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Integrated Research Programme

Smallholder System Innovations in Integrated Watershed Management:
[SSI Programme]

**Strategies of Water for Food and
Environmental Security in Drought-prone
Tropical and Subtropical Agro-ecosystems
(Tanzania and South Africa)**

FUNDED BY

Sida, DGIS, WOTRO, IWMI, UNESCO-IHE, SEI and
Stockholm University

Final Report

1st July 2003 – 30st June 2009

by

UNESCO-IHE & IWMI



UNESCO-IHE
Institute for Water Education



IWMI
International
Water Management
Institute

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List of Abbreviations and Definitions

ACT	African Conservation Tillage
ARC	Agricultural Research Council
BEEH	School of Bioresources Engineering and Environmental Hydrology, University of KwaZulu-Natal
DALDO	District Agricultural and Livestock Development Office
DGIS	the Directorate General for International Cooperation of the Netherlands Ministry of Foreign Affairs
DWAF	Department of Water Affairs and Forestry
ERT	electrical resistivity tomography
<i>fanya juu</i>	contour ridges
FLGs	farmer learning groups
FSG	Farmers Support Group, University of KwaZulu-Natal
IRD	Institut de Recherche pour le Developpement
IWMI	International Water Management Institute
IWRM	Integrated Water Resource Management
<i>lambos</i>	charco dams
MAFS	Ministry of Agriculture and Food Security
MSc's	Researchers doing Masters degree studies
<i>ndivas</i>	storage reservoirs
NWO	Netherlands Organisation for Scientific Research
PBWO	Pangani Basin Water Office
PDs	Researchers doing post-doctorate studies
RELMA	Regional Land Management Unit
SAIPRO	Same Agricultural Improvement Project
SCAPA	Soil Conservation and Agroforestry Project in Arusha
SEBAL	surface energy balance algorithm for land
SEI	Stockholm Environmental Institute
SIDA	the Swedish International Development and Cooperation Agency

SSI	Smallholder System Innovations in Integrated Watershed Management
SSI-SC	SSI Programme Steering Committee
SUA	Sokoine University of Agriculture
SWMRG	Soil and Water Management Research Group, Sokoine University of Agriculture
TMA	Tanzania Meteorological Agency
UKZN	University of KwaZulu-Natal
UNESCO-IHE	Institute for Water Education
VECO	Vredeseilanden Country Office
WOTRO	the Netherlands Foundation for the Advancement of Tropical Research, which resides under the Netherlands Organisation for Scientific Research

Basic Data

Countries: Tanzania, and South Africa

Project name: Smallholder System Innovations in Integrated Watershed Management: Acronym [SSI]
Strategies of water for food and environmental security in drought-prone tropical and subtropical agro-ecosystems (Tanzania and South Africa)

Activity number: WOTRO 01.65.213.00 (WAM 53-338, WAM 53-339, WAM 76-235)
Sida NATUR-2001-3037 Component 7300042801
DGIS DMW 60/04

Executing organisations

Coordinating Institute: UNESCO-IHE, The Netherlands

Counterparts: International Water Management Institute (IWMI),
University of KwaZulu-Natal, School of Bioresources Engineering and Environmental Hydrology (BEEH);
Sokoine University of Agriculture, Soil and Water Management Research Group (SWMRG);
Stockholm University, Department of Systems Ecology (SU)

Project period: 1 July 2003 – 30 June 2009

Final report

Reporting period: 1 July 2003 – 30 June 2009

1. INTRODUCTION

This document is the Final Report of the SSI programme covering the period 1 July 2003 to 30 June 2009.

1.1 The SSI programme

The SSI programme was an applied research initiative studying smallholder system innovations in integrated watershed management. It was funded by the Swedish and Dutch governments through Sida (the Swedish International Development and Cooperation Agency), WOTRO (the Netherlands Foundation for the Advancement of Tropical Research, which resides under the Netherlands Organisation for Scientific Research [NWO]), DGIS (the Directorate General for International Cooperation of the Netherlands Ministry of Foreign Affairs) and by UNESCO-IHE and IWMI. The Stockholm Environmental Institute (SEI) partly finances the SSI-Post Doc position at IWMI (project 5). Additional funds were found at Stockholm University and University of KwaZulu-Natal for supplementing personnel costs.

The SSI programme was a multi-disciplinary initiative aimed at improving the livelihood of rural communities in sub-Saharan Africa. The core of the SSI programme was research, with the overall objective of producing high quality science. At the same time, the programme was applied, and focused on improving the livelihoods of the rural poor making their living in savannah agro-ecosystems by investigating sustainable options of unlocking the potential of smallholder farming systems. The SSI programme thereby contributed to the UN endeavour of achieving the Millennium Development Goals to halve poverty and malnourishment by 2015 in hot-spot regions such as water scarcity prone rural communities in sub-Saharan Africa.

1.1.1 Objectives

The original objectives formulated were:

1. To analyse the hydrological, environmental and socio-economic consequences of upscaling water system innovations in smallholder predominantly rainfed agriculture at watershed scale
2. to develop methodologies and decision support tools for improved rainwater management and equitable sharing of water between upstream and downstream users in nature and society
3. to translate knowledge on the links between intensification of agriculture through water system innovations, and its impacts on water, food and ecosystems at watershed and river basin scale, into useable tools for planning and policy
4. to contribute to human capacity building on integrated resources management with specific focus on balancing water for food and nature, in Southern Africa through PhD, MSc training, and workshops.

Later, in 2004, the scope of the programme was expanded to accommodate an 'Outreach and Action Learning' component, which resulted in the inclusion of three further objectives:

5. to operationalise and contextualise lessons learned from the SSI research

6. to disseminate knowledge and research methodologies from SSI to Sida supported water initiatives in Southern Africa
7. to share lessons learned from the SSI programme with the Dialogue for Water Food and Environment (DWFE) in order to contribute to the development of a Learning Framework (*N.B. The DWFE initiative ceased to exist in 2005*)

The SSI programme generated three distinct categories of outputs:

1. Knowledge building and advancement of science
2. Human capacity building in integrated water resources management
3. Support to institutional, planning and policy development in integrated water resource management.

1.1.2 Programme overview

The SSI programme studied the potential of indigenous and exogenous water system innovations in smallholder farms for improved land and water productivity. These innovations can range from *in situ* practices, such as deep tillage and zero tillage, to infrastructural interventions, such as underground storage tanks and small storage structures. The programme not only aimed to achieve excellence in scientific research but also to deliver results that are of practical use to development planners to improve the livelihoods of rural communities and to disseminate the research findings across sub-Saharan Africa.

SSI investigated aspects such as adoption and adaptation of these innovations (project 1) and the increase in production that result from them (project 2). The effects of these innovations on surrounding systems has often been neglected in previous research, but was highlighted in the programme. This included the study of physical, ecological and social consequences downstream of sites implementing these innovations (projects 3 & 4). A spatial analysis was carried out to identify appropriate sites for implementation of different innovations (project 5). The institutional arrangements and set-up for facilitating adoption and adaptation of good practices were also investigated (project 6) (Figure 1.1).

The SSI programme also contributed to the human capacity building activities on Integrated Water Resource Management (IWRM) carried out by WaterNet in the SADC region. It was one of the two WaterNet research programmes, together with the Challenge Program on Water for Food (CP17), which had a similar scope on agricultural water management and IWRM in the Limpopo basin. In addition, the SSI outreach project funded by Sida created the opportunity to let the local communities benefit and participate in the SSI research. The SSI programme had a strong human capacity building dimension. The programme included 7 PhD projects and 3 Post-Doc researchers, and hosted numerous MSc students from the WaterNet regional Master programme in IWRM and from the participating institutions.

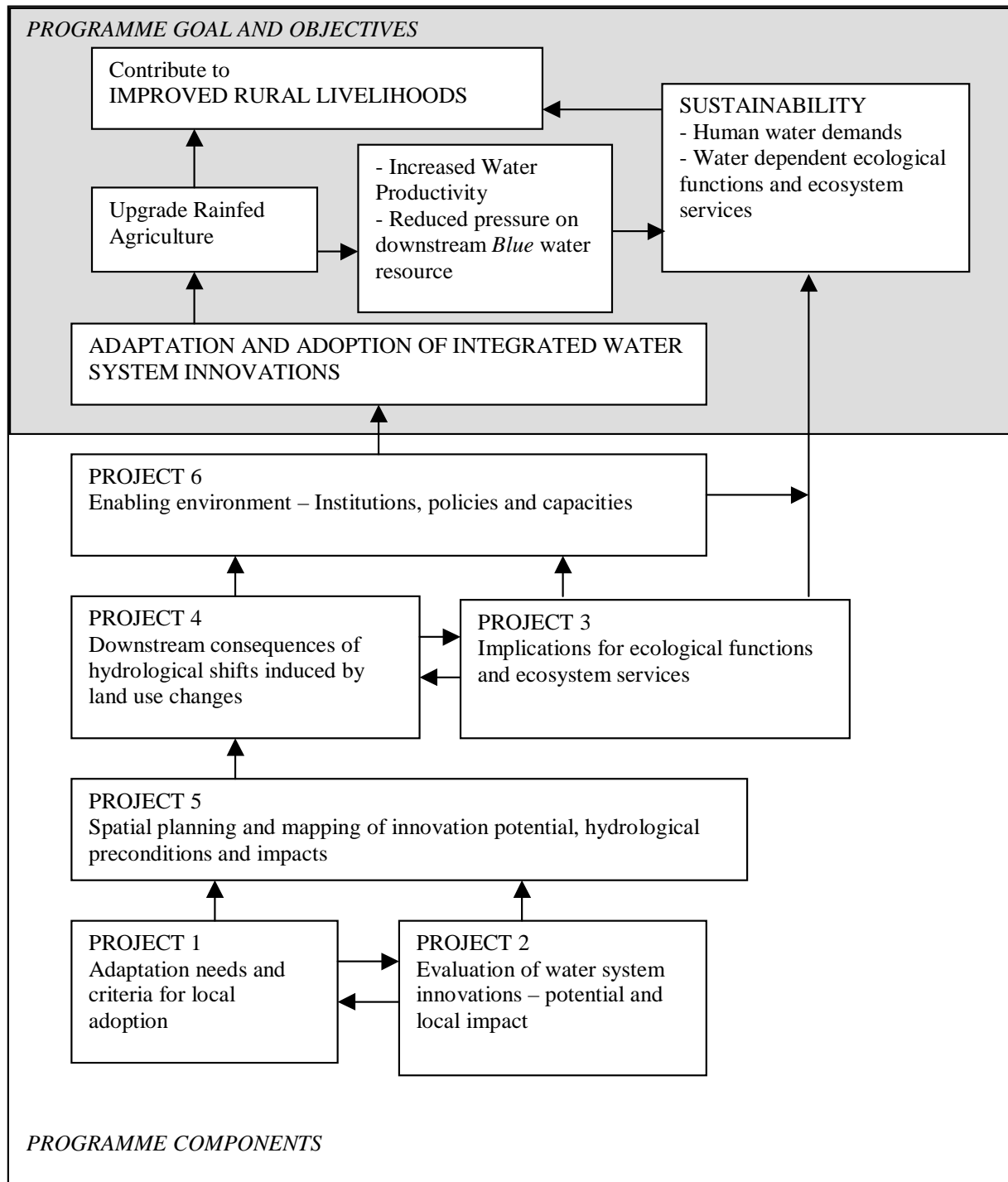


Figure 1.1: Structure of the SSI programme

1.2 Institutions and personnel

The research was primarily carried out by 7 PhDs and 3 Post-doc fellows (see Table 1-1). Five research institutes are involved in the SSI programme;

1. International Water Management Institute (IWMI),
2. UNESCO-IHE Institute for Water Education,
3. University of KwaZulu-Natal, School of Bioresources Engineering and Environmental Hydrology (BEEH),

4. Sokoine University of Agriculture (SUA), Soil and Water Management Research Group (SWMRG), and finally,
5. Stockholm University, Department of Systems Ecology.

The research on the ground was supported by research assistants, who were in the field almost full time, and outreach officers, who facilitated the interactions and outreach with the respective local communities.

Table 1.1: SSI projects and PhD and Post-doc fellows as of December 2008.

Project	Title	PhD fellows	Host institution
Project 1	Adaption needs and criteria for local adoption	Kenneth Masuki Dr. Siza Tumbo (PD)	SUA, Tanzania
Project 2	Evaluation of water system innovations-potential and local impact	Hodson Makurira Job Rotich Kosgei	UNESCO-IHE BEEH, RSA
Project 3	Implications for ecological functions and ecosystem services	Elin Enfors Dr. Line Gordon (PD)	SU, Sweden
Project 4	Downstream consequences of hydrological shifts induced by land use changes	Marloes Mul Victor Kongo	UNESCO-IHE BEEH, RSA
Project 5	Spatial planning and mapping of innovation potential, hydrological preconditions and impacts	Dr Jayashree Pachpute (PD)	IWMI UNESCO-IHE
Project 6	Enabling environment-Institutions, policies and capacities	Hans Komakech	IWMI UNESCO-IHE

2. CONTEXT

2.1 Field research sites

The SSI research was carried out in two river basins in Southern Africa, the Pangani in Tanzania and the Thukela in South Africa. The SSI team selected Makanya catchment in the Pangani basin because it could benefit from previous research that SUA had conducted in this area, including a field office that was available to the SSI researchers. SSI concentrated on the Vudee catchment, a sub-catchment to the Makanya catchment. The SSI team in the Potshini catchment in the Thukela basin was introduced to the area by the Landcare project, which established several trial sites in the area and were one of the partner institutions for SSI. The reasons for the choice of these two sites are discussed in further detail in section 2.3.2.

2.1.1 The Pangani River Basin

The Pangani River Basin is one of the nine drainage basins in Tanzania. It extends from the northern highlands to the north-eastern coast of the country. The hydrology of the Pangani is highly influenced by rivers rising from the mountains and highlands (Kilimanjaro, Meru and Pare Mountains). The Makanya was the pilot catchment for the SSI research. It is located in the South Pare Mountains in the mid-reaches of the Pangani River Basin. It represents typical semi-arid to dry sub-humid rainfed Agrarian conditions, and manifests strong signs of human induced land degradation due to high pressure on soil and water resources. Land use changes upstream affect the hydrology downstream and cause erosion. The SUA team had a long track-record of research in the Makanya watershed before the start of the SSI research programme, focussing on soil and water management and participatory rural development.

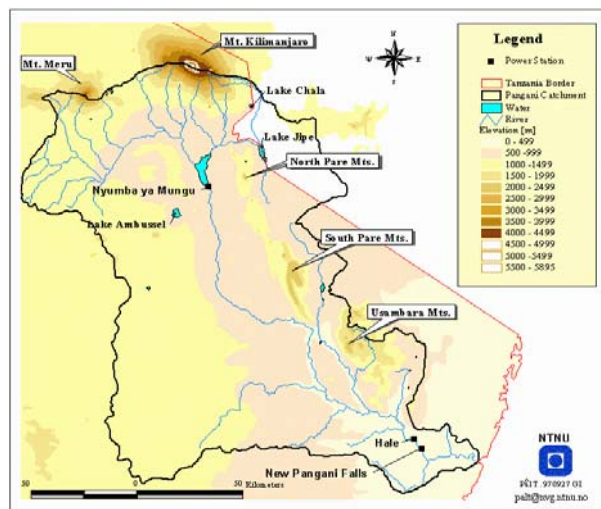


Figure 2.1: Pangani River Basin

Farmers in the Makanya catchment use different types of water system innovations to secure water to their crops, including runoff diversion, storage reservoirs (*ndivas*), charcodams (*lambos*) and tied-ridges.

Farmers in the Makanya catchment use different types of water system innovations to secure water to their crops and household use. Generally, there is substantial adoption of canals (between 12% and 42%), *ndivas* (between 11% and 25%) and terraces (between 7% and 48%). Meanwhile there is little adoption (below 13%) of other technologies including ridges, taps, borders, deeptill, mulching, borders and charcodams.

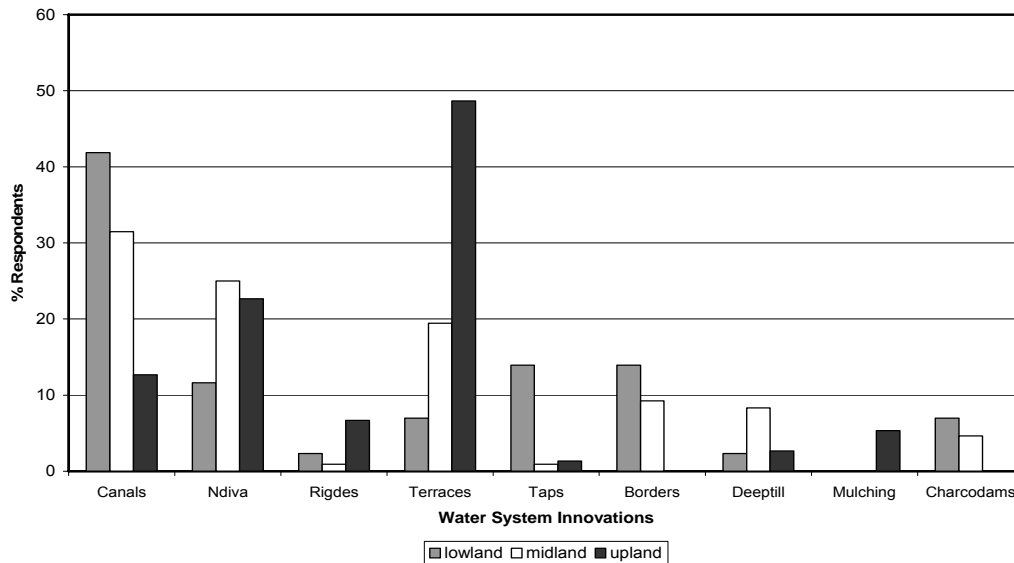


Figure 2.2: Water system innovations as a function of toposequence.

In the upland, terraces, which are an exogenous technology, are the most highly adopted WSIs (48%). However, it decreases towards midslope (19%) and lowland (7%). The greater extent of terraces in the upland compared to midslope and lowland can quickly be justified by the steep terrains in the upland areas. Conversely, respondents in the lowland showed strong adoption of canals (40%). The extent of adoption of canals decreased with altitude (about 20% in the midslope and upland is only 12%). Farmers in the uplands indicated deep gullies in their areas are the reason for low adoption of canals. In the lowland gullies are very shallow and therefore diversion of water is much easier. See for an overview Figure 2.2.

The extent of adoption of *ndivas* is higher in the midslope (25%), followed closely by upland (22%) and far behind in the lowland at 12%. The survival of *ndivas* is mainly through diversion of water from perennial or seasonal rivers. These rivers start in the upland and end in the midslope beyond which you have dry gullies. Details on the information regarding water systems innovation in Makanya catchment is provided in Tumbo et al. (submitted) and Tumbo (2006).

2.1.2 The Thukela River Basin

The Thukela River is the principal river of KwaZulu-Natal province in South Africa. It is a physiographically, climatologically, hydrologically and socio-economically diverse watershed on the east coast of the country. The basin is characterised by a juxtaposition of “first world” commercial agriculture and industrial economies and “third world” impoverished communities dependent upon subsistence farming in degraded areas.

The Potshini catchment in the upper reaches of the Thukela was the pilot study area for SSI research. The ARC (Agricultural Research Council) had set-up an experimental demonstration farm where trials were carried out together with farmers on soil BMP - best management practices - for dry land agriculture including soil fertility management, inter cropping, conservation farming, liming. The objective was primarily crop productivity improvements and soil erosion control. The SSI partnership added the element of water management and research

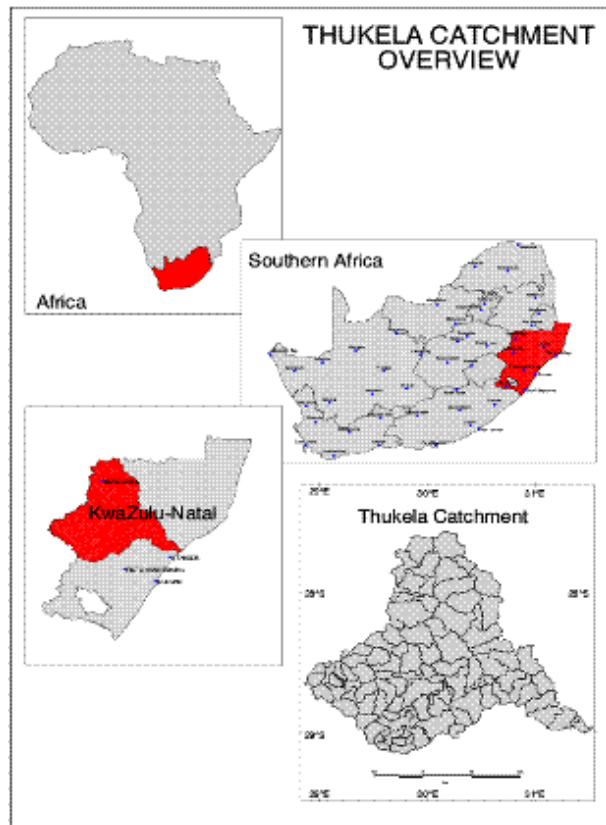


Figure 2.3: Thukela River Basin.

2.2 Programme management

The SSI programme was coordinated by UNESCO-IHE and IWMI. UNESCO-IHE was the overall SSI programme coordinator. UNESCO-IHE and IWMI shared the financial management of the programme, where UNESCO-IHE coordinated the grants from WOTRO and DGIS, while IWMI coordinated the grant from Sida. UNESCO-IHE and IWMI jointly coordinated narrative progress reporting.

The SSI programme established a Steering Committee (SSI-SC), chaired by IWMI, and made up of representatives from the five SSI partner institutions, which was responsible for decisions such as: a) sharing information and address/ take decisions on overarching programme issues, b) take decisions on programme management, c) coordinate SSI programme reporting, d) agree on use of programme funds, e) identify and pursue possibilities of additional funding to SSI and f) the attachment of MSc and PhDs, g) coordinate SSI thematic workshops and other meetings. The field research was coordinated by the two host institutions, SUA and UKZN for Makanya and Potshini, respectively.

The main challenge with this integrated programme was how to integrate the different components of the research. This integration was done at the level of the PhD research projects, where information gathered from other researchers was integrated into their outputs. This resulted in several co-authored (peer-reviewed) publications,

often about integrated research in the same basin. At project level (one discipline) several concept papers were developed to develop the common understanding of the challenges related to a certain discipline. At programme level, several topics have been addressed during SSI meetings, which received input from all disciplines (the themes were: Environment and Livelihoods). This programme integration has been carried out mainly by the supervisory team. The synthesis papers in this report are an example of the integrated output from the SSI research programme.

Each year a scientific workshop was held in one of the research basins, at these meetings all researchers met and exchanged ideas. The original proposal allowed for 4 workshops, instead, at the end of the programme 7 workshops were held:

- Inception workshop 19-23 May 2003, Pietermaritzburg, South Africa (sponsored by WaterNet)
- 1st scientific workshop 19-23 December 2003, Moshi, Tanzania
- SSI Outreach and DWFE Learning Framework Development Workshop, 11-16 July 2004, Pretoria and Drakensberg, South Africa
- 2nd scientific workshop 12-17 December 2004, Pietermaritzburg, South Africa
- 3rd scientific workshop 23-27 January 2006, Same, Tanzania
- 4th scientific workshop 19-24 January 2007, Didima Camp, South Africa
- 5th scientific workshop 20-25 January 2008, Same, Tanzania

2.3 Field research implementation

2.3.1 Field set-up

The main aim of the field research is to identify suitable strategies to improve the use of the primary source of fresh water, which is rainfall (e.g., by promoting the infiltration of rainwater or by improving land preparation) and/or by increasing the supply of water to crops (e.g., through runoff harvesting from adjacent fallow lands, and rooftop rainwater harvesting).

As already mentioned, Makanya catchment was selected for watershed and field level studies within the Pangani Basin. This catchment was selected because already Sokoine University of Agriculture (SUA) had established itself in the catchment in soil and water related research. The catchment had various types of water systems innovations, upstream downstream issues, smallholder agriculture and the Pangani River on the downstream side. All these were pre-conditions for a successful SSI research programme.

In the Makanya catchment, the Vudee catchment was selected as the research site for the small and medium scale hydrological modelling. Most of the farmers participating in SSI activities had their farms within this catchment or were being supplied with water from the stream through small storage structures, locally known as *ndiva*. However, two farm sites were located in Mwembe (see Figure 2-1), outside of Vudee catchment. Five farm sites were used for the water balance study and three farm sites were studied for slow changing variables in the soil. There was one overlapping farm site between the two studies.

In the Thukela basin, following discussions with the various stakeholders, including other researchers and the national and provincial departments of agriculture, the Emmaus area in the upper reaches of the Thukela Basin was identified as being suitable to meet SSI project aims and proposed outcomes. A research field site was established in this area within the Potshini catchment, close to the village of the same name.

The Potshini catchment was considered ideal as the primary SSI research site in South Africa for a number of reasons:

- It is a headwater catchment, so the impacts of activities in the catchment could be monitored without having to account for upstream effects.
- Small agriculture was prevalent, but opportunities for yield enhancements were high as was demonstrated by Agricultural Research Council (ARC) landcare project that was active in the area prior to SSI activities being initiated and the high yields obtained by adjacent commercial farmers.
- The highly seasonal nature of the rainfall pattern suggested that small storage systems and rainwater harvesting could be beneficial in the catchment.
- Although the community had been exposed to some research through the ARC project, there was no evidence of donor fatigue. Rather, from the initial meetings, community leaders expressed an enthusiasm to collaborate with “water and agriculture” initiatives.
- The juxtaposition of a relatively impoverished rural smallholder community and wealthy commercial farming operations which relied on water generated in the upstream village provided unique hydro-political research opportunities.
- The study could complement other research activities in the broader upper-Thukela catchment (hydrological analyses of conserved grasslands and commercial afforestation) by providing different hydrological monitoring in a different landscape.

2.3.2 Farm level installation

In Makanya, the field scale data collection concentrated around 5 research farmers, Wilson Mbwambo, Eliza Mdee, Rajabu Omari, Iddi Mrindakaa and Walter Mjema. These farmers were selected through a meeting between village leaders. Before the selection exercise, a meeting was held between SSI team on one side and extension agents, district officers and village leaders. In the meeting, the SSI team introduced the project and indicated that it will need to have farmers who will volunteer to work with researchers in the programme. Following the meeting, village leaders and extension workers went ahead to identify farmers and the final research farmers were agreed together with SSI researchers. At Iddi's place both the field scale water balance and the slow changing soil variables were investigated. A gully diversion structure diverted water into the field (see Figure 2.4). This is the site with the lowest amount of rainfall, however with this technology the yields observed were the highest. In addition, the *fanya juu*¹ system provided the opportunity to diversify the crops (e.g. next to maize, bananas and cassava's are planted). This is also the site where monitoring will continue for the soil variables, now coordinated by Jennie

¹ Fanya juus are a soil and water conservation technique practiced more commonly in some parts of East Africa. They are basically soil ridges within cultivated land where trenches are dug and the excavated soil is placed upslope to form bunds (Makurira et al., 2009).

Barron. The trials were set out in areas where the farmers often did not farm intensively before (dry rainfed plots), the trial plots clearly showed more productivity and diversity than neighbouring plots. However, none of the neighbours copied the innovations from the research farmers, as it is a labour intensive job.



Figure 2.4: *Iddi Mrindakaa and his family at the diversion structure and the field plots.*

At Walter Mjema's homestead water is diverted from behind his house onto his plot (see Figure 2.5). Walter uses the *fanya juu* to grow grasses to feed his cattle. In addition, Walter uses his rooftop to harvest water, which he collects in a tank near his house. This water is used for domestic use and a small kitchen garden. At this site only the field scale water balance was investigated.

Field scale water balance

The field scale water balance consisted of measuring rainfall, runoff, soil evaporation, transpiration, soil moisture variation measurements. Other on-field measurements taken included monitoring of crop growth, leaf area, infiltration, the effect of different tillage techniques e.g. ripping, *fanya juu*, impact of manure application and/or cover cropping were being observed. Figure 2.5 shows the experimental lay-out.

The experiments were executed for several different farm management techniques, ranging from deep tillage, contour ridges (*fanya juu*) and supplementary irrigation.

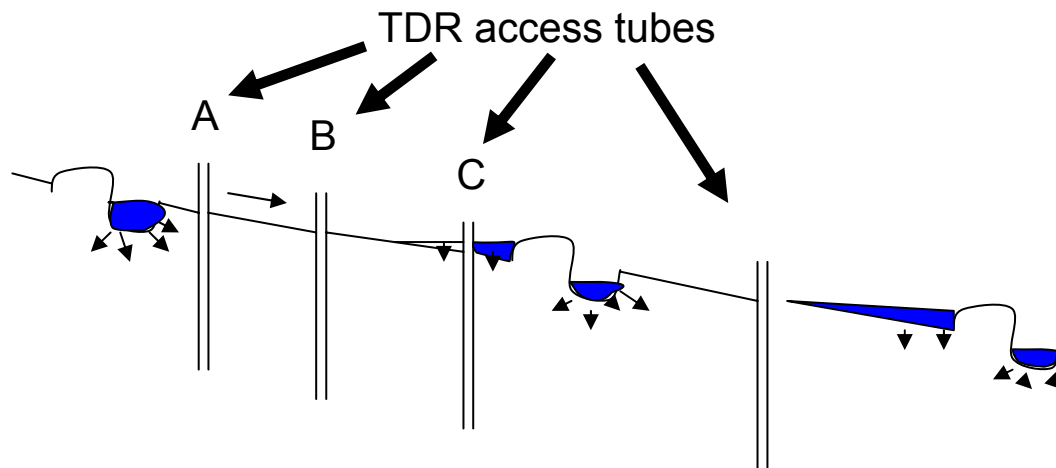


Figure 2.5: *Experimental lay-out of water balance studies, schematisation shows three fanya juus, TDR tubes monitor soil moisture at different locations and depths.*

Slowly changing soil variables

Several slow changing soil variables were monitored, including nutrients, water holding capacity etc. Different treatments were applied to assess how the slow changing soil variables responded. These treatments included ripping versus hand hoe ploughing, mulching, and the use of cover crops (Figure 2.6), were all done under rainfed conditions. During most seasons that were monitored, water was the constraining factor and the yields from the different treatments were very similar. Only after a good rainy season did the treatments show significant difference, with the combination of ripping and mulching performing the best. Continuation of the monitoring should reveal if the yield increase is related to a positive effect on the soil properties.



Figure 2.6: *Monitoring slow changing soil variables.*

In the Thukela catchment, inadequate soil moisture to sustain crop growth throughout the growing season, common in sub-Saharan Africa including most parts of the summer-rainfall region of South Africa, is largely associated with intra-season and annual dry spells that result in yield reduction and sometimes complete crop failure depending on their severity and the stage of crop development that they occur in. The SSI project has undertaken field trials in the Potshini site, to assess the potential

of some rainwater harvesting methods, reported to have been used successfully in the Sahel and Eastern Africa, in an effort to quantify the extent to which they can mitigate dry spells in the Potshini catchment. The water-fertilizer synergy in boosting yields was also investigated. In this particular study, in-situ water harvesting method that is aimed at concentrating rainfall and enhancing its infiltration into the soil and water harvesting with storage, perceived to provide more insurance against the dry periods, especially if they are longer.

In-situ water harvesting and water productivity studies

The in-situ water harvesting trials were based on the principles of conservation agriculture with the control being conventional tillage under the typical farmer's practice. The trials were conducted in two categories, i.e., in 3 farmers' fields (farmer-managed – sites 3, 4 and 11) and in a communal trial site (researcher-managed – site 2). The farmer-managed trials, the experimental set-up was as follows:

- Conservation tillage only
- Conservation tillage with fertilizer added
- Conservation tillage with supplemental irrigation
- Conservation tillage, fertilizer added and supplemental irrigation
- Conventional tillage with supplemental irrigation
- Conventional tillage only



Figure 2.7: Farmer-managed trial site – runoff plots.

In the communal trial site five treatments were monitored:

- Conservation tillage, summer intercrop and mulch;
- Conservation tillage, summer intercrop and grazing;
- Conservation tillage and grazing;
- Conservation tillage, winter intercrop and mulch; and
- Conventional tillage and grazing.

In each runoff plot, a TDR access tube, an automated Watermark® sensor and a tipping bucket with a logging system were installed for monitoring moisture content, wetting fronts and runoff respectively. In addition, sediment load from each of the five treatments in the communal trial sites was investigated.



Figure 2.8: *Communal trial site (researcher-managed) – runoff plots, tipping buckets, splitters and sediment load sampling tanks.*

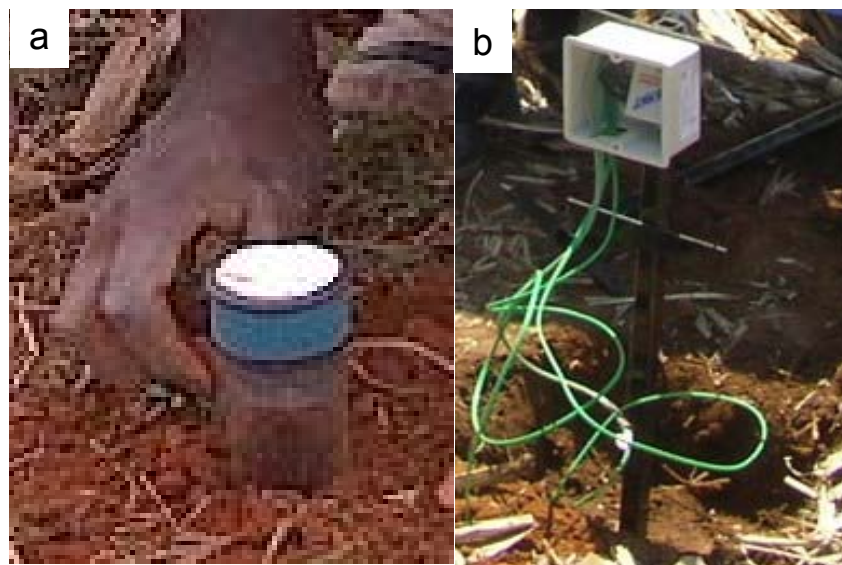


Figure 2.9: *TDR-access tube (a) and Watermark sensor nests (b) installed equipped in all runoff plots.*

To be able to evaluate exhaustively the contribution of the runoff harvesting approaches towards yield improvement, climatic, meteorological and actual crop water-use data was necessary. Rainfall was recorded voluntarily by 16 farmers using manual rain gauges while two automatic rain gauges have been installed in the catchment. A weather station (site 16) was used to capture the meteorological data required as inputs in the Penman-Monteith model for estimating the potential evapotranspiration for approximating the seasonal crop water requirements.

A transpiration meter, the Dynagage Sap Flow Sensor, was used to measure the actual amount of water that an individual plant abstracts from the soil in a specific period. Biomass production was continuously monitored in all crop growth stages by direct measurement of the basic plant morphological parameters e.g. leaf dimensions, height and stem diameter.

Rainwater harvesting storage and utilization

Rainwater storage structures may be above ground, partially below or under the ground surface. In Potshini, two-5 m³ plastic tanks (sites 11 and 16) have been installed, one to collect water from a corrugated iron sheet roof and the other from thatch roof.

After a thorough infrastructural and agrohydrological appraisal, a plastic-lined, 50-m³ underground tank was constructed at one of the farmer's homesteads (site 3) to provide water for total irrigation of vegetables in winter and for bridging intra-seasonal dry spells in summer. A silt trap eliminates most of the coarse particles. A piezometer has been installed to detect water level fluctuations during inflow events as well as when water is abstracted from the tank for purposes of irrigation or other uses.

2.3.3 Catchment level installation

In both catchments the runoff installation was done in a nested catchment approach, where the smallest catchment was located within the next level catchment, which in turn was located in the largest scale catchment.

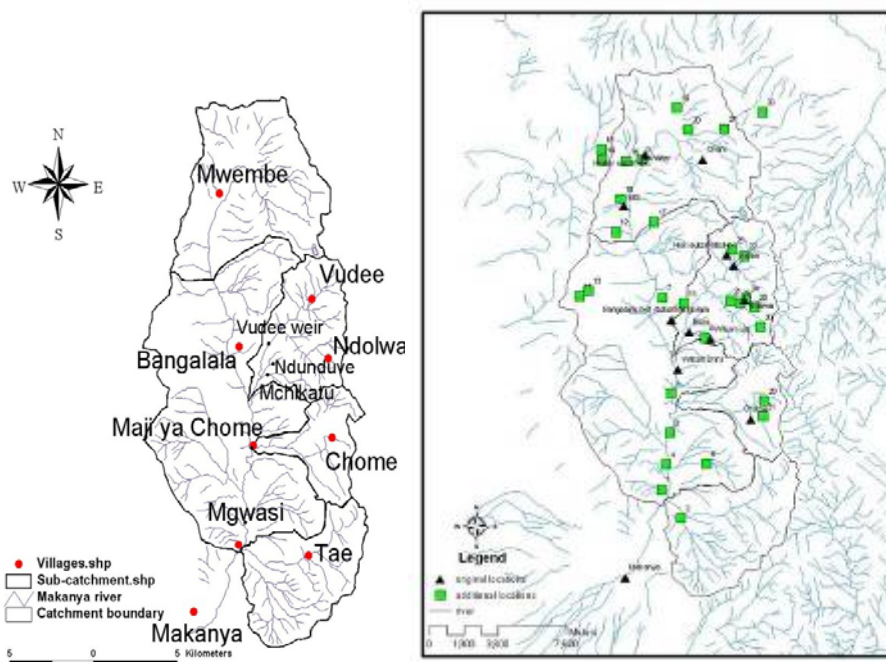


Figure 2.10: Locations of runoff (left) and rainfall (right) measurements (locations with a black triangles were installed in 2004, the green squares were installed in 2006 for the spatial rainfall analysis) in Makanya catchment, Pangani river basin, Tanzania.

In the Makanya catchment, different hydrological determinants and land use changes were studied at different nested catchment scales, where the smaller scale is embedded within the next scale, enabling the research of scale interactions between different critical eco-hydrological parameters. Runoff in the Makanya catchment was monitored at several locations (see Figure 2.11). The main location was Vudee sub-catchment where the SSI programme together with PBWO² installed a compound

² Pangani Basin Water Office

weir in August 2004 (Bhatt et al., 2006). At the weir location the total river flow from the two upstream catchments was measured, just before the Manoo and Mkanyeni micro dams divert the water. The compound weir consists of a V-notch, which is able to measure low flows very accurately and a rectangular shaped weir, which can cope with large flows. This part of the river is perennial and an observer, a neighbouring farmer takes three times a day level measurements. In 2006, a pressure transducer started recording on hourly time steps. In addition, discharge has been measured in two small headwater catchments in Upper-Vudee. The two catchments have different land use, one is mainly dominated by indigenous forest and the second is mainly agricultural land, both catchments have an area of less than 1 km².



Figure 2.11: Runoff measurements in Makanya catchment.

The raingauges network currently consisted of 45 manual raingauges, 6 automatic raingauges and one meteorological station (Figure 2.12). Rainfall measurements were done by the farmers themselves, who were taught how to analyse it. Therefore, the data obtained were not only helpful in defining the spatial rainfall variability in the catchment but were also useful for the farmers.



Figure 2.12: The meteorological station at Bangalala and an automatic rain gauge.

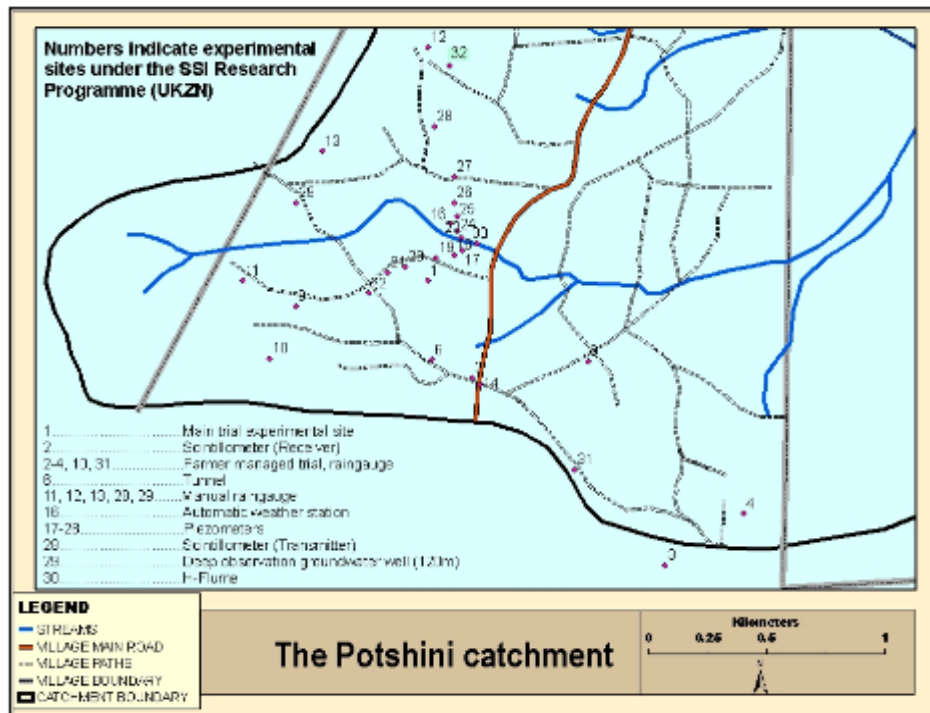


Figure 2.13: The Potshini Catchment monitoring network.

In the Potshini catchment, since 2004, various instruments and structures were installed and constructed in the Potshini catchment for the purposes of monitoring hydrological phenomena at both field and catchment scale. Monitoring was intended to assist in the identification and understanding of the dominant hydrological processes, flow paths and ultimately to investigate the hydrological impact of adapting agricultural water use innovations (rainwater harvesting) within the catchment. The Potshini catchment monitoring network comprised gauging structures and instrumentation, mostly automated, for measuring and monitoring stream flows, overland flow from experimental runoff plots, sediment load, shallow and deep ground water tables, subsurface resistivity using electrical resistivity tomography (ERT), isotopic composition (Deuterium and Oxygen-18) in both surface and subsurface water, volumetric soil moisture content, soil hydraulic parameters and meteorological parameters.



Figure 2.14: The Potshini H-Flume, and Pressure transducer at the outlet of the Potshini catchment.

The application of scintillation techniques (Large Aperture Scintillometer) in estimating total evaporation in the Potshini catchment formed an intermediate observation and a calibration scale for remote sensed estimates of total evaporation from satellite images in the catchment and the Thukela river basin at large, using the surface energy balance algorithm for land (SEBAL). The catchment monitoring network was established in collaboration with other stakeholders, most notably the community members of Potshini (Kongo et al., 2006). The Figures below show some of the instruments and structures comprising the Potshini catchment monitoring network.



Figure 2.15: The Potshini Automatic Weather Station and Large Aperture Scintillometer.



Figure 2.16: Installation of piezometers with Potshini High School pupils during their work experience week (left) and deep observation groundwater borehole (120 m deep, right).



Figure 2.17: Electrical resistivity survey.

