in the study area indicated that N balance for beans was higher on IAR4D farms than non IAR4D farms when compared to other crops (Table 18.1). This is attributed to the ongoing integrated soil fertility management which involves use of mineral fertilizers, organic fertilizers (compost and crop residue reuse) and use of compatible rhizobia strain on bean experiment for IAR4D farmers as compared to the non IAR4D farmers. Use of IAR4D interventions increased P and K balances for IAR4D bean farms when compared to other crops. The NPK stocks for IAR4D farms were higher than those on non IAR4D farms. (960 N Kg/ha, 808 P Kg/ha, 950 K Kg/ha and 618 N Kg/ha, 315 P Kg/ha and 784 K Kg/ha) for IAR4D and non IAR4D respectively

Table 18.1: Crop nutrient balances on IAR4D and non IAR4D farms

Crop	Nitrogen		Phosphorus		Potassium	
	IAR4D	NON	IAR4D	NON	IAR4D	NON
Bean	0.9	-3.01	1.02	0.491	1.2	0.4
Potato	-1.18	-1.45	-0.04	-0.003	-0.283	-0.29
Maize	-0.7	-1.01	2.299	-0.33	3.33	2.447
Sorghum	0.59	-0.5	0.21	0.39	1.566	1.545
Nutrient stocks	960	618	808	315	950	784

Maize had less negative N balance on IAR4D farms when compared to non IAR4D farms for all the crops. This is attributed to the fertilizer experiments which were imposed on IAR4D farms in to characterize the responses of the different maize varieties.

18.4.3 Farm nutrient flows and balances

Interestingly, farm-level nitrogen balance for farms under IAR4D was more negative than the farms that were not under IAR4D interventions (Table 18.2). The difference may be attributed to the initial reluctance by farmers of IPs to use organic manures while expecting that credit would be accessed to procure inorganic fertilizer and yet negotiations were yet to be finalized. The major contributor of inflows of major nutrients on farms is organic manure amounting to 52%, 53% and 56% for NPK, respectively on IAR4D farms. On non-IAR4D farms its contribution is 70%, 88% and 90% for NPK, respectively. BNF (IN4) was the second major nutrient inflow on both farms, due to a traditional practice of rotating beans and other crops. Contributions of other inflows that included mineral fertilizer (IN1), atmospheric deposition (IN3) were small, whilst no grazing (IN2b) were used on any of the farms. The major nutrient outflows include crop products (OUT1) and leaching (OUT3) were higher on IAR4D farms as compared to non IAR4D (Table 18.2). Nitrogen is more leached compared to P and K.

Table 18.2: Average flows and balances for major nutrients (kg/ha) for the two categories of farms

	Nitrogen		**Phosphorus**		**Potassium**	
Inflows	**IAR4D**	**NON**	**IAR4D**	**NON**	**IAR4D**	**NON**
IN1	2	0	1.3	0	1.25	0
IN2	15.37	11.88	2.26	1.63	1.31	3.13
IN2b	0	0	0	0	0	0
IN3	4.22	1.36	0.69	0.22	1.38	0.89
IN4	7.99	3.59	0	0	0	0
ΣInflow	**29.58**	**16.83**	**4.25**	**1.85**	**3.94**	**4.02**
Outflows						
OUT1	-15.24	-10.79	-1.99	-1.69	-8.52	-5.77
OUT2	0	0	0	0	0	0
OUT2b	0	0	0	0	0	0
OUT3	-12.87	-6.13	-2.29	0	-0.15	-0.03
OUT4	-3.87	-1.84	0	-1.33	0	-0.2
OUT5	0	0	0	0	0	0
OUT6	0	0	0	0	0	0
ΣOutflow	**-31.98**	**-18.76**	**-4.28**	**-3.02**	**-8.67**	**-6**
Nutrient balance	**-2.4**	**-1.93**	**-0.03**	**-1.17**	**-4.73**	**-1.98**

IN1 Mineral fertilizers, IN2a Organic manures, IN2b Grazing, IN3 Atmospheric deposition, IN4 Biological nitrogen fixation, OUT1 Crop products, OUT2a Crop residues, OUT2b Manure, OUT3 Leaching, OUT4 Gaseous losses, OUT5 Erosion, OUT6 Human excreta

Balance = ΣIN - ΣOUT

18.4.4 Farm nutrient significant inflows and outflows in Chahi sub-catchment

Atmospheric deposition (IN3) was highly significant ($P \leq 0.05$) for all the nutrients (NPK) under IAR4D farms when a two tailed t- test was run. Organic manure (IN2) was found to be significant for all the nutrients in the two farms, however, under non IAR4D farms, the significance were higher as compared to IAR4D farms. This is attributed to the changes in the un-controlled amounts of manures these farmers use as compared to IAR4D farmers who have almost similar amounts of manures they are applying. The observations in grazing (IN2B) were not significant, this is due to the less livestock in this area and this is in tandem with what Briggs (2002) concluded that in SW. Uganda livestock contributions to nutrient inflows is very little since the number of livestock reared is less.