2.3.4 Establishment in community

The SSI team in the Makanya catchment benefited from previous research that SUA conducted in this area. In Makanya, the field office was already established and maintained for the SSI research. SSI concentrated, in particular with the field installations, on the Vudee catchment, a sub-catchment to the Makanya catchment. The people in the villages Bangalala, Vudee, Mwembe and Ndolwa were actively involved in SSI activities. Five research farmers made their farm fields available for SSI, either in the water balance study or for the slow changing soil variables. More than 300 farmers participated in workshops, questionnaires and discussion groups. A limited number of farmers were involved in intensive daily or weekly data gathering and have helped in construction and installation of several measuring devices. Most of these farmers involved with intensive field data gathering were compensated for their times.

The SSI team in the Potshini catchment had been introduced to the area by the Landcare project, which had established several trial sites in the area and was one of the partner institutions for SSI. Regular meetings (monthly farmer forums) were held, where the SSI team were full participants. Visiting researchers were introduced to the community through these forum meetings. Several farmers participated in SSI activities, through data gathering, making their farm plots available for research purposes and were open to try new techniques on their plots.

A key challenge in SSI was how to integrate research and outreach. Experience in this programme has shown if these two components should be effectively linked to make the approach truly participatory. In this case, farmers who participating in the research were given an understanding of what researchers were intending to do so that farmers identified problems as well as approaches to solve them together with researchers.

2.3.5 Participation of relevant institutions

The SSI researchers, outreach officer and field assistants under the guidance of a communication management expert designed a communication strategy that encompasses all potential stakeholders in the catchment. The strategy identified stakeholders, their respective communication needs and defined potential pathways

and uptake opportunities. Nine typologies of stakeholders for knowledge sharing were identified in the communication strategy/framework, these include:-

1. Farmers: (Research farmers, neighboring farmers, farmers from villages surrounding target villages, farmers outside Makanya catchment, water user and fishery groups)
2. Local authorities: (Village and Ward leadership)
3. Extension officers: (in the target villages, outside the target villages, village level, ward levels and District Executive Director (DED), District Commissioner, Councilors, District Agricultural and Livestock Development Officer (DALDO), Irrigation/Natural Resource –District Extension Officer (DEO)
4. NGO's: (Same Agricultural Improvement Programme, Traditional Irrigation Improvement Programme, Vrededeseilanden Country Office, CARITAS, Same Association of Non-Governmental Organizations, PAMOJA, World Vision-Area Development Programmes)
5. Basin/Zonal/Regional organizations: (Pangani Basin Water Office/NGO-Pamoja, Zonal Irrigation Unit, Met office, TANROADS, regional offices (e.g. hydrology),
6. Research institutes: (Sokoine University of Agriculture, Selian Agricultural Research Institute, Mlingano Agricultural Research Institute, University of Dare es Salaam)
7. National level organizations: (Ministry of Agriculture and Food Security, Ministry of Water and Livestock Development, Ministry of Natural Resources and Tourism, Ministry of Cooperatives and Marketing, President's Office – Regional Administration and Local Governments , Vice President's Office)
8. International partners: (Regional Land Management Unit (RELMA)/World Agroforestry Centre, Water Research Fund for Southern Africa, Southern and Eastern Africa Rainwater Network (SEARNET), Soil and Water Management Network, African Conservation Tillage (ACT), WaterNET and PROMoting Local INNOVation
9. SSI partner institutes: (Sokoine University of Agriculture, Stockholm University, Institute of Hydrology Engineering, University of Kwazulu-Natal, International Water Management Institute)

Several products and information to communicate to each stakeholder were identified. These range from water system innovations, on-farm experimentation, awareness creation, research findings and data sharing. The strategy also analyzed the current knowledge, attitudes and practices of each stakeholder and action to be taken after communication.

In the Potshini catchment, the Agricultural Research Council ARC-Institute for Soil Climate and Water (ISCW) of South Africa and the National and Provincial Departments of Agriculture through their LandCare project have been actively involved in SSI activities. Trial sites and data have been made available for SSI activities and these groups have assisted in the SSI entry into the community. The Farmer Support Group of the University of KwaZulu-Natal (FSG) was facilitating the SSI Outreach component in this area. During the programme partnerships were established with ARC, DoA, DWAF, IRD and Okhahlamba Municipality.

2.3.6 Partnerships with other water initiatives in Southern Africa

The SSI team members participated in various regional and international conferences and workshops and share lessons emerging from the SSI programme, thus ensuring visibility of SSI in key forums through paper presentation, seminars etc. SSI programme was presented at the Advanced International IWRM programme for the Zambezi basin countries, GWP-SA, SADC Regional water sector programme, IRC and at the blue-green initiative. Special SSI/CP sessions were organised during the WaterNet/WARFSA/GWP-SA symposia between 2004 and 2008. These sessions were organised together with the Challenge Programme on Water and Food-WaterNet supported project, which led to a fruitful exchange of lessons from both programmes.

3. RESEARCH OUTCOMES

3.1 The Pangani basin: Makanya catchment (synthesis paper)

3.1.1 Introduction

This synthesis paper compiles the research outcomes from the different projects in the Pangani basin in Tanzania. Makanya catchment in the Pangani basin was selected for intensive field work aimed at answering the research questions. The SSI team selected Makanya catchment because it could benefit from previous research that SUA has conducted in this area. In Makanya, the field office was available to the SSI researchers. SSI concentrated on the Vudee catchment, a sub-catchment to the Makanya catchment. This catchment is characterized by unreliable and inadequate rainfall, significant adoption of different types of water system innovations and with clear impacts of the upstream activities on downstream communities.

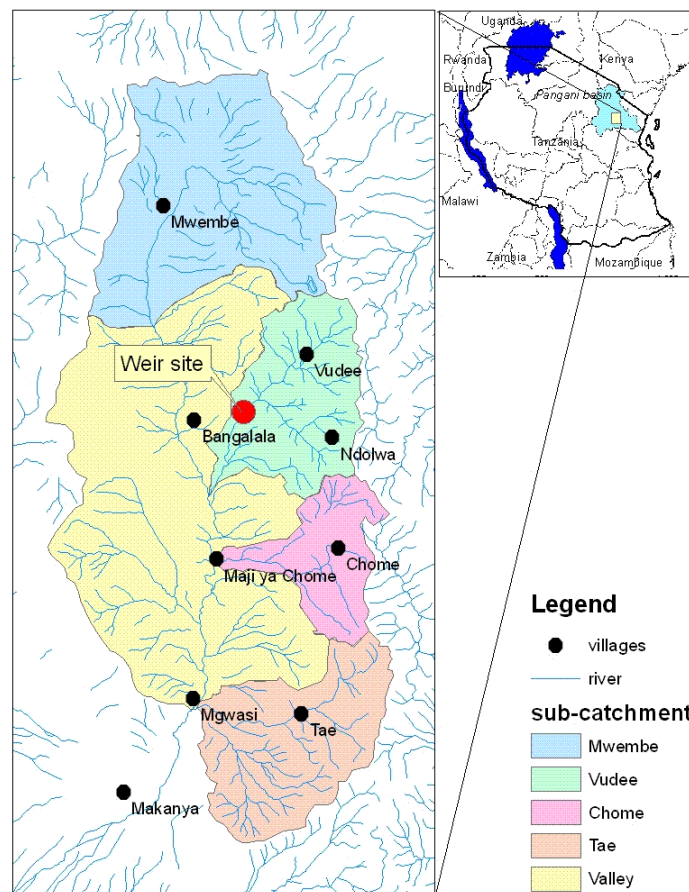


Figure 3.1: Makanya catchment.

3.1.2 Makanya catchment

Makanya catchment (Figure 3.1, area 320 km², latitude 4°15' to 4°21' S and longitude 37°48' to 37°53' E) is located in the middle parts of the Pangani River basin and occasionally drains into the Pangani River during excessive floods. It lies at an altitude ranging from 500 to 2,000 m within the South Pare Mountains. Some 35,000

people live in the Makanya catchment; this number is growing at a rate of about 1.6% per year (URT, 2004). In the past the majority of the population lived in the highlands, where they enjoyed favourable conditions, in terms of health and absence of certain diseases (e.g. malaria). Due to population growth, people migrated to the midlands, where they required supplementary irrigation. The continued need for more agricultural land is putting the remaining forest cover under pressure.

The majority of the population relies on small-scale farming, which is non-mechanized and involves little external inputs. The dominant crop is maize, with harvests averaging just above 1 t ha⁻¹. Agricultural practices by farmers in the catchment vary as a function of location as they are influenced by the local climate, water resources availability and soil type. Three altitude zones with distinct features have been identified within the study area, namely the highlands, midlands and lowlands.

Highlands

The elevation in the highlands ranges between 1,000 and 2,000 m. Population densities are relatively high for an African rural environment (about 180 persons km⁻²). Maize, beans and vegetables are the main crops. Farm holding sizes average around 0.25 ha. The highlands have a relatively cool climate. Due to orographic effects rainfall averages about 800 mm a⁻¹, which is high compared to the mid- and lowlands. Purely rainfed agriculture is therefore possible and is practiced at locations without access to surface water. This is often on steep slopes without soil conservation practices. Soil erosion is a major problem in these areas.

There are many perennial springs from where small rivers originate. The location and discharge volume of these springs is defined by the geology (Mul et al., 2007). Farmers have constructed many small irrigation canals, called furrows that take out water from these streams. Irrigation is practiced as supplementary irrigation during prolonged dry spells in the wet season and as full irrigation during the dry season. Constructing terraces is often a prerequisite for a farmer to get a water allocation from an irrigation furrow; this is obviously not the case for rainfed agriculture.

The soils are mainly *acrisols*, which are characterised by low fertility, shallow depth, and limited moisture holding capacity. Intensive farming and agro-forestry contribute more than 80% of household income (Pachpute et al., 2009). The cultivation of cash crops contributes significantly to household income, which tend to be higher in the highlands (estimated at 180 USD cap⁻¹ a⁻¹) compared to the mid- and lowlands (Pachpute et al., 2009).

Midlands

The elevation in the midlands ranges between 700-1,000 m. Population densities are slightly lower than in the highlands (150 persons km⁻²). Maize is the main crop and is normally intercropped with lablab beans. Farm sizes are relatively large (average 1.1 ha). Higher temperatures, lower rainfall, and the high probability of dry spells during the rainy seasons necessitates supplementary irrigation in this area (rainfall 500-600 mm a⁻¹). Supplementary irrigation is practiced during the wet seasons using water from the perennial streams coming from the highlands. The midlands itself have few springs with small discharges and of poorer quality. Relatively fertile *luvisols* exists. Farming contributes 71% to total household income (estimated at 145 USD cap⁻¹ a⁻¹),

which is substantially lower than in the highlands, as mainly staple crops are grown, and only two seasons can be used for cultivation (Pachpute et al., 2009).

Lowlands

The lowlands, which are lands below an elevation of 700 m, have a population density of 42 persons km⁻², much less than in the other areas. Rainfall is generally insufficient to grow any rainfed crops (annual rainfall amounts to below 500 mm a⁻¹). Due to the many upstream diversions, stream flows no longer reach the lowlands continuously (Mul, 2009). Only large flash floods reach the lowlands. At the outlet of the catchment an irrigation system is located that entirely relies on these floods (Mul et al., submitted). This type of irrigation is internationally known as spate irrigation. Land is covered with scattered shrubs or bushes spread over *luvisols*. Livestock contributes significantly (about 75%) to household income (estimated at 125 USD cap⁻¹ a⁻¹) (Pachpute et al., 2009).

3.1.3 Research activities

The research activities in Makanya were focussed at different spatial scales. At plot level on-farm experiments were carried out. Several innovations were tested for their impact on water productivity and soil resilience. At furrow and sub-catchment scale, water sharing arrangements were investigated, in addition to the efficiency of one of the furrow systems. The functioning of local level irrigation institutions were analysed, including the participation of irrigators in decision-making. At the catchment scale, finally, the hydrology and land use change were analysed, and suitability maps for water system innovations were developed. The following sections elaborate on the research results at these three different spatial scales. The interaction between researchers and farmers is also described where appropriate.

Catchment scale

Mean minimum temperatures range from 16 to 18°C, and mean maximum temperatures range between 26 to 32°C. The catchment has low and unreliable rainfall between 500 – 800 mm a⁻¹ with the higher altitudes receiving more rainfall. The rainfall distribution is bimodal with the short rainfall season occurring October to December/January (*Vuli*) and the long rainfall season (*Masika*) between March and May. Average monthly rainfall and standard deviations are depicted in Figure 3.2 for the Same meteorological station, located at the foot of the South Pare Mountains. Although it is not apparent in the average monthly rainfall series, generally there is a short dry period between the two rainy seasons. High spatial rainfall variability was observed within the Makanya catchment on seasonal totals (Mul, 2009).

Analysis of rainfall data between 1957 and 2004 showed that there is an increase in frequency of long dry-spells³. Before 1980 a dry spell of 21 days or longer occurred in 42% of the *Masika* seasons; since 1980 this frequency has nearly doubled (occurring in 79% of the *Masika* seasons). These dry spells tend to occur during sensitive crop stages at around day 50 and 70 after planting (Figure 3.3), and thus have a large constraining impact on crop yields.

³ Analyses were done on a sub-set of the 1934-2007 data set, because of data availability at the time

The potential evaporation is much higher than the rainfall in the midlands (Figure 3.4). Over a period of four years, only three months recorded rainfall levels that exceeded potential evaporation (i.e. less than 10% of the time). Rainfall is clearly a limiting factor for crop growth.

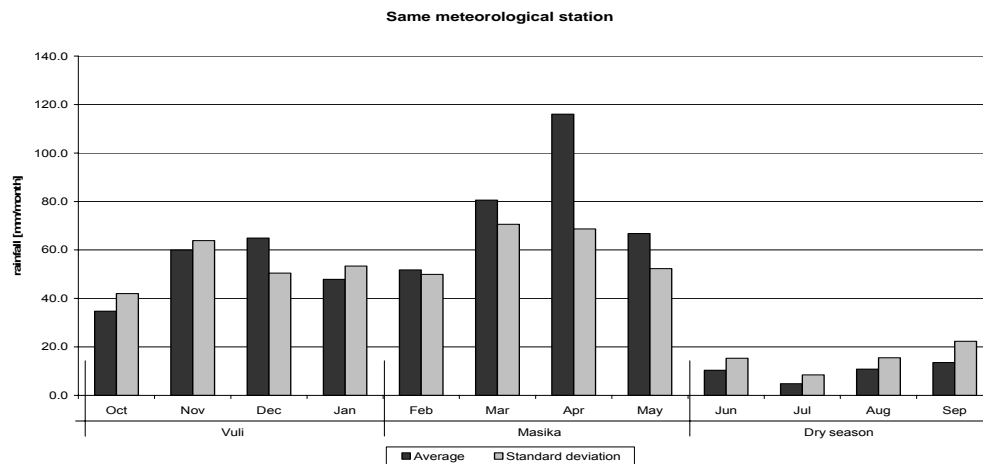


Figure 3.2: Distribution of rainfall in Same (1934-2007) (Mul, 2009).

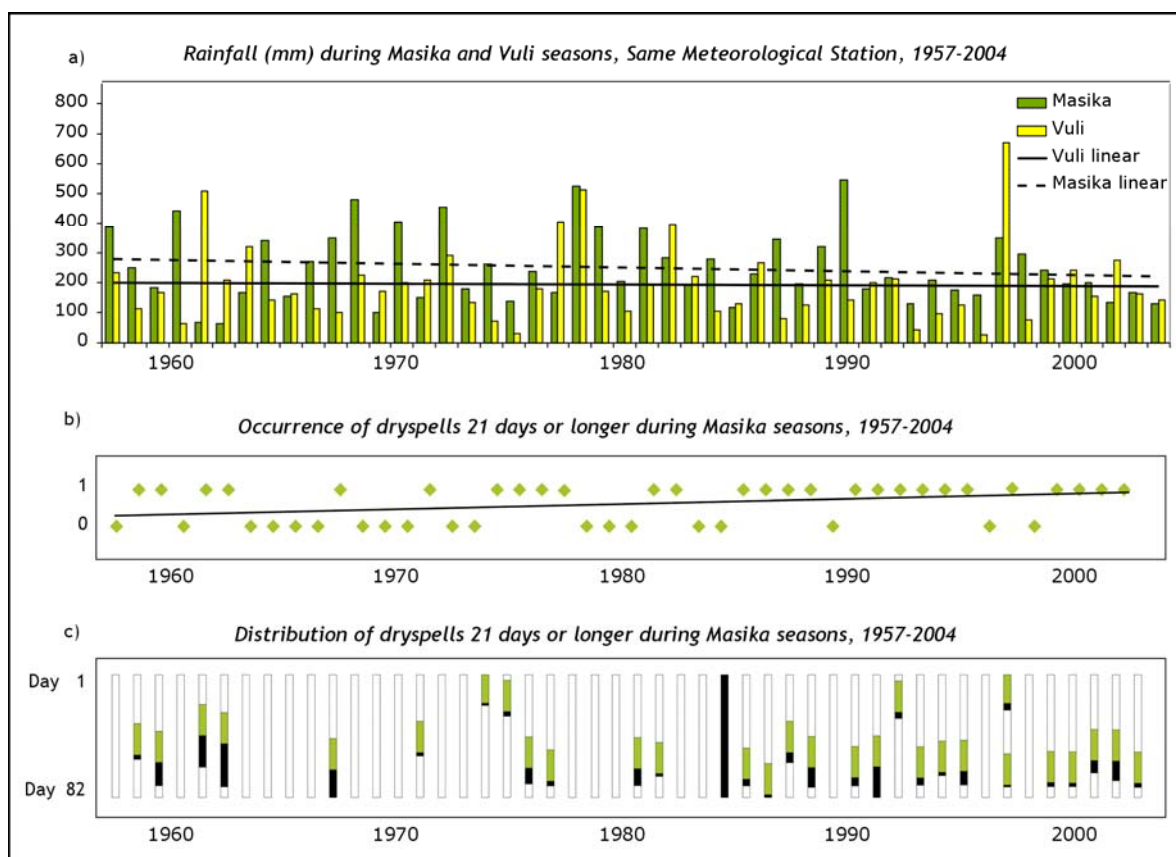


Figure 3.3: Rainfall variations in the Makanya catchment.

a) Over time, Masika season rainfall seems to have followed a declining trend, whereas rainfall during Vuli seasons, although highly variable, doesn't seem to have changed. However, statistically neither of the trend-lines represents any significant changes ($p_{Masika}=0.318$).

b) Regarding the occurrence of dry-spells, a significant increase in the frequency of long dry-spells (21 days or longer) was found during Masika ($p=0.024$). Between the years 1957-1980 a dry-spell of 21 days or longer occurred in 42% of the Masika seasons, whereas the same number for the years 1981-2004 is 79%.

c) The green color marks the start of the dry-spell up until its 21st day, and the black color marks the length of the dry-spell exceeding 21 days. As seen in the figure the long dryspells often occur late in the season, around day 50-70. This is the most drought sensitive growth stage for maize, and long dry-spells during this period most likely lead to severe yield reductions. Using our planting criteria, rainfall was too low for planting in Masika 1985. (Enfors and Gordon, 2007).

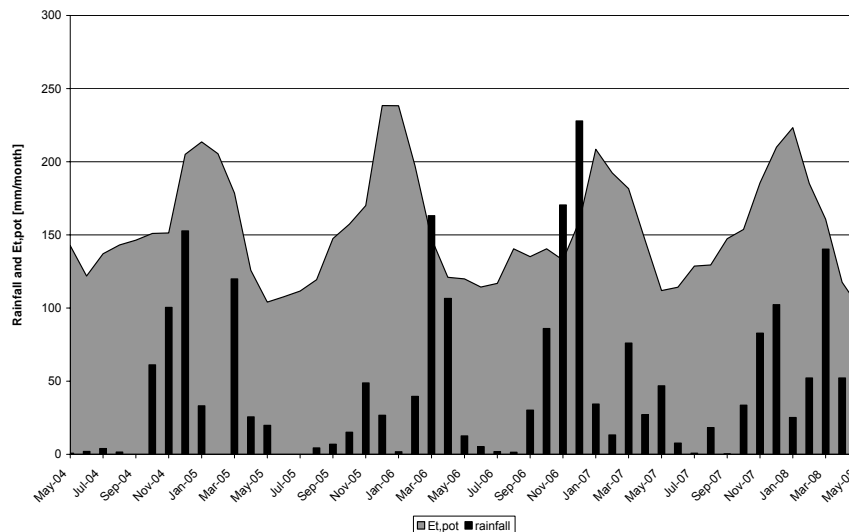


Figure 3.4: Potential evaporation versus rainfall at Bangalala meteorological station (Mul, 2009).

Four tributaries, Mwembe, Vudee, Chome and Tae, join to form the main stream in the Makanya catchment (Figure 3.1), which drains into the Pangani River during exceptional floods (Mul et al., 2006). Two types of floods have been observed, induced by different types of rainfall. High intensity rainfall can generate flash floods which reach the spate-irrigation system located at the outlet of the catchment. The spatial variability of these events is high (Mul et al., 2008b). Figure 3.5 illustrates this by providing detailed spatial information on one such event that occurred on 30 November 2006. Figure 3.5a depicts the spatial variability of that rainstorm based on 11 rainfall stations. However, the true spatial variability of that storm was much greater. This is clearly shown in Figure 3.5b, where also rainfall measurements by 31 smallholder farmers were included. Without such additional information, large errors in total rainfall estimates are made (Figure 3.5c).

Rainfall in one sub-catchment can generate enough runoff to reach the spate-irrigation system. Because of this spatial variability, runoff into the spate-irrigation system is more likely than an extreme event occurring in one of the sub-catchments. Smaller floods infiltrate into the alluvium before reaching the spate-irrigation system. It has been observed that during small floods, the vast majority of the flood originates from groundwater (> 90%) (Mul et al., 2008a). During large flood events, the groundwater contribution is still about 50% of total flow, increasing the outflow from the groundwater reservoir a 100-fold during peak flow and causing a substantial base flow increase after the event (Mul et al., 2008b). The time of concentration is extremely short; within one to two hours the flood peak reaches the outlet of the catchment flowing into the spate-irrigation system. During an event in March 2006,

rainfall intensities reached 50 mm hr^{-1} , while the entire storm lasted only 4-5 hours. Rainfall intensities far exceeded the infiltration capacity of the soils and overland flow was common. The flows exceeded also the absorption capacity of the alluvium of the main valley of the catchment, replenishing the local aquifer and feeding the downstream spate-irrigation system.

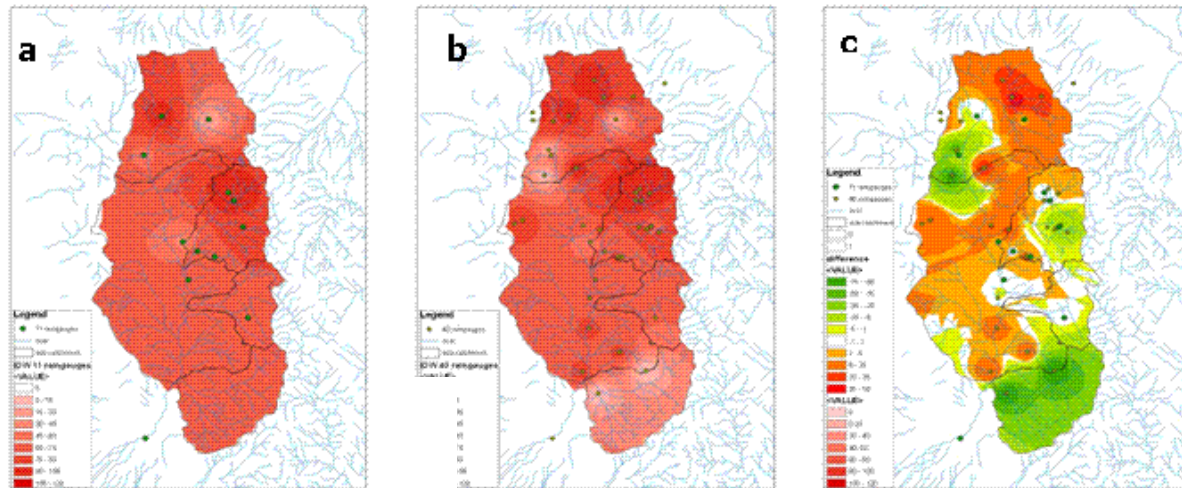


Figure 3.5: *Spatial rainfall measured during 30 November 2006 event with a) 11 rain gauges, b) 42 rain gauges, and c) differences between the two interpolations in mm d^{-1} .*

Land use change in the upstream parts has also impacted on the runoff generation. An analysis on land cover change in the Makanya catchment between 1954 and 2001 showed that the area under agriculture increased from 37% to 55%, while bushland and forest decreased from 34% to 23% and 4% to 2% respectively (see Figure 3.6). With lack of historical data and exact data on water use and processes in the valley, we were unable to quantify the impact on the hydrology. In addition, increased water usage upstream for domestic and agricultural use has change the flows to downstream significantly.

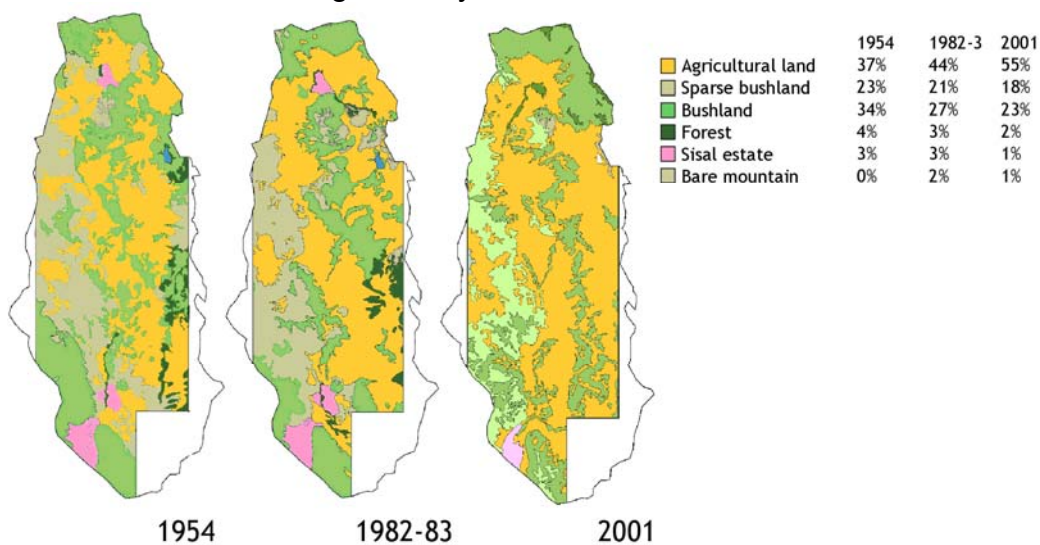


Figure 3.6: *Land cover changes in Makanya catchment (Enfors and Gordon, 2007).*

Furrow and sub-catchment scale

Smallholder farmers are the major water user in the area. A detailed analysis was done on the water users in the Vudee sub-catchment, which covers an area of 25 km². The area has 38 irrigation furrows with 20 micro dams. The furrow systems are primarily used for supplementary irrigation (highlands and midlands) and dry season irrigation (highlands only). Most farmers are connected to furrow systems, often combined with a small reservoir, capacities ranging from 200 to 2,000 m³. These micro dams receive water from a diversion canal from the main river and supply areas ranging from a couple of hectares to about 400 ha (Makurira et al., 2007). The furrow systems often date back to before colonial times. The oldest micro dams were constructed at the beginning of the 20th century. The micro dams are used as overnight storage and time-series measurements along the canal were used to compute conveyance losses. Furthermore, detailed methodology is given in Makurira et al. (2007).

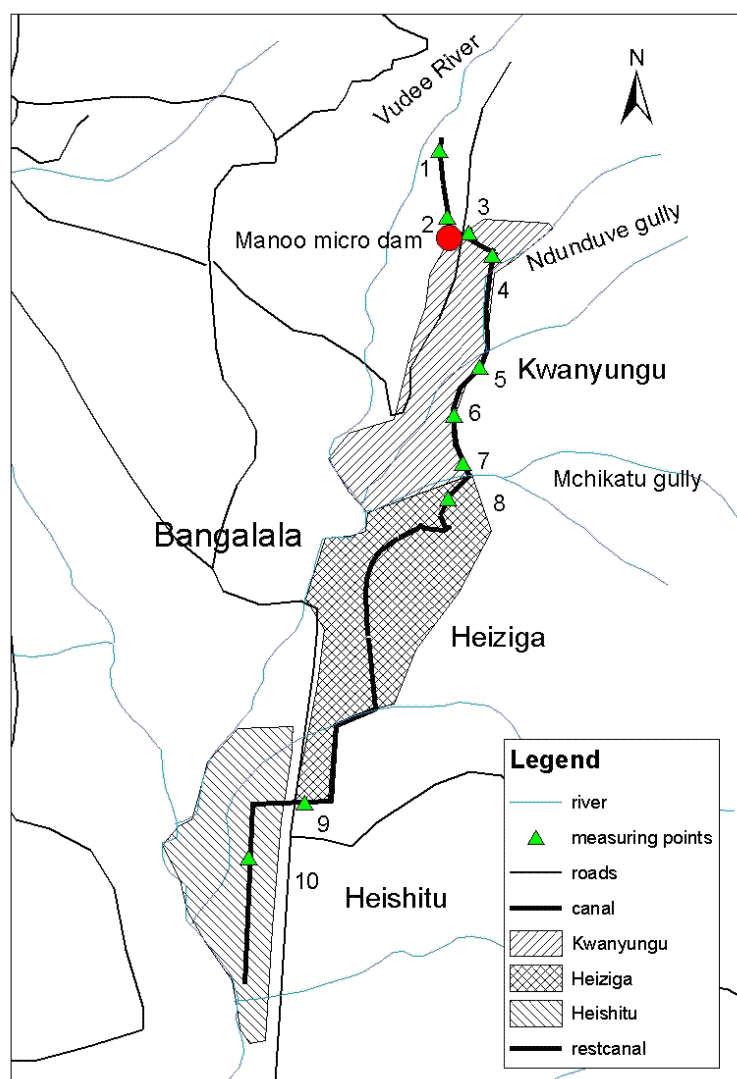


Figure 3.7: *Command area of Manoo furrow system and discharge measurement locations (Makurira et al., 2007).*

A detailed study was conducted on one of the furrow systems in the midlands, Manoo micro dam (Figure 3.7). The capacity of its micro dam is 1,620 m³. It serves

150 members with 400 ha of land. For the most downstream fields, located 3.5 km from the dam, conveyance losses exceed 80% (Makurira et al., 2007). An allocation from the furrow system is mostly wanted during long dry spells, when river discharges are low. Under such circumstances, combined with the limited capacity of the system (canal and storage capacity) and the large conveyance losses, only few of the farmers connected to the furrow system can receive an irrigation turn. As an illustration, only two of the five research plots received supplementary irrigation during the 2005 *Masika* season, receiving only 85 mm and 41 mm of river water (Mutiro et al., 2006). Farmers located near the micro dam tend to be favoured in allocation irrigation turns, minimizing conveyance losses.

Farmers who own plots in the furrow systems tend to adopt improved farm management practices and tend to have better access to marketing networks and information sources (Enfors and Gordon, 2008). However, this only buffers their farming system to a certain degree: during the severe drought of 2005 furrow farmers experienced similar levels of food insecurity as rainfed farmers.

In the lowlands, on the plains, farmers have developed so-called charco dams, a locally developed type of dug-out ponds that capture surface runoff. Charco dams are shallow storage structures, 1 to 3 m deep, constructed using household labour and owned by individual farmer or community. These ponds impound surface runoff from adjacent land or ephemeral streams. The presence of *luvisols* in lowlands is suitable since the subsurface layer lying at 1 to 3 m depth is clayey, favorably minimizing seepage losses. The optimum pond size is considered as one that prevents drying up at any time in the year. Simulation analysis has shown that a family with average size animal herd requires 1000 to 1100 m³ of water. In a normal rainfall year 150 m³ charco dam is sufficient but in a dry year 320 m³ charco dam will be sufficient; however, this will require more labour input for construction and desilting (Pachpute et al, 2008). The pond water is not used for crop production. Principal reasons behind this are low labour density and lack of low-tech affordable water application method. *Constraints* Storage capacity of charco dams surveyed under this study ranges from 35 to 2,000 m³. Only 8% ponds are equipped with a silt trap. It was observed that 46% of ponds dry up within 1.5 months from wet season, 22% within 2 months and only 32% remain useful until the onset of the next rainy season (Pachpute et al, 2008). Principal reasons are fluctuation in water supply due to rainfall variability, higher evaporation losses and storage capacity reducing over the wet season due to moderate sediment deposition from overland flow. Due to labour scarcity, instead of constructing optimal sized ponds, farmers prefer to divert flood water from river to fill the drying ponds. This results in comparatively heavy deposition of sediments at the pond bottom. Construction of optimal size charco dam, effective silt trap and minimization of evaporation losses (e.g. by cultivating wind barriers of medicinal cacti *Euphorbia candelabrum*) are essential for water availability from charco dams.

Institutions

Before Independence, local institutions regulated access to natural resources. Chiefs are said to have effectively controlled a catchment from the source to the foot of the mountain. After Independence, the institution of the chief was formally abolished and the socialist government introduced a programme of villagisation whereby people were forced to move to new villages where access to health care and education was

provided. These villages were now the recognised institutions at the lowest level. Watersheds would typically contain several wards and villages, which had now become responsible for natural resources management. They however lacked the authority and capacity to coordinate water using activities beyond their jurisdiction, namely at the watershed scale. This is an additional aspect in defining why the river has dried up at the outlet of the catchment. In addition, from the early 1990s individually or group-owned furrows were forced by the village government to open up and to accommodate other villagers as well. This not only increased the pressure on the limited river water resources, but also weakened the existing and age-old furrow institutions, because it blurred the distinction between members and non-members and hence created a situation of more or less open access to this natural resource (Enfors and Gordon, 2007).

Each commonly owned furrow (with or without a micro-dam) is managed by a water user group (WUG). WUGs have been operating for a long time under changing political and natural environments. These groups often had developed effective ways of dealing with, and resolving conflicts. WUGs have increasingly been formalised since the late 1990s, often assisted by local or international NGOs. WUGs face several challenges, in particular with respect to the process of decision making. In many instances the original developers of a furrow system have the highest stake in their system, and the allocation of irrigation water is often influenced by the relationship one has with the furrow leaders, including friendship and family ties. But also the esteem and standing one has in the village counts: retired civil servants, members of the police or military officers tend to be respected and may receive an irrigation turn before others (Komakech et al., 2008).

The management of natural resources, in particular water resources, has been severely affected by changes in the administrative structure. Natural resources are no longer managed at the catchment scale but at village level. However, some of the past practices still persist in the present. The steadily increasing use of river water, together with regular droughts, has resulted in periodic water scarcity and has made people aware of the need for coordination at the catchment scale. Since the 1940s villages have attempted to establish explicit agreements concerning water sharing between highland and midland water users. The reason why upstream villagers were willing to take the need of downstream users into account may be explained in terms of the linkages that exist between them. One such linkage is in the form of kinship ties, which make people take the needs of their next kin into account. Another linkage is created through the reliance of upstream villagers on the staple foods, such as maize, produced by their downstream colleagues. This allows the highlanders to specialise in the production of cash. The multiple interdependencies between highlands and lowlands facilitates the establishment of agreements, and stabilises them in an increasing plural legal setting (Kemerink et al., 2009).

The creation of the Unyindo association is a good illustration of this development. In 2004 the two villages of Ndolwa (highland) and Bangalala (midland) formalised their agreements by establishing this umbrella association of 8 water user groups, comprising approximately 400 families (Table 3.1, note that some families have plots in more than one furrow system).

Table 3.1: Members of the Unyindo association of water user groups.

Water User Group	Hamlet	Village	No. families
Heivumba	Masheko	Ndolwa	10
Kitala	Masheko	Ndolwa	60
Kitieni	Kitieni	Ndolwa	40
Kwanashanja	Mjingo	Ndolwa	40
Manoo	Kwanyungu	Bangalala	150
Mkanyeni	Mkanyeni	Bangalala	70
Mombo	Mtwana	Ndolwa	60
Ndiveni	Ndiveni	Ndolwa	20

Figure 3-8 shows fluctuations in the discharge at the foot of the mountains as a result of the agreements between the highlands and the midlands. A clear diurnal pattern can be observed, with the highest flows occurring early in the morning, which is consistent with the agreements between Vudee and Bangalala to release water for the downstream village during the night. On Sundays the decrease of the flow is indeed less than during the other days, which corresponds with the aim not to irrigate on Sundays and leave the water in the river bed to the benefit of the environment and lowland water users. Also the stronger drawdown on Wednesday is the result of an institutional arrangement. This can be attributed to the abstractions from the Ng'ombe furrow system upstream of the gauging weir, which diverts water mainly on Wednesdays within the irrigation turns of Manoo furrow system.

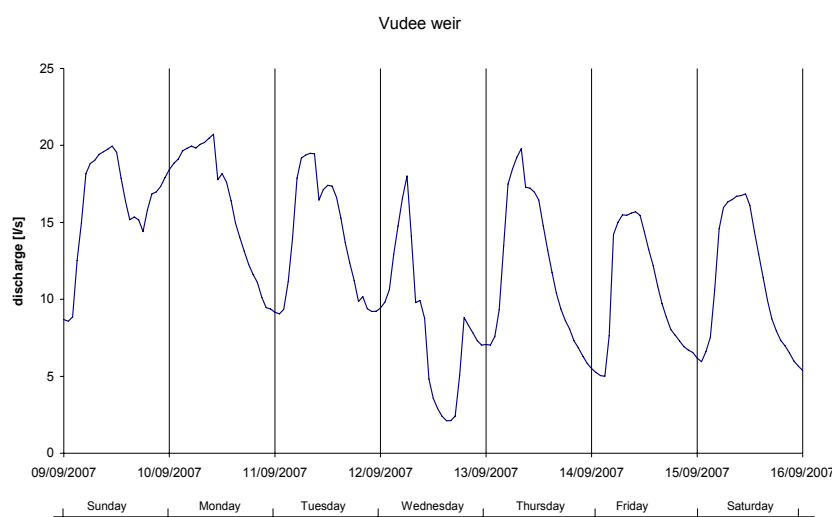


Figure 3.8: Water level fluctuations as a result of upstream abstractions.

No agreements exist with these communities and the lowland farmers (Mul et al., submitted). With the base flow no longer reaching Makanya, lowland irrigators have had to adopt their irrigation practices to flood-based spate irrigation. The downstream farmers are not only negatively affected, as flash floods generated in the highlands also have positive impacts downstream. These floods reach Makanya, replenish the

unsaturated zone and local groundwater bodies and deposit fertile sediments (Komakech et al., submitted). However, it is unsure how future increases in water requirements will affect the situation, as there is no institution that effectively monitors the catchment scale challenges.

In the past, it has been observed that flows downstream have altered due to upstream land use and management. In particular the river diversions have impacted the downstream flow significantly. As most of the flow is generated in the highlands and the experimental plots were located in the midlands, no changes have been observed. Water captured at the farmer plots often would not have reached more downstream users, and only infiltrated into the alluvium. Water quality of the alluvial aquifer is deteriorated by the springs coming from regional aquifers, which contain volcanic residue (Mul et al., 2007). Reduced replenishment from the mountains and local runoff due to increased water usage, will probably deteriorate the water quality, however this was not measured. On the other hand, the losses in the irrigation system will replenish the aquifer, and therefore improve the water quality. In addition, in this area few boreholes exist where locals obtain their water. It therefore seems that small scale water harvesting techniques in the midlands improve the agricultural productivity significantly (as it supplements the inadequate rainfall), but in the current setting does not aggravate the situation of the downstream community. To improve on the downstream situation, a large community will have to forgo their opportunities, which is unlikely to occur. The downstream community however should make sure the upstream community does not also tap into the resource they are currently using.

Plot scale

Challenges

Farm level research of SSI in Makanya specifically focused on plots that lacked access to surface water resources in the midlands of the catchment. Generally, rainfall in this area is unreliable and inadequate. For example, the crop water requirement for a particular maize variety (TMV1), which matures in 115 days and is suitable for semi-arid conditions, amounts to 508 mm season⁻¹, whereas annual rainfall in Makanya is less than 600 mm a⁻¹ and is spread over two distinct wet seasons. Moreover, rainfall does not fall evenly during each season and long dry spells occur frequently (Figure 3.9, Fischer, 2008). Many farmers search for ways to access surface water resources in order to supplement the little rain. The village government is advocating that everybody is entitled to become a member of a furrow system (see previous section). The on-farm experiments of the SSI programme assessed the possibilities of improving the yields on locations outside the reach of the furrow systems. Farmers without access to river water can improve their water supply by rainwater and runoff harvesting. As an additional strategy, short season varieties of maize may be chosen. In Makanya, the agricultural extension service promotes the *Kito* maize variety, which requires less water and matures within 90 days.

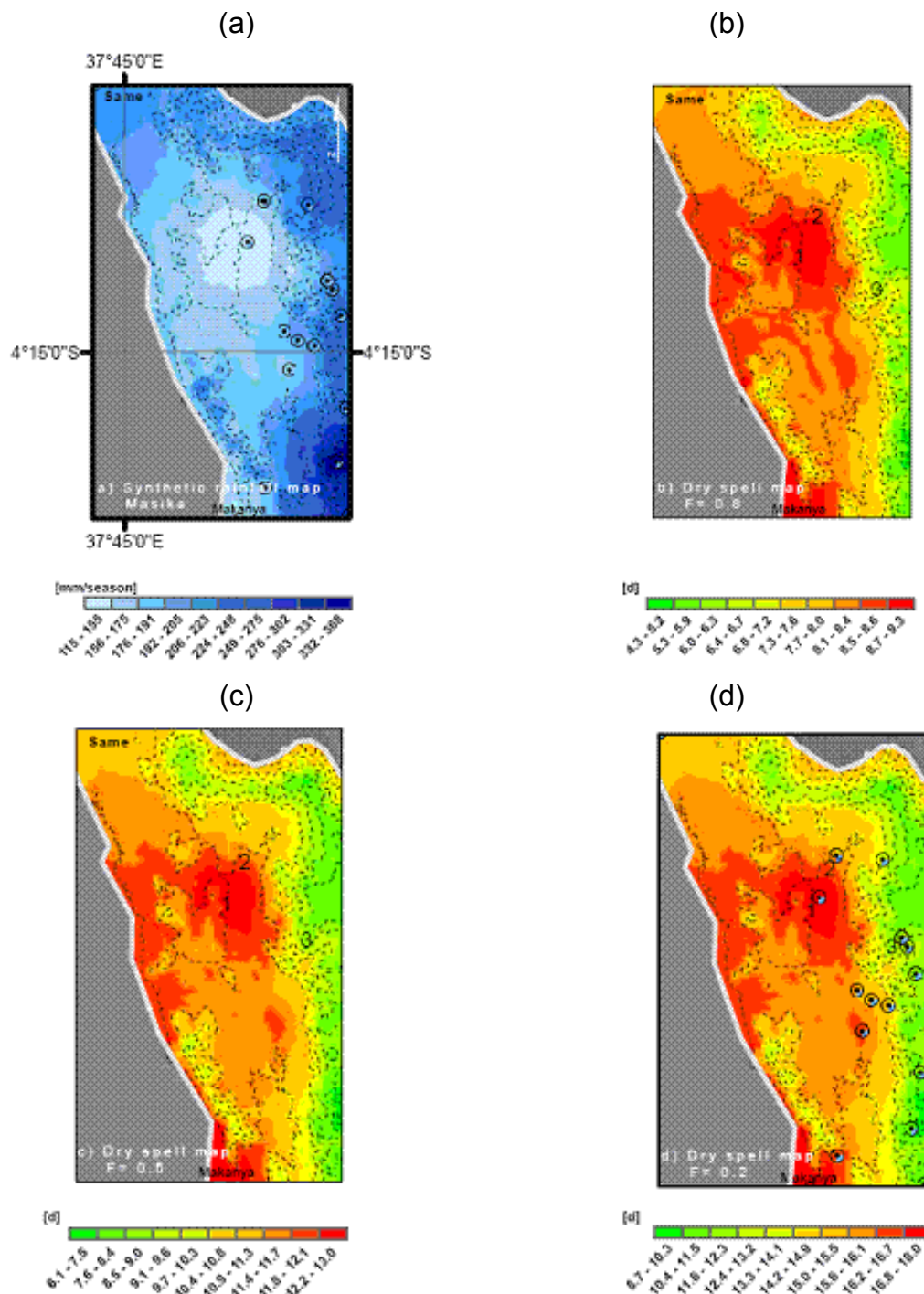


Figure 3.9: Dry spell maps for Masika season, a) average Masika rainfall [mm/season], b) dry spell length 80% probability [days], c) dry spell length 50% probability [days], and d) dry spell length 20% probability [days] (Fischer, 2008).