All outputs were significant for all the nutrients under IAR4D except cattle manure (OUT 2b) since the total livestock unit is very less in this area as compared to non IAR4D farms. Erosion (OUT 5) showed the highest significant difference ($P \leq 0.000$) under IAR4D due the control measures which have been implemented under these farms as compared to the other farms.

	Nitrogen				Phosphorus				Potassium			
Farm	**IAR4D**		**NON**		**IAR4D**		**NON**		**IAR4D**		**NON**	
Flow	t. val	sig	t.val	sig	t.val	sig	t.val	sig	t.val	sig	t.val	sig
IN1	1.193	0.242 Ns	.	.	.911	0.066 Ns	.	.	2.173	0.038*	.	.
IN2	3.489	0.004*	2.593	0.021*	2.918	0.011*	3.154	0.007*	2.948	0.011*	3.167	0.007*
IN2B	1.36	0.193 Ns	2.219	0.044*	1.145	0.271 Ns	1	0.334 Ns	1.246	0.246 Ns	2.045	0.06 Ns
IN3	6.04	0.000*	6.043	0.000*	1.919	0.076 Ns	1	0.334 Ns	6.043	0.000*	1.705	0.11 Ns
IN4	3.192	0.007*	3.272	0.006*	.	.	.	.	.	.	.	.
OUT1	-3.058	0.009*	-3.045	0.009*	-3.358	0.005*	-1.871	0.082 Ns	-3.25	0.006*	-3.014	0.009*
OUT2a	-3.308	0.003*	-2.972	0.006*	-1.01	0.321 Ns	-1.00	0.326 Ns	. -3.520	. 0.001*	-1.098	0.283 Ns
OUT2b	-1.404	0.182 Ns	-1.39	0.189 Ns	-1.404	0.182 Ns	-1.382	0.189 Ns	-1.404	0.182 Ns	-1.367	0.193 Ns
OUT3	-3.728	0.002*	-3.726	0.002*	-0.890	0.378 Ns	-1.614	0.117 Ns	-3.417	0.004*	. 4.14	0.000*
OUT4	-3.773	0.002*	-3.108	0.008*	-1.415	0.160 Ns	-2.97 2	0.006*	-1.01	0.321 Ns	-1.00	0.326 Ns
OUT5	-2.173	0.38 Ns	-1.482	0.149 Ns	-1.227	0.230 Ns	-1.482	0.149 Ns	-1.614	0.117 Ns	-1.55	0.323 Ns

Table 18.3: Farm nutrient significant inflows and outflows in Chahi sub-catchment

IN1 Mineral fertilizers, IN2a Organic manures, IN2b Grazing, IN3 Atmospheric deposition, IN4 Biological nitrogen fixation, OUT1 Crop products, OUT2a Crop residues, OUT2b Manure, OUT3 Leaching, OUT4 Gaseous losses, OUT5 Erosion, OUT6 Human excreta. * P < 0.05, Ns not significant

18.5 Conclusion and Recommendations

Farm-level nitrogen balances for both farm categories were negative. Phosphorus and Potassium balances are positive but very low. Most of the crop nutrient balances are negative and those which are positive are very low, implying that the current low- external input is not sustainable. The major avenues for nutrient inflows and losses are organic manures, biological nitrogen fixation and crop products harvested and sold and leaching.

Due to high costs, non availability and other constraints related to input use especially mineral fertilizer use and scarcity of ready markets for the outputs in this area, farmers have limited access to these markets. The feasible option is increased use of other sources of N P K as for sustainable fertility management especially if high yields are to be maintained. Forward – backward linkages should also be strengthened in order to contribute more favorable balances. We recommend that farmer's market institutional linkages should be supported more to increase access to credit, tap premium prices, increase profitability and increase investments in soil fertility management.

18.6 References

Briggs, L. and Twomlow, S.J., 2002. Organic material flows within a small holder highland farming system in south west Uganda. Agriculture, Ecosystems and Environment 89, 191-212.

De Jager, A., Nandwa, S. M., & Okoth, P. F.,1998. Monitoring nutrient flows and economic performance in african farming systems (NUTMON). I. Concepts and methodologies. Agriculture Ecosystems and Environment 71(1/2), 37–48.