In some seasons the catchment experienced severe droughts. A dramatic example were the low rainfall levels experienced in Makanya during two consecutive seasons, *Masika* and *Vuli* seasons of 2005 (Figure 3.10). This resulted in almost total crop failure in *Masika* 2005 and complete failure in *Vuli* 2005/06. Maize became very scarce and its price tripled from 0.1 to 0.3 USD kg⁻¹ between August 2005 and March 2006 on the local market. People were forced to sell capital goods, such as cattle, in

order to generate cash to purchase the required food. As a result, livestock prices plummeted to 10% of normal prices (which is normally 175 to 250 USD per head but during this period dropped to 17.5 to 25 USD).

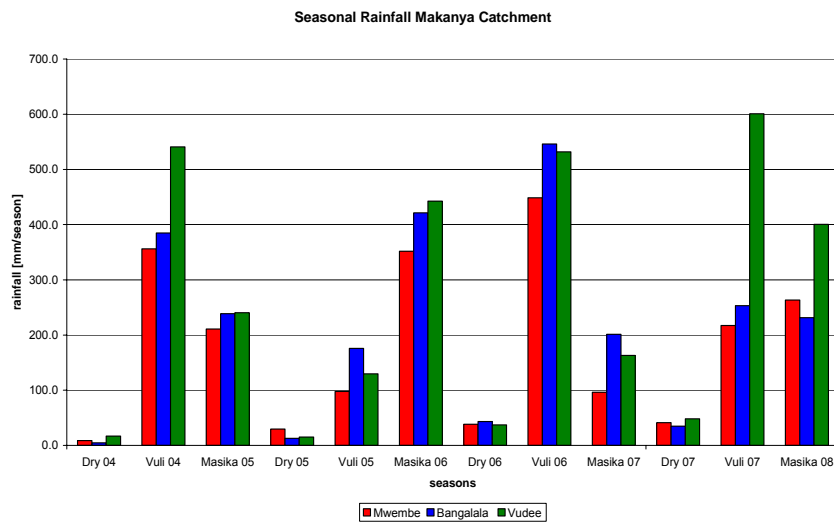


Figure 3.10: Seasonal rainfall in Mwembe, Bangalala (both midlands) and Vudee (highland).

In coping with dry spells, droughts and subsequent crop failure, farmers follow several survival strategies. They foremost purchase additional food from local markets, while supplementing diets by harvesting wild fruits and vegetables from the surrounding natural resources. Those households who still have, will consume the food stocks of the preceding season. Others will rely on food relief, food gifts and food-for-work projects. This means that in drought years households completely deplete their food stocks and herd of poultry, small ruminants and livestock built up during previous seasons, while still relying on the environmental services as well as on the cash earned from wage labour (Figure 3.11, Enfors and Gordon, 2008).

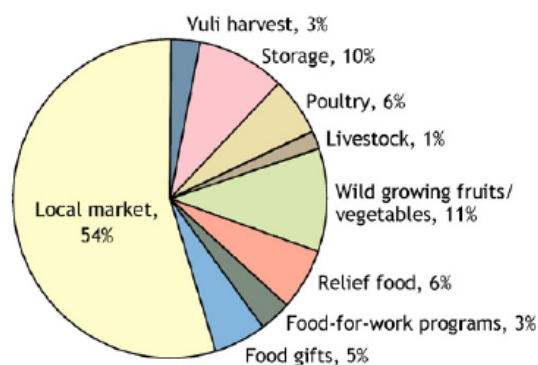


Figure 3.11: Relative importance of different food sources after the drought (Enfors and Gordon, 2008).

Farmers' development strategies are completely upset during severe droughts, derailing their long term investment plans. The regular shocks of recurring droughts are difficult to overcome and each time sets farmers back to a starting position (Enfors and Gordon, 2008). This challenges their development perspective.

Experimental set up

The project introduced several technologies including rippers, fanya-juu, farmer field schools and rain gauges among others. Most farmers perceive a positive impact after interacting with the SSI program. For example, Mr. Idd Mrindakaa said he has learned mulching, water diversion techniques, ripping, use of cover crops and other techniques. He has noted improvement in soil fertility, reduced soil erosion, reduced water and moisture loss, increased crop diversity, and improve crop yield. His yield of maize has increased from between 2 and 4 tins to between 20 and 24 bags of maize. Johnson Hosea increased his yield from 6 bags in 6 acres before project intervention to 34 bags in after intervention by the SSI program. Mrs Walter and Ms. Elizabeth Mdee, a farmer in Mwembe village, adopted the use of ripper, runoff diversion and implementation of fanya-juu. She has noted that fanya-juu has been very effective in changing and stabilizing the landscape, reducing soil erosion and land has become more fertile. The yields have improved and they have been able to grow and harvest animal feeds in the fanya-juu.



Figure 3.12: Research farmer who adopted fanya-juu terraces and innovated to include bananas.



Figure 3.13: Farmer outside the project intervention who is adopting fanya-juu terraces and banana innovation.

Furthermore, Ms. Elizabeth Mdee, farmer in Bangalala, noted that the ripper is very useful as it saves time in planting, allows proper spacing and facilitate RWH for crop production. Furthermore, some farmers share rippers and/or draft animals with others or hire from those owning them. She also observed that ripping after tillage has been more useful for crop even though this is contrary to what she learned in FFS. In scaling-out rippers through FFS, she has trained three other farmers in the village as a result one farmer has bought his own ripper, the other two made their own.

Additional knowledge related to proper crop management which farmers, especially research farmers, reported to have gained from the SSI program include estimation of command area based on available water in the *ndiva*, estimation of water that enters the farm; importance of mulch, crop covers and keeping crop residue in the farm. They have also learnt close monitoring of crop growth, keeping records of important events related to the crop e.g. planting dates, dry-spells and seed varieties. Farmers also received training on pesticides. Farmers have discovered that most traditional experts do not know or care about the harmful effects of pesticides. As a result farmers also don't care so much. However, the same experts previously

propagated their usage to farmers. Since receiving training, Ms. Elizabeth Mdee has spread information about nine (9) neighbours on the effects of pesticides including Ntikija Musa who was using it in his gardens.



Figure 3.14: Farmers in a group picture after completing training in integrated pest management.



Figure 3.15: Application of ashes to control pest on cabbage plant after training and exchange visit by one farmer.

Another technology brought by SSI program was rain gauges. Scientifically, in rainfed agriculture the amount of rainfall events and amounts guide implementation of different farm operations especially primary tillage and planting. The total amount of rainfall received is an indicator of good or bad season. Therefore, SSI program introduced rain gauges to farmers so that farmers can learn on how to read, record, store and interpret rainfall events for decision making in crop production. In the long term and for sustainability reasons the network of rain gauges was to be supervised by TMA because they will be the data custodian.

Farmers do see the usefulness of rain gauges through rainfall data that is collected. For instance, Ms. Elizabeth Mdee said they can use to compare the differences in rainfall amounts of the same date (e.g. planting date) in different years. Also, other farmers occasionally ask for information from data readers when they are faced with a serious decision to make e.g. whether the rainfall event that has occurred can support planting. Farmers observed that there are constraints in adopting rain gauges. For example, farmers with rain gauges have to read rainfall data at 9:00 am every morning instead of going to their farms to work.

On measurement of water flow in Bangalala, the reader of the water level at the weir in Bangalala said that it is important to continue measuring water levels. It seems he was now able to relate the water levels and excessive water use upstream. He was able to describe the reason of changes in water levels and said is because of irrigation activities upstream during day-time. He said farmers and people who allocate *ndiva* water occasionally visit the weir and ask information about water levels.

To investigate the potential for increased crop yields through the use of different soil and water system innovations, the SSI program conducted on-farm experiments at 10 different locations. At each location a selection of on-farm experiments was conducted. Six sites were used for the water balance assessment and five sites for the soil resilience study (with one site overlapping). The detailed methodology of the on-farm experiments are given in Makurira et al. (2007), Enfors et al. (submitted) and Mutiro et al. (2006). The following section provides an overview of the results. Detailed results can be found in the above reference papers.

At all research plots the effect of ripping was assessed, either in combination with terraces (*fanya juu*) or with applying manure and cover crops, or both. At some locations surface runoff water harvested from adjacent fallow land supplemented the rainfall. The foremost finding is that water is the limiting factor in crop production; any additional improvement only occurs if water supply is sufficient. This was shown by the 40% increase in yield at three plots combining ripping, runoff diversion and *fanya juu* terraces plus manure. The purely rainfed plots only showed differences in yields during one good rainfall season (41% increase for the ripping with manure plot). Soil resilience improved, measured by the change in organic matter (increased 17%), nitrogen (+30%), and microbial activity (+100%). These are indications that a combination of ripping and applying manure may have a long term beneficial effect on crop yields in successive years. However these long term effects could not be studied during the course of the current research programme.



Figure 3.16: Fanya juu at Iddi Mrindakaa's farm.

A minimum rainfall amount of about 300 mm season⁻¹ is required for conventional agricultural practice to achieve a crop yield that exceeds 1 ton ha⁻¹. However, for plots treated with a combination of ripping, mulch and manure (m+m), rainfall of 244 mm was sufficient to realize yields of about 1 ton ha⁻¹ (see Table 3.). This finding shows that conservation tillage may have the potential to shift the breakpoint towards a lower rainfall level (Figure 3.17, Enfors et al., submitted).

Table 3.2: Average grain yield and biomass per treatment shown for all experimental seasons. The first two yielding seasons provide mixed results. Only V06/07 show a clear treatment effect. During the subsequent seasons there seems to be a tendency towards a treatment effect, in terms of improved yields on RM plots. */marks treatments that significantly differed from the control.**

	M05 ^a (kg/ha)		V05/06 (kg/ha)		M06 (kg/ha)		V06/07 (kg/ha)		M07 ^b (kg/ha)		V07/08 ^c (kg/ha)	
	Grain	Biom.	Grain	Biom.	Grain	Biom.	Grain	Biom.	Grain	Biom.	Grain	Biom.
C	321	1709	0	0	2584	6583	2075	6412	392	1457	512	1941
CM	257	1644	0	0	2295	5674	2388	8529*	493	1915	737	2372
R	215	1345	0	0	1969	5076	1763	7012	204	1080	511	1921
RM	310	1994	0	0	2390	6292	2934*	10572**	489	2337	957	3114
Prob. for no effect	0,82	0,46	NA	NA	0,24	0,26	0,01	0,01	0,11	0,26	0,33	0,02

^a Block E3 is excluded due to complete crop failure, ^b Block E1 and E3 are excluded due to complete crop failure

^c Block E3 is excluded due to crop failure, W1 excluded due to external disturbance (further clarification might be needed)

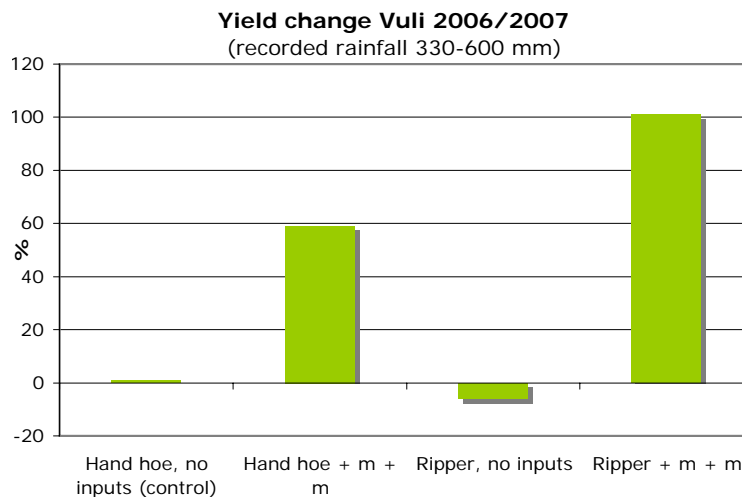


Figure 3.17: Yield change for the soil resilience study sites (*m+m* stands for mulch and manure).

A general finding of the investigations in Makanya is that with only 300 mm of seasonal rainfall, a combination of ripping, applying 50 kg ha⁻¹ of manure and supplying 100 mm of additional runoff water results in a doubling of the yield of *Kito* maize variety, from 1 to 2 ton ha⁻¹ (Makurira et al., submitted). Additional runoff water was supplied through gully diversions and furrow irrigation. Water balance analyses showed that ripping the soil increases infiltration rates while simultaneously minimising bare soil evaporation. This may increase water productivity by 11% as less water evaporates unproductively (Mutiro et al., 2006).

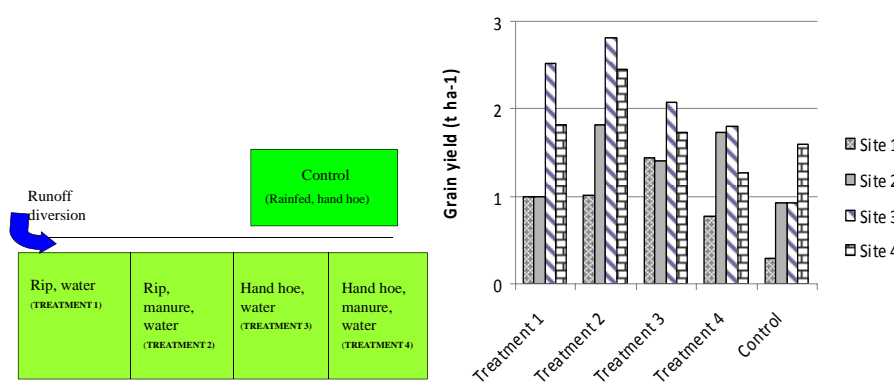


Figure 3.18: Average grain yield per treatment for the 4 water productivity study sites (Makurira et al., submitted)

In the case of water tanks investigation, the sub-surface runoff harvesting tanks only 50m³ could be harvested with supplementary irrigation potential of 400 m² per annum in a good year and only 304 m² per annum in a dry year. Farmers use the water mainly for domestic purpose and irrigating vegetable crops during dry season (Pachpute et al., 2009). In the case of rooftop water harvesting systems, it was found the tanks are capable of storing 2 to 10 m³. Most farmers uses them for domestic purposes and irrigating vegetables. The gross annual benefits of the vegetable garden were estimated to US\$ 322 per annum (Pachpute et al., 2009).

Improving rural livelihoods

This section describes two of the research farmers located in the midlands, without access to surface water, who participated in the SSI programme and not only improved their maize yields, but also managed to improve their livelihoods (see Boxes 1 and 2 below).

Box 1: The Mjema family

Mr Walter Mjema's family consists of himself and his wife and their 5 children. The family cultivates two plots: one is a steep plot next to the house and the other is a small plot in a furrow system.

The SSI team worked closely with Walter aiming to improve the productivity of the plot next to his house, before his primary focus was a plot supplied by a micro dam, and he occasionally would harvest something from the home plot, but only during good seasons. The research focused on increasing water supply and infiltration rates, while reducing erosion rates. Runoff from the plots itself was trapped by constructing *fanya juu* terraces. Deep tillage (ripping) reduced soil evaporation. Runoff generated from a nearby hillslope was redirected towards the plot. These interventions increased maize yield to 1.8 ton ha⁻¹, while adding manure and cover crops would result in yields of 2.4 ton ha⁻¹ or more (site 4, Figure 3.18).

Improved crop yields were not the only achievement. An NGO helped Walter to build a 20 m³ water tank next to his house for roof harvesting of rain. Having potable water nearby most of the time allowed Walter's wife to spend more productive hours in the field, mainly for weeding. In addition, Walter decided to grow grasses for his cattle on the *fanya juu*, where no maize could grow. He also ventured into growing sunflower for cooking oil and constructed a fish tank. Because Walter is diversifying in food crops, cash crops and livestock, and has a water tank near his home, the household can better cope with shocks.

Walter's oldest son now attends boarding school and all his daughters are attending school as well. Currently Walter is doing a diploma course at Sokoine University of Agriculture on agricultural extension.



Box 2: The Mrindakaa family

Mr Iddi Mrindakaa's family consists of himself, his two wives and 17 children.

The Iddi family cultivates several plots, three of which are monitored in the current research. In one plot, similar to Walter, additional water is diverted from an adjacent gully to supplement water to the plot, which is ripped and terraced (*fanya juu*). The other trial plots were set out to improve yields by using different soil improvement

techniques, but without supplementary water. On these rainfed plots yields improved by applying a combination of ripping and applying mulch and manure during good rainy seasons. During dry seasons, however, water is the limiting factor and no substantial harvests were achieved by any of the alternative treatments. After a good rainy season, in contrast, soil structure improves, which may result in improved productivity in subsequent seasons.

The trial plots that received additional water from the gully in combination with the *fanya juu* terrace system and deep tillage, show great potential (improving the yield from 1 to more than 2 ton ha⁻¹). However, the labour needed to construct the gully diversion and the *fanya juu* system has prevented the neighbours to apply similar innovations.

Surprisingly, with an additional 100 mm of supplementary irrigation water, the yields obtained at Iddi's plots (site 3 in Figure 3.18) were by far the highest of all trial plots, even though they received the least amounts of rainfall (190 mm season⁻¹ compared to 400 mm season⁻¹). Not only did Iddi's maize yield improve, he also planted sugar cane and bananas in the ditch and cassava on the benches of the terraces (*fanya juus*) he constructed. Iddi diversified crops, including crops such as cow peas and sweet potatoes.



Iddi and his two wives produce sufficient food crops for sale, in addition to their household requirements. Iddi recently acquired a motorbike to move around.

3.1.4 Outreach: structuring the interactions between farmers and researchers

Investigation carried out in the Makanya catchment showed that stone and grass terraces are widely adopted technologies especially in the highlands (Figure 3.19). Factors that led to their diffusion were investigated so as to draw lessons that can be used for scaling-out the other water system innovations studied in the SSI programme. Major reasons for higher level of diffusion of terraces in the highlands and midlands were found to be the interventions by the external agents (especially NGOs), which increased awareness and know how on terraces, employment of interactive communication pathways and use of self-help groups and development of markets for high value produce grown in the terraces.

Areas with strong adoption were found to have strong social ties. Groups and networks were found to be statistically significant in influencing diffusion of terraces and micro dams. Other factors included interactions with different people (for terraces) and interpersonal communications, number of groups affiliated with and trust on local government (for micro dams). Reasons provided by farmers in the villages with low adoption included lack of external support (NGOs), lack of capital, biophysical factors and lack of know how.

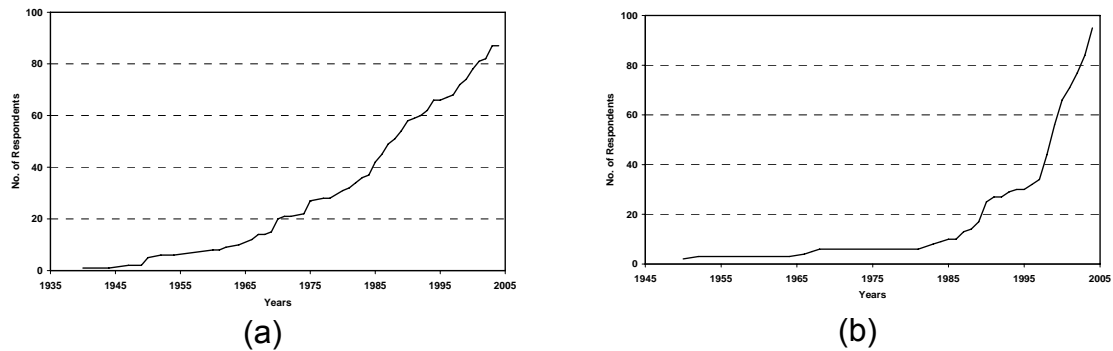


Figure 3.19: Spread of (a) diversion canals and (b) terraces over time (Tumbo et al., submitted).

Increased adoption of terraces in the highlands and midlands reduced soil erosion and increased irrigation efficiency using water from Ndivas. Before the interventions by NGOs most farmers' fields practiced flat cultivation for seasonal and vegetable crops. This resulted in significant loss of water and significant tension among farmers because farmers had to use more water to meet crop requirement.

The innovations tried by farmers and which were introduced by SSI research team such as *fanya juu*, ripping and rain gauges were positively received by farmers and institutions involved (a local NGO, SAIPRO; District Agricultural Office, Tanzania Meteorological Agency – TMA and Ministry of Agriculture). SAIPRO, Ministry of Agriculture and District Agricultural Office supported the SSI programme by supplying additional rippers to farmers and still the three institutions have continued to support farmers in the area. In 2009 the District Office supplied Camel to support ripping in Bangalala village. Tanzania Meteorological Agency has taken all strategic rain gauge stations (10 stations) and the Agency is supporting those farmers with recording material. SAIPRO and District Agricultural Office has continued to support farmer field schools so that *fanya juu* will continue to be introduced to farmers.

3.1.5 Action research

The SSI program employed participatory action research and other methods to scale-out its processes and technologies. The SSI program worked with farmers to evaluate a range of 'best bet' water innovation systems and evaluate the impact of farmers participatory and action research. Specifically, the program evaluated the use of manure, mulching, *fanya juu* terraces, ripping with *Magoye* ripper and diversion of gully water into farmers' fields. In addition, the program introduced rain gauges, river water measuring equipment, water storage systems and farmer field schools to enable farmers to experiment and analyze specific situations, decisions and outcomes. Farmer field schools were introduced to extend technologies being tried by researchers in research environment to be tried by farmers themselves and beyond research farmers so that farmers can evaluate the technologies and increase adoption because they will be testing them under their own conditions with minimum supervision by the SSI staff. Farmer field schools are not new in Tanzania therefore SSI had the opportunity to introduce it to farmers. Also, the farmer field schools introduced in Makanya focussed on water system innovations whereas as other similar schools have dealt more with agronomic management. Farmer field schools have continued to be spread beyond Makanya catchment by NGOs and the District.

The program built several relationships with different actors (Same-DALDO, MAFS, SAIPRO, RELMA, TMA, SCAPA, ACT, Liana, VECO and PBWO⁴) in order to facilitated adoption of various knowledge, techniques and technologies such as increased ripper usage, good network of rain gauges, use of farmer field school, use of local people in training other farmers and building water storage systems.

Evaluation of these initiatives showed that the SSI program became the main source of information to farmers (47.2%) followed by FFS (33.3%). This evaluation was based on questionnaire with specific questions on technologies that were introduced by SSI, which previously did not exist within the community. Also, farmers reported increased adoption of technologies by farmers (ripping – 41% and conservation agriculture 19%). Crop yield was also reported to increase from 1.1 to 2.9 t ha⁻¹ and increased the number of households that had surplus for sale from 15% to 79%. The reported increased yields are within the findings reported in formal experimental plots managed by the SSI program. Most farmers cannot afford to buy rippers and some farmers do not own oxen. Involvement of Ministry, District office and NGOs assisted farmers to get oxen and rippers. These institutions are very active in recent years in supporting any positive idea brought by Universities. The Ministry through the district supplied 25 rippers and the District supplied Camel so that they can be used to pull rippers.

3.1.6 Programme impact

A survey was conducted in September 2008 to 35 farmers located in different villages in the catchment to see the impact of SSI activities. The immediate impact of farmers' engagement in the research process and their adoption of various WSI's was clearly seen on crop production, food consumption patterns, increased finances from selling of surplus produce and their household expenditure patterns.

Crop Production

Crop production was mainly assessed against maize, which is the major food crop grown in the study area. The maize yield figures were collected during the interview based on the farmers' recall of their harvest before 2004 when SSI program has not started and 2007 three years of SSI in the catchment. The results for maize production before and after SSI program (Figure 9.1) showed that there has been significant increase in maize production a after the adoption of WSIs in study site. The maize yield increase was as high as 1.8 t/ha (163%) increasing from 1.1 t/ha before to 2.9 t/ha following adoption of WSIs in a year with good rainfall. The increase was highly significant at ($P = 0.0002$). The increase, although realised after the presence of SSI in the study area, could not be attributed fully to SSI. However the presence of SSI has in one way or the other triggered some factors that stirred up the process of adoption of some local technologies which have been in the areas for a long time. These factors include: introduction of animal draft technology leading to timely and better crop husbandry such as timely land preparation, planting using improved seeds and weeding; establishment of farmer field school groups that enhanced experiential and social learning among farmers; exchange visits, video shows and training sessions that exposed farmers to various endogenous and exogenous water system innovations; and good researcher-extension-farmer interactions during implementation of activities.

⁴ see list of abbreviations for explanation

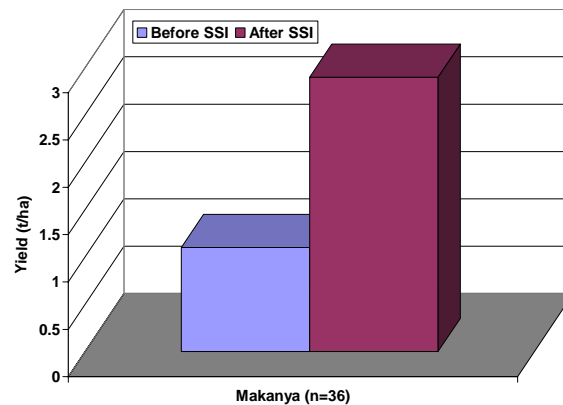


Figure 3.20: Maize yield comparison before and after SSI Project.

Mean yield across the landscapes is presented in Figure 9.2. The results showed that there has been a marked improvement in mean yields after SSI project compared to before the project. The increase is attributed to adoption of WSIs in these landscapes. The Midland has experienced an increase of 2.3 t/ha while the lowlands realised an increase of 1.4 t/ha in a good rainfall season. The high mean yields increase in midlands is attributed to application of a wider range of WSIs as compared to lowlands which have been receiving very scanty rains and thus mainly depend on runoff diversion from ephemeral streams. The midlands have a number of alternate options of WSIs as compared to the lowlands.

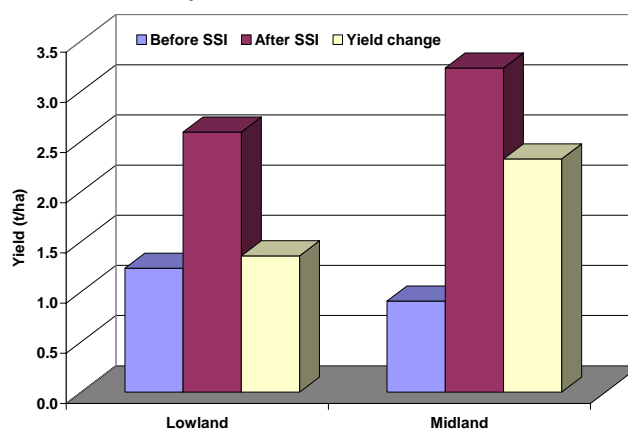


Figure 3.21: Maize yield comparison before and after SSI Project across two landscapes (Lowlands and Midlands).

In addition to increase in yield, farmers have been able to increase their total production per household because they can now cultivate much bigger areas with animal draft technologies. Most farmers indicated that they have multiple farms distantly located. It was very difficult in the past to ensure that all of their farm plots are prepared and planted on time. Furthermore, farmers in the highlands (Malindi and Mhero villages) who participated in several study tours all have adopted new banana varieties, including the farmers who accessed information from them. The banana technology is linked to WSI through terrace, roof-top water harvesting and *ndivas* due to its water requirement. Therefore, farmers have improved their water harvesting techniques to ensure that the improved banana varieties succeed in their

areas because of their higher yields compared to the local varieties. One farmer from Malindi village has fully adopted agro-forestry in his farm as a result of his willingness to innovate given the opportunity he got during study tours.

Benefits from improved yields

The increased crop yields provided opportunities for the farmers in the study area to improve their food consumption pattern and also explore the option of selling the surplus produce to realize some extra income. Results showed that before adoption of WSIs most farmers (85%) were using their crop harvest for their household food consumption and only 15% of farmers had surplus for selling. However, after adoption of WSIs about 79% farmers had enough food production and surplus for selling (Table 9.1).

Table 3.3: Farmers consumption of their crop harvest before and after SSI in Makanya catchment.

WSI	Before Adoption of WSIs		After Adoption of WSIs	
	Food (%)	Food and sale (%)	Food (%)	Food and sale (%)
Ripping	27	3	9	21
Borders	6	6	0	12
Cover crops	18	0	6	12
Fanya chini	3	0	0	3
Fanya juu	12	0	3	9
Contour	3	0	0	3
Deep tillage	9	3	3	9
Fanya juu + Ripping	6	3	0	9
	85	15	21	79

Source: Field Data 2007

Figure 9.3 shows the incomes obtained by farmers in the study area through selling of maize crop. In total about 38.9% of farmers were reported to have earned some income from selling maize in Makanya. Of them, about 19.4% farmers reported earning more than TZS 59,000 (> \$45) as a result of adopting WSIs in the SSI program.

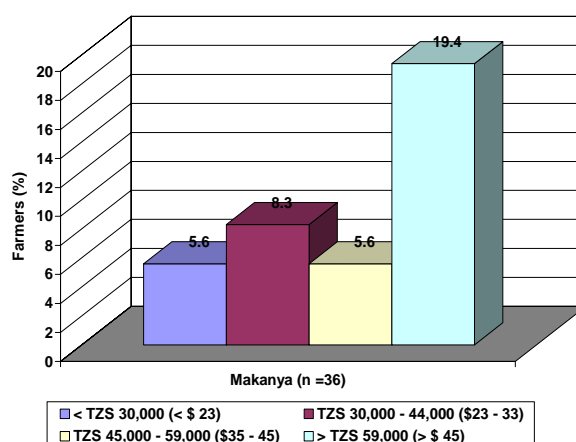


Figure 3.22: Percentage of farmers who realized income from selling maize crops.

The improved productivity and income gains have also had an impact on the expenditure and food consumption patterns of the farmers in the study area from just buying food for the household consumption to investing into education, health and clothing (52%); household upkeep (26%) and investing on shelter, business and livestock keeping and building grain storage facilities (23%), (Table 9.2).

Table 3.4: Farmers expenditure of their increased income as a result of harvesting surplus yield due SSI in Makanya catchment.

WSIs	Family expenditure on education, health and clothing (%)	Household upkeep e.g. food (%)	Invest on shelter, business, livestock and storage facility (%)	Total (%)
Ripping	23	6	6	35
Borders	3	0	6	10
Cover crops	3	16	0	19
Fanya-chini	0	0	3	3
Fanya-juu	6	3	0	10
Contour	3	0	0	3
Deep tillage	6	0	3	10
Fanya juu + Ripping	6	0	3	10
	52	26	23	100

Source: Field Data 2007

SSI impact on social learning and networks

The SSI program has also made a significant impact on the social learning and networks in the catchment. The Farmers groups and networks established during the research process provided an enabling environment for interaction among themselves and for accessing external support and recognition. The groups also provided a forum for discussing non-farm, off-farm and farm-linked activities. As a result of frequent interactions and inclusion of both male and female farmers in the training and research processes more women and men are now willing to work with each other and with groups in their communities. They are also more involved in community life. Farmers are showing better confidence in themselves and are capable of making arguments and raising issues of concern to their lives and the community and hence contributing effectively to community change. They often visit the SSI field offices and demand advisory services from the researchers and the outreach officer. Some even feel they can contest for leadership in a larger community. In addition, more people are willing to invest in terms of financial and labour resources in implementing WSIs in their fields and trying out new innovations.

Farmers and communities (through networks) have also developed more capacity in trying innovations and seeking new opportunities. Water has been made more readily available through RWH, freeing up time that women had to devote previously to water fetching time is now available for farm work, small business (e.g. several farmers from Makanya and Mgwasi are regularly selling maize, beans and

vegetables at Makanya market every week to cater for their household needs). New crops and new knowledge have been introduced in the area (e.g. cucumber, eggplant, bananas and drip as well as pitcher-micro irrigation systems at Abdallah Sekiete in Makanya). Children are no longer held longer to assist fetching water they have more time for their studies and playing. Better health has been enhanced since there is ample water for household use.

3.1.7 Farmer Learning Groups

Nine farmer learning groups (FLGs) were formed in the Makanya catchment, which were used as a mechanism to allow the neighbouring farmers to learn about and adopt innovative practices from the research farmers. Several training sessions and study tours were organised for the FLGs, on issues such as conservation tillage, interpretation and use of rainfall data for agricultural purposes, training on productive use of water and best practices for using pesticides. The main aim was to capacitate the farmers to improve their understanding of their production systems and improve their productivity. Drawing on their local knowledge, the farmers thereby became more capable to make decisions on applying and/or adapting an innovation to the local environment.

3.1.8 Conclusions

Crop yields of farming households in Makanya are affected by the limited amount of rainfall and its temporal and spatial variability. To overcome this challenge, supplementary irrigation has been practiced for a long time in this area. However, many areas in the midlands lack access to surface water resources, and need increased water supply through improved rainwater and runoff harvesting systems. Although water supply is the main constraining factor, soil fertility has also decreased under the continuous land pressure and abandonment of the fallow system. Improving and securing agricultural productivity requires a combination of measures by improving the water supply as well as the soil fertility.

The first and primary strategy is to improve the use of the primary source of fresh water, which is rainfall. The aim is to increase the infiltration of rainfall water, also during storm events, through improved soil preparation measures. This will also reduce soil erosion. Typical measures include ripping the subsoil and building terraces such as *fanya juu*.

The second strategy aims at increasing the supply of water to crops, through e.g. gully, runoff, runoff harvesting from adjacent fallow lands, and rooftop rainwater harvesting.

Once water supply (either from rainfall or otherwise) is sufficient, additional measures can improve crop productivity, such as adding mulch and manure and using cover crops. This also improves soil properties (such as organic matter and nitrogen content as well as microbial activity), which has a positive long term effect in that it improves soil fertility and therefore increases the cropping system's resilience to dry spells.

Although these techniques have clear benefits, not all farmers are applying them. The major constraining factor is that many farmers are not in a position to make the required investments, both in cash and in kind (mainly labour). Another constraining

factor is adequate technical information on the possible intervention measures. However, once investments have been made, farmers can improve, and more importantly, secure, their incomes substantially and lift themselves out of the poverty trap (Enfors and Gordon, 2008).

External agents (such as NGOs) were effective change agents, especially in villages with higher diffusion of terraces. On that basis, it can be ascertained that external agents played a big role in influencing diffusion of terraces. However NGOs do not always have sufficient professional knowledge themselves to adequately advise the farmers. In areas with higher government contribution, the extent of adoption is also very high (Tumbo et al., submitted). It is possible that the Government provided indirect incentives such as regulatory measures (fines and taxes) and enabling incentives (land security, market development and credit facilities).

The increase in uptake of innovations has, in the past, created additional challenges, such as expanding agricultural areas at the expense of natural forests and reduced river flows as a result of increased river water diversions by furrows. Local arrangements have been set-up to share the water equitably. These arrangements do not extend to the scale of the entire catchment, where the impacts of increased water use upstream have led to reduced flow and the drying up of rivers during certain parts of the year. The innovations which were studied in the midlands at the plot scale, however, have little impact on downstream users during base flow, especially because these do not rely on river diversions. The impact on flood flows on the other hand is not yet quantified, in particular as a result of the uptake of a large number of innovations.

3.1.9 Recommendations

Improving yields and improving rural livelihoods is not simply a matter of applying a certain innovation. Many innovations developed elsewhere often require specific adaptations to local circumstances before they generate improvements. People need not only to be trained in how to apply a certain innovation; they also need to have the capacity to critically monitor the results, and where needed to develop their own adaptations. Sometimes innovations are abandoned because they were imposed from outside, the farmers were not really convinced that they actually worked, and apparently they did not fulfil the expectations. Therefore the main aim of the SSI outreach component was to improve the capacity of farmers to assess for themselves whether an innovation would work and would fit their farming system.

A good example is Walter, one of the cooperating farmers, who always had a keen interest in the measurements done at his field plot, and he is now better able to judge which combinations of new and old practices benefits the farm. Another example is the rain gauges which have been distributed to smallholder farmers throughout the catchment. SSI researchers have trained them how to record rainfall events, to analyse seasonal rainfall data, compare them with previous seasons, to confront this knowledge with crop yields obtained, and compare this neighbouring farmers. In so doing, a body of knowledge and of critical reflection is being build up among groups of farmers, which hopefully will lead to farmers sharing and exchanging experiences and selecting, experimenting and adopting new and better farming techniques and practices. This new type of agricultural extension is enhancing farmers' capacities, but it also benefits the researchers: the rainfall recorded by 31 farmers proved very

important for assessing the spatial rainfall variability in the catchment (Figure 3.5 above).

Although the SSI programme has clearly shown the potential benefits of some water system innovations, they often require a substantial investment in cash or in labour. Such investment levels are sometimes beyond the capacity of poor farming households. Moreover there is not necessarily an immediate positive return to the investment. Therefore such investments are often not eligible for micro credit schemes. Helping farmers invest in their land is arguably an important role that the government should take up. It should be explored which supportive roles and interventions the government, and other players, can unlock the investment potential of small-scale farmers.

Table 3.5: Summary of Key findings in the Pangani river basin

Scale	Theme	Key finding(s)	Recommendations			Reference publication
			Farmers	Extension/Researchers	Policy makers	
Catchment scale	Environmental degradation	- Land use changes are apparent in the Makanya catchment (agriculture increased from 37% to 55%, while bushland and forest decreased from 34% to 23% and 4% to 2% respectively between 1954 and 2001)	-improve productivity through higher yield per ha, instead of expanding agricultural land areas	- develop and disseminate techniques to improve yields without expanding area	-make sure the remaining forest cover is protected	Enfors and Gordon, 2007
		Hydrological changes	<ul style="list-style-type: none"> - Before 1980 a long dry spell was happening 20% of the time, after 1980 this is 80%. - River flows at the outlet of the Makanya catchment have ceased during low flows 	<ul style="list-style-type: none"> -improve soil resilience and storage to overcome long dry spells -use crop varieties with short growing season -improve water use efficiency 	<ul style="list-style-type: none"> - develop and disseminate techniques to improve soil resilience - develop and disseminate techniques to built storage systems - promote use of short season crop varieties - develop ways to improve water use efficiency - develop ways to distribute water to downstream 	<ul style="list-style-type: none"> - promote use of short season crop varieties - promote the construction of small distributed storage systems - develop plan to improve the understanding of upstream-downstream interactions

			Recommendations			
	Scenario analysis					Enfors et al., 2008
	Spatial and temporal rainfall variability	- the rainfall in the area is not uniform and in particular for high intensity events the spatial variability is large	-diversify in the locations of plots - develop storage for excess water (i.e. in the soil or tanks)	- develop and disseminate strategies to overcome dry spells	-promote use of short season crop varieties	Mul et al., 2008b
Sub-catchment scale	Institutional arrangements	-Water sharing arrangements have been built for generation between the highlands and the midlands -Downstream users are affected by the increase in usage upstream	- improve water use efficiency to increase the "pie" -consider downstream users in water allocation between upstream	-develop and disseminate appropriate technologies for using water at different locations in the catchment	-incorporate the indigenous water allocation mechanisms into the formal water allocation procedures -develop a catchment wide forum -emphasise the interdependencies between upstream and downstream	Mul et al., submitted, Kemerink et al., 2009. Komakech et al., 2008

			Recommendations			
	Irrigation efficiency and effectiveness	<ul style="list-style-type: none"> -Irrigation efficiency of the indigenous irrigation systems is about 20% -The water availability is insufficient to supply sufficient water to all users in the irrigation system 	<ul style="list-style-type: none"> -improve the efficiency of the irrigation application -reduce irrigated area with respect to available water -Reduce distance and water losses between river and irrigated areas by grouping them near the source 	<ul style="list-style-type: none"> -develop and disseminate appropriate technologies for increasing efficiency 	-	Makurira et al., 2007
	Hydro-geology	<ul style="list-style-type: none"> -The geology is defining the flow paths in the catchment -Groundwater in the valley has low water quality 	<ul style="list-style-type: none"> -Base flow is a reliable source of water for supplementary irrigation -use of groundwater in the valley is not advisable 	<ul style="list-style-type: none"> -improving efficient of use of base flow will extend the applicability of this water source 	<ul style="list-style-type: none"> -emphasise the importance of base flow and the limited availability of the resource 	Mul et al., 2007a,

			Recommendations			
	Base flow and flood generation	-A large percentage of the flow is coming from the groundwater -A large percentage of the rainfall during flood flows is stored in the catchment	-surface water for irrigation is a reliable source -access to surface water is essential	-promote occurrence and location of groundwater resources is essential in estimating the availability of the resource	-emphasise the importance of base flow and the limited availability of the resource -emphasise the importance of the upstream (ground water) storage for downstream water usage	Mul et al., 2007b, 2008a, 2008b
Plot scale	Runoff diversion and fanya juu/ water productivity	-water productivity can be improved by: + reducing soil evaporation + increasing infiltration + reducing surface runoff	-the use of ripper increases the productivity only when there is available water and mulch and manure are applied simultaneously	-promote the combined use of ripper, rainwater harvesting and applying mulch and manure		Mutiro et al., 2006, Makurira et al., 2008, 2009
	Constraining factors in smallholder rainfed farming	-rainfall is the main constraining factor	-improve water supply to field through rainwater harvesting and runoff diversion techniques	-develop and disseminate strategies to overcome dry spells		Makurira et al.,

			Recommendations			
	Soil resilience	-Soils in Makanya have low nutrient levels, which is reduced by the intensive agriculture practiced. Increasing the nutrient condition improves the soil resilience for further use	-adding nutrients to the plots is essential to maintain a productive plot -	-develop strategies to improve the soil resilience and use of mulch and manure	-	Enfors et al., submitted
	Poverty trap	Frequent recurring droughts affect the resilience of the people, who need to invest their savings into buying food	-reducing the risk of complete crop failure, through improving the soil resilience, supply additional water to the crop, grow less water demanding crops	-develop and disseminate strategies to reduce risk of complete crop failure		Enfors et al., 2008

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3.2 The Thukela basin: the Potshini catchment (synthesis paper)

3.2.1 Introduction

The Potshini catchment (E 29.3679⁰ S 28.8145⁰) is located in the Bergville District, KwaZulu-Natal Province in South Africa. It is in the foothills of the Drakensberg mountains at an average altitude of 1,310 m and is predominantly a smallholder farming area. From a water management perspective, it is a sub-catchment of the Quaternary Catchment⁵ number V13D in the Thukela River basin. The Thukela river basin is comprised of 86 Quaternary Catchments with a total area of 29,036 km², with the Quaternary Catchment V13D having an area of 285 km². Figure 3.23 and Figure 3.24 show an overview of the Thukela river basin and the Potshini catchment respectively. The Potshini catchment comprises two nested sub-catchments, with an area of 1.2 km² (gauged by an H-Flume) and 10 km² (gauged by a pressure transducer) respectively (Figure 3.24 and Figure 3.25) (Kongo et al, 2007).

The mean annual precipitation at Potshini is approximately 700 mm.a⁻¹ and the estimated mean annual potential evaporation is between 1,600 and 2,000 mm.a⁻¹ (Smith et al., 2004). Rainfall is highly seasonal with rains occurring during the summer season (September to April), often with heavy rains characterized by thunderstorms and occasional hailstorms. The maximum and minimum temperatures recorded in the catchment since 2004 are 34 and -4°C respectively. Frost is common during the dry winter season (May to August) and has often destroyed growing vegetative materials in the catchment, including vegetables in homestead gardens in the catchment.

The main land uses in the catchment include the predominant smallholder farming (crop production) during summer, which constitutes approximately 60% of the total land in the catchment, and grazing (Kongo et al., 2006). The smallholder farms are individually owned while grazing areas and boreholes installed by the local authorities are considered common property. The main sources of water for domestic use in the community are bore holes, springs and the Potshini stream (Kongo, 2008). Due to local topography and high summer rainfall, a good drainage network has developed in the Potshini catchment with most of the streams being perennial and providing water for domestic use to the upper part of the catchment, while replenishing reservoirs used for irrigation by commercial farmers downstream. Clear distinction between smallholder and commercial farmers in the Potshini catchment is shown in Figure 3.24.

⁵ Quaternary Catchments (QC) in South Africa are the smallest delimitations of a river basin upon which policies and decision with regard to water resources management are based upon. The QC were defined and established by the National Department of Water Affairs and Forestry

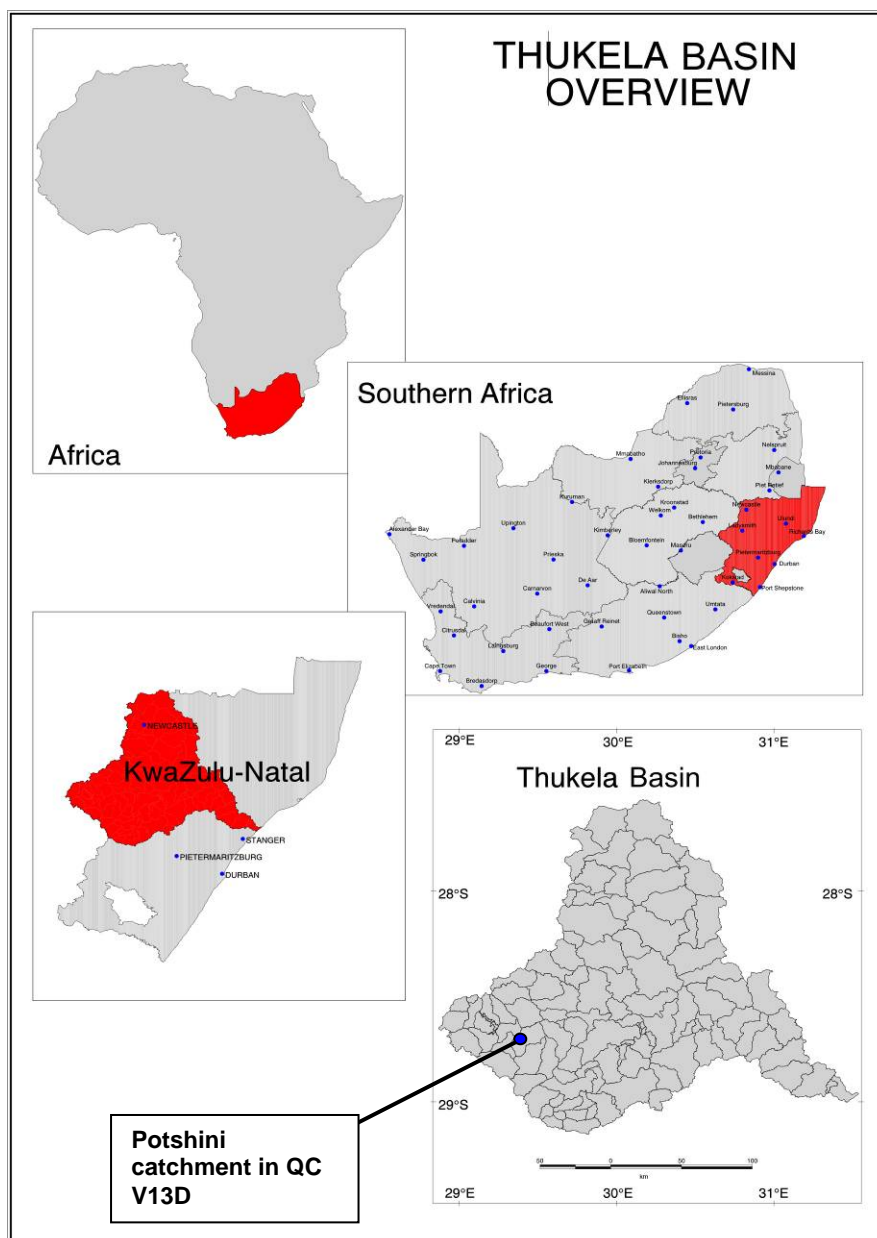


Figure 3.23: An overview of the Thukela river basin.

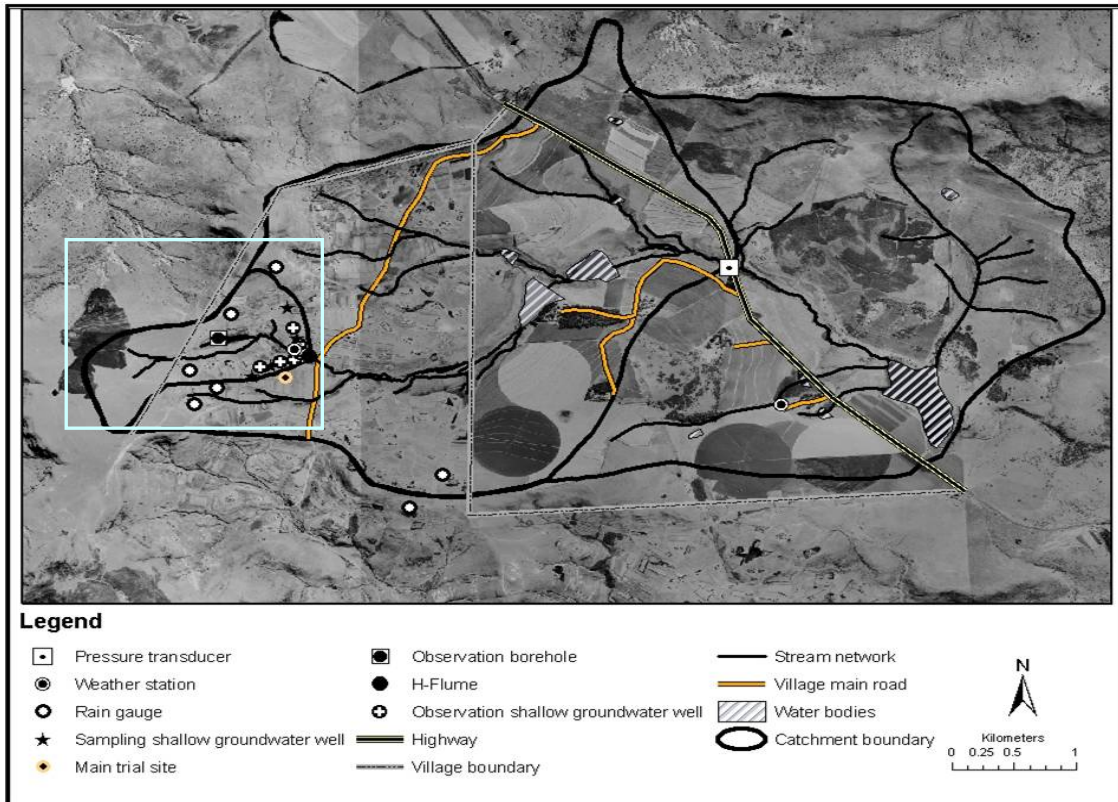


Figure 3.24: *The 10km² Potshini catchment. The straight line to the left of the western most centre pivot is 2m deep ditch separating the commercial farmer and small scale farmers lands.*

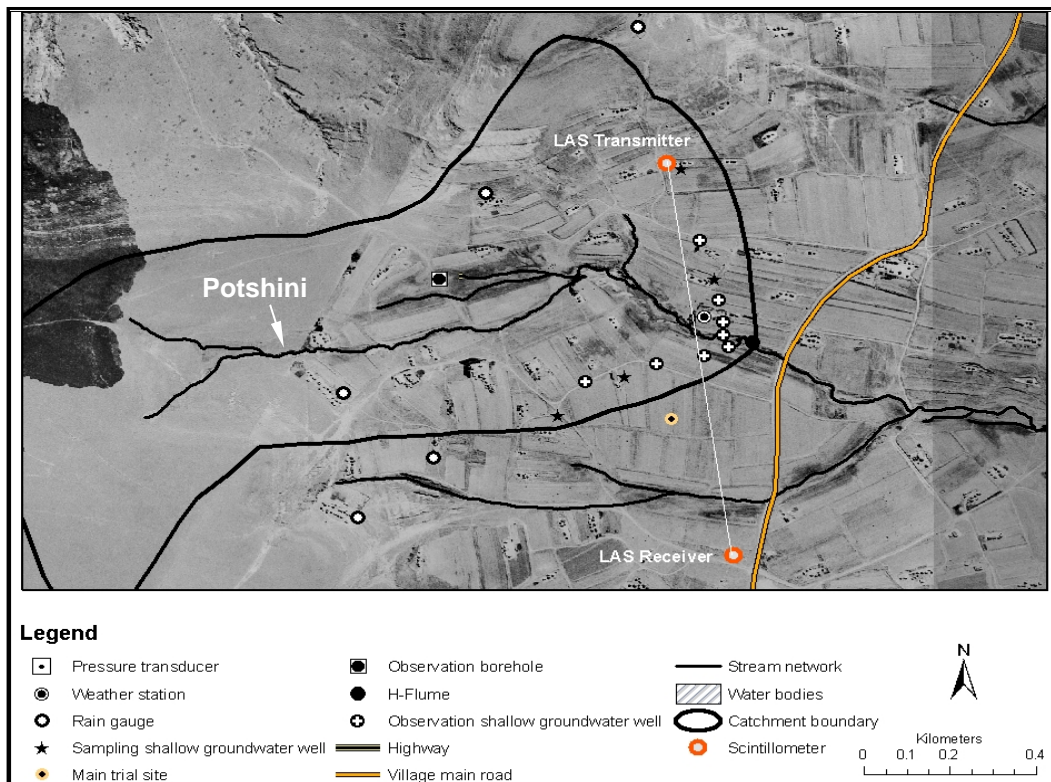


Figure 3.25: *The 1.2km² Potshini upper sub-catchment. Hydrological monitoring was focussed in this sub-catchment.*

The soil pH in the Potshini catchment and surrounding areas is generally acidic and hence liming is advised to optimise crop production. This was evident when the KwaZulu-Natal Provincial Department of Agriculture successfully rolled out (2004 and 2005) a funding package for providing lime to smallholder farmers in Potshini, where significant increase in crop production was observed in many smallholder farms.

3.2.2 The SSI Programme in the Thukela

The SSI programme, in the Thukela river basin, started in January 2004 with two full-time PhD students; Victor Kongo who spearheaded research on biophysical hydrological research while Khumbu Zuma was engaged on socio-economic aspects of the SSI research. Unfortunately, Khumbu's research was short-lived, as she resigned from the SSI programme in mid 2004 and hence the SSI research capacity was affected until mid 2005 when another PhD student, Job Rotich was recruited. One aspect of Khumbu's research was to understand existing farmer innovations, as the Makanya based Project 1a was unable to address this aspect in the Thukela. Consequently, her departure left a gap in the research project in terms of a baseline against which any innovations implemented could be assessed. Since the inception of the SSI programme in the Thukela basin, the SSI team took a proactive approach and engaged with various stakeholders, including other research institutions, at different levels of participation and many opportunities and benefits were realised in the course of these interactions. This process was enhanced further when the outreach component of the SSI programme came into effect in 2005 and the FSG was appointed to lead the outreach and learning process while engaging various stakeholders, many of whom have since contributed significantly to the implementation of the SSI programme in the Thukela river basin. To date, numerous research and or developmental projects/programmes have been and are still being implemented in Potshini and its neighbouring communities many of which are directly related to SSI activities in the Potshini catchment as detailed in Section 4.3.

It should be noted that, even though the outreach and learning process was, we believe, effectively implemented in the Thukela basin through joint efforts by the researchers and FSG, it was sometimes perceived as an extra task and time constraint to the student researchers who, arguably, had a primary objective of producing high quality research for examination purposes. One of the lessons that could be drawn from the implementation of the outreach and learning component in the SSI programme is that the researchers need to be introduced, from project inception, to the vagaries of outreach especially in similar multidisciplinary programmes. However, this was not the case with the SSI programme where the outreach component came into effect in the second year of the programme when most of the researchers were already at an advanced stage of implementing their research work plans.

3.2.3 Integrating research and outreach

Conventional research projects are often not geared to packaging their research findings into forms that are appropriate for easy understanding and uptake by the different stakeholders, including local communities. This is due to the associated cost implications (e.g. time, resources) and to some extent lack of expertise and lack of a "culture" which aims to effectively translate the rather complex research findings into knowledge that is understood at appropriate levels. However, since 2004, the SSI

research programme in the Thukela river basin, with the guidance of the Farmer Support Group (FSG), took a deliberate initiative to engage the various stakeholders, ranging from the Potshini Community to Local, Provincial and National bodies. The FSG facilitated this process by developing a learning framework highlighting the fundamental and basics of various research approaches and techniques that were being, or were to be applied while sharing information and results emanating from the research projects being implemented in the catchment (see Section 4.3). Thus, a curriculum for learning and sharing was developed and implemented through the Farmer Life School (FLS) approach. Implementing of that plan saw farmers learning and sharing their experiences within and outside the community through the *Sivusimpilo Okhahlamba* Farmers forum and a number of Farmer Learning Groups was instrumental in maintaining groups of an appropriate size who could effectively participate in the sessions of the FLS and other activities undertaken in the project. The participatory nature of the project through the use of FLS, enabled the members of the Learner Groups to deal with issues of interest to them, but linked to the project. The FLS, coupled with the cross visits and field days allowed the outreach programme to incorporate a broad range of issues related to the SSI project.

3.2.4 Key research fronts in the Potshini catchment

The main economic activities in the Potshini community are smallholder farming and keeping livestock. Thus, these activities have a major influence on the livelihood of the community and any effort that could improve the productivity, e.g., of smallholder farmers, could have far reaching benefits to people's livelihoods. A typical example was the introduction of rainwater harvesting and storage techniques in the Potshini catchment by the SSI programme for providing irrigation water for homestead gardens during the dry winter season (May to September). This was an opportunity to improve the rural livelihoods in the Potshini community whilst offering research opportunities to assess the factors that could influence the adaptation process of such a water use innovation. Thus, the SSI programme in Potshini identified four research fronts that could contribute to the improvement of livelihoods in the Potshini community and within the overall objectives of the SSI programme. These were:

1. Assessing the potential of water system innovations to improve crop production at field scale.
2. Maximizing land use productivity at field scale for smallholder farmers.
3. Determining and understanding the dominant hydrological processes in the Potshini catchment.
4. Assessing the possible hydrological consequences of upscaling water use innovations in the Potshini catchment.

3.2.5 Participatory hydrological monitoring

To attain some of the objectives of the SSI programme, it was imperative to establish a catchment monitoring network in the SSI research catchment, the Potshini catchment (Figure 3.24 and Figure 3.25) in the Thukela river basin (Figure 3.23), to conduct a detailed hydrological monitoring exercise. The process of establishing the Potshini catchment monitoring network is detailed in Kongo et al. (2007). The Potshini catchment monitoring network consists of gauging structures and instruments, most of them automated, for measuring and monitoring stream flows and sediment load, overland flow generated from runoff plots, shallow groundwater

table, volumetric soil-moisture content, soil-moisture wetting fronts, soil hydraulics properties and meteorological parameters. Additional instrumentation for measuring transpiration (Heat Pulse Method) and total evaporation (scintillometer) were also applied. The Potshini catchment monitoring network was established to accomplish a threefold mission aimed at:

- Monitoring the hydro-climatological regime of the Potshini catchment in an effort to have an in-depth understanding of the hydrological regime of the catchment and investigate the hydrological impacts of adoption and adaptation of water use innovations in the Potshini catchment and the Thukela river basin at large, through catchment monitoring, hydrological modeling and remote sensing techniques, at different spatial and temporal scales. The information generated has been useful for decision making for policy development and reforms in the agriculture and water sectors as far as adaptation of rainwater harvesting techniques is concerned (See Sections 3.1.8 and 4.3).
- Establish a capacity to assess, monitor and manage water and environmental resources in the Potshini catchment, especially relevant to the local community, in collaboration with various government departments (extension officers) through training on the basic methodologies of catchment monitoring.
- Provide an opportunity for future and further research through the establishment of a long-term catchment monitoring network with a potential for upscaling and integrating into other networks. The network comprises several permanent structures which other researchers may use in their studies in the future. Such researchers will benefit from the already established relationship with the local leaders and the community at large which has been developed through the involvement of the community in various monitoring activities.

The SSI programme introduced a participatory catchment monitoring approach in the Potshini catchment where the smallholder farmers voluntarily participated in monitoring the main hydrological fluxes including rainfall, surface runoff and stream flows while hosting and safeguarding some of the various monitoring equipment installed in the catchment, some of which were expensive (Kongo, 2008). Such a participatory engagement, generated much goodwill from the smallholder farmers based on respect and trust, thus crating a solid base upon which other projects that followed and collaborated with SSI were built.

Although the catchment monitoring network at Potshini is relatively new (established 2004), it has the potential to become an integral part of the decision-making process, from field (farm) to national level, on water and agricultural policy related development, and already, the groundwater monitoring has been included in the South African groundwater monitoring framework. The longevity of such networks is enhanced through a combination of well-planned data-collection strategies, training activities, scientific collaborations and publications. Training activities in the form of training workshops, seminars, field visits, field days, etc., have been useful to both researchers and the communities where the network has been established, and in future these should include the sharing of such a practical experience and information with other relevant stakeholders. In the SSI programme, this has been achieved through its learning and outreach component which was implemented by the FSG.

3.2.6 Water system innovations in Potshini

Water System Innovations, as defined in Rockström et al. (2004), can be locally inspired or adapted from outside the target community. The main economic activities in the Potshini community include smallholder farming and livestock keeping. Some of the water use innovations that were introduced by SSI in the Potshini community include rainwater harvesting tanks for collecting and storing water in both subsurface and surface, homestead gardens (Kosgei et al., 2008b), tower and trench bed gardens (Sturdy et al., 2008). The SSI programme continued to build on the research endeavours pertaining to conservation tillage practices i.e. *in situ* rainwater harvesting that were introduced in Potshini by the Landcare programme (Smith et al., 2004), as reported in Kongo et al. (2006) and Kosgei et al. (2007).

3.2.7 Main research outcomes from the Thukela basin

Both biophysical and socio-economic related research on water resources management with a specific focus on water use innovations were conducted in the Potshini catchment in the Thukela river basin. This section details the main research outcomes in the Thukela river basin and a summary of these outcomes is highlighted in Table 3.14.

Hydrology and water resources in Potshini

The runoff response of the Potshini catchment varies over the rainfall season and is a function of the both the magnitude and intensity of a rainfall event (Kongo, 2008). Rainfall of magnitude greater than 30mm/day or intensity of 14mm/h was observed to induce a response at the 1.2 km² catchment. The stream flow, as measured by an H-flume at the outlet of the catchment, is an integral of various components including surface runoff and interflow during the wet season while subsurface discharge from shallow groundwater dominates during the dry winter season. Thus, any anthropogenic activity that may alter the recharge of shallow ground water in the catchment during the wet summer season may significantly affect the stream flows regime during the dry season. One of the research objectives of the SSI programme was to investigate the potential hydrological impacts of intensification or upscaling of water use innovations in the Pangani and Thukela river basins through monitoring and subsequently detailed agrohydrological modelling exercise. Initial assessment of the potential downstream hydrological impacts of large scale adoption of storage based runoff harvesting systems downstream of the Potshini catchment was carried out through a modelling exercise using the *ACRU* model (Schulze et al., 1995) from which it was found that in the upper-Thukela catchment, no significant impact on the downstream flows is likely even when there is a large-scale uptake of runoff harvesting. This is a consequence both of the hydroclimatic characteristics and the high proportion of impervious surfaces associated with human settlements (De Winnaar, 2008).

The long term mean annual rainfall in the Potshini catchment is 700 mm yr⁻¹ which is received over one rain season (October to April). Such an amount is sufficient for successful implementation of rainwater harvesting strategies, both from roof tops and diversion/accumulation of surface runoff from impervious surfaces (e.g. homesteads, pathways) and roads. However, there is a high evaporative demand (contributed by high wind speeds) during the dry winter season and hence pragmatic measures

should be taken to reduce depletion of soil moisture or evaporation of harvested water.

Agriculture

Adoption and adaptation of water use innovations in the Potshini catchment has led to significant improvement in crop production for many smallholder farmers, with some of the farmers being able to produce surplus for sale to neighbours and in the local market (Smith et al., 2004; Kosgei, 2009). For example, some of the smallholder farmers who were introduced to, and adopted, conservation tillage managed to double their maize crop production, reaching a mean of 4 tons/hectare (for fertilised and limed 1ha plots) while diversifying their production through intercropping pulses and maize and recently (2007) the planting of fruit trees and vegetables under rainwater harvesting systems. It should be noted that typical maize yields under dryland conditions on adjacent commercial farms are in the order of 7-9 tons/hectare.

Planting dates is one of the key factors to have a significant impact on crop production in rainfed agriculture. The SSI programme conducted research on the appropriate planting dates in the Potshini catchment and its surrounding as elaborated in Kosgei (2009) and concluded that best planting dates for the region around Potshini is the first two weeks of December. Based on dry spell analysis, this is when there is enough accumulated soil moisture to sustain the emerging plant and lowest probability of dry spells.

Low temperatures during the dry winter season (as low as -5 °C) and frost significantly affects crop growth in the Potshini catchment. Thus, the gains accrued through adaptation of water system innovations to smallholder farmers with regard to crop production during the winter season may be thwarted by biophysical constraints. Crops that are resistant to low temperatures and frost should be encouraged during the winter season and frost protection measures such as shade cloth or traditional “thatched” fencing should be encouraged.

This information was communicated to the smallholder farmers in Potshini and neighbouring communities during field days and the upper Thukela farmer’s forum, a monthly meeting where smallholder farmers from other communities visit fellow farmers in one of the communities on a rotational basis. The farmers have appreciated the results and many of them have managed to put these findings to practice with appreciable returns (See Section 4.3).

Through the SSI programme, the smallholder farmers in Potshini and surrounding communities have been made aware of better use of production resources, e.g., land. For example, the introduction of rain water harvesting techniques to store water for use in irrigating vegetable gardens and domestic use during the dry winter months in the Potshini community has showcased the potential to utilize land throughout the year for crop production. The introduction and further research on tower gardens have proved that crop production can successfully be done on smaller surface areas in the homesteads with less water, and of low quality (grey water), i.e., more production per unit area with limited water resources (Sturdy et al., 2008, FSG report, 2008, Kosgei, 2009).

Trench beds in vegetable gardens, which were introduced by the SSI programme, appear to consistently retain greater moisture throughout the profile than traditional

beds in Potshini during regular rainfall events and short (less than 7 days), well spaced dry spells. However, it was noted that that some of the soil hydraulic properties notably the greater connectivity between pore spaces in the trench beds relative to control beds (traditional beds) may result in gradual but consistent moisture losses during prolonged dry spells. This suggests that while trench beds provide better water availability to plant roots than traditional garden beds during consistent rains, they may be less advantageous during prolonged dry spells and in the dry winter months (Sturdy et al., 2008).

Environment related research

Research on environmental issues in the Thukela basin was undertaken as cross-cutting themes aimed at integrating ecosystem goods derived from the biophysical environment with the services derived by society.

Ecosystem services to complement crop production

Ecosystem services were analyzed both on-farm and off-farm in the upper Thukela region. The focus was on how the use and perception of ecosystems have changed over time and how important they are in the livelihoods of the people in the area at present. Detailed analyses are provided in Hendriksson (2006)

This analysis focused on survival strategies used by the farmers in Potshini and how they have dealt with crop failure or yield reductions in the past and in the present. Ecosystem goods that are used by the farmers include: water, wood for fire and building material, straw, grass, fodder, wild herbs, wild animals, medicine herbs, mushrooms, mud and manure. The results from the study indicate that the dependency on local ecosystem goods has decreased over the past 10-30 years, while several other survival strategies have become increasingly important. Some other strategies include the use of social grants, trading with neighbours, remittances, gifts, take work within the local area, selling cattle, tobacco or handicraft, and simply going hungry.

It was concluded that farmers are not as dependent on ecosystem goods for reducing the effects of yield reductions as originally hypothesised. Currently, most farmers have the capacity to purchase complementary food when yields are reduced. An issue raised but not dealt with was whether the village might be in a process of losing local ecological knowledge related to the use of ecosystem goods which raises questions for future studies concerning the effect of moving their dependency on ecosystem goods and services from a local social-ecological system into a global market.

Historical changes in ecosystems

Focus group discussions were held in 9 different sub-wards including Potshini and the surrounding areas in order to understand how farmers experience changes in the resource base and how farmers perceive the importance of various disturbances that have occurred over time. The results indicate that most of the resource systems that the farmers are using for ecosystem goods and services have, according to their perceptions, been very degraded and that most resources today are seen as being in

a “very bad” condition. Initial analysis suggests that there might be a particular time, from 1970 to 1980 related to wider political change and instability in South Africa, when there was a “jump” in resource degradation, particularly as it relates to livestock increases and changes from ‘good’ to ‘bad’ grass (good and bad are terms used by the farmers). They also state that there have been few responses to this degradation. One reason suggested is the rapid institutional change occurring at the moment with very little monitoring of resource change in the communities. This change includes coinciding factors such as decreased land availability, breakdown of traditional institutions, an increasing gap between generations and new “pulling forces” for the younger generation. But they also have seen several recent development initiatives in the area that might counteract this, such as the then ARC-Landcare project (Smith et al., 2004) and the SSI programme which they believe could help them to change this.

Regulating ecosystem services on agricultural lands

The levels of four regulating ecosystem services of interest in the study area i.e. erosion control, nutrient retention, carbon sequestration and water provisioning was compared for three land uses, i.e., commercial forestry, commercial dry-land farming and smallholder farming relative to virgin grassland (Blanck, 2008). The study was based on expert interviews and ranking, and a literature survey. The results indicate that there is a variation in the generation of ecosystem services between the three land uses. Experts estimate that both commercial agriculture and commercial forestry maintain a capacity to generate regulating ecosystem services at a level close to natural potential. Small-scale agriculture, on the other hand shows a reduction for all four regulating ecosystem service compared to the reference area. The results show that there is great variation within all land uses depending on management practices. No-tillage, i.e., the practice where crop residues are left on the fields after harvest, is mentioned as a method that would improve ecosystem services at multiple levels. Thus, with better management practices such as reduced tillage it would be possible to improve the ecosystem’s ability to generate certain ecosystem services (e.g., erosion and nutrient retention). Some experts state that it is even possible to exceed the level that is originally generated. Strong linkages generating synergisms and/or trade-offs have been found between the selected ecosystem services. Thus, techniques aiming to improve a particular ecosystem service (e.g. erosion control) are most likely to benefit the generation of multiple services (for example also enhance carbon sequestration).

Socio-economic factors

In addition to the economic benefits to the smallholder farmers, some of the water use innovations introduced in the Potshini community by the SSI have enhanced social networking through different platforms in the community over and above the numerous farmer meetings, field days and training sessions. For example, the homestead gardens introduced in Potshini have enhanced social networking especially amongst women who often meet to discuss issues of interest as they buy vegetables from fellow neighbours or as they learn from one another on the best management practice of their gardens. These vegetable homestead gardens, established after the introduction of rainwater harvesting techniques by the SSI

programme, have been a source of earning to the smallholder farmers and a source of time saving by the farmers as they do not have to travel to Bergville town, the nearest market, to buy vegetables especially during the dry winter season (See also Section 4.3). There is an abundance of freely-growing indigenous vegetables in the catchment during the wet summer season in the catchment and hence the homestead gardens have bridged the deficiency during the winter season, thus enabling an all-year round supply with the benefit of adding value to the nutritional intake by the many families who now have a high possibility of getting a balanced diet.

Most of the rainwater harvesting storage systems introduced in the Potshini community require relatively high capital investment which may not be feasible to many smallholder farmers and is a major constraint. However, it was clear to the farmers that there are substantial benefits associated with rainwater harvesting and storage systems, e.g., subsurface storage tanks. Such an appreciation and need by the farmers was a motivation to the SSI programme and other research and development projects in Potshini to solicit for funds from the South African Water Research Commission and Department of Water Affairs and Forestry to roll out grants to the smallholder farmers for installation of rainwater harvesting and storage systems. Consequently, the WRC funded researchers have initiated a project in Potshini where 40 homesteads will acquire plastic tanks with a total capacity of 20,000 litres (4 x 5,000 litre tanks) as illustrated in Figure 3.26, Figure 3.27 and Figure 3.28. Farmers have also started to form task-groups and/or associations, with the assistance and facilitation of the SSI outreach team, through which they can apply for funding from various institutions including government agencies, to implement their own development plans.



Figure 3.26: Plastic tanks (5,000 litres) installed in the Potshini catchment under a WRC funded project.



Figure 3.27: *More tanks awaiting to be installed in Potshini.*



Figure 3.28: *An Aerial photograph of part of Potshini showing distribution of the rainwater harvesting tanks.*

The homestead gardens, and other innovations introduced to the community, have also provided the smallholder farmers a low-risk learning environment for experimentation through trial comparisons which they have co-managed with the SSI team (researchers and outreach) and the extension personnel, particularly those from the Bergville office of the Provincial Department of Agriculture. This participatory learning process has improved the confidence of most of the smallholder farmers in explaining the rationale of the innovations introduced in community as well as imparting problem-solving skills and tools, enabling informed decisions, which are

also applied in other aspects of rural life. However, a holistic approach to agricultural innovation development and extension is needed to address both socio-economic and biophysical dynamics that influence adoption and dissemination of innovations. (Sturdy et al., 2008; FSG report, 2008).

3.2.8 Impact of the SSI Programme in the Thukela basin

To assess the impact of the project in Potshini and the surrounding municipal district, a formal data collection process was undertaken. A questionnaire was designed and administered to a sample of forty nine (49) households in Potshini. The sample, subdivided between members and non-members of the SSI FLGs and comprised twenty seven members (55%) and 22(45%) non-members.

Acquisition of Knowledge

Results indicate that some 85% of the FLG members have acquired knowledge and skills compared to only 4% of non-members. This indicates that there is a clear difference in the manner in which knowledge and skills are acquired by the two groups (X^2 p-level = 0.0001). The flow of knowledge and skills to the non-members is limited, an issue which should be addressed in future work.

Table 3.6 shows the range of skills that SSI members learnt through the project. It also shows the percentage of the members who have used the acquired knowledge. The knowledge available through the project is of a varied nature, covering water related aspects to nutrition, and marketing and business development. The varied nature of the knowledge acquired reflects the FLS approach used in the project.

Table 3.6: Percentage of project members who have acquired and have used knowledge.

Skill	Percentage who acquired knowledge	Percentage who Used knowledge
Water conservation	95.8	70.4
Using trench beds	83.3	70.4
Storing water in tanks	79.2	29.6
Channeling water run-off	75.0	37.0
Making gardens	91.7	91.7
Making compost	79.2	44.4
Planting trees	79.2	79.2
Organic pest control	91.7	79.2
Growing vegetables	79.2	79.2
Market and business management	75.0	18.5
Nutrition	79.2	70.8

n = 27

Most members have acquired knowledge on water conservation and establishing gardens. Organic farming knowledge has been acquired through compost making and organic pest control. Use of the knowledge acquired varies, depending on what inputs are required for its use. For example, most households have implemented the making of gardens, planting of trees, organic pest control, and growing of vegetables.

However, the construction of water storage tanks requires financial resources and only households who could access support managed to establish them. The project has developed the business skills of 75% of the members but only 18.5% have been able to put this knowledge to good use. This is because production is still low and not much scope for marketing has been realised.

Nutrition

Nutrition is a topic covered during some sessions of the FLS. The knowledge acquired could also affect the availability of nutritious food at household level. Some 87.5% of the households that acquired some knowledge stated that the knowledge had resulted in better nutritional status of the households in various ways. The project activities have increased the access of households to balanced nutritious diets, healthy eating habits, for example through the use of less oil when cooking (Table 3.7). Respondents indicated that members of their households were no longer falling sick as often as before.

Both members and non-members noted that their health improved somewhat as a result of the project. Chi-square tests suggest that there is a significant difference in the distribution between members and non-members and their realisation of better health. Only 32% of non-members realised better health compared to 69% of the members. Therefore, the results from this sample imply that membership of SSI FLS had a positive impact on health.

Table 3.7: Health and nutrition impacts of the project.

	Frequency	Percentage
Variety, balanced diet, fresh food, healthy food	15	53.6
Don't get sick often	8	28.6
Use less oil/fat	5	17.9
Total	28	100.0

Three main measures have been promoted to improve health (Table 3.7). Eating of fresh green leaf vegetables and use of less oil are the major routes used for establishing healthy diets.

Table 3.8: Measures that households have taken to improve health.

Measures	Frequency	Percentage
Fresh vegetables, variety, always have food which they like	13	52
We boil food	8	32
Do not get sick often, health and physical strength improved	4	16
Total	25	100

Access to education

The project activities impacted on access to education. Seven farmers indicated that the project had allowed them to send children to school. The farmers indicated that this was either through income realised directly selling produce or by saving on the money that could have been used for buying food.

Crop Production

The project dealt with production techniques that could have an impact on crop production levels, e.g., soil fertility, pest and disease control, land preparation (Table 3.9). Kosgei et al. (2007) showed that the minimum tillage technique which the project was assessing against conventional tillage could result in maize yield increases of 168% above those of the conventional treatments under certain climatic conditions. Survey results showed that maize production per household increased significantly after the introduction of the SSI project. The significant production increases were realized by both members and non-members. However, there has not been a significant change in the production of beans and potatoes. A contrast by membership shows that members realize higher production than non-members before and after the SSI project (Figure 9.4).

To some extent, this suggests that members tend to be drawn from better farmers and that the project could be producing spill over effects on non-members. The increase in maize production is greater for non-members than members. Non-members' maize production increased by 154% compared to 40% for members.

Table 3.9: Crop production before and after SSI project for members.

Crop	Timing	Mean (tonnes)	t-statistic
			significance level
For members (n=27)			
Maize	Before SSI	2.41	0.001
	After SSI	3.37	
Beans	Before SSI	0.78	0.821
	After SSI	0.85	
Potatoes	Before SSI	0.67	0.129
	After SSI	0.93	
For Non-members (n=22)			
Maize	Before SSI	0.95	0.000
	After SSI	2.41	
Beans	Before SSI	0.55	0.888
	After SSI	0.50	
Potatoes	Before SSI	0.36	0.576
	After SSI	0.41	

However the same phenomenon could indicate that there are other factors not induced by SSI that result in increased maize yields. Nevertheless, the role of the SSI project is prominent.

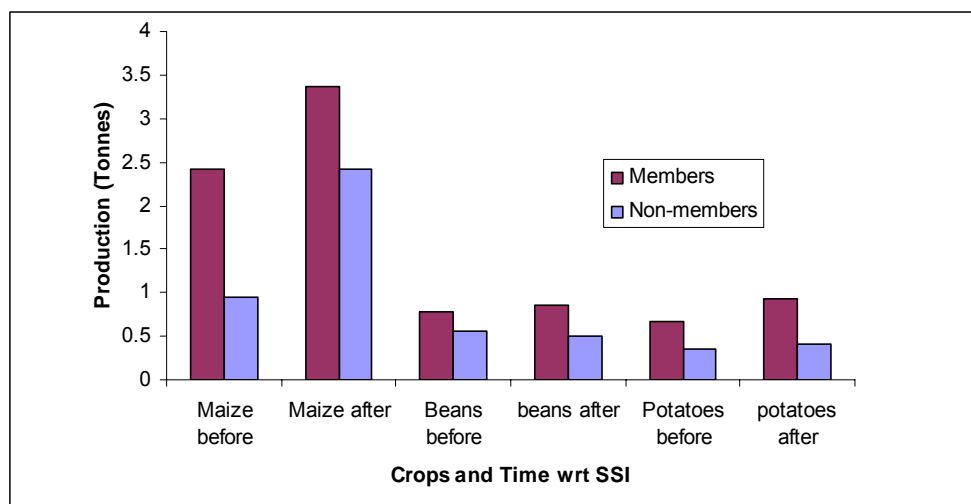


Figure 3.29: Yield comparison before and after SSI Project by membership.

Financial Benefits

Income sources in Potshini are from government grants, salaries, remittances, farming, building and knitting, crafts, taxi, traditional healer. Some 92% of the households receive government grants. There are significant differences across households in the income levels. The average total household income is ZAR1,100 per month. However, the same significant differences in income levels do not exist between the households of members and non-members. This would seem to suggest that the SSI project has not yet had any significant impact on income levels and that income is still largely determined by factors exogenous to the project. However, this type of measure does not take account of income in kind, i.e., farm produce consumed within the household.

Being a member is not necessarily influenced by the presence of employed members within the household. In general the proportion of households with employed members was low. Only 26% of the members' households had employed members, compared to 9% of the non-members. There were no significant differences in the distribution of membership to households with and without employed members (χ^2 p-sig. level = 0.13).

The level of participation in the marketing of crops was not significantly different between group members and non-members. Therefore, as yet, the project has not yet had an impact on the level of income through marketing of field crops. Even though members produce more maize than non-members, this does not translate into higher marketing activity in the former group.

The SSI project has allowed its members to produce vegetable crops for the market. By contrast, non-members are not yet marketing vegetables. Table 3.10 shows the proportion of members who marketed their produce.

Table 3.10: Participation in the Marketing of Vegetables.

Vegetable	% of Members	X ² p-sig. level
Cabbage	37	0.001
Spinach	37	0.001
Green Pepper	7	0.192
Tomatoes	26	0.010
Beetroot	11	0.107
Carrots	11	0.107

No non-members marketed any crops

In all cases, no non-members sold any vegetables. Statistically significant differences arise with respect to cabbages and spinach where a greater proportion of the members participate in the marketing than non-members.

Results show that no farmer was making income from vegetables before the inception of the SSI project. Only one farmer was making less than R200 from green peppers. The numbers of households that realized income from selling vegetables increased with the advent of the project. Non-members did not realise any income as they were not involved in the marketing of vegetables. Table 3.11 shows that income levels realised are still low. Cabbages, spinach and tomatoes were the crops in which most people participated.

Table 3.11: Income that the project members realised from vegetables after the project.

Vegetable	0-R100	R101-R200	R201-R300
Cabbages	29.6	3.7	0
Spinach	25.9	7.4	7.4
Green pepper	3.7	7.4	0
Tomatoes	18.5	0	7.4
Carrots	7.4	3.7	0
Beet Root	7.4	0	0

n = 27

The distribution of sale of crops differs across membership. Members sell some field crops while no non-members are involved in selling field crops. As already indicated, yield levels are generally higher for members than for non-members. It would be more likely that members have more surplus available for marketing (Table 3.12).

Table 3.12: Percentage of households marketing crops.

Crop	Percentage of Members	X ² p-significance level
Maize	37	0.001
Beans	22	0.018
Potatoes	11	0.107
Sorghum	14	0.362

Table 3.13: Income realized from field crops by members.

Income Range	Maize	Beans	Potatoes	Sorghum
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R101 - R200	0	7.4	3.7	3.7
R201 - R300	18.5	0	3.7	0
R301 - R400	7.4	0	0	0
R401 - more	3.7	3.7	0	0
Total	27.6	11.1	7.4	3.7

As expected, the highest percentage of households (27.6%) realise income from maize. It has already been shown that yields increased partly due to participation in SSI (Table 3.13).

The project has had a definite influence on the ability of the SSI participants to finance household level expenses. This is evident from the significant differences in the distribution of ability to make purchases across membership. While 63% of members indicated that the project influenced them to make purchases, only 4% of the non-members said the same. Chi-square tests show that this statistically significant difference could be attributed to membership (X^2 p-level = 0.0001). Some 52% of households of members bought various goods, 4% paid school fees. Another 7% bought food or saved money. Bearing in mind the fungibility of money, the general observation should be that the project activities increase the disposable income available members' household.

Of the 63% of the households which managed to sell produce, 41% managed to save some of the money but the amounts saved are small. Some 22% of the households saved less than R1,000.

No households have access to formal credit sources. Households have to rely on accumulations of their savings, remittances etc. for resources to finance their activities. There are also informal sources of credits, and farmers borrow from each other. Remittances are a significant source of income there is no significant difference in the access to remittances between the members and non-members.

Social grants

The majority of households receive social grants such as old age pensions, disability grants and child support grants. Across the sample, 82% receive social grants. There are no differences in receipt of grants across membership. Some 48% of the SSI members who were grant recipients felt that the importance of social grants had decreased due to the project activities.

Besides remittances and social grants, some households also have family member resident on the farm, who work and receive a regular income. Across the sample, 37% of the sample has at least a resident member of the household member working and getting a regular income. There are no significant differences between members and non-members with respect to presence of a family member with a regular source of income. The survey shows that 55% of those with a regular income thought that the project resulted in a decrease in the importance they accorded to such income.

The project had other secondary impacts such as allowing 41% of the members to build or repair houses or other structures at the homestead probably through the additional income realised. Participation in the project improved access to water, e.g., tanks for 48% of members. Members perceived that the project revived or increased

their access to indigenous knowledge. Some 26% accessed seed knowledge, 37% soil fertility, and 30% received knowledge on pest control measures.

Only project members have planted trees, with 92% planting less than six while seven percent planted between 7-12 trees. Everyone, members and non-members thought that the project had resulted in an increase in the tree population in the area. The fruit trees planted will result in income and food when they start bearing fruit. Some of the fruit trees have started to bear fruit.

In summary, the project has been beneficial in a number of ways, but is largely confined to the members of the Learner Groups. The project has not been successful in enabling the greater participation and impact of those who were not members of the SSI-formed learner groups. To achieve greater impact, the project will need to deliberately target information to non-members, as it is currently doing with members. Non-members should be invited to events such as field days. Conversely, the project could organise more activities which allow for public participation. Farmers should be encouraged to communicate amongst themselves as farmer-to-farmer communication.