Ebanyat, P., Ridder, N., De Jager, A., Delve, R., Bekunda, M. and Giller, K., 2010. Drivers of land use change and household determinants of sustainability in smallholder farming systems of Eastern Uganda Popul Environ 31, 474–506 .

Forum for Agricultural Research in Africa., 2009. Status of natural, social, financial, human and physical capital in the Lake Kivu Pilot Learning Site. Sub-Saharan African Challenge Programme. FARA, Accra, Ghana.

Henao, J. and Neidert, J., 1999. Estimation of nutrient depletion associated with agricultural production in Uganda. Draft, International Fertiliser Development Centre, Muscle Shoals, Alabama, U.S.A.

Kaizzi, C.K., Ssali, H., Nansamba, A. and. Vlek, P., 2002. The potential, and benefit of velvet bean (mucuna pruriens) and inorganic N fertilizers in improving maize production under soils of different fertility. Policy workshop, 17-19, April 2002 Africana Hotel, Kampala Uganda. Mimeo, Center for Development Research (ZEF) University of Bonn, Germany.

Nambiar, K.K.M, Gupta, A.R, LIS, O., 2001. Biophysical, chemical and social economic indicators for assessing Agricultural sustainability in Chinese Coastal Zone. Agriculture, Ecosystems and Environment 88(2), 129-136.

Nkonya, E., Kaizzi, C. and Pender, J., 2005. Determinants of nutrient balances in a maize farming system in eastern Uganda. Agricultural Systems 85, 155–182.

Sanchez, P. A., Izac, A. M. N., Valencia, I. and Pieri, C., 1996. Soil fertility replenishment in Africa: A concept note. Chitedze Research station/ Bunda College. Lilongwe, Malawi. Sasakawa Africa Association, Mexico City.

Shephered, K.D., Ohlsson, E., Okalebo, J.R., Ndufu, J.K., David, S., 1996. Potential impact of Agroforestry on soil nutrient balances at the farm scale in the east African highlands. Fert. Res 44, 87-99.

Smaling, E. M. A., 1993. An agroecological framework for integrated nutrient management with special reference to Kenya. PhD Thesis. Wageningen Agricultural University, Wageningen.

Ssali, H., 2001. Soil organic matter in Uganda and its relationship to major farming system. A resource paper submitted to the International Food policy Research Institute (IFPRI).

Stoorvogel, J.J., Smaling E.M.A., 1990. Assessment of soil nutrient depletion in Sub- Saharan Africa 1983-2000. Report 28 DLO Winand starring Center for integrated land, soil and water research (CSC-DLO), Wageningen Netherlands.

Stoorvogel, J. J., Smaling, E.M. A. and Windmeijer, P.N.,1993. Calculating soil nutrient

balances in Africa at different scales. I. Supranational scale. Fertility Research 35, 227 - 237.

Vlek, P. L. G., 1990. The role of fertilisers in sustaining agriculture in sub-Saharan Africa. Fertiliser Research 26, 327–339.

Walaga, C., 1999. Experiences in participatory Soil Fertility Research and Development in Kabarole and Pallisa Districts, Uganda. Environmental Alert, P.O. Box 11259, Kampala, Uganda. Soil and Water Conservation Society of Uganda Conference Proceedings. Printed in Uganda. All rights reserved. ISBN 9970 814 01 0.

Wortmann, C.S., 1999. Nutrient budgets: Understanding the problems, causes and trends of Soil resource degradation. Department of Agronomy and Horticulture. University of Nebrasha Lincoln. 279 Plant Science, Me 68 583, USA. Soil and Water Conservation Society of Uganda Conference. Proceedings. Printed in Uganda. All rights reserved. ISBN 9970 814 01.

Wortmann, C. S. and Kaizzi, C. K., 1998. Nutrient balances and expected effects of alternative practices in farming systems of Uganda. Agriculture, Ecosystems & Environment 71(1), 115–129.

Whitbread A. M., Blair G. J., Konboon, Y., Lefroy, R. D. B., Naklang, K., 2003. Managing crop residues, fertilizers and leaf litters to improve soil C, nutrient balances and the grain yield of rice and wheat cropping systems in Thailand and Australia. Agriculture, Ecosystems and Environment 100, 251-263.

Centre for International Capacity Development
CICD
Zentrum für Entwicklungsländerforschung und Weiterbildung
ZEW

Universität Siegen
D-57068 Siegen
Germany
Tel.: 0049-(0)271-740-4438
Fax: 0049-(0)271-740-4382
info@cicd.uni-siegen.de
www.cicd.uni-siegen.de

ISSN 1868-8578