Addressing HIV/AIDS through “Soup Kitchen”: A farmers initiative

Farmers involved with SSI have initiated a scheme through the FLS, the aim of which is to take care of individuals infected and affected with HIV/Aids. The project seeks to provide supplementary feeding to the sick and orphans in Potshini. Those who have access to grants and pensions are not included as they are expected to have adequate food. The project, called *Snethemba*, is funded by the Department of Social Development. Different healthy foods, including vegetables, are cooked and meals provided. The project procures its produce locally, thus creating a new market for the FLGs. Consequently, the FLGs and the Department of Social Development have signed a memorandum of understanding (MOU) for the FLGs to supply vegetables to Snethemba project.

Through its activities in Potshini, the SSI project acknowledges the differences attributed by gender, HIV-Aids, poverty and income and does not discriminate its members and research farmers on the basis of HIV-Aids, poverty and income. It maintains a good gender balance in terms of its learning group members and research farmers and- as mentioned above- has made significant impact in bringing water closer to the households, freeing up time for various other social and cultural activities, instilling greater confidence, income diversification, better health and nutrition and bringing communities together.

3.2.9 Methodologies and decision support tools introduced in Potshini

Several research methodologies and technologies were introduced and applied by the SSI programme in Potshini and Thukela at large. These methodologies and technologies were applied and tested with success and it is suggested that several of these could be used in other areas, probably under similar conditions. One of the technologies introduced was the use of a polythene liner in subsurface rainwater harvesting tanks. This was found to be much cheaper compared to other linings, e.g., concrete lining. However, the main reason for using the polythene liner was the fact that the Potshini catchment has a relatively high shallow groundwater table which

could subject rigid lining material to excessive pressure with a high possibility of failure. Subsequent construction of subsurface tanks by local NGOs after the establishment of the Potshini hydrological monitoring network could draw on SSI research to make informed decisions, based on measurements and analysis of the fluctuation of shallow ground water on the suitability of different lining materials and appropriate rainwater harvesting systems for the area (Kongo et al., 2006).

Relatively new and innovative techniques were tested and applied in the Potshini catchment in hydrological studies. These included geophysical methods (ERT) for characterizing the spatial subsurface hydrological determinants at field (Kosgei, 2009) and catchment scale (Kongo et al., 2006) and scintillation and remote sensing techniques applied to quantify the variation of total evaporation from field to river basin scale (Kongo, 2008). These are novel approaches in this setting and research findings highlight their applicability to other catchments and river basins, particularly in addressing scale issues in hydrology and as a contribution to the Prediction in Ungauged Basins (PUB) initiative (Sivapalan et al., 2003).

One of the challenges in implementing rainwater harvesting techniques is in locating the best and or potential sites while taking into account the hydrology of the area and other biophysical parameters such as soils, topography etc. The SSI programme developed and tested a GIS procedure for locating the potential sites for implementing rainwater harvesting techniques at the Potshini catchment (De Winnaar et al., 2007). Once again, such a procedure can be applied in other catchments provided the biophysical parameters are known at the desired spatial and temporal scale.

3.2.10 Contribution to management of water resources-upstream and downstream users

Monitoring the quantity and quality of water resources at different scales is fundamental to sustainable water resources management. Through the SSI programme and with the participation of the local community, various permanent structures and equipment for monitoring the hydrological fluxes in the Potshini catchment were installed (Kongo, 2008). The permanent equipment and structures, mostly automated, include an H-flume, piezometers for monitoring stream flow levels, weather station and shallow groundwater wells. Through such efforts, the confidence in studies to quantify the water resources of the catchment is improved, and there is a sound basis for further studies on process hydrology and integrated water resources management in the catchment.

The Potshini community is located on the upstream of commercial farmers who have small dams for irrigation purposes. Unfortunately the relationship between the commercial farmers and the local community is often strained (Kemerink et al., 2009), particularly because livestock from the smallholder farmers roam onto the commercial farmer's property. However, by virtue of knowing the quantity and quality of water monitored at the upstream gauging station (H-flume), some of the commercial farmers have now appreciated the fact that the upstream Potshini community is equally a water user and hence the possibility of having a common platform in the near future for engaging and negotiating between upstream community and the commercial farmers on allocation, use of water resources and other issues has improved.

3.2.11 Contribution to planning and policies

Through collaboration and networking with other relevant national and regional projects/programme, the SSI research programme has added value and complimented other programmes through sharing of information, data and experience with a broader objective to build capacity in research while contributing to national planning and policies on improvement of rural livelihoods through sustainable water use management.

In 2005, the KwaZulu-Natal Provincial Department of Water Affairs and Forestry (DWAF) initiated a programme in several districts, including the Bergville district, for mentoring smallholder farmers (emerging farmers) and facilitating the integration of emerging farmer's water user association with mainstream commercial farmer's associations. The formation, governance and support of institutions for water resources management at various levels was a research thrust for the SSI programme. The DWAF initiative was an opportunity for the SSI researchers who ultimately contributed significantly to the process in the Bergville district even though, these efforts have been hampered by the lack of clear policies in DWAF on the setting up of such associations.

The introduction of rainwater harvesting systems in the Potshini catchment was guided by the need to have robust systems while taking into account their affordability and adaptability by the local community. Such a process required the computation and comparison of relative costs of different types of storage tanks and especially the lining. The cheapest and most robust lining option for the Potshini catchment was found to be polyethylene (Kosgei, 2009). The national Department of Water Affairs and Forestry benefited from the SSI cost analysis in its roll-out programme for providing grant packages to smallholder farmers to install rainwater harvesting systems on their farms as the SSI contribution helped to raise awareness that the grant packages offered were far less than the real costs for installing a rainwater harvesting system. It has since then adjusted its grant package from ZAR5,000.00 to ZAR10,000.00.

In 2006, the SSI research programme conducted a survey to establish the status of food security in the Potshini community. One of the key findings from the survey was that most of the families in the community could not afford regular meat proteins in their meals due to its high cost and instead utilised the cheaper option of beans (Kosgei, 2009). These results and other relevant information were communicated to the Bergville district office of department of Agriculture by the SSI research team through the local extension officer who subsequently informed the Provincial office. A consequence of this process was that the Potshini community was enlisted in the 2007 and 2008 Provincial Department of Agriculture's programme of providing free seeds for dry beans to smallholder farmers. Dry beans have a ready and competitive market in the province with a price more than ten times higher than maize. Consequently, some smallholder farmers have opted to grow only beans and use the money from the sale of beans to buy maize at a cheaper price, thus enabling them to even purchase more maize from fellow farmers than they would actually have harvested. Similarly, the *Okhahlamba* municipality in Bergville district, who have been collaborating with SSI in various development projects in Potshini (See Section 4.3), have since then formally recognized and included the SSI programme as one of its rural development programmes in its area of jurisdiction. This comes after

demonstrable community development initiatives by the SSI in the Potshini community and surroundings. Thus, the SSI programme could apply for funds from the municipality to implement community developmental projects in the *Okhahlamba* municipality and did so, resulting in the provision of fencing material for many smallholder farmers.

The SSI programme has added depth to the School of Bioresources Engineering and Environmental Hydrology (SBEEH) of the University of KwaZulu-Natal research endeavours in rainwater harvesting and other related fields e.g research on stream flow reduction activities. Such an effort has led to the recognition of the School as one of the few institutions in the region doing research in rainwater harvesting and hence other institutions (locally and internationally) with similar research interest have been consulting and linking with SBEEH as a resource base in this regard.

3.2.12 Capacity building

Apart from achieving some of the objectives of the entire programme, the SSI in the Thukela basin managed to impart skills and build capacity of various institutions and individuals in the Potshini community and surroundings. These include:

1. Two PhD, two MSc and many honours degrees have been awarded to the SSI research team in the Thukela basin.
2. The SSI community facilitator, Mr. Thabane Madondo has been enrolled for diploma course at the University of KwaZulu-Natal. He is expected to finish in 2011.
3. The Potshini research catchment has been a field laboratory for both undergraduate and postgraduate students from the University of KwaZulu-Natal where these students undertake various hydrological field experiments. Learners from the nearby Alexander High School have also been visiting the catchment for their introduction course in natural sciences and landscape management.
4. The smallholder farmers in Potshini have become more knowledgeable through their interaction with the SSI researchers, their own experimentation especially through the input and facilitation of the FSG as detailed above.

3.2.13 Challenges and opportunities in outscaling water use innovations in the Thukela

Cost and biophysical factors

The adaptation and uptake of most of the water use innovations in the Potshini community have been a challenge for most of the smallholder farmers in Potshini and neighbouring communities. As highlighted above, this is mainly due to financial constraints. However, there are other underlying factors that have an influence on the adaptation process besides the cost implications. For example, the sustainability of an innovation in the context of the social and biophysical dynamics of a community needs to be well understood before an innovation is introduced. In the Potshini catchment, for example, most of the smallholder farmers who were given inputs for conservation tillage research trials on their farms did not adapt the practice in their farms and reverted to conventional tillage practices after the trials. This could be

attributed to the fact that, as highlighted in Kosgei (2009), basic crop and soil management practices (e.g., weeding, application of pesticides, control of soil pH etc) play a more significant role in crop production than availability of soil moisture (e.g., facilitated through conservation tillage) in years that receive adequate rainfall. It is also important to note that the grazing management in the Potshini community, where livestock are left to graze freely in the smallholder farms during the dry winter season, is extremely problematic for sustaining efforts to successfully implement conservation tillage in the catchment because of the destruction of mulch and crop residues on the soil surface which are eaten and trampled by livestock.

Consequently, it was observed that conservation tillage practices only play a significant role in improving crop production during years that have a late onset of rainfall and high intra seasonal rainfall variability, especially when low rainfall occurs during the critical growth stage of crops. In fact, conventional tillage systems performed better than conservation tillage with regard to crop production in years that had early onset of rainfall with less intra-seasonal rainfall variability (Kosgei, 2009).

There are many occasions when the crop and soil management practices have not been given priority by some of the smallholder farmers and this has led to poor crop production in their farms. For example, the mean annual precipitation in Potshini is 700 mm/annum and occasionally some of the smallholder farmers have complained of excess rainfall during the peak of the rainfall season (January to March), over successive days, which has deterred them from weeding their crops.

Capacity to manage and sustain innovations

The SSI programme introduced rain water harvesting systems in the Potshini catchment, beginning in 2005, to collect and store rain water from roofs (both grass thatched and iron roofs) and surface runoff generated from impervious surfaces on homestead compounds. The rain water that was harvested from the roofs was stored in 5000 litre plastic tanks while the surface runoff was stored in a subsurface-polythene lined 52000 litre tank with an iron roof to safeguard children from falling into the tank and also reduce evapotranspiration while catching the rain that falls on the roof and channelling it to the subsurface tank. The harvested water was mainly used for irrigating vegetables in homestead gardens, which were introduced by the SSI programme (Kosgei 2009), during the dry winter season. A treadle pump was used to raise the water from the subsurface tank to a smaller plastic feeder tank, located at a higher elevation, before draining into a drip irrigation system for a vegetable garden of an area of 100m². Several lessons were learnt through this process with regard to adaptation needs of such an innovation. The first one is the capacity to manage and maintain such utilities by the smallholder farmers. In Potshini, it was observed that the wooden rafters of the iron roof on top of the subsurface tank were breaking down, after being subjected to moist/humid conditions for long time. However, the smallholder farmer did not take a leading initiative to repair the roof. Thus, one could have opted for steel rafters in an effort to make the roof more robust even though it is acknowledged that this could have severe cost implications.

The treadle pump broke down often due to failure of rubber seals at the suction and delivery chambers and the spare parts were difficult to source locally. The company that makes such pumps is based in Kenya from where the spares had to be sourced. Thus, the sustainability of using the pump is in doubt and the smallholder farmer has

occasionally borrowed a petrol-powered pump or used a bucket to lift the water. The last two methods of lifting water from the tank are expensive and tedious respectively.

The role of government departments and other institutions

The cost of constructing a 54,000 litre subsurface rainwater harvesting tank with a polythene lining in the Potshini community was ZAR17,000 while the cost for purchasing a plastic 5,000 litre tank was ZAR2,400. These are relatively high investment costs for smallholder farmers in Potshini to afford and/or risk. The uptake of such innovations by the community members has been slow with none of the smallholder farmers investing personal savings in rainwater harvesting structures. However, since 2006, there has been continued initiative from two Water Research Commission projects in Potshini on adaptation of rainwater harvesting storage structures in the community through provision of subsidised packages for farmers to build/install rainwater harvesting tanks in their homesteads. However, the uptake and sustainability of such an initiative is yet to be determined given the dynamics associated with adaptation of innovations in Potshini and other similar communities.

Many smallholder farmers in Potshini were enthusiastic to have homestead vegetable gardens during the dry winter season, when they were introduced by SSI in 2005. However, several challenges emerged after the freely grazing livestock, rodents and birds fed on the vegetables due to lack of any other vegetative material in the catchment. Thus, fencing (to safeguard the vegetables from livestock) was crucial for uptake of the homestead gardens by the local community. Some of the smallholder farmers were innovative in protecting the crops from birds and rodents by constructing “umbrella” structures surrounding each crop using sticks. Thus, it is significant that the uptake of the homestead gardens in Potshini was enhanced when the local *Okhahlamba* municipality sponsored fence material for homestead gardens measuring 20x10 m for 20 farmers, through the efforts of their outreach partners, the Farmer Support Group as highlighted above. Some of the farmers who received the fencing material managed to produce enough vegetables and of high quality to sell to neighbours or in the local market at a profit. These farmers drew water from nearest sources (e.g., pumping wells, springs, harvested rainwater etc.) and other smallholder farmers who did not benefit from the municipality sponsorship took their own initiative and used local material and or their own resources to procure fencing material for homestead gardens. Some smallholder farmers who are located close to perennial water sources have continued to manage their homestead gardens and a few other farmers located far from water sources have occasionally teamed up with such farmers and expanded the gardens to accommodate their interest.

Many households in the Potshini community depend on various other sources of income including remittance and social grants, with social grants contributing over 90% of the income used to bridge the food shortages (Kosgei, 2009). These grants assure the target families/homesteads of basic needs thus creating temporary comfortable environment for the families. Whilst beneficial, the grants have the potential to hinder the motivation and drive to be self reliant leading to slow uptake of water use innovations for improving livelihoods in the community.

In summary, the main lesson that we could learn from the adaptation process of the various water use innovations introduced in the Potshini community (e.g., conservation tillage, rainwater harvesting systems, homestead gardens etc) is that

innovations need to be adapted to local conditions for uptake and sustainability. However, the adaptation process needs time for both the researcher and local community to learn, understand and manage the local conditions including the socio-economic and biophysical dynamics. Each innovation may have different time requirement before it can be adopted by a community depending on the time required to study and understand the dynamics influencing the innovation (e.g., soils, hydrometeorology, cost, risk of investment, etc. for the case of rainwater harvesting), the need by the community, supportive structures (e.g., government departments, local NGOs, etc.). Generally, government institutions that are responsible for social welfare, environment and water resources management have a big role to play in upscaling and or institutionalizing water system innovations through drafting of relevant policies and merging common development programmes for sustainable use of water resources (Kemerink et al., 2009).

Table 3.14: Summary of Key findings in the Thukela river basin.

Theme	Key finding(s)	Recommendations			Reference publication
		Farmers	Extension/Researchers	Policy makers	
Manifestation of crop production limitations in smallholder rain fed farming	<p>In the 1951-1999 period there is an advance of about two weeks in the onset of rains relative to the 1901-1950 period.</p> <p>There is an increase of dry spell occurrences early in the growing season.</p> <p>The optimum sowing date falls within the first two weeks in December.</p> <p>There is a high risk of failure to achieve optimum yield in maize production.</p>	<p>Land preparation to be done earlier to allow adequate moisture accumulation and timely sowing.</p> <p>Soil and water conservation measure need to be incorporated.</p> <p>Diversification of crops is necessary to ensure returns to investments.</p>	<p>Need to investigate the frequency and effects of intra-seasonal dry spells.</p> <p>Develop and disseminate suitable soil and water conservation technologies.</p> <p>Provide information on the appropriate crops that can be produced alongside or instead of maize.</p>	<p>The week that the <i>Induna</i> gives instructions to the community for cattle to be driven away from the farmlands in anticipation of land preparation and sowing should be revised.</p> <p>Measures to caution crop production losses resulting from dry spells need to be provided.</p> <p>Financial support to develop physical structures for water conservation and storage need to be entrenched in annual development plans.</p>	Kosgei, 2009

		Recommendations			
Field-scale hydrological responses to tillage systems	<p>The rainfall partitioning process was mainly influenced by characteristics of rainfall events and the soil surface.</p> <p>There was more runoff from No Tillage (N_T) plots at the start of the season than in Conservation Tillage (C_T). The reverse was observed later in the season.</p> <p>Although there were no significant differences (p≤0.05) in soil moisture depths, runoff depths, crop transpiration and soil evaporation between (No Tillage) N_T and C_T, N_T allowed for more infiltration, less runoff and more crop transpiration, relative to (conservation Tillage (C_T.)</p> <p>N_T systems are suitable within a certain range of rainfall.</p> <p>Without adequate residue cover (to reduce soil evaporation, rain drop impacts and enhance infiltration), as commonly observed in Potshini due to livestock grazing patterns, C_T systems are generally seasonally better in infiltration and water retention.</p>	<p>To adopt a tillage systems suitable to local conditions and note that N_T systems necessitate adequate residue cover.</p> <p>Use soil and water conservation practices to reduce soil moisture losses which are substantial at the start of the season.</p>	<p>To make suggestions regarding tillage based on detailed studies rather than the common belief that N_T systems perform better than Conservation Tillage.</p> <p>Use of a number of techniques to monitor fluxes adds more value to the study and is likely to give reliable results.</p> <p>There is a need for more field-based research to directly quantify soil evaporation, crop transpiration and deep percolation.</p>	<p>To provide regulations that support tested and proven technologies.</p> <p>To recognize that communities tend to develop a consistent livelihood over time that may conflict with biophysically proven technologies. Hence there is need to provide guidance for co-existence.</p> <p>The amount of runoff has implications on quantity and quality downstream generation of goods and services: water allocation, water quality issues and hydraulic structures need to be pegged on the actual estimated runoff.</p>	<p>Kongo, 2008</p> <p>Kosgei, 2009</p>

		Recommendations			
Characterizing the dominant surface and near surface changes in soil hydraulic properties due to tillage	<p>On a seasonal basis, 50% of the sites showed significantly higher hydraulic conductivity in N_T compared to C_T. These sites were considered suitable for N_T while the other sites were regarded appropriate for C_T.</p> <p>A combination of tillage and soil physical properties led to statistically significant differences in hydraulic conductivity measured using tension disc infiltrometer;</p> <p>Plants in N_T plots are likely to suffer more from water stress at the beginning of the season as compared with those in C_T plots because the water content at wilting point in N_T at this time is higher;</p> <p>Seasonally, crops could be sustained longer in N_T than in C_T; however, there was more available water content in C_T.</p>	<p>There is no superior tillage system but need detailed analysis of soil physical and hydraulic properties to determine the most suitable tillage system to use.</p> <p>Plant water stress at the start of the season (and/or at any critical growth stage) should be minimized</p>	<p>Conduct detailed studies on soil physical and hydraulic properties and link this to rainfall characteristics prior to recommending specific tillage systems.</p>	<p>Land use potential, classification and allocation need to be based on, among other factors, soil physical and hydraulic properties;</p> <p>The sizing of hydraulic structures in transport systems e.g. culverts, bridges, barrages, etc that is normally the mandate of policy makers depend on the runoff generating characteristics of the catchment which is affected by soil hydraulic properties.</p> <p>Sediment load is proportional to the runoff generated; hence operation of reservoirs could be improved with adequate knowledge of soil hydraulic properties.</p>	Kosgei, 2009

		Recommendations			
Structural, agrohydrological and socio-economic appraisal of rainwater harvesting storage tanks	<p>Runoff from homestead courtyards and surrounding impervious surfaces was found adequate to bridge 180 days dry spell in an area of 200m² under vegetables.</p> <p>The cost of rainwater harvesting storage structures (RHSTs) is high. Use of underground tanks ensures that runoff from all areas, including those previously disregarded is captured. Furthermore, the soil resists some of the water pressure, reducing the required wall thickness and this way the overall cost of the tank is decreased.</p> <p>Lining underground RHSTs with a 600 µm polythene sheet was shown to be suitable and cost-effective; and</p> <p>The capacity to weld plastic into different shapes is available in most urban centres in South Africa and may not be the case in other regions of SSA which presents a challenge on the use of this technology elsewhere.</p>	<p>Runoff should be viewed in a 'productive' rather than a 'destructive' manner: hence the need to harvest and store as much runoff as possible.</p> <p>To increase production per unit area as crop production is possible all the year round with RHSTs;</p> <p>The RHSTs should be well sited, sized and designed to include sediment exclusion devices.</p> <p>The material(s) of construction need to be adequately appraised to ascertain suitability.</p>	<p>A careful analysis of rainfall-runoff, crop water requirements and sediment loads within the length of time being considered is crucial.</p> <p>Sediments remain a challenge and there is still a need to design and test more efficient traps to eliminate as much sediment as possible;</p> <p>It is necessary to evaluate the status in other regions of the capacity to weld plastic into desired shapes as well as consider import costs from the nearest and/or most convenient source before making recommendations to farmers.</p> <p>To ensure that rubber seals used in treadle pumps to be manufactured locally instead of sourcing from Eastern Africa.</p>	<p>The legislation regarding excavations beyond a certain depth in South Africa requires a permit. This creates unnecessary bureaucracies that smallholder farmers find costly and time-consuming and should be reviewed.</p> <p>The cost of construction materials for RHSTs need to be subsidized;</p> <p>Imports targeting RHSTs need to be duty-free within the region.</p> <p>More structures in public institutions and development agencies should be created to offer financial support to smallholder farmers to construct or install RHSTs.</p>	Kosgei, 2009

		Recommendations			
<p>Impacts of biophysical and policy interventions on household food and income</p>	<p>N_T gave substantial increase in growth that was hard to trace back to a physical soil measurement: there was a possibility of conversion of soil evaporation into useful transpiration (shown to be higher in N_T) and this explains the increase in growth.</p> <p>Livestock production remains an important enterprise in the community and ways of its co-existence with viable technologies e.g. no-tillage systems needs to be investigated.</p> <p>The construction and use of RHSTs is expected to depend on whether external support is available or not.</p> <p>Suitable feedback mechanisms of research findings are necessary if the focus and depth of science as well as livelihoods are expected to change.</p> <p>Long-term support was observed to have more impact if entrenched into policies that address the unique conditions of smallholder resource-poor rainfed farmers.</p>	<p>Only tested technologies developed in collaboration with the farmers and which the results have been interpreted in relation to farmers' constraints are suitable for adoption.</p> <p>Internal sources of fundraising to finance RHSTs e.g. using proceeds from sale of farm produce, livestock or social welfare need to be considered.</p> <p>Collective production and marketing strategies should be used for critical volumes and price bargains, respectively.</p> <p>The carrying capacity on the communal grazing needs to be observed if grazing on maize fields is to be avoided.</p>	<p>There is need to distinguish feedback to different stakeholders; and</p> <p>Integrating research, outreach and development leads to hybrid approaches and improves the confidence of the results and a better adoption rate.</p> <p>Need to conduct an analysis of production and market research.</p> <p>The grazing carrying capacity of the communal land needs to be established and suitable recommendations made.</p>	<p>The government to fact-track the land redistribution process.</p>	<p>Kosgei, 2009</p>

		Recommendations			
Participatory catchment monitoring	<p>The local community has a better understanding of the dominant hydrological processes in the catchment</p> <p>Participatory approach in catchment monitoring has long term benefits including the opportunity for the relevant stakeholders, notably the local community, to gain insight into the hydrological regime of their locality.</p> <p>Participatory catchment monitoring approach requires a constant effort to initiate and sustain a learning process, through which the local community and other relevant stakeholders are able to appreciate and recognize the importance of catchment monitoring, notwithstanding the willingness of the community to participate in the monitoring exercise</p> <p>The level and stage of participation of each stakeholder differs but ultimately contributes to the success of the catchment monitoring process.</p>	<p>Monitoring of the main hydrological parameters, e.g rainfall, should be every body's concern including smallholder farmers for sustainable water resources management.</p>	<p>Workshops, field days and seminars need to be organized in collaboration with other stakeholders to disseminate information to local communities on the importance of catchment monitoring.</p>	<p>Catchment monitoring should be integrated in other development plans and initiatives in a community and at all forums, with due recognition of the social dynamics of the communities living in the catchment.</p>	Kongo, 2008

		Recommendations			
Surface and subsurface water interactions	<p>-There is a correlation between the rainfall intensities and the fluctuation of the shallow ground water table in the Potshini catchment, with subsiding ground water levels mimicking the recession part of the stream flow in the catchment.</p> <p>- Shallow ground water contributes around 75% of the stream flow during the dry season. Thus, the surface water and shallow ground water systems in the Potshini catchment are closely linked.</p>	<p>Farmers need to consult with extension and researchers on the best land uses and practices that may not significantly change the partitioning of the rainfall in the catchment.</p>	<p>Complementary applications of tracer studies, geophysical measurements and classical hydrometric measurements have the potential to quantify and identifying end members of a hydrograph. Thus, a cocktail of techniques is required in carrying out detailed process hydrology studies.</p>	<p>Any land use changes in the Potshini catchment that may influence the occurrence of shallow ground water will have a direct effect on the stream flows especially during the dry winter season. Thus, a detailed research on the impact of respective land use on the occurrence of shallow groundwater should precede the introduction of any land use in the catchment.</p>	Kongo, 2008

		Recommendations			
Estimation of spatial variation of evaporative fluxes.	Field estimates of total evaporation from a Large Aperture Scintillometer (LAS) and those derived from satellite images using the SEBAL were comparable with the relative error ranging from -14 to 26%, indicating a reasonable agreement between the two methods.		There is a potential of applying remote sensing as a contribution to monitor the impact of lands use on catchment hydrology by quantifying total evaporation at various spatial and temporal scales from natural and managed landscapes in South Africa.	More researchers and or institution in the region need to familiarize with such novel techniques given their contribution and significance with regard to understanding system dynamics in ungauged river basins in southern Africa and worldwide. Thus, institutional frameworks need to be put in place for continuous training of more researchers and extension personnel on new scientific approaches and their applicability for management of water resources.	Kongo, 2008

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4. OUTPUTS

4.1 Research outputs

The SSI Programme produced a variety of knowledge products, ranging from theses, research reports, research papers, journal articles, conference papers, synthesis reports, working papers. Annexures 2 and 3 give details of the outputs that have been generated by the SSI until 2009. The following is a summary list of the research outputs:

5. Theses

- Post-Doc report (1)
- PhD theses (4)
- Licentiate thesis (1)
- MSc theses (19)

6. Research papers and reports

- Journal papers (21)
- Proceedings (29)
- Submitted to Agricultural Water Management (10)
- Working Paper series (4)
- Reports (15)
- Policy Briefs (2)

4.2 Human capacity building outputs

In parallel with the research activities, the SSI programme was also about human capacity building. First of all the Post Doc and PhD researchers within the SSI programme, who for a large part were from developing countries, were given the opportunity to develop skills in conducting field-based research. MSc researchers complemented the research activities. A list of the outputs from the human capacity building component follows; A complete list of all participants in the capacity building programme is given in Annexure 4.

4.2.1 PD researchers

During the entire SSI programme duration 4 PD researchers participated in the programme. These researchers originated from 3 different countries (India, Sweden and Tanzania). They were not only funded through the main research funding agencies, but SEI also contributed for two of these PD researchers. Currently one researcher is continuing with her research and is expected to finish in 2010 (Dr Barron). Three of the PD researchers are still working for their respective institutes. Dr. Tumbo has continued to work at SUA and managed to get a new project on climate change adaptation to agriculture funded by DFID and IDRC. This project has helped SUA and other collaborators to continue to

use existing equipment and is addressing some issues emerged from SSI programme. Dr Pachpute returned to her university teaching and research position in India after finalising her PD project at IWMI South Africa.

4.2.2 PhD researchers

During the programme duration, 11 researchers were registered as PhD researchers. In the first two years, 3 researchers resigned from the programme (Ms Zuma, Ms Kinoti and Mr Chikozho), either because they got better opportunities elsewhere or did not manage to develop an acceptable PhD proposal, and were replaced by 2 new PhD researchers (Mr Kosgei and Mr Komakech). One PhD researcher (Ms Kemerink), a staff member from UNESCO-IHE joined the SSI-programme at a later stage and is funded through UNESCO-IHE. The PhD researchers originated from 7 different countries (Kenya, Netherlands, South Africa, Sweden, Tanzania, Uganda and Zimbabwe). Currently 4 PhD researchers have graduated and two are finalising (Mr Makurira is expected to defend early 2010, and Mr Masuki in November 2009). The other two started later during the programme and are expected to finalise their research at a later stage.

From the graduated PhD researchers, one has continued her employment at UNESCO-IHE (Ms Mul), and is involved in teaching and research projects in the SADC region. Ms Enfors has started her employment at the Stockholm Resilience Centre working on several projects in Sub-Saharan Africa. Mr Kosgei returned to his home country, Kenya and Mr Kongo recently joined SEI in Dar Es Salaam and is involved in several research programmes. Mr Makurira is expected to continue working at University of Zimbabwe and Mr Masuki is currently working for an NGO in Kampala. Most graduates from the SSI programme are still involved in capacity building and research programmes in the region.

4.2.3 MSc researchers

During the programme, 19 MSc students participated in the SSI programme, several students were not even registered at the participating institutes and most of the funding came from other sources, such as WaterNet, MSF, and own accountants (see annex for full details). The students came from 8 different countries (Germany, Netherlands, South Africa, Sweden, Tanzania, Uganda, United States of America, Zimbabwe) and 9 different institutes.

4.2.4 Student projects

Several students also joined the SSI programme to do research as part of their masters programme, they either worked on a project or had an internship attached to the SSI programme. These students came from Germany and the Netherlands and were all funded outside of the main SSI programme funds.

4.3 Outreach and knowledge sharing

The SSI Outreach component was built around three main focus areas:

1. Outreach and action research within the SSI programme
2. Exchange of lessons from SSI and contribution to the global water, food and environment agenda
3. Dissemination and sharing of knowledge, research methodologies, and lessons learned

4.3.1 Outreach and action research within the SSI programme

The objective was to strengthen participatory action research within the SSI programme and to promote the application of action research methodologies for adaptive management and adoption of SSI findings. Several sub activities were undertaken in both basins to actively involve farmers, extension workers, NGOs and government departments in SSI research and thereby build capacity and awareness with regard to viable smallholder water systems innovations for improved production and livelihoods.

Formation and strengthening of Farmer Learning Groups (FLG) and promoting farmer to farmer learning

In the Pangani basin, nine farmer learning groups (FLGs), ranging in size from 5 to 20 members, were formed in 9 different locations in the Makanya catchment. The groups have their own leadership and have been useful in disseminating SSI information and promoting adoption of water systems innovations.

In Thukela, two strong FLGs have been formed comprising of 30 members each. The groups have grown in strength to the stage where all the members actively participate in the activities of the group. Besides working with FLG the SSI programme also worked with farmer institutions like the youth group, Siyazama, and another one comprising of elderly males called Sakhisizwe. These groups have become strong producers of fresh vegetables, able to access the growing market in the nearby town of Bergville.

The groups met regularly at their field plots, some of which were designated by the group as learning sites for their Farmer Field School (FFS) training sessions where they not only learnt about improved production practices from one another but also allowed neighbouring farmers to learn about these innovative practices from the group. An extension worker or outreach officer was usually present to facilitate discussions on different aspects of farming. Occasionally the researchers also attended these field days.

The curriculum for the FLGs and FFS evolved continuously in response to the requirements and circumstances of the target beneficiaries, after identification of knowledge gaps and assessment of training needs. For example, in Thukela, following farmers' evaluation of the 2006 FLG sessions, topics such as business

skills and marketing were included in the following year's curriculum. In addition, topics already dealt were retained due to the growth in membership in the groups and to cater to the needs of new members, such as Nutrition, Seedling production, Soil fertility, Water usage, Pests, diseases and Storage.

SSI also facilitated networking among different FLGs by bringing together members from various FLGs to make everyone aware of each other's activities and encourage information exchange. Farmers and farmer groups have been helped to form functional-related networks among and between them by working together in FFS activities where they observed and held discussions. The process involved supporting some farmers to perform field visits to other key farmers with successful Water System Innovations (WSIs), enabling farmers to observe and discuss the adopted innovations and their associated pros and cons so as to enhance further adoption

Farmer to farmer training proved to be an effective mechanism to encourage mutual learning and promote adoption and adaptation of water system innovations in the two basins. Farmers were provided a platform where they could share their experiences and knowledge with their colleagues and also with a wider public. For example, Mr Nicholas Madondo, a lead farmer from the Potshini catchment, was assisted by FSG to attend the Farmer Led Documentation (FLD) workshop held in Uganda. Upon his return, Mr Madondo developed and submitted a proposal that was accepted for funding by the NGOs PELUM and Prolinnova. These financial resources allowed both Potshini FLGs to apply photography as a means of FLD. The FLG members documented activities in their participatory garden experiments and shared the results at a session of the Farmer's Forum held in their area.

Another Potshini FLG member, Mr. Thabane Dladla, participated at the South African day during the Forum for Agricultural Research in Africa (FARA) symposium held in Johannesburg in 2007. A video showing how he and the rest of the FLG members are innovating was developed and shown at the symposium. He also visited a variety of stands where many technologies were on display, including WSIs, which he reported on to his fellow-farmers when he returned to Potshini, noting that such activities were very useful in exposing the farmers to other wide ranging issues in agriculture.

SSI also organised cross visits and study tours as a means of promoting co-learning and exchange of lessons and experiences among farmers and extension workers in both basins. Farmers from the Makanya catchment undertook visits to fellow farmers in the Arusha region and learnt about some aspects of conservation agriculture, horticulture production, drip irrigation, and charco-dam management. In Thukela, as a follow-up to the SSI supported cross visits to raise farmers' awareness to different WSIs, the Potshini farmers were motivated to conduct experiments to adopt the innovations they had seen on the visit. These experiments resulted in adoptions as farmers experienced, first hand, the benefits of the innovations. When the Okhahlamba municipality provided farmers with fences for bigger gardens, the same innovations were implemented in new

gardens. Potshini farmers were also exposed to environmentally friendly farming methods, particularly organic insecticides and organic soil fertility management.

Technical training in the use of water systems innovations (WSIs)

Regular training sessions formed an integral part of the capacity strengthening of the FLGs in the two basins. In the Pangani basin, among the topics covered were: soil and water conservation techniques, including application of zero tillage, use of cover crops, and pests and weed control. In addition, workshops were conducted for about 50 rainfall data collectors in the Makanya catchment on the importance and interpretation of the recorded data for agricultural use by farmers. It was also hoped that such initiatives would contribute to guaranteeing continued data collection in the catchment beyond the life of the SSI project, thus providing a valuable support to the farmers in the area.

To further ensure the functionality of the SSI field equipment and structures in the Makanya catchment and ensure local ownership by the relevant government and basin authorities, there was regular follow-up on all the river flow equipment. Data were downloaded, the concerns of the readers were heard and advice given.

In the Thukela basin, monthly meetings of the farmers' forum Sivusimpilo Okhahlamba Forum (SOF) provided an opportunity for sharing experiences on good practices and innovations. Each forum session was organised around a theme, such as: soil fertility management, marketing, water conservation, farmer-led joint experimentation, water harvesting, pests and disease control, and savings and credit facilities.

Farmers were also encouraged to design and undertake their own experiments with respect to adoption and adaptation of WSIs. These efforts were supported by SSI as well as government agencies and NGOs. For example, in Potshini a small farmer-led project examined the scope for producing potatoes using crop residues and grass. In Makanya, group-based farmer experimentation was set up in the FLG locations with each group being provided with a farm plan, a ripper, seeds and agro-chemicals with which they could attempt to implement conservation agriculture techniques in a common selected plot.

Engagement with local and basin-level institutions

In both basins, the SSI outreach endeavoured to ensure that the extension officers working in the field sites were involved in all activities of the SSI programme, including training sessions and study tours. Extension officers play an important role in organizing and conducting farmer field days, building awareness and training farmers on water systems innovation and assisting the FLGs.

In Thukela, Sivusimpilo Farmers' Forum that also includes communities beyond Poshini, has been the vehicle for sharing of SSI findings. This was done through

exchange visits, farmer-to-farmer engagement and presentations by SSI facilitators and researchers. The SSI project facilitator attended monthly Action Research (AR) meetings at FSG where he presented the progress and experiences of SSI outreach program. As members of the AR meeting also work in the Okhahlamba Municipality, this resulted in experiences in different areas being incorporated into the practices taken to other farmers and development practitioners in the district. Regular project updates to the Okhahlamba Local Municipality and the Mayor have resulted in their commitment to assist efforts toward agricultural development. A request for financial assistance for the FLGs, and particularly the homestead gardens, was granted and twenty homestead gardens were fenced. The municipality indicated that it would fund more gardens if the first group of gardens were established and utilised. These gardens created a platform for the wider adoption of the WSIs because the availability of protected plots was often presented as the bottleneck to adoption of WSIs.

Contacts established with Pangani Basin Water Office (PBWO) led to collaboration in the construction and monitoring of the weir at Vudee-Ndolwa river. Discussions held with the Tanzania Meteorological Agency (TMA) resulted in them agreeing in principle to take over the monitoring of the over 50 rain gauges installed by SSI programme in the Makanya catchment beyond the end of SSI. TMA also agreed to utilise the community-based data readers who were trained under the SSI programme.

The SSI project also engaged with and brought stakeholders like ARC, DoA, DWAF and IRD together in the Potshini catchment. Although no formal memoranda of understanding were signed by the different stakeholders in Potshini, each institution undertook its activities in a spirit of cooperation and mutual respect.

4.3.2 Exchange of lessons from SSI and contribution to the global water, food and environment agenda

Lessons learnt from action research in the SSI programme were regularly shared within its projects across the two study basins, other Sida-supported initiatives in Southern Africa, and other similar projects contributing to the global agenda on water, food and the environment.

Exchange of lessons within the SSI programme

Every year, the entire SSI team met for intensive week-long interactions during the annual scientific meetings (see section 2.2 for details) where there was systematic exchange and critical analysis of results, findings, lessons learnt and challenges faced during the implementation of the SSI programme. In addition to this annual event, the team members interact have had are regular discussions and exchanges among them in the field. Most of the SSI researchers also attended and presented papers at the annual WaterNet Symposium, held in a different southern African city in October-November every year. They have made

use of this occasion to meet and share results, discuss progress, and make future plans.

Establishing partnerships and sharing knowledge with 1-2 Sida supported and other water initiatives in Southern Africa

The SSI programme established linkages with other water initiatives in the region to share SSI findings with these programmes and also learn from their own experiences. Active partnerships were notably established with the Global Water Partnership in Southern Africa (GWP-SA), WaterNet (where SSI was recognised as a WaterNet programme) and the Challenge Program on Water and Food (CPWF). SSI contributed actively to various stakeholder dialogues, symposia and workshops organised by these organisations. In addition, linkages were established with Every River has its People (ERP), and the Zacpro 6.2 project, where SSI team members contributed to the Sida-supported training programme on integrated water resources management (IWRM).

Sharing lessons in various global water forums

SSI team members participated regularly in various regional and international conferences and workshops and presented papers and posters based on SSI research, thus ensuring greater visibility and awareness about SSI.

The SSI programme contributed to the advanced international IWRM programme for Zambezi basin countries, the GWP-SADC multi-stakeholder water dialogues, the annual WaterNet/WARFSA/GWP-SA symposium, and at the Blue-Green initiative side session at the World Water Week in Stockholm in 2007.

At the 8th WaterNet Symposium, SSI work and results were showcased at a special session on 'Communicating science to stakeholders' co-convened by IWMI, GWP-SA, SADC-Water and IRC. A special SSI/CPWF session was also organised at this same symposium, together with the Challenge Programme on Water and Food-WaterNet supported project which led to a productive exchange of results and findings from both programmes. The session was attended by about 60 professionals and highly appreciated.

At the 9th WaterNet symposium, in addition to papers presented by SSI researchers in the various thematic sessions, a special SSI session focussing on SSI Impact-from farmers to policy makers was organised, which generated a lot of fruitful discussion and useful suggestions for the SSI research team.

Sharing lessons within the basins

Partnerships and continuous engagement with key stakeholders in the two basins such as DALDO, PBWO, TMA, SAIPRO, VECO, Ministry of Agriculture and Food Security (MAFS) and ADPs in the Pangani basin, and with ARC, Department of Agriculture, DWAF, IRD and the Okhahlamba Municipality in the Thukela basin served as good conduits for sharing of results and findings of the

SSI programme. They also helped to reinforce local ownership of the various SSI activities in the basins.

Regular meetings were organized for exchange of experiences and the stakeholders were also invited to participate in different outreach activities and training sessions. In the Thukela basin, the most recent report back session to the Okhahlamba municipal council in 2008 was attended by 13 Ward councillors including the Mayor, Deputy Mayor, Council Speaker, different Managers and the Potshini community leadership. Both research and outreach components of the SSI were presented, highlighting the project's successes and challenges since its inception. The contributions of the Okhahlamba Municipality and the provincial Department of Agriculture and Environment to the success of SSI in Potshini were recognised; such as the funding provided by Municipality for fencing which helped overcome the problem of roaming livestock that discouraged farmers from growing crops in winter. The municipality pledged to continuing supporting the project as part of its developments activities.

Special mention should also be made of the Harvest Day organised in Potshini on 23 May 2008 by the University of KwaZulu Natal with the support of SSI to celebrate the achievements of the SSI project since its inception in 2003/04. In addition to the farmers and residents of Potshini, the participants included traditional leaders from the local and district level, representatives of the Okhahlamba Municipality, officials from government departments, smallholder farmers from eight neighbouring communities, and neighbouring large scale commercial farmers. In total, over 300 persons participated in this event, with some participants coming from distances as much as 60 km. The local community expressed its appreciation of the research and outreach activities undertaken by SSI.

From time to time the research sites in the two basins also hosted visitors from outside the basin, both local and foreign, from various universities and research institutes, government agencies, NGOs, farmer groups, and private companies. The visitors were generally interested in talking to SSI researchers and participating farmers to observe and learn more about the SSI research and development experiences in regard to smallholder water systems innovations. For example, after the Potshini farmers hosted farmers from other communities, all participants noted that such exchanges were of mutual benefit, creating good opportunities for learning from each other. Farmers also took great pride and encouragement from knowing that the visitors value what they are doing, particularly with respect to water systems innovations.

4.3.3 Dissemination and sharing of knowledge, research methodologies, and lessons learned

SSI research processes and results were systematically recorded and documented, a range of public awareness materials and knowledge products

were produced and shared with relevant audiences, locally, nationally, regionally and internationally.

On the research front, the SSI programme has produced 21 peer-reviewed journal papers, 29 articles in conference proceedings, 4 working papers, 2 policy briefs, 4 PhD theses, 1 licentiate thesis, 19 MSc theses, 15 technical reports, plus several posters presented at scientific meetings. The full list is given in annexures 2 and 3. The participation of SSI team members in various regional and international scientific forums has also contributed to extending knowledge and awareness about SSI research to wider audiences. SSI team members also make use of SSI research results in the pedagogical materials they use in their academic teaching and professional training assignments.

Under the auspices of the outreach component, formal surveys were conducted to document and assess the impact of SSI on crop production and livelihoods in each basin. The results have been presented in sections 3.1.6 and 3.2.8.

5. CONCLUSIONS

The SSI programme has succeeded in generating outputs in all three of its focus areas, namely:

1. Knowledge building and the advancement of science
2. Human capacity building in integrated water resource management
3. Support to institutional, planning and policy development in integrated water resource management

5.1 Knowledge products

At the start of the project, SSI envisaged to address three objectives with respect to knowledge generation:

1. to analyse the hydrological, environmental and socio-economic consequences of upscaling water system innovations in smallholder predominantly rainfed agriculture at watershed scale
2. to develop methodologies and decision support tools for improved rainwater management and equitable sharing of water between upstream and downstream users in nature and society
3. to translate knowledge on the links between intensification of agriculture through water system innovations, and its impacts on water, food and ecosystems at watershed and river basin scale, into useable tools for planning and policy

Having reached the end of the project, it may be concluded that a wealth of knowledge was indeed generated at these three levels or realms: the farmer's field, the catchment and at the institutional level. However, our depth of understanding at these three levels differs; so far most has been learned at the level of the farmer's field and at catchment level. Our understanding of, and impact on, policy and planning, at the institutional level beyond the local scale has been more limited. This section briefly summarises our findings at these three levels in both research locations. The full findings have been published in 21 journal papers, 4 PhD and 19 MSc theses, 29 articles published in peer-reviewed proceedings, and several technical reports and working papers. In addition 10 papers are currently undergoing review and will hopefully all appear in a special issue of the journal *Agricultural Water Management* on the SSI programme.

Driving forces

In both research locations, Makanya, Tanzania and Potshini, South Africa, long-term trends in land use, rainfall and governance were analysed, and similar driving forces of change can be identified.

The Makanya landscape has changed profoundly during the last decades: whereas 37% of the catchment area was cultivated in 1954, in 2001 this had increased to 55%, while bush-land decreased from 57% to 41%. Moreover, and importantly, the frequency of critical dry-spells (longer than 21 days) has doubled over the same period: now four out of five seasons are affected by such damaging dry-spells. Also the ecosystem services have decreased, leading to a decline in the so-called ecosystem insurance capacity. Consequently the catchment has moved to a more degraded state. Feedbacks between the declining soil water availability and the ecosystem insurance capacity results in declining yields, cultivation of more marginal land, and further loss of ecosystem services, eroding the system's productive potential (Enfors, 2009).

Local farmers at the Potshini site also observe a trend of degrading resource systems. A preliminary analysis suggests that from 1970 to 1980 there may have been a jump in resource degradation, directly linked to livestock increases and changes from 'good' to 'bad' grazing (good and bad are terms used by the farmers). Farmers indicate that they have been unable to respond to, and arrest the degradation process, and this may be due to a combination of factors, including decreased land availability, the breakdown of traditional institutions, an increasing gap between generations and new "pull forces" that lure the younger generations to the cities.

Enfors (2009) identified three main drivers for the observed changes in Makanya: institutional changes affecting natural resource management, increasing pressure on the land, and increased dry-spell frequency (see Figure 5.1). In the Potshini catchment similar drivers and trends were identified over a similar temporal scale. These trends mean that currently small-scale farming systems in the semi-arid savannah zones operate on a thin line between failure and success.

Farmers therefore seek to add blue water to their fields, for example by means of runoff harvesting from adjacent fields and gullies. Makurira et al. (2009) found that terraced fields that received additional fluxes of water during rain storms led to (a) significant increases in water infiltrating into the soil and thus to a net decrease of storm runoff downstream of the treated plots, (b) a 40% increase in crop transpiration and a more than proportional increase in grain yield, and (c) a significant increase of deep percolation of water feeding groundwater.

In Potshini, soil nutrients and soil acidity as well as water constrain crop production. Runoff harvesting and storing this runoff in underground tanks offers opportunities to not only bridge dry spells during the rainy season but also to develop small irrigated vegetable gardens during the dry winter season. The capacity of smallholder farmers to store water in a decentralised and distributed manner was identified as a crucial factor in buffering livelihoods against climate variability.

Access to increased water storage capacity combined with conservation tillage has the potential of reducing the frequency of crop failure and stabilise yields, and thus will allow smallholder farmers to accumulate capital and further invest in their productive systems (Figure 5.2). Moreover, increased crop yields lead to an more efficient use of water (the vapour shift resulting from reduced non-productive evaporation).

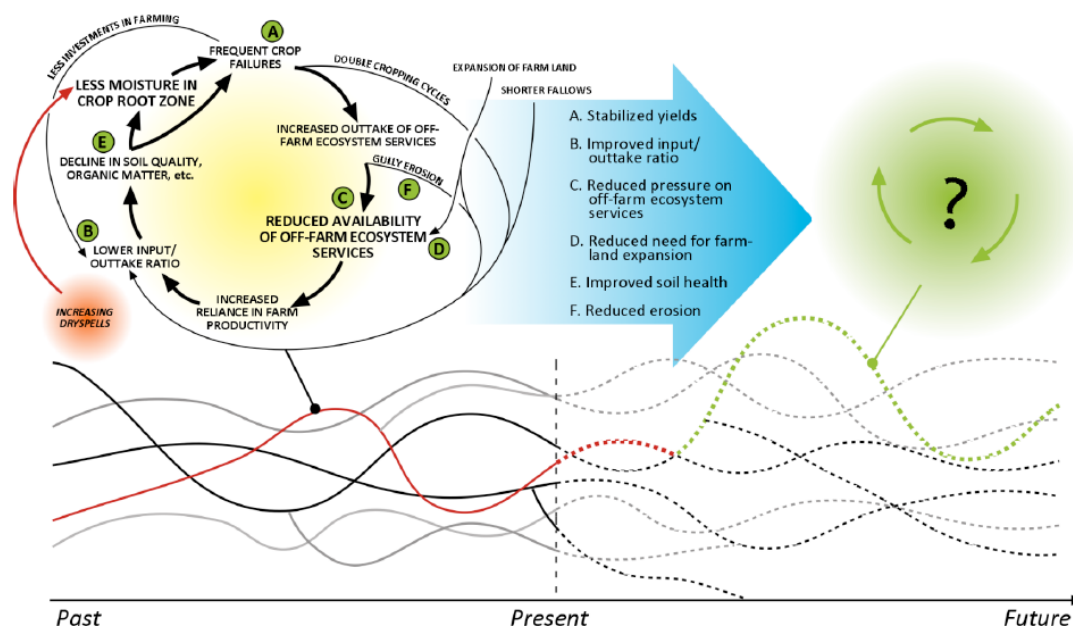


Figure 5.2: Shifting trajectory of development (Source: Enfors, 2009).

Environment

The ability of the watershed in both basins to support their populations is threatened and declining due to degradation of natural resources and increasing

population pressures, as described above. In addition, documented increasing frequency of dry spells in the Makanya catchment reduces the security of the farming system. Water system innovations on farm can help mitigate degradation of natural resources and improve environmental functioning in many ways. The programme research supports the hypothesis that intensification of management of these degraded systems resulting in increased production, rather than causing increased degradation, can result in improved environmental outcomes. A win-win for development where it is possible.

The SSI programme increased understanding of these dynamics in a several areas. First, improved water management and associated practices such as improved organic matter management and changes in tillage systems improved soil quality and reduced soil erosion, preserving and improving both soil and water quality. Second, increased land and water productivity is possible through water systems innovations in Makanya and Potshini watersheds. This increased productivity on existing cultivated lands can reduce pressure to encroach on natural areas. In Makanya this is particularly important because the local population is very dependent on natural resources in uncultivated areas during times of stress such as drought. In this case there is close dependency between preservation of the larger natural environment (and not only on farm resources) and the livelihoods of the people. However whether or not this potential reduced encroachment is realized will depend on whether policy and institutions support this outcome. Third, the conventional small holder farming system in Thukela results in degradation of regulating ecosystem services (erosion control, nutrient retention, carbon sequestration and water provisioning) as compared to a reference area, but improved practices can reverse this.

Socio-economics

It is clear that many water management interventions tested in the SSI programme can be very effective in increasing food production. Impacts on livelihoods of adopters in the study catchments include increased food security, increased incomes, and associated benefits in ability to send children to school. Field studies demonstrated that water management innovations which include water storage and delivery infrastructure (tanks ponds, pumps etc.) provide the most benefit because they provide access to water for supplemental irrigation to bridge dry spells and full irrigation in dry seasons. *In situ* (deep ripping, conservation tillage, etc) methods were only effective to increase yields after a certain threshold of rainfall was achieved, and when sufficient organic material inputs were available for soil fertility maintenance and mulch. Economic studies however point out clearly that innovations involving infrastructure are often not affordable for small-scale farmers. Overcoming economic barriers to adoption is a clear area for policy intervention.

Catchment level

Hydrologic linkages and tools for planning

Specific characteristics of surface- and groundwater interactions in the Makanya catchment determines the impacts of water management interventions on off-site uses. Due to land use changes and human interventions diverting river flows, the flow regime has changed, but this is mainly felt in the downstream part of the catchment. Because most of the stream flow that connect the highlands with the lower catchment are generated in the highlands (steep gradient), SSI's experimental plots located in the midlands had minimal impact on water availability downstream. Water captured at the farmer plots often would not have reached more downstream users in any case, instead, infiltrating into the alluvium. It therefore appears that small scale water harvesting techniques in the midlands improve agricultural productivity significantly (as it supplements the inadequate rainfall), but in the current setting does not aggravate the situation of the downstream community, and it may sometimes even lead to an increased groundwater recharge. However, the more traditional river diversions tend to significantly influence downstream flow. The downstream community mainly depends on the irregular flood flows that reach them during or after storm events. It is fortunate that these storm flows have relatively little value for upstream communities, since the latter cannot use them with current technologies (Mul, 2009).

The runoff response of the Potshini catchment varies over the rainfall season and is a function of both the magnitude and intensity of a rainfall event (Kongo, 2008). Rainfall of magnitude greater than 30 mm/day or intensity of 14 mm/h was observed to induce a response at the 1.2 km² catchment. The stream flow, as measured by an H-flume at the outlet of the catchment, is an integral of various components including surface runoff and interflow during the wet season while subsurface discharge from shallow groundwater dominates during the dry winter season. Thus, any anthropogenic activity that may alter the recharge of shallow ground water in the catchment during the wet summer season may significantly affect the stream flows regime during the dry season. One of the research objectives of the SSI programme was to investigate the potential hydrological impacts of intensification or upscaling of water use innovations in the Pangani and Thukela river basins through monitoring and subsequently detailed agrohydrological modelling exercise. Initial assessment of the potential downstream hydrological impacts of large scale adoption of storage based runoff harvesting systems downstream of the Potshini catchment was carried out through a modelling exercise using the *ACRU* model (Schulze et al, 1995) from which it was found that in the upper-Thukela catchment, no significant impact on the downstream flows is likely even when there is a large-scale uptake of runoff harvesting. This is a consequence both of the hydroclimatic characteristics and the high proportion of impervious surfaces associated with human settlements (De Winnaar, 2008).

A major challenge in implementing rainwater harvesting techniques is in locating the best and or potential sites while taking into account the hydrology of the area and other biophysical parameters such as soils, topography etc. The SSI programme developed and tested a GIS procedure for locating the potential sites

for implementing rainwater harvesting techniques at the Potshini catchment. Such a procedure can be applied in other catchments provided that the requisite biophysical parameters are known at the desired spatial and temporal scale.

The above findings were based on meticulous measurement programmes using relatively novel research techniques, such as geophysical methods for characterizing the spatial subsurface hydrological determinants at field and catchment scale. In addition, scintillation and remote sensing techniques were applied to quantify the variation of total evaporation from field to river basin scale, notably in the Potshini catchment. Also, the SSI programme established a participatory catchment monitoring network in the two study catchments. Smallholder farmers voluntarily participated in monitoring the main hydrological fluxes including rainfall, surface runoff and stream flows while hosting and safeguarding the monitoring equipment installed in the catchment. Such a participatory engagement generated goodwill, trust and mutual benefit to the farmers and researchers alike. The monitoring set-up has also created unique opportunities for future and further research to study the potential for upscaling water system innovations. Future researchers will also derive additional benefit from the already cordial relationship established with the local leaders and the community at large during the SSI programme.

Institutional level

In the Makanya catchment institutional arrangements over water have emerged gradually, starting from the local level (Komakech et al., 2008; submitted; Kemerink et al., 2009a). Makanya is a water constrained catchment, and with increasing water use the interdependencies between the users are becoming apparent. Actions and decisions made by users in one location in the catchment now predicated upon others located in different parts of the catchment. To cope with the challenges of interdependencies, farmers overtime have developed various strategies. Some of these were initiated in the 1930s, including the water-sharing arrangements between farmers along a furrow, between furrows, and between villages located within one sub-catchment. At the catchment scale, no such water-sharing arrangements have developed so far. However, in other parts of the Pangani basin, so-called river committees have emerged that do play a role in regulating access and use of scarce river water (Komakech et al., 2009). At the level of the sub-catchment, farmers continue to (re-)negotiate water sharing arrangements, drawing on their history and new arrangements connecting them (e.g. weddings). At the level of a village (e.g. Bangalala), the river water is allocated between furrows following simple but robust and transparent rules, which function without any formal institution put in place to monitor and enforce it. All this interconnectedness of actors in the catchment may explain the successful functioning of the furrows. The long time that these furrows have been operated have created a practice of dealing with differing interests and how to mediate them.

These local level institutions interface with national policies and basin-wide institutions established more recently. Attempts from the Pangani Basin Water

Office to link up with local level institutions have so far proven problematic due to lack of a common understanding of key concepts. Unless institutions at both the basin and local levels attempt to understand each other's realities, no effective linkages can be established and coordinated water management will not be possible.

The upstream part of the Potshini catchment is part of a former Zulu homeland and is inhabited by smallholder farmers. At the downstream end of the catchment commercial farms are located. After majority rule was attained in 1994, the new government took on the transformation of the discriminatory legal systems. The Constitution was rewritten, as well as most laws such as the National Water Act. Although the new water act is comprehensive and provides powerful legal tools to address poverty eradication and redress inequities inherited from the past, so far this has not translated into improved access to and control over water resources in Potshini. Water law on paper is not sufficient (Kemerink et al., 2009b). To increase the physical access of the smallholder farmers to (productive) water, distributional issues such as the availability of hydraulic infrastructure and the capacity to manage, maintain and operate the infrastructure, need to be tackled simultaneously. The disconnect between the water and land reform and the insecurity in land tenure in the former homelands makes investing in hydraulic infrastructure unattractive for the smallholder farmers. The government has fortunately started a programme to subsidise investment in hydraulic infrastructure in the previous disadvantaged former homelands. The expectations of the impact on reduced livelihood vulnerability of the rainwater harvesting storage systems that are currently being introduced in the Potshini community are therefore high, also in the face of the expected enhanced climate variability in future.

These interesting institutional dynamics have been studied using various approaches, testing several theories (the concept of hydro-solidarity, actor-network theory) and using innovative methods (agent-based modelling).

5.2 Capacity building

5.2.1 Academic

During the life of the SSI programme, 11 researchers were registered for their PhDs. In the first two years, 3 researchers resigned from the programme, and were replaced by 2 new PhD researchers. One PhD researcher, a staff member from UNESCO-IHE joined the SSI-programme at a later stage and is funded through UNESCO-IHE. There was good gender balance among the PhD researchers (5 female; 6 male) and broad geographical diversity, originating from 7 different countries (Kenya, Netherlands, South Africa, Sweden, Tanzania, Uganda and Zimbabwe). Currently 4 PhD researchers have graduated and two are finalising their research.

Nineteen (19) MSc students also participated in the SSI programme, several of whom were not even registered at one of the participating academic institutes in

SSI. Furthermore, most of their funding came from sources other than SSI, such as WaterNet, MSF, and some of them depended on their own resources (see annex for full details). The students came from 8 different countries (Germany, Netherlands, South Africa, Sweden, Tanzania, Uganda, United States of America, Zimbabwe) and 9 different institutes.

In addition, members of the local community who took an active part in the participatory hydrological monitoring in the Potshini catchment such as the community officer and one of the lead farmers have enrolled for diploma courses in relevant fields of study.

5.2.2 Non-academic

The SSI programme, notably through its outreach component, worked closely with farmers in conducting participatory action research to evaluate a range of 'best bet' water system innovations and scale-out promising processes and technologies. One of the main lessons learnt from the adoption and adaptation process of the various land and water systems innovations (e.g., conservation tillage, rainwater harvesting systems, homestead gardens, mulching, *fanya juu* terraces, ripping with *Magoye* ripper etc) was that innovations need to be adapted to local conditions for uptake and sustainability. Thus, one of the key features of the SSI approach was to improve the capacity of farmers to assess for themselves whether an innovation would work and would fit their farming system. This capacity building thus aimed at overcoming common inhibitions of adoption by increasing capacity for local adaptation and innovation based around water system interventions.

The SSI programme also actively supported the emergence of a local capacity to assess, monitor and manage water and environmental resources in the study catchments in ways that are especially relevant to the local community. This was done through the provision of training (directly or through the use of farmer field schools or using local lead farmers as intermediaries) in collaboration with various government agencies (extension officers) on the basic methodologies of catchment monitoring. The programme devoted considerable effort to (a) establishing a monitoring network including a range of instrumentation on the field sites, and (b) involving local communities in participatory field monitoring and data collection. Rain gauges, river water measuring equipment and water storage systems were installed, and farmer field schools set up to enable farmers to experiment and analyze specific situations, decisions and outcomes. Indeed, the involvement of members of the local community in the building of water storage systems and in various monitoring activities led to the establishment of strong linkages between themselves and the SSI programme and resulted in enhancing mutual knowledge and understanding of crop, land and water management issues in the study catchments.

SSI researchers have trained participating farmers on how to use the rain gauges to record rainfall events, analyse seasonal rainfall data and compare them with previous seasons; and finally, to confront this information with crop yields

obtained and compare results with neighbouring farmers. Some of the more enterprising individuals such as Walter, one of the lead farmers in Makanya, always showed a keen interest in the measurements done at his field plot. He is now better able to judge which combinations of new and old practices benefits his farm.

A body of knowledge and of critical reflection has thereby been, and continues to be, built up among groups of farmers, which will hopefully lead to them sharing and exchanging experiences and selecting, experimenting and adopting new and better farming techniques and practices. This innovative type of agricultural extension has not only enhanced farmers' capacities, but has also benefited the research team: for example, the rainfall data recorded by 31 farmers in Makanya made a major contribution to assessing the spatial rainfall variability in the catchment.

The investments made in setting up the monitoring network, including several permanent structures, also allow the collaborating partner institutions in the two catchments to continue using the field locations as field research laboratories and demonstration sites for farmers, researchers, extension agents, and even school-goers.

5.3 Support to institutional, planning and policy development in integrated water resource management

Generally, government institutions that are responsible for social welfare, environment and water resources management can play an important role in institutionalising support for the uptake of water system innovations, such as through the drafting of relevant policies and promoting synergies among development programmes for sustainable use of land and water resources. The SSI programme has only partially succeeded in fully engaging with these government institutions. Meetings and report back sessions of the SSI programme often included various representatives of local government who agreed to either continue SSI initiatives in their areas, or to incorporate SSI innovations into extension efforts at larger scales. But clearly supporting changes at policy level requires more specific planning for impact at the outset of a programme. One example of successful engagement however is the South African water department's grants programme for rainwater harvesting and storage systems. This grant programme was designed with input from the SSI programme cost analysis and was rolled out in Potshini in close collaboration with the researchers. In this case the SSI programme provided much needed information for appropriate grant design. Future projects could increase their influence by doing needs assessment for policy and planners at the outset, and tailoring some of their research and outputs to suit their needs.

Along these lines the SSI programme has contributed to knowledge about key areas for policy attention in the future. It has shown the potential benefits of adopting certain water system innovations, while a major constraining factor for

adoption is that many farmers are not in a position to make the required investments, both in cash and in kind (mainly labour), which are often beyond the capacity of poor farming households. Moreover such investments are often not eligible for micro credit schemes. Catalysing and facilitating initiatives that help farmers to overcome such bottlenecks, if not extending direct assistance to farmers to invest in their land, is arguably an important role for government. There is therefore a need to explore and clarify the respective roles and responsibilities of government and other role-players in helping to unlock the investment potential of small-scale farmers. A greater effort should also be deployed to provide adequate technical information about the possible intervention measures to prospective farmer-beneficiaries. Once the requisite investments have been successfully realised, farmers can not only improve but also secure their incomes substantially and lift themselves out of the poverty trap.

5.4 Integrating research and outreach

The SSI research programme engaged proactively through collaborative field research and networking with a wide range of stakeholders in both basins, from farmers, extension agents and NGOs to research institutions, technical personnel of line agencies and policy-makers. The advent of the SSI outreach and learning component, that effectively came into operation in 2005, offered a unique opportunity for the SSI programme and its stakeholders to derive even greater mutual benefit from these interactions.

The numerous research and developmental projects currently being implemented in the Potshini catchment and its neighbouring communities, bear testimony to the success of the efforts initiated by the SSI team to include and involve other stakeholders in the catchment. In the Makanya catchment, the relationships developed by the SSI programme with entities such as Same-DALDO, MAFS, SAIPRO, RELMA, TMA, SCAPA, ACT, LIANA, VECO and PBWO¹ facilitated dissemination of knowledge and adoption of various techniques and technologies such as increased ripper usage and use of rain gauge networks. Evaluation of these initiatives revealed that the SSI programme had become a major source of information for almost 50% of the farmers in Makanya.

Thanks to the SSI programme, the smallholder farmers in the study catchments and the surrounding communities have increased their awareness and their ability to make better use of available land and water resources. For example, the introduction of rain water harvesting techniques to store water for irrigating vegetable gardens and domestic use during the dry winter months in the Potshini community has showcased the potential to utilize land throughout the year for crop production.

In the Makanya catchment, the nine farmer learning groups (FLGs) that were formed played a key role in promoting and disseminating learning among farmers; a mechanism was thus created to allow neighbouring farmers to learn

¹ see list of abbreviations for explanation

about and adopt innovative practices from the research farmers. In addition, several training sessions and study tours were organised for the FLGs, covering topics such as conservation tillage, interpretation and use of rainfall data for agricultural purposes, training on productive use of water and best practices for using pesticides. Such initiatives have contributed to enhancing the farmers' understanding of their farming systems and to demonstrating how they can improve their productivity through combined use of their intrinsic indigenous knowledge and practices together with the land and water system innovations developed with the SSI programme.

Through collaboration and networking with other relevant national and regional projects/programme, the SSI research programme has added value and complemented other programmes through sharing of information, data and experience with a broader objective to build capacity in research while contributing to national planning and policies on improvement of rural livelihoods through sustainable land and water use management.

The outreach and learning component of the SSI programme came into effect in the second year of the programme when most of the researchers were at an advanced stage of implementing their research work plans. Hence, the implementation of the outreach and learning component programme was initially looked upon as an extra task and an additional time constraint by the researchers whose primary objective was to produce high quality academic research. However, it is a noteworthy achievement that ultimately the outreach and learning processes were effectively jointly implemented by the SSI research teams once the advantages and added value of such an approach to promote research uptake were made clear, resulting in a win-win situation for both researchers and stakeholders. Nevertheless, one of the lessons that could be drawn from the SSI experience is that it would be highly desirable if the researchers in similar multidisciplinary programmes are introduced, from the beginning, to the advantages and challenges of outreach and on how best to make it an integral part of their research.

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6. ANNEXURES

Annexure 1 Projects

- Project 1A: Kenneth Masuki
- Project 1B: Siza Tumbo
- Project 2A: Hodson Makurira
- Project 2B: Job Rotich
- Project 3A: Elin Enfors
- Project 3B: Line Gordon
- Project 4A: Marloes Mul
- Project 4B: Victor Kongo
- Project 5: Jayashree Pachpute
- Project 6A: Hans Komakech
- Project 6B: Jeltsje Kemerink

Annexure 2: Papers and reports

- Journal papers (20)
- Proceedings (27)
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Annexure 3: Theses

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Annexure 4: Human capacity building

- PD researchers
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Annexure 1 Projects

Project 1A: Dynamics of Farm-Level Adoption of Water System Innovations in Semi-Arid Areas: The Case of Makanya Watershed in Same District, Tanzania

Researcher: Kenneth F. G. Masuki
Institute: Sokoine University of Agriculture
Supervisor(s): Prof. A. Z. Mattee and Prof. F. B. Rwehumbiza
Starting date: January 2004
PhD defence: Expected later 2009

Initial aim/research problem(s)

One important way to increase agricultural productivity is through the introduction of improved agricultural technologies and management systems. National research programs in most countries have worked to develop new agricultural technologies and management practices. A challenge for agricultural researchers, however, is to understand how and when new technologies are used by farmers in developing countries (Doss, 2006.). Over the years, researchers have worked to answer challenging questions about agricultural technology adoption.

Growth of food production in sub-Saharan Africa (SSA) has, during the last decades, primarily been achieved through expansion of agricultural land and increase in water use. Rainfed agriculture in SSA constitutes > 95 % of the agricultural land use. However this region hosts the largest proportion of water scarcity-prone areas (Rockström et al., 2004). Improving the productivity of rain-fed agriculture needs to look into bridging the dry spells; therefore water system innovations in the rain-fed agriculture are a key to addressing food security and poverty alleviation (SSI, 2003). Hatibu and Rockström (2005) reported that rainfed agriculture and other depletion of water by green flows have as yet an untapped potential for improving livelihoods in semi-arid areas through income and food security.

As African agriculture remains largely rain-fed in water scarcity circumstances, much work on technology development and adoption studies is anticipated (Place et al., 2002a). Extensive research indicates that integrated soil and water management and water management innovations can contribute to significant upgrading of rain-fed agriculture which is the dominant livelihood base in large parts of SSA (Rockström and Falkenmark, 2000; Hatibu et al., 1999; Agarwal and Narain, 1997). In semi-arid areas, the challenge is to develop water conservation technologies and related management methods, and to promote innovation by smallholder farmers. Farmers in semi-arid areas are aware that agricultural production can be improved substantially through concentration of scarce rainwater as well as provision of supplementary water during critical times (Hatibu et al., 2002). Rockström et al. (2004) argue that there are great opportunities to improve rural livelihoods through the adaptive adoption of smallholder water system innovations.

The main objective of this study is to determine the critical conditions for sustainable adoption of smallholder water system innovations at farm-level over time in Makanya watershed. This study will help to understand dynamics of adoption at farm level and therefore the crucial conditions which could contribute to higher adoption rates of the innovations.

Specific objectives are:

1. To identify the current key water system innovations and their adaptive development.
2. To investigate crucial determinants of adoption of the key WSIs at farm level over time.
3. To investigate short and/or long term dynamics of farmers' practice, attitudes and perceptions of different technologies in order to promote faster adoption of the WSIs
4. To evaluate strategies, tools and approaches for promoting farmer-led water systems innovation process.

INTRODUCTION

Farmers in semi arid areas of Pangani basin practice different types of WSIs which include in situ capture and management of rainwater, collection, concentration and/or diversion of run-off and collection and storage of runoff (Hatibu et al., 2002). Indeed, a wider range of WSIs already exist and are being used successfully by some farmers in the watershed (Masuki et al., 2004), yet their wider adoption in smallholder farming environments remain relatively low. The study by Senkondo et al. (1998) reported adoption of WSIs to be about 35% in Western Pare Lowland (WPLL). Despite the fact that the overall adoption may look higher, the study by Hatibu et al. (2002) revealed that adoption of in-situ WSIs was only 32%, use of micro and macro catchment was only 24%, diverting run off to crop field was only 22% and diversion and storage 22%, of all plots of respondents in the WPLL.

This study was aimed at finding out why the adoption rates of WSIs are still low and such knowledge would lead to better understanding of the dynamics of adoption at farm level and therefore the crucial conditions which could contribute to higher adoption rates of the innovations. The knowledge obtained from this study will help the decision and policy makers to embed these crucial conditions when planning for any intervention in this or any other area with similar biophysical, socio-economic, and institutional environment like the study area.

Methodology

Primary data was collected in the field using both quantitative and qualitative methods. Quantitative data was collected using household surveys conducted in the study villages. The quantitative data include variables that touch household capital endowments (Age, sex and education level of the head of household; family size, farm size, rate of adoption and extent of adoption). Different tools of participatory methods mainly key informants, focused group discussions and physical field observations were used to collect qualitative data. Secondary data was collected through literature reviews from several grey literatures at the SWMRG documentation unit, Sokoine National Agricultural Library (SNAL), The Directorate for Research and Post Graduate Studies and projects such as the Tanzanian Agricultural Research Project II and Agricultural Sector Development Programme (URT, 2003) and various websites. Some field related information was obtained from fellow SSI researchers from their respective research work. Also most of valuable information on Pangani Basin was collected from Pangani Basin Water Office publications. The data were analysed using explorative methods (descriptive, correlation and non-parametric). Some confirmative analyses were employed to qualitative data sets to show relationships among variables.

GENERAL FINDINGS

Community and Farm level adoption of WSIs

The analysis of the origin of the smallholder WSIs showed that in general about seventy two percent (72%) of the innovations currently practiced at community levels are indigenous and only 28 % are exogenous. The landscape level cross-analysis showed that 70% and 75% of the currently WSIs practiced in the highlands and midstream respectively are indigenous, while about 96% practiced in the lowlands are indigenous.

Generally each household has adopted at least 2 innovations and most of the households do not go beyond 4 WSIs per plot. The adoption intensity was found to be higher in lowlands whereby more than 68% of farmers in the lowlands have 4 innovations in their farms. This is due to the fact that crop production in the lowlands is highly constrained to water and moisture compared to the midlands and highlands where availability of water and moisture for crop production is higher. Therefore farmers in the lowlands implement diverse innovations in the same farm plot as a strategy to coping with drought shock that normally strikes the area before the crops reach maturity. This is done to maximise use of available water and moisture in the field.

Farm-level adaptive management of WSIs

Farm-level adaptive management in the Makanya catchment was done through a number of tools and methods, including farm-level experimentation and farmer field school (FFS) groups to enhance learning by experimentation and doing. Farmers who were involved in FFS groups have adopted a number of water system innovations as a result of learning by doing. During my interaction with farmers I found that 41% of all farmers involved in this study have adopted ripper technology 19% have adopted cover crops (conservation agriculture), while borders, fanya juu terraces and deep tillage were each adopted by 11% of the respondent farmers. The farmers attributed this comparatively higher adoption of ripper to its technological characteristics of simple to use and effectiveness to harvest rain water in the field.

Potential of WSIs in improving rural livelihoods and poverty reduction

The immediate impact of farmers' livelihoods as a result of their engagement in the research process and their adoption of various WSI's was clearly seen on crop production, food consumption patterns, increased finances from selling of surplus produce and their household expenditure patterns. Crop production was mainly assessed against maize, which is the major food crop grown in the study area. The maize yield figures were collected during the interview based on the farmers' recall of their harvest before 2004 when SSI program has not started and 2007 three years of SSI in the catchment. The results showed that there has been maize yield increase as high as 1.8 t/ha (163%) increasing from 1.1 t/ha before to 2.9 t/ha following adoption of WSIs in a year with good rainfall. The increase was highly significant at ($P = 0.0002$).

The increased crop yields provided opportunities for the farmers to improve their food consumption pattern and explore option of selling the surplus produce to earn some income. In this study I found that before adoption of WSIs most farmers (85%) were using their crop harvests for household food consumption and only 15% of farmers had surplus for selling. However, the situation improved after adoption of WSIs whereby about 79% farmers had enough harvests for food and surplus for selling. Further analysis showed that those who adopted ripper technology reported higher increase in

crop production from 6% who had surplus for selling before adoption to 30%² of the farmers who have surplus for selling after adoption of the WSIs.

Further, the study revealed that WSIs that involve supplementary irrigation had higher returns to land and labour therefore have potential for improving household livelihood based on crop enterprises involved. Results show that run-off diversion for lablab enterprise recorded higher returns to land (TSh 222,266) and labour (TSh 202) than other WSIs in the lowland. In the midland, diversion of stream flows had the highest returns to land (TSh 451,655) under Lablab enterprise. While in the uplands, ndiva had higher returns to land (TSh 2.9 m) and labour (TSh 6,613) for vegetables. . In most cases, the returns to labour in per capita terms realized under best-bet WSIs exceed the national and dollar poverty lines. The national poverty line is estimated at about TSh 200/person/day (TSh 73,877/person/year based on 1995 prices). Also, returns to land for the seasons lasting in three months timeframe indicate a significant income generating potential of WSIs for crop production.

Dynamics in farmers' adoption attitude and perception

Analysis of farmers' adoption dynamics was performed based on the innovations that are already adopted and are on use for so long. The storage and conveyance type include all innovations which involve diversion and conveyance of water to the storage structures. The results showed that adoption of most of these innovations were realised more than 40 years ago (up to 1970). Between 1971 and 1990 the rate of adoption was low then higher adoptions were experience in 1990s but went down again in 2000s. Borders have higher adoption which stands at slightly less than 40% while others showed decreasing trends in 2000s.

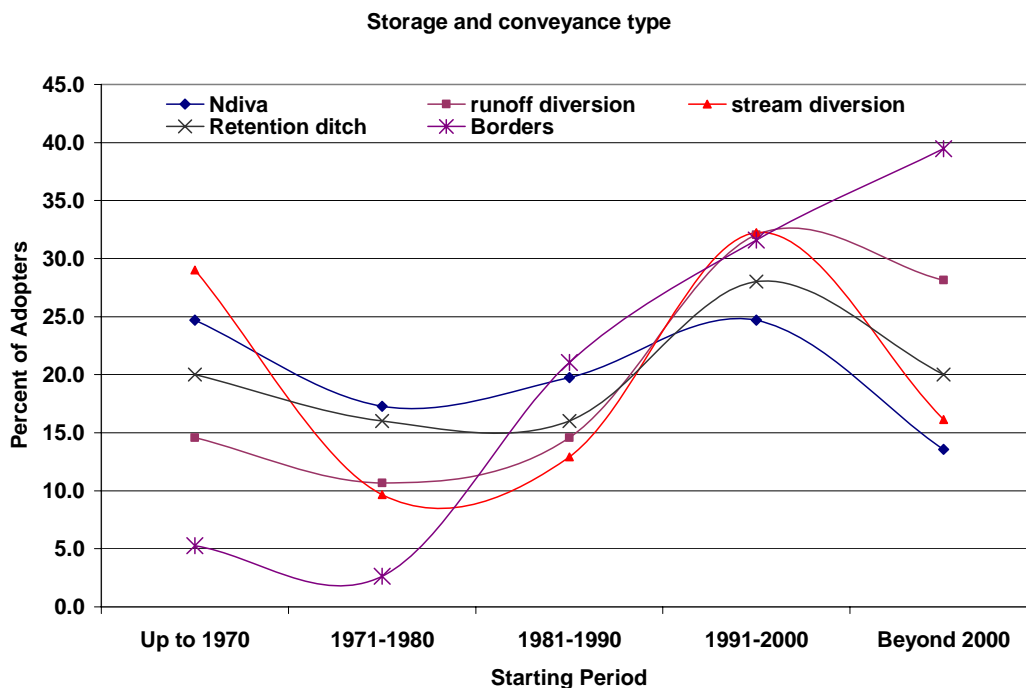


Figure 1 Time series adoption of storage and conveyance type of WSIs.

² Percent total of those who used ripper only and those who used ripper and Fanya juu terraces

Factors affecting adoption of WSIs in the Makanya Catchment

Determinants of technology adoption at household level include household capital endowments (capital assets - human, natural, physical, financial and social), land tenure and access to market and services have influenced adoption of WSIs in Makanya Catchment. Results in general show that there are positive relationships between adoption of WSIs with human capital (education level, training of farmers, household labour and age of farmers); natural capital (farm size); physical (ownership of livestock and house type); financial capital (liquid asset - bank account) and social capital (farmer association and networks) and access to market and policy environment.

Strategies and approaches for scaling-up of Water Systems Innovation

Scaling-up of potential water system innovations entails active communication, interaction and interrelation amongst key stakeholders through social and institutional networks. In this study, communication focused at knowledge sharing among researchers, to improve the research process itself; and knowledge sharing between researchers and users, for enhancing promotion and uptake of technologies by farming communities for improved WSIs. The SSI program has employed participatory action research (PAR) and other methods to scale-up its processes and technologies. The SSI outreach program has facilitated knowledge sharing through farmer field school (FFS). The FFS is composed of a community of practice which is a group of people working together who have a shared goal or expertise and regularly engage in exchanges and learning based on their common interests, in this case - water system innovations.

Farmer Field Schools (FFS) were the main vehicles for conducting participatory action research in the catchment. The FFS approach was an effective approach for technical education and capacity building. Farmers generate knowledge that is functional and necessary to improve their production and livelihood potential. FFS also helped to empower farmers because apart from generating knowledge, they are both the users of such knowledge as well as its owners. The FFS activities in the Catchment included training and practice on how to use ripper, how to train oxen, conservation farming and use of improved seed. The FFS sessions were held once a week whereby the farmers would learn from one farmer's field to another on rotational basis. The FFS approach has improved understanding and knowledge of the farmers to have positive perception on the performance of the water system innovations and improved adoption of the water system innovations tested by SSI researchers. Also through FFS there has been high acceptance of the Fanya juu terraces and construction of water tanks in Mwembe village and ripping techniques in Bangalala village. The farmers involved in FFS are empowered to share knowledge and experience to other farmers this promotes scaling-up and disseminate the technologies and knowledge gained.

Future implications for action of similar research interventions

Farmers have enhanced adaptation of some WSIs to suit some conditions at farm level. This implies that systematic innovation system is inevitable for any technology to be adopted at farm level; in this case sustainable projects would need prior introduction and acceptance by farmers before implementation of any interventions.

Most of the constraints to adoption of innovations are related to socio-economic determinants. This implies that successful promotion of novel technologies to farm and community levels should address socio-economic constraints for smooth uptake of technologies.

Human capital enhancement in the form of knowledge regarding technological options expands choices available to farm households and is a key feature of the empowerment process thus needs consideration in case of planning for research interventions.

The experience with interactive and participatory approach in knowledge sharing from this project could be used to enhance adoption of improved technologies elsewhere with similar socio-economic settings. The significant change stories could be used to influence policy and decision making processes that would influence positive action towards improving the livelihoods of poor farmers.

A gender-equity approach to catchment management recognizes that men and women have particular needs, knowledge, interests and aspirations, and thus contribute to the conservation of water resources in different ways. Rethinking gender aspects in the plans and strategy for dissemination and scaling up of community level innovations is important so that the aspirations of the local community and its members are fulfilled in a way that reinforces the nation's efforts to reduce poverty.

Project 1B: Investigation and Development of Framework for Diffusion of Water System Innovations at Community Level

Researcher: S. D. Tumbo
Institute: Sokoine University of Agriculture, Tanzania
Supervisor(s): Prof. H. F. Mahoo
Starting date: 1st January 2004
Ending date: 31st December 2005

ORIGINAL OBJECTIVES

Among the many factors that contribute to growth in agricultural productivity, innovations are the most important (IFAD, 2003). Water system innovations (WSIs) are defined as those innovations that improve productivity and/or conservation of water for crop production. Such innovations include deep tillage, mulching, cover crops, terraces, drip irrigation and water harvesting. Most of the WSIs have been developed from indigenous knowledge at one location. The same developed WSIs when transferred to neighbouring communities (even in the same country) they become exogenous innovations. Rogers (2003) defines innovation as an idea, practice, or object that is perceived new by an individual or other unit of adoption.

Substantial amount of applied research in technologies, such as WSIs, has been undertaken but diffusion has been limited. It should be noted that diffusion is more linked to studies on the spread of innovations (Rogers, 2003; Foltz, 2003; Koundouri et al., 2003; Shrestha and Bell, 2002; and Sheikh et al., 2003), which is the focus of this study. To date, very little is known on the actual reasons for non-adoption on larger scales, and the preconditions that need to be in place to enable adoption. At small scale, e.g. individual/farm level, significant amount of work has been done to understand factors which affect adoption of an innovation (Wubeneh and Sanders, 2006; Flett et al, 2004; Marra et al., 2003; Semgalawe, 1998). Most of these studies found factors such as gender of household head, marital status, farm size, labour sharing, and growing of cash crop as determinant for adoption.

In adoption at community or watershed level (diffusion) these household or farm level characteristics become less important especially if ones deal with an innovation which works and some farmers have adopted. Kristjanson et al., (2002) stated that the rate of adoption of new technologies among farmers in many developing countries has been below expectation. Place et al., (2002) observed that natural resources related innovations exhibit pockets of high rates of adoption while others with nearly identical household and agro-ecological characteristics do not. Semgalawe (1998) observed that, for soil conservation activities, promotional activities and support services motivate people to adopt the technologies. She adds that, for sustainable adoption, these incentives should be made available for a time long enough for adopters to appreciate the technology. Jansen et al. (2006) noted that access to markets had a strong influence in the adoption of live barriers and terraces, because these technologies are less profitable in areas far away from population centres. Jansen noted specific policies and incentive structures are needed in order to speed up the adoption process. In other words, they add, lack of capital and low profitability of many conservation practices are factors limiting the diffusion of these technologies. Therefore, it is important to investigate and identify other underlying factors which are beyond household and agro-ecological characteristics.

Gündel et al., (2001) cited one of the factors, which was the lack of effective scaling-up strategy in the participatory action research (PAR) projects. The argument is supported by adoption studies in Iraq, Jordan and Syria, which found farmers participating on a project had a very higher level of adoption compared to non-participating farmers (IFAD, 2004). This implies either the project lacked communication strategy or the communication strategy did not include non-participating farmers. Franzel et al., (2004) emphasized on the need for strong support for extension activities and involvement of farmers. Hatibu et al., (2002) found that extension assistance was one of the factors that influence adoption in addition to the type of technology, farmers' characteristics, market incentives and rules. This calls for PAR method to include a strong component of communication strategy that will also involve extension agents in and outside the target areas (NRSP, 2002).

The focus of this paper is the understanding of the diffusion of existing innovations, especially exogenous ones, which is an important factor that can contribute to the extent of adoption for the targeted community/watershed. Tracking diffusion of innovation overtime is likely to reveal the innovation-decision period (IDP) and therefore the minimum project period required for a given intervention to have impact on a particular community. The IDP is that length of time required for an individual or organization to pass through the innovation-decision phase (Rogers, 2003). It is therefore the period from first knowledge about an innovation to the decision to adopt or reject. It is hypothesized in this paper that for short term change agents especially research and development projects to be successful in the wider adoption of innovation, the period of the project should also be guided by the IDPs of innovations and the community in question. Smale and Jayne (2004) noted that the lead times for plant breeding average roughly a decade, while new livestock technologies may demand 15 to 20 years.

The argument above, also calls for identifying and tracking of exogenous and endogenous technology and determining their IDPs. However, the methods for determining the exogenous-ness of an innovation and IDPs in areas with limited documented information, such as in sub-Saharan Africa, do not exist. Furthermore, the issue of a technology being exogenous or endogenous is quite controversial because of several reasons. First (Reference), in some societies, even though the technology was not originally from the community, people wouldn't like to admit that it was imported from another location. Second, if the technology was introduced several decades ago, it is difficult to trace it back and determine exactly when it was introduced. The investigators will have to depend highly on the accounts of old members in the community.

This study developed two methods and applies them to WSI in order to understand some underlying factors behind successfully adopted exogenous technologies, which will help to guide development and research agencies in their project design and implementation, to achieve higher rates of diffusion of innovations.

The greatest challenge for improving water management especially in the semi-arid areas is not so much innovations of physical technologies, but rather innovations in the approaches that facilitate adoption of well tested techniques (Due and Gladwin, 1991; Pretty, 1995). This study explores the diffusion of smallholder water system innovations in the Makanya watershed and in the process identifies other important elements, beyond household and agro-ecological characteristics, that are necessary for wider adoption of exogenous water system innovations.

The specific objectives of the study were:

- (1) To develop methods for determining exogenous-ness and IDPs for WSIs;
 - (2) To determine the extent of adoption (diffusion) of different WSIs;
 - (3) To determine factors behind diffusion for WSIs, which have really achieved diffusion; and
 - (4) To recommend other elements in the diffusion process that can lead to increased rate and wider adoption of WSIs.
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ABSTRACT OF RESEARCH

Scaling-up of water system innovations such as soil and water conservation innovations is important for sustainable and increased agricultural production. Disappointment has been on the failures in the scaling-up initiatives and therefore much focus is not on the generation of new technologies rather than on approaches to effect wider uptake of innovations. This study proposes a framework for scaling-up water system innovations at community or watershed level. The study utilized findings from studies which were conducted in the Makanya Watershed in the Pangani Basin, Tanzania. In the studies, it was found that out of many existing water system innovations, terraces, diversion canals and small reservoirs have been widely adopted. Terraces were seen as more exogenous innovations whereas diversion canals and small reservoirs were categorized as endogenous innovations. The categorization was based on the method that was developed in this study. The investigation also found that terraces took more than a decade to diffuse which agreed to other agricultural and natural resources based innovations. The study suggested the use of innovation-decision period as a means to forecast the length for innovation diffusion. Interactive communication pathways were seen as a cornerstone that will allow actual diffusion to occur and importance of external change agent was seen as a stimulant of the process. Groups and networks was statistically significant in influencing diffusion, however, the findings were based in a community where trust level was very high. Therefore, the proposed framework consists of three stages, which are pre-implementation, intermediate and implementation stages. In the first stage emphasis is given in the evaluation of the innovations while the second stage emphasize on the introduction of the innovations to appropriate authority, identification and establish working relations with change agents and the last stage is the actual process of employing effective communication pathways, monitoring, evaluation and re-planning. The framework is not cast on concrete but can be used as a guide and reviewed during scaling-up process; however, if appropriately adapted and employed, the likeliness for scaling-up to occur is very high.

KEY PUBLICATIONS

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Project 2A Water productivity in rainfed agriculture

Researcher: H. Makurira
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Supervisor(s): prof. Dr. ir. H.H.G. Savenije, prof. S. Uhlenbrook, prof. Dr. J. Rockström, Dr. A. Senzanje
Starting date: 1st January 2004
PhD defence: 2009

ORIGINAL OBJECTIVES

Food security in most sub-Saharan Africa is threatened by increased water shortages particularly for crop production purposes. A large part of the population within the semi-arid zones of sub-Saharan Africa are mainly subsistence farmers who depend mainly on rainfed agriculture for their livelihoods. Traditional agricultural techniques generally appear not to produce enough harvests which are needed to attain food security with recorded yields of, for example, maize falling below 1 t ha^{-1} (Bhatt et al., 2006) when compared to $4\text{--}8 \text{ t ha}^{-1}$ obtained in commercial farming systems. While there are several reasons to explain these low yields (e.g. poor soils, bad farming practices and increased population pressures) sub-optimal moisture at field scale is, arguably, the most significant factor for these low yields in arid and semi arid zones. Interventions are hence necessary to increase moisture availability and hence support the attainment of decent yields. Dry spell occurrence in two out of three years, and droughts, in one out of ten years, severely impact on crop productivity even in seasons where the total rainfall received might appear to be normal (Rockström, 2003). Another important challenge to water productivity is the clear inefficiency of water use at field scale where significant quantities of water are lost out of the root zone through unproductive processes such as runoff, deep percolation and evaporation. There is therefore a need to improve efficiency of use by capturing as much water as possible for use in crop production processes especially at smallholder farm scale.

If indeed the majority of the population is surviving on rainfed agriculture then more emphasis should be placed on rainfed systems in order to contribute towards food security given the challenge of water scarcity for crop productivity. Irrigation systems have been widely applied for commercial agriculture but, in the case of smallholder farmers, such systems are generally unaffordable hence the need to promote simple, more efficient and low cost technologies to increase water availability at field scale. However, there is also a limit to how far such technologies can be applied at smallholder farm levels without compromising the hydrological system at larger spatial scales.

While it is agreed in principle that most rainwater harvesting techniques being applied at the moment are inadequate and inefficient, there is not much known in the area of understanding the soil moisture dynamics at field scale hence it is difficult to tell whether available moisture is insufficient for crop growth or that it is a question of the partitioning processes at field scale where more water is being channelled towards unproductive processes. Without such proper understanding of water partitioning at such small but important scales, interventions to promote water use efficiency proceed without sufficient information on the hydrological functioning of such interventions. After local hydrology is understood and where potential benefits of improved techniques have been identified would it be necessary to understand the impact of any such interventions at larger scales.

Main Objective

To contribute towards improved food security for smallholder rainfed farming systems through a better understanding of soil moisture dynamics from observations at smallholder farm scale.

Specific objectives:

- To assess the present levels of crop productivity under the existing cultivation practices,
 - To identify inefficiencies in current smallholder rainfed agricultural systems,
 - To propose alternative systems which can demonstrate that there is scope for realising improved yields,
 - To set up measurement structures to monitor water balances at field scale and, hence, identify inefficient processes that affect productivity,
 - To quantify water use efficiencies for the present and “improved” scenarios,
 - To link grain productivity to water partitioning at field scale, and hence,
 - recommend simple, affordable and practical practices for rainfed agricultural systems to achieve higher yields in existing conditions.
-

ABSTRACT OF RESEARCH

The challenge of achieving the Millennium Development Goals (MDGs) on food security is, to a large extent, achievable through balancing water, nutrients and farm management practices. For sub-Saharan Africa, water is believed to be the limiting factor to crop productivity yet the majority of the population relies entirely on rainfed agriculture without access to dry spell mitigation mechanisms such as irrigation infrastructure. The region frequently resorts to food imports as harvests are generally too low with maize yields, for instance, oscillating below 1 t ha⁻¹ in rainfed subsistence farming systems compared to at least five times more in commercial systems. These low yields are mainly attributed to dry spell occurrences during growing seasons. The challenge is then to bridge these dry spells. Supplemental irrigation is the most common solution to bridge these dry spell but it is not always a feasible solution for semi-arid rural communities hence the need to advance simple soil and water conservation techniques that promote soil moisture retention.

This research was conducted in the semi-arid Makanya catchment of Northern Tanzania where the average rainfall of between 400-600mm a⁻¹ and split between two rainfall seasons per year is not generally sufficient to support many common food crops. The performance of maize, the staple food crop, was studied where the hand-hoe technique is traditionally used for tillage. As promising alternative tillage techniques, deep ripping, infiltration trenches in combination with in-field bunding (*fanya juu* systems) and storm flow diversions were introduced at pilot study plots to promote more soil and water retention within the root zone. A comprehensive on-site measuring network was set up to measure the amount of water generated and the subsequent water partitioning processes to establish if these improved interventions result in effective soil moisture retention within the root zone. The parameters measured include rainfall, inflow and outflow in the study plots, soil evaporation, transpiration and soil moisture variation. A participatory approach was adopted where the relevant farm owners were actively involved in setting up the research, monitoring and interpretation of results. From the

observations, the HYDRUS2D model and spreadsheet modelling were applied to get better insight into soil moisture dynamics and predict impacts under different scenarios.

During the research period, gross rainfall ranged between 186-407 mm/season. Diverting storm water increased water availability on plots by up to 90%. Bi-weekly soil moisture monitoring using TDR probe revealed that soil moisture ranged between 10-30% for sites with improved techniques and rarely exceeded 15% for traditional systems. The most significant soil moisture fluctuations as a result of infiltration occurred at depths of up to 50cm and not deeper. These soil moisture fluctuations were confirmed by geophysical methods using the Electrical Resistivity Tomography (ERT) technique. The upper 50cm of the soil structure was found to be the most relevant as the root systems do not go deeper than this level. The model results also show productive water processes consume 30-40% of the available water in the water balance. As a result of the improved tested techniques, yields for maize increased from less than 1 t ha⁻¹ to as much as 4.8 t ha⁻¹ depending on techniques applied and the amount of water diverted onto the trial plots.

It was concluded that water is the limiting factor to productivity and that a combination of rainwater harvesting and conservation agriculture can contribute to improved grain yields by as much as 80%. However, a combination of water diversion, application of manure and conservation tillage was found to produce even higher yields suggesting that water other factors besides water availability contribute to crop productivity. From the observed data, modelling techniques can be applied to explain the effectiveness of improved cultivation techniques at field scale. The zones of greatest moisture retention are around the trenches and bunds where, as a result, better harvests are expected due to ponding effects and the deposition of nutrient rich fine sediments. These zones also contain higher moisture levels even during dry seasons which can support dry season alternative cropping such as cassava, pawpaw and fodder. The partitioning analysis revealed that the tested techniques resulted in more diversion of moisture to transpiration processes but better management of available water through reduction of evaporation and deep percolation can increase the potential for obtaining even better yields.

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Project 2B Rainwater harvesting systems and their influences on field scale soil hydraulic properties, water fluxes and crop production

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Starting date: 1st July 2005
Submission: 17th December 2008
PhD award: 30th March 2009

ORIGINAL OBJECTIVES

Water is increasingly becoming a limiting resource to crop production in arid and semi-arid lands (ASALs) and is responsible for substantial yield losses annually. These lands are often occupied by resource poor smallholder rainfed farmers who have little resource capacity to establish conventional infrastructure to mitigate this situation. It is necessary to develop, in conjunction with key stakeholders, adequate tools and methodologies tailored to enable these farmers deal with the existing and anticipated crop production drawbacks such as dry spells and droughts. The potential technologies have to be appraised to ascertain their environmental, economic and social appropriateness.

Water harvesting approaches that may be in the form of *in-situ*, runoff-based or storage-based have been identified and promoted as measures that can improve water availability in the root zone and thus enhance yields. These practices influence mechanisms of lateral flow, infiltration, storage, redistribution and residence times of water at field scale. Such alterations in flow paths have not been adequately studied in ASALs where small perturbations at field scale upstream of a catchment may have significant effects downstream. Quantifying these fluxes using modern state-of-the-art techniques enables better understanding of productive and non-productive water transition processes and thus to evaluate cropping and management systems. This may only be achieved if knowledge of the current water flow paths is established, evaluated and optimised. Information on the level of crop production enhancement with the use of various water harvesting technologies is scanty especially in summer-rainfall zones such as Southern Africa. In addition, yield improvement does not entirely depend on availability of water but is also influenced by its seasonal distribution, soils, nutrient levels, weed and pest control, timing of operations among other factors. These factors need to be considered when evaluating the success/failure of water system innovations (WSIs). The impacts on the soil properties arising from WSIs are scarcely available in literature.

This study focused on the potential of rainwater harvesting and storage and further investigated the induced changes in the soil hydraulic properties, water fluxes and crop production. With respect to crop production among smallholder rainfed farmers in South Africa, the following needed to be identified:

- a) What is the difference between the potential and the typical yields? Could dry spells and/or droughts be responsible for this?
- b) What is the perception of farmers to dry spells and what realistic hydrological transformations can be undertaken to improve on-farm yields while safeguarding ecosystem productivity? To what extent are they likely to improve yields of smallholder rainfed farmers?
- c) What key soil properties influence moisture transitions in the study area?

- d) Which combination of rainwater harvesting technologies, water delivery systems and water application method(s) leads to optimum water productivity?
- e) Are there opportunities for synergistic productivity improvements by integrating soil and water management?
- f) What processes and conditions are necessary prior to the implementation and adoption/adaptation of crop improvement technologies in the study area?

The research reported herein aimed to address these concerns through a focused study in the Potshini catchment, Thukela Basin in South Africa, guided by the hypothesis and objectives described below.

Hypothesis and objectives:

The overall hypothesis of this study was that an evaluation process can be developed that allows for the determination of the suitability of rainwater harvesting technologies and the assessment of biophysical and socio-economic changes in the Thukela River basin. The general objective of the study was to identify and implement suitable WSIs and analyze their influences on soil hydraulic properties, water fluxes and crop production. The specific objectives were to:

- determine the frequency, severity and effects of droughts and dry spells on crop production;
- identify water flow paths resulting from two tillage practices and assess their impacts on crop production;
- investigate the effects of tillage on soil hydraulic properties; and
- identify and evaluate rainwater harvesting technologies, water delivery systems and viable application methods.

To achieve these objectives, desktop studies, field instrumentation and monitoring of assorted parameters and laboratory analyses of various samples were performed.

ABSTRACT OF RESEARCH

South Africa, in common with many parts of Sub-Saharan Africa, is facing increasing water shortages. Limited available water arising from a low and poorly distributed rainfall, must supply domestic, agricultural, industrial and ecosystem needs. Agricultural activities of smallholder farmers, who largely occupy arid to semi-arid areas, are rainfall-driven as they do not have the capacity to develop conventional water sources, such as boreholes and large dams. This situation has led to persistent food shortages, low income and a lack of investments, resulting in high dependency levels of which examples include over reliance on social grants, household crop production that largely relies on external inputs and availability of cheap unskilled labour. A growing global perception that water for agriculture has low value relative to other value uses could further jeopardize the already over exploited agricultural water. Developing economies such as South Africa are likely to favour, in terms of water allocation, e.g. electricity generation through steam turbines relative to irrigation needs because industry plays a more significant role in the economy.

While substantial scientific research has resulted in enhanced yields through in-situ water harvesting and soil and water conservation, as well as crop and soil fertility management and plant breeding, less work has been done to assess the impact of intermittent dry spells on crop yield, particularly with regard to smallholders. Indeed, the interventions that have been promoted to smallholders may provide little buffer against such events. In addition, the increase in yield from many such efforts has been marginal and inconsistent, leading some to conclude that semi-arid environments are

hydrologically marginal, have no significant agricultural potential and any attempts to intensify agricultural activities would lead to severe environmental degradation.

This study investigated the rainwater harvesting and storage potential among rainfed farmers in a summer-rainfall region of South Africa. The influences of this practice on soil hydraulic properties, water fluxes and crop production is detailed in subsequent chapters.

Using historical meteorological data, this study commenced with an investigation of the factors that influence the length of maize (*Zea Mays L.*) growing seasons notably the prevalence of early season dry spells and late season low temperature which could be responsible for persistent low maize yields amongst smallholder rainfed farmers. An increasing trend of dry spells was observed which was found to influence sowing dates and the length of the growing season.

The influence of no-tillage (N_T) as an intervention to secure more root-zone soil moisture was investigated in comparison to conventional tillage (C_T) practices. Field experiments, with the aim of quantifying the extent to which water productivity and yields can be improved among smallholder rainfed farmers in the Potshini catchment, Thukela basin; South Africa, were conducted during both the dry and growing seasons from 2005/06 – 2007/08 seasons at four sites with similar soil textural properties and slopes. Each site was developed as a runoff plot and was fitted with moisture and runoff measuring devices. Meteorological parameters were measured from a weather station installed nearby. A snapshot electrical resistivity survey was used to compliment soil moisture profiling. The analyses of the different measurements provided information on various water flow paths and potential downstream hydrological effects. The average cumulative runoff was 7% and 9% of seasonal rainfall in N_T and C_T treatments over the three seasons.

Changes over time in soil hydraulic properties due to tillage were examined at two depths through infiltration tests and determination of their bulk densities. These included changes in steady state infiltration rate and hydraulic conductivity, interaction between soil infiltration and soil characteristics and water conducting porosity and water retention. In 50% of the sites, N_T treatments showed significantly higher hydraulic conductivity compared to C_T treatments.

In response to an unexploited opportunity identified to produce vegetables in winter, an assessment of the potential for runoff water harvesting systems using polyethylene lining as an alternative cost-effective construction method for underground rainwater storage systems, particularly in areas where groundwater levels fluctuate rapidly was undertaken. The process from conceptualization through design, construction and utilization of the stored water is described and recommendations for the design and construction of such systems made.

Finally, various case studies which highlight the potential impact of improved soil profile moisture storage, the additional benefits of water stored in tanks and recommendations for tailored policies to support household food and income generation were made.

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Project 3a: BUILDING RESILIENCE AND INTENSIFYING FARMING: THE POTENTIAL OF SMALL-SCALE WATER SYSTEM INNOVATIONS IN SEMI-ARID AGRO-ECOSYSTEMS

Researcher(s): Elin Isabella Enfors
Institute: Department of Systems Ecology, Stockholm University
Supervisor(s): Dr. Line Gordon, Prof. Carl Folke, Dr. Johan Rockström
Start date: March 15, 2004
PhD defense: May 15, 2009

ORIGINAL OBJECTIVES

The aim of this research project is to examine if the use of small-scale water system innovations (SWSIs) can increase the resilience in semi-arid agro-ecosystems. The study is based on the assumption that water system innovations will lead to stabilized / increased yields under smallholder farming conditions when water is a limiting factor to the agricultural production. It is hypothesized that the use of water system innovations affects both biophysical factors in the environment and the management of natural resources, at field scale as well as at agro-ecosystem scale. The relations between the intensification of agriculture (achieved through SWSIs), the generation of ecosystem services, and the management of natural resources, will thus be analyzed within this project at both field and agro-ecosystem scales. Biophysical as well as social factors will be studied. The project consists of three parts: a baseline study, a field-scale study and a agro-ecosystem scale study. The baseline study aims at analyzing the current state and resilience of the agro-ecosystem, including its historical profile. The field-scale study aims at investigating the effects from the use of water system innovations on slowly changing soil variables and on farmers' management of their farming land. The agro-ecosystem scale study aims at investigating the effects from stabilized yield levels on farmers' natural resources management in the agro-ecosystem.

THESIS TITLE

Traps and Transformations: exploring the potential of water system innovations in dryland sub-Saharan Africa

THESIS ABSTRACT

In semi-arid and dry sub-humid sub-Saharan Africa (SSA), high poverty levels in combination with a heavy reliance on small-scale rainfed agriculture make rural livelihoods difficult. Upgrading current farming systems, in a way that safeguards productivity beyond field-scale, is urgent for local communities. This thesis builds on an in-depth case study of the Makanya catchment in Tanzania, and focuses on the potential of small-scale water system innovations (SWSIs), such as rainwater harvesting and conservation tillage, for increasing on-farm productivity while at the same time

supporting multi-functional landscapes. It takes an integrative approach, inspired by resilience thinking, to advance the understanding of SWSIs in relation to dynamics and complexity in smallholder agro-ecosystems in dryland SSA.

The thesis consists of five papers that approach questions of alternative development trajectories for smallholder agro-ecosystems, and effects of SWSIs on key variables in the system, from varying perspectives. Paper I presents a conceptual model for interpreting multi-equilibrium dynamics in dryland agro-ecosystems, and analyzes Makanya's development over the past 50 years. Paper II investigates farmers' strategies to deal with drought and the impact of the local *Ndiva* supplemental irrigation system on coping capacity. Paper III studies the effects of conservation tillage on yields and controlling soil variables. Paper IV explores four future scenarios for the catchment, and discusses the potential role of SWSIs across them. Paper V moves beyond the local scale, and maps dryspell frequency and trends over time in a drylands-in-SSA perspective.

The results show that smallholder farmers in agro-ecosystems such as Makanya depend on a wide array of on- and off-farm ecosystem services for their sustenance. The productivity of the surrounding landscape is especially important when crops fail. Furthermore, long dryspells constitute a major constraint in these agro-ecosystems. In Makanya long dry-spells have become twice as common over the past 50 years, and frequently cause crop failures. This is a driver for land degradation, and it seems to maintain a climate-related poverty trap. SWSIs provide opportunities for dryland farmers to shift their agro-ecosystems towards more productive trajectories through a number of mechanisms, including lowered crop failure frequency, altered on-farm water balances, and improved soil quality.

Although this is promising, the task of transforming these systems is tremendously complex. For SWSIs to be effective, prerequisites are farming system solutions that integrate improved water- and nutrient management, and broad-based investments that focus on a much wider range of issues than the water management technology in itself. Moreover, given the large uncertainty about the future in these regions, investments in small-scale farming should be designed so that they benefit local communities across a range of potential futures. Participatory scenario planning can both help agricultural intervention programs to identify robust investment strategies and help rural communities such as that in Makanya to navigate towards desirable development trajectories.

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Project 3B Building resilience of the eco-hydrological landscape: Dynamics of ecosystems and farming systems under intensification of rainfed agriculture

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Initial aim/research problem(s)

The adoption of smallholder systems innovations implies change of both biophysical and social parameters (quantified and analysed in other projects in this programme) with effects on social-ecological systems at several scales. Ecosystems generate goods (e.g. food, timber, fibre) and services (e.g. pollination, nutrient retention, carbon dioxide sequestration) on which the welfare of society depends.

The main research question raised in this project is how the capacity of aquatic and terrestrial ecosystems to produce goods and services can be sustained when faced with hydrological flow shifts as a result of land use changes in semi-arid tropical watersheds. The research will be carried out in the two studied river basins in the programme; the Thukela basin in South Africa and the Pangani basin in Tanzania.

The focus is on how change of agro-hydrological process is interlinked spatially and temporally with other ecosystem processes (mobility of organisms, food web interactions, abiotic-biotic relations etc), land management and social institutions. The project will analyse how agricultural innovations can help build or sustain the resilience of the socio-ecological systems in the catchments and thus make them less vulnerable to change. The dynamic role of freshwater for ecosystem services will be the focus of the project that adopts a cross-scale approach to interactions between various systems in the studied watersheds.

Social capacity to manage biodiversity, ecosystem services and resilience in an adaptive way is in itself one component of resilience in linked social-ecological systems. Being 'adaptive', i.e. being able to cope with uncertainty, complexity, and change is a key property when managing complex systems. This has been termed "adaptive management" and has been widely advocated as a paradigm that society should adopt. It is built on a recognition that ecosystems are complex "adaptive" and "self organising" and that in order to utilise such systems sustainably, society must be able to adapt to change or surprise in them.

Methods from both natural and social science will be used and the result analysed within the framework of ecosystem management. One overarching research question is whether an adaptive management process can build resilience in the social-ecological system by emphasising learning from change and innovations and focusing on monitoring feedbacks across temporal and spatial scales. The research hypothesis behind this emphasises the importance of flexible institutions and organizations locally and which are nested across scales, with well functioning information flow between scales. It also emphasises diversity and redundancy of "knowledge reservoirs" that can be important mechanisms for coping with changes and surprises.

The methodology will build primarily on mapping of stakeholders in the region, analysis of ecological knowledge (scientific/local/traditional) and management practices and institutional arrangements in the region. It will build on participatory methods and qualitative interviews. It will depend on the findings in the other projects in the programme and be closely linked to the PhD project 3a (which focuses more on biophysical aspects of ecosystem resilience).

Alterations in the original planning of the project:

Originally, this project was developed for a 2 year research program. Unfortunately the available funding only covered a bit less than one year of research. Efforts to seek more funding through SIDA-Sarec did not come through. This implied less time in field and less time for writing of papers. Despite this I have still remained heavily involved in the SSI-project throughout the years, but more in terms of a supervisor for MSc students and for Elin Enfors (project 3 PhD-student).

Results

Analyzing ecosystem services in the Thukela basin

Ecosystem services have been analyzed both on-farm and off-farm in the Potshini/Thukela region. The focus has been on how the use and perception of ecosystems have changed over time and how important they are in current livelihoods.

Ecosystem services to complement crop production:

The first study focused on survival strategies used by the farmers in Potshini and how they dealt with crop failure or yield reductions in the past and in the present. Ecosystem goods that are used by the farmers include: water, wood for fire and building material, straw, grass, fodder, wild herbs, wild animals, medicine herbs, mushrooms, mud and manure. The results from the study indicate that the dependency on local ecosystem goods has decreased over the last 10-30 years, while several other survival strategies have become increasingly important. Some other strategies include the use of social grants, trading with neighbours, remittances, gifts, take work within the local area, selling cattle, tobacco or handicraft, and going hungry.

It was concluded that farmers are not as dependent on ecosystem goods for reducing the effects of yield reductions as we originally thought. Today, most farmers have the capacity to buy complementary food when yields are reduced. One issue raised but not dealt with was whether the village might be in a process of losing local ecological knowledge related to the use of ecosystem goods. The report also raises questions for future studies concerning the effect of moving their dependency on ecosystem goods and services from a local social-ecological system into a global market.

Seasonal calendars of resource use as well as timelines to establish years where yield reductions have been problematic for the farmers.

Historical changes in ecosystems:

Focus group discussions were held in 9 different sub-wards in the Emmaus region in order to understand how farmers experience changes in the resource base and how farmers perceive the importance of various disturbances that has happened over time. The results indicate that most of the resource systems that the farmers are using for ecosystem goods and services have, according to their perceptions, been very degraded

and that most resources today are seen as being in a very bad condition. Initial analysis suggests that there might be a particular time in between the 1970's and the 1980's where there was a jump in resource degradation, particularly as it relates to livestock increases and changes from 'good' to 'bad' grass (good and bad are terms used by the farmers). They also state that there have been few responses to this degradation. One reason is suggested to be the rapid institutional change occurring at the moment with very little current monitoring of resource change in the communities. This change includes coinciding factors such as land availability decreased, breakdown of traditional institutions, increasing gap between generations and new "pulling forces" for younger generation. But they also see several new development initiatives that might counteract this (e.g. the 'landcare' project (ARC) can help them change this).

Regulating ecosystem services on agricultural lands:

The levels of four regulating ecosystem services (erosion control, nutrient retention, carbon sequestration and water provisioning) was compared among four types of land uses (forestry, commercial farming and smallholder farming on was compared). The study was based on expert interviews and ranking, and a literature study. The results show that there is a variation in the generation of ecosystem services between the three land uses. Experts estimate that both commercial agriculture and commercial forestry maintain a capacity to generate regulating ecosystem services at a level close to natural potential. Small-scale agriculture, on the other hand shows a reduction for all four regulating ecosystem service compared to the reference area. The results show that there is great variation within all land uses depending on management practices. No-tillage, which is when the crop residues are left on the fields after harvest, is mentioned as a method that would improve ecosystem services at multiple levels. Thus, with better management practices such as for example reduced tillage it would be possible to improve the ecosystem's ability to generate certain ecosystem services (e.g. erosion and nutrient retention) and some experts state that it is even possible to exceed the level that is originally generated. Strong linkages generating synergisms and/or trade-offs have been found between the selected ecosystem services. Thus, techniques aiming to improve a particular ecosystem service (e.g. erosion control) are most likely to benefit the generation of multiple services (for example also enhance carbon sequestration).

Analyzing resilience in Makanya, Tanzania

For the results of the work with Elin Enfors (Project 3, PhD student), see her report. Two master students also worked in the Makanya catchment under my supervision.

Thomas Gerenstein finished a thesis related to the inclusion of a more adaptive management approach to Natural Resources Management in the Makanya catchment. He first conducted a review of adaptive management literature and identify key components that provide potential for successful adaptive management, i.e. 1) different sources of knowledge, 2) stakeholder involvement, 3) key individuals, 4) ability to self-organize, 5) organizational structure, 6) ability for monitoring and 7) capacity to live with uncertainty. The results of the field work revealed a great variation in how these factors was distributed in the village. It was found that there are substantial differences regarding important factors in adaptive management between two sub-villages within Bangalala, indicating that implementations of adaptive management in natural resources management will need very different approaches, even within a small geographical area since there are great variations in the socio-ecological structure.

Anna Engdahl finished her thesis related to the planned biodiversity and intensification of agriculture in the Pangani basin, based in the Makanya catchment. The study was done as a comparison between farmers in sub-villages of Bangalala who are connected to NDIVA-systems, and farmers in another sub-village of Bangalala who are not connected to an NDIVA. The role of biodiversity for ecosystem resilience have been emphasised in studies from many different ecosystems, but not for agricultural systems. In the developed part of the world, intensification of farming has often led to a loss of biodiversity, thus also leading to negative consequences for resilience. The thesis illustrated how the concept of functional diversity, redundancy and response diversity can be used in an agricultural setting where socio-economic values of the species are important in addition to ecological importance. An assessment of species diversity of crops and livestock revealed a higher diversity, in terms of redundancy within functional groups, and in terms of cross-scale (temporal and spatial) response diversity in the fields of the NDIVA-connected farmers. However, the higher diversity came at the cost of increased use of agrochemicals, which has shown to erode agro-ecosystem resilience in many other studies. This emphasises the importance of holistic assessments of complex socio-ecological system as a way to reveal trade-offs between different dimensions of resilience.

Publications and other output:

Publications (journals)

- Enfors, E. I., Gordon, L.J. 2008. Dealing with drought: The challenge of using water system technologies to break dryland poverty traps. *Global Environmental Change*, 18: 607–616
- Enfors, E. I., L. J. Gordon, G. D. Peterson, and D. Bossio. 2008. Making investments in dryland development work: participatory scenario planning in the Makanya catchment, Tanzania. *Ecology and Society* 13(2): 42. [online] URL: <http://www.ecologyandsociety.org/vol13/iss2/art42/>
- Enfors, E., Gordon, L.J. (2007) Analysing resilience in dryland agro-ecosystems: A case study of the Makanya catchment in Tanzania over the past 50 years. *Land Degradation & Development*, 18(6) 680 - 696
- Rockström, J., Folke, C., Gordon, L., Hatibu, N., Jewitt, G., Penning de Vries, F., Rwehumbiza, F., Sally, H., Savenije, H., Schulze R. 2004. A watershed approach to upgrade rainfed agriculture in water scarce regions through Water System Innovations: an integrated research initiative on water for food and rural livelihoods in balance with ecosystem functions. *Physics and Chemistry of the Earth*, 29: 1109-1118

Publications (book chapter)

- Gordon, L.J, Enfors, E. 2008. Land degradation, ecosystem services and resilience of smallholder farmers in Makanya catchment, Tanzania. In Bossio, D., Geheb, K. (eds) *Conserving land, protecting water*, CABI, UK. pp 33-50.

Honors Theses supervised by Line Gordon:

Josefin Blanck (2007) Bundles of ecosystem services: an intercomparison of commercial agriculture and a national park in Upper Thukela, South Africa. Department of Systems Ecology, Stockholm University.

Johanna Henriksson (2004) Mapping small-holder farmers use of ecosystem goods and services in Thukela, South Africa – with a special focus on times of crop failure. Department of Systems Ecology, Stockholm University.

Thomas Gerenstein (2005) Potential for adaptive management in a smallholder semi arid landscape -revealing large organizational differences over a small geographic area. Field study in the Makanya region, Tanzania. Department of Systems Ecology, Stockholm University.

Anna Engdal (2005) Intensification and diversity in semi-arid agro-ecosystems: A case study of Bangalala village, Tanzania. Department of Systems Ecology, Stockholm University.

Presentations of work at international conferences

2008 Making investments in dryland development work, presentation at Sida research conference Meeting Global Challenges in Research Cooperation, Uppsala, Sweden 28 May

2008 Invited speaker Turbulent Waters, Development and Food Security at Resilience Seminar in Honour of Professor C.S. Holling, Royal Swedish Academy of Science, 5 Nov

2007 Invited keynote speaker “Resilience Thinking” at the Riskbase/Aquaterra cross-cutting issues workshop, Venice, 3-4 December

2006 Invited speaker at SWH seminar as a side event to Stockholm Water Symposium. “Water, agriculture and resilience - mapping vulnerability to regime shifts”. August.

2006 Invited talk at Symposium on Resilience in Southern Africa, National Botanic Gardens, Pretoria. “Water and resilience of agricultural landscapes 2 cases at 2 scales”. April.

2006 Resilience Alliance Writers Workshop on Water and Resilience in Agricultural Landscapes, Oxford

2004 SIWI/CA international seminar in conjunction with Stockholm Water Symposium. Presentation of the paper “Freshwater for increased resilience of agro-ecosystems”. August.

Project 4A Understanding hydrological processes in an ungauged catchment in sub-Saharan Africa

Researcher: M.L. Mul
Institute: UNESCO-IHE Institute for Water Education
Supervisor(s): prof. Dr. ir. H.H.G. Savenije, prof. S. Uhlenbrook
Starting date: 1st January 2004
PhD defence: 6 February 2009

ORIGINAL OBJECTIVES

With increasing population the pressure on available water resources is increasing through domestic water use and even more through food production. In developing countries, water that is used for food production accounts for 70-90% of the total water consumption. With all easily accessible and cost effective water resources already being exploited, new areas for exploitation can be very costly and could have a detrimental effect on the environment. Increasing “Blue water” use is therefore no longer a sustainable solution. A new approach to the problem is to increase the “Green water” usage, that is water stored in the unsaturated zone and send back to the atmosphere through transpiration (Falkenmark, 1995). The challenge is to increase total crop production through increasing crop per drop of water instead of through increasing the stress on the available “Blue” water resources.

In developing countries most of the available blue water resources is used for food production. The major part of that water is used for large-scale irrigation. If the required increase in food production would be produced by large-scale irrigation it would result in a drastic increase in water demand. In sub-Saharan Africa about 95% of agricultural area is occupied by small-scale predominantly rainfed agriculture. Hence, it becomes clear that on-farm technologies in smallholder farms have been identified as a possible solution to the problem.

In the previous decades the impact of the introduction of new technologies in smallholder farms has been tested and studied at farm level. These studies looked into increasing crop production and partitioning of rainfall (transpiration, evaporation, runoff) at a very small scale. An aspect which has hardly been studied, is the impact on downstream water users and water using systems. The possible scales of impact are from the small sub-catchment where the technologies are located to the entire river basin. Along these scales different impacts are predicted. The impacts can be classified in physical and in social terms. Most of the time the social impacts are also related to the physical impacts. The physical impacts are to a large extent related to hydrological impacts, such as changes in the hydrological regime, rainfall partitioning and resulting changes in erosion and sedimentation.

Hydrological modelling tools will be used in this study to estimate these impacts at different scales. There is a knowledge gap in how these different scales are linked; every modelling scale has different dominating hydrological processes, resulting in different governing equations for each of these models. For example, on small scale (temporal and spatial), Hortonian overland flow is very much dominant in terms of catchment response on the other hand base flow coming from groundwater is dominant at a large scale. Governing equations tend to become simpler on larger scale, as a result of evening out of hydrological processes (Savenije, 2001). The challenge here lies in how

to link these hydrological processes at different scales and therefore how to link different hydrological models.

A derivative from the physical impact is the social impact on the downstream water users and water using activities. Conflicts between water users have been observed in many areas, however these conflicts in most cases are related to “Blue water” abstractions and allocation. Farmers practising on-farm water harvesting techniques can influence the physical response of a catchment, however they are not recognised as water users in water allocation issues. The new Water Act in South Africa is starting to include this type of water use as stream flow reducing activities. This is a way of including these types of water uses in river basin management plans. However a quantification of the impact of these technologies, both in physical and socio-economic terms, is needed before a thorough trade-off analysis can be made between all water users in either a catchment or the entire river basin. Based on this information an integrated river basin or watershed management strategy can be developed.

Whereas the technologies have proved to have positive effects on the farmers livelihood and income, it is not clear what the downstream implications are if every farmer in an area decides to implement the technologies. There are also no guidelines on which technologies require certain physiological and geographical characteristics of the plot. This would prevent farmers implementing inappropriate technologies and causing more harm than benefit.

Specific objectives:

- To assess the current hydrological changes in the Makanya catchment due to water system technologies at different spatial and temporal scales
- Identification of dominating hydrological processes at different scales in hydrological modelling
- Identify linkages between different scale hydrological models and equations
- To identify the inter linkage between upstream and downstream users.
- To identify the trade-offs to be made between water for crop production and ecological services.
- To estimate the place of rainfed agriculture and water system technologies in Integrated River Basin Management
- Find a suitable strategy for implementing water system technologies in the Makanya catchment
- Develop generic methodology for decision making for implementing water system technologies
- To identify commonalities and differences in the modelling tools, TAC^D and ACRU
- To identify commonalities and differences in trade-offs between water for crop production and ecological services

ABSTRACT OF RESEARCH

Ungauged catchments can be found in many parts of the world, but particularly in sub-Saharan Africa. Information collected in a gauged catchment and its regionalisation to ungauged areas is crucial for water resources assessment. Especially farmers in semi-arid areas are in need of such information. Inter and intra-seasonal rainfall variability is large in these areas, and farmers depend more and more on additional surface and

groundwater resources for their crop production. As a result, understanding of the key hydrological processes, and determination of the frequencies and magnitudes of stream flows, is very important for local food production. This is particularly true for the ungauged Makanya catchment in Tanzania, which is the subject of this study.

In the absence of long-term hydrological data, hydrological processes have been studied through a multi-method approach. Regular rainfall and runoff measurement devices were installed in a nested catchment approach. High spatial and temporal resolution data have been collected over a period of 2 years to capture all the hydrological processes. Spring samples have been taken to identify groundwater flow systems. Hydrograph separation with hydro-chemical data has been performed to identify and quantify the origins and flow pathways of the water during flood flows. Electrical resistivity tomography (ERT) has been used to map the subsurface structure at selected sites. Finally, a conceptual model has been developed to test the hypothesised conceptualisation of the flow paths.

Agricultural practices by farmers in the catchment vary as a function of location as they are influenced by the local climate, water resources availability and soil type. Three zones with distinct features have been identified within the study area. In the highlands, it is cooler, rainfall is more abundant and there are perennial springs. Here irrigation is practiced as supplementary irrigation in the wet season and as full irrigation during the dry season. In the midlands only supplementary irrigation is practiced using the remainder of the perennial streams coming from the highlands. Here the high probability of occurrence of dry spells requires supplementary irrigation. In the lowlands, base flow has dried up and spate-irrigation is practiced during the rainy season, whereby flash floods are diverted from the main river onto the farm land.

In the highlands, the occurrence of perennial springs is defined by the geology. These springs discharge a substantial amount of water. In the midlands, few springs exist, yielding a substantially lower amount of discharge, with poorer quality. Abundance of spring water from the highlands is both used in the highlands and the midlands for irrigation. However, due to the many diversions, the rivers do no longer reach the outlet of the catchment, as they do not exceed the infiltration capacity of the alluvium. Only large flash floods reach the spate-irrigation system in the lowlands.

Two types of floods have been analysed in the catchment, induced by different types of rainfall. High intensity rainfall can generate flash floods which reach the spate-irrigation system. Smaller floods infiltrate into the alluvium before reaching the spate-irrigation system. It has been observed that during small floods, the vast majority of the flood originates from groundwater (> 90 percent). During an extreme event, the groundwater contribution is still about 50 percent of the total flow, increasing the outflow from the groundwater reservoir a 100-fold during the peak flow and causing a substantial base flow increase after the event. The time of concentration is extremely short, within one to two hours the flood peak reaches the outlet of the catchment flowing into the spate-irrigation system. The rainfall during the March 2006 event was such an extreme event, with intensities as high as 50 mm hr^{-1} , while the entire event lasted only 4-5 hours. During this event, rainfall intensities exceeded the infiltration capacity of the soils and overland flow was common. The flows exceeded also the absorption capacity of the alluvium of the main valley of the catchment, replenishing the local aquifer and feeding the downstream spate-irrigation system.

The temporal resolution of the observed data is 15 min. This level of detail was necessary to capture the rapid catchment response during peak flows. The observation data, unfortunately is not complete as extreme events damaged the structures and affected the reliability of the observations. Moreover, 7 out of 10 instruments were lost, stolen or damaged which hampered the data collection.

A conceptual hydrological model has been developed to test the rainfall-runoff hypotheses. The model is able to model in a process-based fashion the flows at the foot of the mountain, incorporating the observed hydrological processes. The model yields good results for a simulation of a 2-year period at hourly time step (Nash-Sutcliffe efficiency: 0.79 and Log Nash-Sutcliffe: 0.90). This model contains a large number of parameters, of which several parameters could be identified from the data. However, automatic optimisation of the remaining parameters is hampered by equifinality. Hence, the strategy chosen is step-wise calibration using multiple performance criteria judging hydrograph performance visually. If the hydrological model would be used for upscaling farming practices, then one should realise that the hydrological processes in the valley of the catchment are different from the highland processes and need to be studied in further detail before the model can be upscaled to the catchment level.

The current hydrological and water resources situation, as in many parts of Africa, is also a result of anthropogenic influences. Increased water usage in the upper parts of the catchment generated the need for agreements between highland and midland water users. No agreements are in existence between these two groups and the lowland farmers. With the base flow no longer reaching Makanya, the farmers were forced to change their irrigation practices. Changes in land use in the upstream parts have also impacted on the hydrological processes. However, with a lack of historical data, we were unable to quantify this. The downstream farmers are not solely negatively affected, as flash floods generated in the highlands reach Makanya, replenish the unsaturated zone and local groundwater bodies and deposit fertile sediments. Currently, there is a balance between the upstream and downstream farmers, whereby yields are produced by each system. However, it is unsure how future increases in water requirements will affect this balance.

KEY PUBLICATIONS

- Mul, M.L. 2009. Understanding hydrological processes in an ungauged catchment in sub-Saharan Africa. PhD thesis UNESCO-IHE, Delft, the Netherlands.
- Mul, M.L., Mutibwa, R.K., Uhlenbrook, S., Savenije, H.H.G., 2008. Hydrograph separation using hydrochemical tracers in the Makanya catchment, Tanzania. *Physics and Chemistry of the Earth* Volume 33, Issues 1-2, Pages 151-156.
- Mul, M.L., Savenije, H.H.G. and Uhlenbrook, S., 2008. Spatial rainfall variability and runoff response during an extreme event in a semi-arid, meso-scale catchment in the South Pare Mountains, Tanzania. *Hydrology and Earth System Sciences Discussions*, 5, 2657-2685.
- Makurira, H., Mul, M.L., Vyagusa, N.F., Uhlenbrook, S., Savenije, H.H.G., 2007. Evaluation of community-driven smallholder irrigation in dryland South Pare Mountains, Tanzania: A case study of Manoo micro dam. *Physics and Chemistry of the Earth* Volume 32, Issues 15-18, Pages 1090-1097.

- Mul, M.L., Mutiibwa, R.K., Foppen, J.W.A., Uhlenbrook, S., Savenije, H.H.G., 2007. Identification of groundwater flow systems using geological mapping and chemical spring analysis in South Pare Mountains, Tanzania. *Physics and Chemistry of the Earth* Volume 32, Issues 15-18, Pages 1015-1022.
- Mutiro, J., Makurira, H., Senzanje, A., and Mul, M.L., 2006. Water productivity analysis for smallholder rainfed systems: A case study of Makanya catchment, Tanzania. *Physics and Chemistry of the Earth, Parts A/B/C*, Volume 31, Issues 15-16, 2006, Pages 901-909.
- Mul, M.L., Savenije, H.H.G., Uhlenbrook, S., and Voogt, M.P., 2006. Hydrological assessment of Makanya catchment in South Pare Mountains, semiarid northern Tanzania. *Climate Variability and Change—Hydrological Impacts* (Proceedings of the Fifth FRIEND World Conference held at Havana, Cuba, November 2006), IAHS Publ. 308, 37–43.

Project 4B Balancing water for food and environment: Hydrological determinants across scales in the Thukela river basin-South Africa

Researcher: Victor Kongo
Institute: University of KwaZulu-Natal
Supervisors: i) Prof. Graham Jewitt
ii) Prof. Simon Lorentz
Starting date: Jan 2004
Submission: December 2007
PhD award: 30th March 2009

ORIGINAL OBJECTIVES

Increased withdrawals and deterioration of water quality in the Thukela basin, as a result of agricultural, urban and industrial development, has raised concerns of how to secure water flows to sustain ecosystem services. More concern has become evident with the promulgation of the 1998 National Water Act (NWA), which includes the concept of the "Reserve", and hence the need for knowledge on water flows required to sustain water dependent ecosystems and basic human activities i.e the reserve. Of course, the driving force behind the increased withdrawals is the growing population that needs food security. Nevertheless, the sustainability of food security largely depends on exploration and exploitation of two main natural resources i.e land and water through agricultural production processes. Sustainability of food security in rainfed agriculture in arid and semi-arid areas of tropical Africa (rainfed smallholder agriculture) has been subjected to numerous setbacks and the main being unreliable rainfall. This has led to the introduction or adoption of water use innovations by smallholder farmers with the objective of conserving, preserving and ensuring availability of adequate soil moisture for crop production over time. These innovations are expected to be adopted on a large scale (with time and over large areas) in the advent of intensified and extensive smallholder rainfed agriculture and little is quantitatively known on what kind of impacts such an upscaling of intensified water use (rainwater) could have on downstream water users, including the aquatic ecosystems in a river basin. It must be noted that water use by agriculture is hydrologically sensitive due to the large amount crops directly consume through evaporation and transpiration often with little or no return flows to the surface and sub-surface components of the hydrological cycle. It has been established that water system innovations for upgrading of rainfed smallholder farming are not new but are rarely assessed and have never been analysed from a broad spatial and temporal perspective in order to understand system impact at large spatial scales. This research study is aimed at carrying out such an upscaling analysis in the Thukela river basin in South Africa.

ABSTRACT OF RESEARCH

The experience drawn from establishing the catchment monitoring network in Potshini, a rural community in Bergville District in South Africa, has proved that there are more opportunities and gains (both material and ideas) to benefit from involving other stakeholders. The level and stage of participation of each stakeholder differs but ultimately contributes to the success of such a process. The Potshini catchment monitoring network has several permanent structures and instrumentation which will benefit other researchers for a long period of time. The structures and instruments have been installed in individual farms belonging to willing smallholder farmers in the Potshini community. A number of the farmers have volunteered to monitor some of the hydrological processes and take readings accordingly. The traditional leadership in

Potshini agreed to host and support the SSI research programme and the local leaders (elected) facilitated, to a great extent the linking of the SSI researchers to the local municipality officials while the extension personnel from the Department of Agriculture in Bergville District and the ARC-Landcare project in Bergville played a key role in linking the SSI research programme with other similar projects and stakeholders in the Bergville district and beyond. Furthermore we have shown that the participation of a local, relatively poorly educated community in a hydrological monitoring programme need not compromise the quality of the scientific endeavour nor the level of sophistication of the instrumentation used. The participatory process of establishing the Potshini catchment monitoring network has emerged as a positive impact to the local community and other stakeholders with regard to appreciating the research findings and above all, the ability to sustain the goodwill of the local community in safeguarding the instruments and structures comprising the network.

The relative contribution of the shallow groundwater fluxes to the integral stream flows in the Potshini catchment was estimated from the shallow groundwater levels measurements and complimented with ERT mapping and using the Darcy's equation. It was found out that during the dry winter season, the shallow groundwater fluxes were estimated to contribute close to 75% of the stream flows in Potshini, with insignificant contribution of around 0.1% during the rainfall events. These fluxes, especially during rainfall events, seem to be low and this could be attributed to the existence and influence of macro pores and preferential flow paths which are not accounted in the application of the Darcy's law, which is simplistic. The effect of a "pressure wave" in the subsurface flows induced by displacement of "old" water by "new" water could not be captured in the Darcy's law as well, and which could have lead to high amount of subsurface discharge into the stream. Thus, tracer studies would have been useful in this case in estimating the relative contribution of the subsurface water especially the "old" and "new" water to the total stream flows. Hence, surface and subsurface water in a catchment cannot be isolated from each other but forms an integrated system that has to be understood within its integral context.

Total evaporation (E_T) was computed from Large Aperture Scintillometer (LAS) measurements in the Potshini catchment using the surface energy balance equation based on 1 minute data statistics and compared to the remote sensed SEBAL estimates of actual evaporation in the catchment, derived from MODIS satellite data, and the potential evapotranspiration estimates computed using the FAO-56 method. Generally, the LAS and SEBAL estimates of E_T were comparable with the relative error ranging from -14 to 26%, indicating a reasonable agreement between the two methods. These results compare well with results from similar studies in other countries of different climatic conditions. All the FAO-56 estimates were above the SEBAL and LAS E_T values, an indication that the latter were within the measurement range considering the fact that the experiment was carried out during the dry winter season. SEBAL estimates of net radiation, sensible and soil heat fluxes were comparable to the field measurements with reasonable relative accuracies. It could be more interesting to compare the E_T estimates with data from Class A-pan or Lysimeter as another validation strategy for the methods discussed in this paper. Nevertheless, it is recognised that no single method of measuring E_T is without problems and uncertainties due to the many factors influencing its occurrence especially on large spatial scales. However, the ability of the SEBAL methodology to produce reasonable estimates of E_T provides the potential for practical application on a river basin scale water balance studies by providing estimates of E_T over large spatial extents. It would be interesting and useful to carry out a detailed

analysis, applying both the scintillation and remote sensing techniques, to determine the evaporative water use by the various landuses in the Thukela river basin. Such a study would generate useful information with regard to water productivity and equity in water resources in the basin.

The evaporative water use of twenty four land use classes in the upper Thukela river basin, over an area of 3028 km² was assessed from *ET* images derived from SEBAL analysis. The main land use in the area of interest was to be unimproved grassland (cf. The S.African National Land use map developed in 2000) occupying 71% of the total study area. The land uses with the highest evaporative water use was found to be commercial forest plantations, with Eucalyptus and Pine generating the highest green water flows. High evaporation rates over water bodies were observed during the wet summer season when both the natural and man-made water bodies were likely to be at full capacity. This study highlighted the heterogeneity associated with spatial variation of *ET* with respect to land use classes and the possibility of applying remote sensing to overcome such a challenge, with more prospects for assessing the impacts of land use change, e.g upscaling or intensifying certain land uses, to hydrological systems. However, the uncertainty associated with low resolution satellite images for mapping *ET* over small areal extents was found to be a challenge as illustrated by the irregular results from wetlands and water bodies.

Key publications

- Kongo M.V. 2008. Balancing water for food and environment: hydrological determinants across scales in the Thukela river basin-South Africa. PhD thesis. University of KwaZulu-Natal, South Africa
- Kongo .V.M., Jewitt, G.P.W., Lorentz S.A. 2007. Establishing a catchment monitoring network through a participatory approach: A case study from the Potshini catchment in the Thukela river basin, South Africa. Colombo, Sri Lanka: International Water Management Institute. P66. (IWMI Working Paper 120)
- Kongo V.M., Jewitt G.P.W., Lorentz S.A. 2007d. Evaporative water use of different land uses in the Thukela river basin assessed from satellite imagery. In Proceedings of the 13th SANCIAHS symposium, 6th & 7th September 2007, Waterfront, Capetown-S.Africa.
- Kongo, V.M. and G.P.W. Jewitt, 2006. Preliminary investigation of catchment hydrology in response to agricultural water use innovations: A case study of the Potshini catchment- South Africa. Physics and Chemistry of the Earth, Volume 31, Issues 15-16, Pages 976-987.
- Kongo, V.M., Kosgei, J.R., Jewitt, G.P.W., Lorentz, S.A., 2007. Establishment of a catchment monitoring network through a participatory approach in a small rural catchment in South Africa. Hydrol. Earth Syst. Sci. Discuss., 4, 3793–3837
- Kosgei, J.R., Jewitt, GPW., Kongo, V.M., Lorentz, S.A. 2007. The influence of tillage on field scale water fluxes and maize yields in semi-arid environments: A case study of Potshini catchment, South Africa. Physics and Chemistry of the Earth Volume 32, 1117-1126.

Project 5: Spatial planning and mapping of water system innovations and assessment of their hydrological impact

Researcher: Dr. J. S. Pachpute
Institute: IWMI, South Africa
Supervisor(s): Dr. Hilmy Sally
Starting date: 1st January 2007
End date: 31st December 2008

Dr. J. S. Pachpute joined post doctoral duties in SSI programme on 17th Jan 2007 at Southern Africa office of International Water Management Institute under the supervision of Dr. Hilmy Sally, Head, IWMI, SA and Project leader, SSI programme.

The initial objectives of her post doctoral research as advised by her SSI advisory committee, involved synthesis of the research work conducted by PhD scientists and assessment of hydrological impacts of Water System Innovations at larger scale (larger than the study catchments Makanya and Potsheni) in Pangani (Tanzania) and Tugela (South Africa) river basins. Fieldwork in Makanya was undertaken in March 2007 and Jan 2008.

During March 2007, the data and or observations on following aspects were collected:

- i) GPS locations of selected micro dams, micro dams' dimensions, cropping pattern and yield levels in reference to location of micro dam, size of micro dam catchment and command, number of farmer members, process of operation and maintenance of micro dams by Water Management Committees, dimensions and catchment characteristics (soil, land use/cover, gradient, geology) of failed and feasible micro dams.
- ii) GPS locations of selected dug out ponds, dug out pond dimensions, number of livestock animals watered by each dug out pond, pan evaporation data.
- iii) GPS locations of roof top runoff harvesting tanks, actual water storage, dry season water usage, constraints and potentials.
- iv) GPS locations of subsurface runoff water harvesting tank, actual storage and wet season runoff storage potential, cropping pattern and irrigation methods, constraints in using the stored water for crop production
- v) Flow data of Makanya river, rainfall data of several raingauge stations installed in the watershed, climatological parameters monitored daily by automatic weather station
- vi) Soil samples were collected from locations of hydrological and agricultural interest and were analysed for texture and soil nutrients. The hydraulic conductivity/ infiltration data was collected from different land uses and land cover sites.
- vii) Data on crop seasons, pattern, crop growth stages, yield levels were collected
- viii) The experiment on pitcher irrigation method was designed and implemented. The observations were planned and the easy to understand tables were prepared and handed over to the recruited person for data collection over the next three crop seasons.
- ix) Ground truth data was collected for preparing land use land cover map.

In Jan 2008:

The land use land cover map was validated through field surveys. The socio-economic data on household characteristics such as household size, income, number of livestock animals was collected. The proportion of various livelihood activities in household income was assessed.

In addition to the data collection through fieldwork, data available on internet was studied, selected and downloaded, mostly on soil characteristics, population, household characteristics, agricultural systems, government resolutions towards agricultural development, activities of other developing and NGOs, research institutes. Remote sensing and GIS analysis was conducted to develop the soil and land use land cover information. The spatial layers of WSI locations, population, labour density, agro-ecological zones, etc were developed and used in hydrological synthesis of the study area.

Most of the data in V13 D (Tugela catchment) was downloaded from websites and or obtained by contacting the concerned authorities. Data collected was on soils, land use land covers, groundwater levels, flow data of little Tugela, rainfall and other climatological data. The KZN Municipal website displays wardwise, most of the socio-economic and Govt schemes' data. The spatial layers of above information were prepared in GIS and used for further analysis and modeling work.

The remote sensing and GIS datasets of soil, landuse, cultural and socio-economic parameters were developed for both Makanya and Little Tugela catchments. The LANDSAT images and landuse, soil, groundwater, agronomic, climatic and socio-economic datasets for larger Pangani and Tugela river basin are collected from several authentic sources and some of them are updated for field conditions.

The Soil and Water Analysis Tool (SWAT) potentially can assess the productivity and hydrological impacts of Water System Innovations in a medium size catchment; therefore this model was selected, developed and run for Makanya and Little Tugela catchments. Calibration of these models is completed based on the observed flows of Vudee and Little Tugela rivers. As per the SSI programme structure and research plan, the PhD researchers working on Project 4 are yet to complete the field to catchment level modelling work towards impact assessment, accordingly, its link with SWAT model may be formed in future plans.

Before completion of her contract with IWMI, SA, Dr. Pachpute completed write up of following research papers.

1. RS and GIS based multi-criteria evaluation for locating water system innovations in Pangani river basin of Tanzania,
2. Sustainability of rainwater harvesting systems in rural catchment of Sub-Saharan Africa,
3. A package of water management practices for sustainable growth and improved production of vegetable crop in labour and water scarce Sub-Saharan Africa

The Paper at Sr. No. 1 is already presented in ICID conference and published after peer review and the second paper is accepted after revision by the Int Journal of Agricultural water management for publication. The third paper is resubmitted after incorporation of reviewer's comments and the final acceptance from Int. Journal of Agricultural Water Management is awaited. The final manuscripts of above three papers can be seen in the appendix – A.

On 16th Jan 2009, Jayashree Pachpute completed her contract with IWMI SA and resumed her duties on 19th Jan 2009 under M.P. Agricultural University, Rahuri, India. For future correspondence, her email address is: jaishree_kumkar@rediffmail.com. In future, depending on her engagement in University job, she will write 4 to 5 journal papers, especially on upscaling of WSIs, productivity and hydrological impacts.

Special challenges:

International journal has appreciated the research work and accepted the papers for publication; this is encouraging towards writing more number of papers on sensible issues. However, looking at the engagements in university job, it's challenging to try concentrate on writing papers.

To get the financial support towards stipend during leave and facilitation (internet charges, private editors' fees) at least for over six months sometimes after mid 2009 has been essential. Applications are already sent to few foundations; hopefully the funds will become available from July 2009.

Suggestions/recommendations for further work:

NIL

Acknowledgement:

I am grateful to Johan Rockström and Jennie Barron from SEI side for providing the necessary support for my post doctoral research.

Key publications

J.S. Pachpute, 2007. RS and GIS based multi-criteria evaluation for locating water system innovations in Pangani river basin of Tanzania. Presented in ICID Second Regional Conference, Held in Johannesburg, South Africa, 6-9, November 2007 and Published on CD.

Pachpute, J.S., Tumbo, S.D., Sally, H., Mul, M.L., 2009. Sustainability of rainwater harvesting systems in rural catchment of sub-Saharan Africa. *Water Resources Management*. online, DOI 10.1007/s11269-009-9411-8.

J.S. Pachpute. 2009 A package of water management practices for sustainable growth and improved production of vegetable crop in labour and water scarce Sub-Saharan Africa. Under review by *International Journal of Agricultural Water Management* after revised resubmission

Project 6: **Agent-based modelling for collaborative catchment water management in the Pangani river basin, Tanzania**
Researcher: Hans C. Komakech
Institute: UNESCO-IHE Institute for Water Education
Supervisor(s): prof. dr. ir. Pieter van der Zaag, Dr. Ir. Andreja Jonoski;
 Dr. Barbara van Koppen
Starting date: 1st January 2007
End date: 2011

ORIGINAL OBJECTIVES

Many developing countries are searching for appropriate management models that would enable equitable and sustainable water resources management in water stressed basins. Regrettably, these new institutions are of little relevance to the day to day challenges faced by most the users and often distorts the solidarity based water sharing reality constructed by users over a long period of time (e.g. turn taking, access/property right and sanction mechanism). Moreover such solidarity based approaches, if well understood, could be a substitute for, or used to improve catchment wide structures for water resources management. This research proposes to address the possibility of up-scaling local level solidarity based water institutions in order to improve river basin management. It explores the concept of local level hydrosolidarity reported by many scholars and attempt to establish the necessary conditions for up-scaling it.

The objective of the research is threefold: First, to understand the existing institutional landscape in a selected catchment: this will provide insight into the interface between local and government-led water management norms and practices. Second, to understand how solidarity based institutions operate in practice. In other words understanding the mechanisms that drive cooperation at the local level (e.g. turn taking in villages – between farmers sharing a furrow, between two furrows, between distant villages and within a catchment). Third, develop modelling tools for considering alternative scenarios for catchment or river basin management. Fourth, confront new knowledge with the formal institutional arrangements so as to deepen theory on how water institutions work in practice.

ABSTRACT OF RESEARCH

As the pressure on the water resources mount within a river basin, institutional innovation may come into place not as a result of a planned sequence of adjustments, but arising out of the interplay of several factors. The increasing pressure on the Pangani River basin water resources requires judicious institutional arrangements at increasingly larger spatial scales. Local level institutions that have evolved over time interface with national policies and basin-wide institutions established more recently. Attempts from the Pangani Basin Water Office to link up with local level institutions have so far proven problematic due to lack of a common understanding of key concepts. Unless institutions at both the basin and local levels attempt to understand each other's realities, no effective linkages can be established and coordinated water management will not be possible.

This abstract draws from the results of ongoing research in the Pangani river basin, Tanzania. The research seeks to understand and describes the development of water-sharing practices between neighbouring villages and furrows and how it is being sustained. Using actor-network theory, the dynamics of these local arrangements is being analysed. Our approach is to follow the water through its flow path from up to downstream and thus the actors. This is being complemented by an in-depth description of: water use development in the basin from a historical perspective; the attempts to establish “paper” water rights of furrow systems and the levying of water users; and interventions that aim at increasing the water use efficiency.

Indicative findings includes: what appears to be a willingness to forego short-term benefits for long-term benefits may also be interpreted as resulting from power struggles. Local water sharing practices are a relational effect of heterogeneous materials networked together dynamically, rather than originating from solidarity. Thus, the analysis reveals the complex nature of water networks in a catchment. At this stage in the project, attempt is being made to develop an agent based model of catchment water use system. The model once completed will be used as an exploratory and explanatory tool.

KEY PUBLICATIONS

Hans Komakech, Barbara van Koppen, Jeltsje Kemerink, Henry Mahoo & Pieter van der Zaag (2009). Pangani river basin over time and space: How to bridge local and basin realities (Submitted to Agricultural Water Management Journal)

Hans Charles Komakech, Marloes Mul, Pieter van der Zaag and Filbert B.R. Rwehumbiza (2009). Potential of spate irrigation in improving rural livelihoods: case of Makanya spate irrigation system, Tanzania (Submitted to Agricultural Water Management Journal)

Hans Charles Komakech, Pieter van der Zaag, Andreja Jonoski and Barbara van Koppen (2008). Can actor-network theory help to understand water-sharing practices in Makanya catchment, Tanzania? Paper presented at WaterNet conference in Johannesburg, South Africa October 29 – 31, 2008

Project 6B Understanding the development of water sharing arrangements in legal plural settings in Sub-Saharan Africa

Researcher: J.S. Kemerink
Institute: UNESCO-IHE Institute for Water Education
Supervisor(s): Prof. Dr. Ir. P. van der Zaag, Dr.Ir. R. Ahlers
Starting date: 1st April 2007
PhD defence: scheduled for end 2011

ORIGINAL OBJECTIVES

The initial research focus is on the driving forces behind the (un)willingness of water users to share water with downstream users and to understand how access to and control over water is negotiated. The research looks at the biophysical, social and economic dependencies between water users and how this is related to the power dynamics that influences the local negotiations over water. The plural legal context of post-colonial societies is taken into account and the impact of historical developments and external interventions on the sharing of water between various (groups of) water users will be analysed.

ABSTRACT OF RESEARCH

Within the Pare culture natural resources are sacred and cannot be owned by human beings. Therefore traditionally it is believed that people living in the catchment should have equal access to water and conflicts over water should be solved through mutual agreements. This implies an ethical base for the development of water sharing arrangements. However, often other behavior is observed in the water sharing practice. In the past it was the chief who distributed natural resources between the people and priority rights for certain groups were common. Nowadays water distribution in the case-study area is the responsibility of democratically elected village governments and under their authority water allocation committees have been established. Nevertheless, as described in the research, not all negotiation processes have (yet) led to mutual agreements nor do all agreements represent equal access to water for the different (groups of) water users. As such it can be concluded that hydro-solidarity might play a role in the ideological view on water resources management between the smallholder farmers, however, it has little influence on the actual water sharing within the plural legality.

As described in the research nowadays various normative orders influence the negotiation over water in the Makanya catchment. The legal conditions have become more plural over time as more layers of normative orders have added to the legal spectrum. This has resulted in a current governance structure that is influenced by historical eras such as African traditionalism, colonialism, socialism, democracy and capitalism. This plurality has created more balance in power as the legitimacy of authority of the clans has been reduced and the authority of other groups has gained more legitimacy. However, the legal plural conditions have not made the prospect of access to and control over water equal for all water users. Water users actively utilize the various normative orders that legitimize their claims and therefore serve their interests, so-called forum-shopping (von Benda-Beckmann, 1981; Meinzen-Dick and

Pradhan, 2005). However, at the same time it is the leverage position of the water users that defines to which extent they can influence the social meaning of rights and therefore the legitimacy given by the community to the various normative orders. Advantaged (groups of) water users can therefore easier utilize their authority and influence the outcomes of the negotiations over water than less advantaged groups. The paper illustrates that the level in which water users are advantaged or disadvantaged is shaped by historical markers (e.g. tradition, beliefs), biophysical conditions of the farming land (e.g. location, soil) and socio-economic background of the water user. One important factor in the socio-economic background is the level of connectivity to other water users as claims on water are exerted through the social networks of the water users.

From the analysis above it can be concluded that ethical dimensions in decision making based on commonly accepted norms and rules do exist and potentially can be strengthened. However, in the complex reality of the legal plural conditions it is unlikely that they will gain sufficient legitimacy to become the dominant socially accepted norms if introduced as universal normative order. Asymmetrical distribution of power is an intrinsic part of every society and well-established water users will actively resist to changes in water distribution except if it is an obvious win-win situation. Unless this is recognized within the hydro-solidarity concept, it risks staying a theoretical concept or at most becoming (yet) another normative layer added to the legal plurality in which water resources are managed. Therefore we argue that, instead of searching for a universal normative order, the hydro-solidarity concept should embrace the plural legal reality by incorporating the dynamic and context-specific conditions of water use. Legal plural analysis can serve as framework to identify the context-specific ethical dimensions in each of the normative orders that influence the negotiations over water. These dimensions can be different for the various normative orders. In this way hydro-solidarity can be strengthened from within each normative order respecting its legitimacy and acknowledging the water users using the normative order to claim their rights. Potentially this will lead to a more realistic mechanism to reconcile conflicts over water.

KEY PUBLICATIONS

- Kemerink, J.S., R. Ahlers, P. van der Zaag (2007) Driving forces behind the development of water sharing arrangements in traditional irrigation systems in northern Tanzania, Proceedings of 8th WaterNet/WARFSA/GWP-SA symposium, November 2007, Lusaka, Zambia.
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- Kemerink, J.S., R. Ahlers, P. van der Zaag (2009) Contested water rights in post-Apartheid South Africa: the struggle for water at catchment level. Proceedings of 10th WaterNet/WARFSA/GWP-SA symposium, October 2009, Entebbe, Uganda.
- Mul, M.L., J.S. Kemerink, N.F. Vyagusa, M.G. Mshana, P. van der Zaag, H. Makurira (*submitted*) Water allocation practices among smallholder farmers in the South Pare Mountains, Tanzania; can they be up-scaled?, *submitted to Agricultural Water Management*.

Annexure 2 Research Papers

Journal papers (21)

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Submitted to Agricultural Water Management (special SSI issue)

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- Dlamini, Orchard, Jewitt, Lorentz, Titshall, Chaplot., **Quantifying interrill erosion in a sloping-land-agricultural catchment of KwaZulu Natal, South Africa.**
- Enfors, E., Baron, J., Makurira, H., Rockstrom, J., and Tumbo, S.. **Yield and soil system changes from conservation tillage in dryland farming: a case study from North Eastern Tanzania.**
- Komakech, C.H., Mul, M.L., van der Zaag, P., Rwehumbiza, F.B.R.. **Potential of spate irrigation in improving rural livelihoods: case of Makanya spate-irrigation system, Tanzania.**
- Komakech, C.H., van der Zaag, P., van Koppen, B. **Pangani river basin over time and space: how to bridge local and basin realities?**
- Kongo, V.M., Jewitt, G.P.W. **Evaporative water use of different land uses in the Thukela river basin assessed by satellite imagery.**
- Kosgei, J.R., Jewitt, G.P.W. **Food production and household income among smallholder rainfed farmers: do biophysical and policy interventions have a common role in arid and semi-arid lands?**
- Makurira, H., Savenije, H.H.G., Uhlenbrook, S., Rockstrom, J., Senzanje, A.. **The effect of improved on-farm techniques on maize yield and water productivity in sub-Saharan rainfed agricultural systems.**
- Mul, M.L., Kemerink, J.S., van der Zaag, P., Vyagusa, N.F., Mshana, G. and Makurira, H.. **Water allocation practices among smallholder farmers in South Pare Mountains, Tanzania; The issue of scales.**
- Tumbo, S.D., Mutabazi, K.D., Byakugila, M.M., Mahoo, H.F. **An empirical framework for scaling-out of water system innovations: lessons from diffusion of terraces in the Makanya watershed in northern Tanzania.**

Working Paper series (4)

- Bhatt, Y., Bossio, D., Enfors, E., Gordon, L., Kongo, V., Kosgei, J.R., Makurira, H., Masuki, K., Mul, M., Tumbo, S.D., 2006. **Smallholder system innovations in integrated watershed management (SSI): Strategies of water for food and environmental security in drought-prone tropical and subtropical agro-ecosystems.** Colombo, Sri Lanka: International Water Management Institute 59p. (IWMI Working Paper 109; SSI Working paper 1).
- Kongo, V. M.; Jewitt, G. P. W.; Lorentz, S. A. 2007. **Establishing a catchment monitoring network through a participatory approach: A case study from the Potshini catchment in the Thukela river basin, South Africa.** Colombo, Sri Lanka : International Water Management Institute. 66pp. (IWMI Working Paper 120; SSI Working paper 2).
- Mutiibwa, R.K., Mul, M.L., Foppen, J.W.A., Uhlenbrook, S., Savenije, H.H.G., 2008. **Surface water/groundwater systems analysis in the semi-arid South Pare**

Mountains, Tanzania. Water Mill working paper 7. UNESCO-IHE, Delft, the Netherlands.

Mutiibwa, R.K. ; Mul, M.L. ; Foppen, J.W.A. ; Uhlenbrook, S. ; Savenije, H.H.G., 2008. **Tracking groundwater flow systems using geological mapping and chemical spring analysis in South Pare Mountains, Tanzania.** Water Mill working paper 2. UNESCO-IHE, Delft, the Netherlands.

Reports (15)

Salomon, M. and V. Sithole, 2005. **Participatory Action Research Training Report- Session 1**, 17 December 2004, Pietermaritzberg, South Africa. Farmer Support Group, South Africa

Salomon, M., 2005. **Participatory Action Research Training Report- Session 2**, 11-14 March 2005, Moshi Tanzania. Farmer support Group, South Africa

van Doremaele, K.J.A., van Houwelingen, A.W., Schipper, P.P. and van Vugt, E.A. 2007. **Charco dams, research on evaporation.** 4th year project report Delft University of Technology. Supervisor H.H.G. Savenije

UNESCO-IHE and IWMI, 2004. **Status report, WOTRO support research programme.** May- September 2003.

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UNESCO-IHE and IWMI, 2008. **SSI Annual Progress Report Number 5**, 1st Jan -31st December 2007.

UNESCO-IHE and IWMI, 2009. **SSI Annual Progress Report Number 6**, 1st Jan -31st December 2008.

UNESCO-IHE and IWMI, 2004. **SSI 1st Scientific workshop report** 19-23 December 2003, Moshi, Pangani River Basin.

UNESCO-IHE and IWMI, 2006. **SSI 3rd Scientific workshop report "Integration"**. 23-27 January 2006, Same, Pangani River Basin.

UNESCO-IHE and IWMI, 2007. **SSI 4th Scientific workshop report.** 19-24 January 2007, Didima Camp, Thukela River Basin.

UNESCO-IHE and IWMI, 2008. **SSI 5th Scientific workshop report "Synthesis"**. 20-25 January 2008, Elephant hotel, Pangani River Basin.

Voogt, M.P., 2005. **Hydrological history of the Makanya River, changes in stream profile examined**. Practical work report Delft University of Technology. Supervisors; M.L. Mul, W.M.J. Luxemburg.

Policy Brief (2)

IWMI, 2005. **Smallholder System Innovations (SSI) in Integrated Watershed Management**. SSI-Facts sheet. <http://www.unesco-ihc.org/content/download/2849/29703/file/SSI-%20Facts%20Sheet-2004.doc>

IWMI, 2007. **Smallholder System Innovations (SSI) in Integrated Watershed Management: Science for decision makers**. SSI Policy Brief No.1. www.iwmi.cgiar.org/Publications/Other/PDF/SSI_Brief.pdf

Annexure 3 Theses

PhD theses (4)

Enfors, E.I., 2009. **Traps and Transformations, exploring the potential of water system innovation in dryland sub-Saharan Africa.** PhD thesis, Stockholm University. ISBN 978-91-7155-863-3, pp 56.

Kongo, V.M., 2008. **Balancing water for food and environment: Hydrological determinants across scales in the Thukela river basin-South Africa.** PhD thesis, University of KwaZulu-Natal.

Kosgei, J.R., 2009. **Rainwater harvesting systems and their influences on field-scale soil hydraulic properties, water fluxes and crop production.** PhD thesis, University of KwaZulu-Natal.

Mul, M.L., 2009. **Understanding Hydrological processes in an ungauged catchment in sub-Saharan Africa.** PhD thesis, UNESCO-IHE. ISBN 978-0-415-54956-1, pp 130.

Post-Doc report (1)

Tumbo, S.D., 2007. **Investigation and development of framework for diffusion of water system innovations at community level.** Post-Doc report Sokoine University of Agriculture. 96 pages.

Licentiate thesis (1)

Enfors, E.I., 2007. **Traps and Transformation: Water System Innovations in Dryland Environments.** Licentiate in Philosophy Thesis 2007:1, in Natural Resources Management. Department of Systems Ecology, Stockholm University

MSc Theses (19)

Ågerstrand, M., 2006. **Ecological risk assessment of pesticide use among small-scale farmers in a semi-arid tropical agro-ecosystem.** Degree Thesis in Ecotoxicology, Department of Systems Ecology, Stockholm University, May 2006. Supervisor: E. Enfors.

Albinsson, Y., 2007. **Water use efficiency at field scale – Effects of conservation management in an agro ecosystem in Tanzania.** Degree thesis in environmental science. Department of Ecology, Lund University. Supervisors: E. Enfors, J. Ardö.

Blanck, J., 2008. **Managing for regulating ecosystem services in the Upper Thukela region, South Africa.** MSc thesis, Stockholm University, Sweden. Supervisor: L. Gordon.

Brandt, M., 2006. **Pesticide use & livelihood security among smallholder farmers in semi-arid sub-Saharan Africa.** A knowledge, attitudes & practice study in Bangalala village, Tanzania. Degree Thesis in Ecotoxicology, Department of Systems Ecology, Stockholm University. Supervisor: E. Enfors.

- Bohté, R., 2008. **Hydrograph separation using hydrochemical and isotope tracers in a semi-arid catchment: a case study in Makanya, Tanzania.** MSc thesis, Delft University of Technology. Supervisors: M.L. Mul, T.A. Bogaard.
- De Winnaar, G 2009. **Tools to assess the ecohydrological impacts of water system innovations.** MSc thesis. University of KwaZulu-Natal. Supervisor: GPW Jewitt.
- Engdahl, A., 2005. **Intensification and diversity in semi-arid agro-ecosystem: a case study of Bangalala village, Tanzania.** MSc thesis, Stockholm University, Sweden. Supervisor: L. Gordon.
- Fischer, B.M.C., 2008. **Spatial variability of dry spells. A spatial and temporal rainfall analysis of the Pangani Basin and Makanya catchment, Tanzania.** MSc thesis, Delft University of Technology, the Netherlands. Supervisors: M.L. Mul, H.C. Winsemius.
- Gerenstein, T., 2005. **Potential for adaptive management in a smallholder semi arid landscape -revealing large differences over a small geographic area.** MSc thesis, Stockholm University, Sweden. Supervisor: L. Gordon.
- Gordijn, F., 2005. **Learning across scales: a case study on learning and knowledge sharing to up-scale small holder systems innovations in integrated watershed management in sub-Saharan Africa.** MSc Thesis, Wageningen University, The Netherlands. Supervisor: B. Bruins, J. Woodhill, Y. Bhatt and H. Sally.
- Hållén, C., 2007. **Effects of conservation management on soil microbiology in a Tanzanian agro-ecosystem.** Degree thesis in environmental science. Department of Ecology, Lund University. Supervisors: E Enfors, H. Wallander, and E Bååth.
- Hendriksson, J., 2005. **Mapping small-holder farmers use of ecosystem goods in Potsheni, Thukela Drainage basin, South Africa. Focus on times of Crop failure.** MSc thesis, Stockholm University, Sweden. Supervisor: Line Gordon.
- Mihayo, D.G., 2008. **Adaptive adoption of rainwater storage systems by farmers: A case of Makanya ward in Same district.** MSc in Agricultural Economics. Sokoine University of Agriculture, Morogoro, Tanzania. Supervisors: E.M. Senkondo and S.D. Tumbo.
- Mutiro, J., 2005. **Water Productivity Analysis for Smallholder rainfed systems. A case study of Makanya catchment, Tanzania.** MSc. Thesis. Department of Civil Engineering, University of Zimbabwe, Zimbabwe. Supervisor: H. Makurira and Co-Supervisors: A. Senzanje and M.L. Mul.
- Mshana, G.M., 2005. **Institutional set-up for smallholder farmers in IWRM, a case-study of ndiva ya Manoo in Makanya catchment, Tanzania.** MSc. Thesis. Department of Civil Engineering Faculty of Engineering, University of Zimbabwe, Zimbabwe. Supervisors: Makurira, H. and M.L. Mul.
- Mutiibwa, R.K., 2006. **Groundwater flow systems in the Makanya catchment, Tanzania.** MSc. Thesis. UNESCO-IHE Institute for Water Education Supervisors: M.L. Mul, J.W. Foppen and S. Uhlenbrook.

- Salehe, H. M., 2007. **Effects of tenure arrangements, assets and capital endowments on adoption of charco dams at farm level in Makanya village, Same district.** MSc Thesis. Department of Agricultural Education and Extension, University of Agriculture, Morogoro, Tanzania. Supervisors: A.Z. Mattee and H. Mahoo.
- Sturdy, JD 2008. **Understanding agricultural innovation adoption processes and garden scale water use through farmer-driven experimentation.** MSc thesis. University of KwaZulu-Natal. Supervisors: GPW Jewitt and SA Lorentz.
- Vyagusa, N. F., 2005. **Water allocation Practices for Smallholder Farmers in South Pare Mountains, Tanzania; a case study of manoo micro-dam (ndiva).** MSc. Thesis. Department of Civil Engineering Faculty of Engineering, University of Zimbabwe, Zimbabwe. Supervisors: M.L. Mul and H. Makurira.

Annexure 4 Human capacity building

A list of all those who benefitted from the human capacity building component of the SSI Programme is given below.

Post-doctoral (PD) researchers

Name	Institution	Country	Period	Sponsor	Status	Title
Dr. Siza Tumbo	Sokoine University of Agriculture	Tanzania	2004-2006	DGIS/ WOTRO	Finished	Investigation and development of framework for diffusion of water system innovations at community level
Dr. Line Gordon	Stockholm University	Sweden	2004-2006	Sida	Completed	Analyzing resilience and ecosystem services and their contribution to rural livelihoods
Dr. Jennie Barron	SEI/ York University	Sweden	2007-2009	SEI	Ongoing	
Dr. Jayashree Pachpute	IWMI	India	2007-2008	SEI	Completed	Spatial planning and mapping of water system innovations and assessment of their hydrological impact

PhD researchers

Name	Institution	Country	Period	Sponsor	Status	Title
Kenneth Masuki	Sokoine University of Agriculture	Tanzania	2004-2007	WOTRO-Sida	Ongoing	Dynamics of Farm-Level Adoption of Water System Innovations in Semi-Arid Areas: The Case of Makanya Watershed in Same District, Tanzania
Khumbu Zuma	UKZN	South Africa	2004	Sida	Resigned	
Hodson Makurira	UNESCO-IHE	Zimbabwe	2004-2009	Sida/ DGIS	Finalising	Water productivity in rainfed agriculture

Name	Institution	Country	Period	Sponsor	Status	Title
Job Rotich	UKZN	Kenya	2005-2008	Sida	Graduated April 2009	Rainwater harvesting systems and their influences on field-scale soil hydraulic properties, water fluxes and crop production.
Elin Enfors	Stockholm University	Sweden	2004-2009	Sida	Graduated May 2009	Building resilience and intensifying farming: the potential of small-scale water system innovations in semi-arid agro-ecosystems
Marloes Mul	UNESCO-IHE	Netherlands	2004-2009	WOTRO/Sida	Graduated February 2009	Understanding Hydrological processes in an ungauged catchment in sub-Saharan Africa
Victor Kongo	UKZN	Kenya	2004-2008	Sida	Graduated April 2009	Balancing water for food and environment: Hydrological determinants across scales in the Thukela river basin-South Africa
Jeniffer Kinoti	UNESCO-IHE/ IWMI	Kenya	2004-2005	UNESCO-IHE/ IWMI	Resigned	
Claudious Chikozho	UNESCO-IHE/ IWMI	Zimbabwe	2004-2005	UNESCO-IHE/ IWMI	Resigned	
Hans Komakech	UNESCO-IHE/ IWMI	Uganda	2007-2010	UNESCO-IHE/ IWMI	On-going	Agent-based modelling for collaborative catchment water management in the Pangani river basin, Tanzania
Jeltsje Kemerink	UNESCO-IHE	Netherlands	2007-2012	UNESCO-IHE/ DGIS	On-going	Understanding the development of water sharing arrangements in legal plural settings in Sub-Saharan Africa

MSc researchers

Name	Department	University	Year	Sponsor	Supervisor	Title
Ågerstrand, M.	Systems ecology	Stockholm University	2006		Enfors	Ecological risk assessment of pesticide use among small-scale farmers in a semi-arid tropical agro-ecosystem

Name	Department	University	Year	Sponsor	Supervisor	Title
Albinsson, Y.	Ecology	Lund University	2007		Enfors	Water use efficiency at field scale – Effects of conservation management in an agro ecosystem in Tanzania.
Blanck, J.		Stockholm University	2008		Gordon	Managing for regulating ecosystem services in the Upper Thukela region, South Africa
Bohté, R.	Civil Engineering	TU Delft	2008	Lamminga / section hydrology TU Delft	Mul	Hydrograph separation using hydrochemical and isotope tracers in a semi-arid catchment: a case study in Makanya, Tanzania
Brandt, M.	Systems ecology	Stockholm University	2006		Enfors	Pesticide use & livelihood security among smallholder farmers in semi-arid sub-Saharan Africa.
De Winnaar, G.	BEEH	UKZN	2007		Jewitt	Identification of potential runoff harvesting areas using GIS
Engdahl, A.	Systems ecology	Stockholm University	2005		Gordon	Intensification and diversity in semi-arid agro-ecosystem: a case study of Bangalala village, Tanzania
Fischer, B.M.C.	Civil Engineering	TU Delft	2008	OA	Mul	Spatial variability of dry spells. A spatial and temporal rainfall analysis of the Pangani Basin and Makanya catchment, Tanzania
Gerenstein, T.	Systems ecology	Stockholm University	2005		Gordon	Potential for adaptive management in a smallholder semi arid landscape -revealing large differences over a small geographic area.
Gordijn, F.		Wageningen University	2005		Bhatt	Learning across scales: a case study on learning and knowledge sharing to up-scale small holder systems innovations in integrated watershed management in sub-Saharan Africa
Hällén, C.	Ecology	Lund University	2007		Enfors	Effects of conservation management on soil microbiology in a Tanzanian agro-ecosystem.

Name	Department	University	Year	Sponsor	Supervisor	Title
Hendriksson, J.		Stockholm University	2005		Gordon	Mapping small-holder farmers use of ecosystem goods in Potsheni, Thukela Drainage basin, South Africa. Focus on times of Crop failure
Kessler, T.	Hydrology and geohydrology	Stuttgart University	2008	Erasmus	Mul	Investigation of runoff generation responses in steep, semi-arid headwater catchments, South Pare Mountains, Tanzania
Mihayo, D.G.	Agricultural Economics	Sokoine University of Agriculture	2008		Tumbo	Adaptive adoption of rainwater storage systems by farmers: A case of Makanya ward in Same district.
Mutiro, J.	Civil Engineering	University of Zimbabwe	2005	WaterNet	Makurira	Water Productivity Analysis for Smallholder rainfed systems. A case study of Makanya catchment, Tanzania.
Mshana, G.M.	Civil Engineering	University of Zimbabwe	2005	WaterNet	Makurira	Institutional set-up for smallholder farmers in IWRM, a case-study of ndiva ya Manoo in Makanya catchment, Tanzania.
Mutiibwa, R.K.	Hydrology	UNESCO-IHE	2006	WaterMill/DGIS	Mul	Groundwater flow systems in the Makanya catchment, Tanzania.
Salehe, H. M.	Agricultural Education and Extension	Sokoine University of Agriculture	2007		Mahoo	Effects of tenure arrangements, assets and capital endowments on adoption of charco dams at farm level in Makanya village, Same district.
Sturdy, J.	BEEH	UKZN	2007	Rotary	Jewitt	Building an understanding of water use innovation adoption processes through farmer-driven experimentation.
Vyagusa, N. F.	Civil Engineering	University of Zimbabwe	2005	WaterNet	Mul	Water allocation Practices for Smallholder Farmers in South Pare Mountains, Tanzania; a case study of manoo micro-dam (ndiva).
Carlson, T.	Systems ecology	Stockholm University	2007		Gordon	Bundles of ecosystem services across different land-uses in Emmaus Catchment, Kwa-Zulu Natal

Student projects

Name	Institution	Period	Sponsor	Supervisor	Title
Voogt, M.P.	TU Delft	2005	OA	Mul	Hydrological history of the Makanya River, changes in stream profile examined
Faber, O.	Freiburg University	2006	OA	Mul	Development of TAC ^D for the Makanya catchment
van Doremaele, K.J.A., van Houwelingen, A.W., Schipper, P.P., van Vugt, E.A.	TU Delft	2006	OA	Mul	Charco dams, research on evaporation

Research assistants and Outreach facilitators

Name	Task	Period	Location
Monique Salomon	Outreach	2004-2006	South Africa
Maxwell Mudhara	Outreach	2007-2008	South Africa
Vuzimuzi Sithole	Outreach	2004-2005	South Africa
Sizabele	Outreach	2005-2006	South Africa
Michael Malinga	Outreach	2007-2008	South Africa
Istamil Msangi	Research assistant project 2 and 4	2004-2006	Tanzania
Omari Mhina	Outreach	2005-2007	Tanzania
Maliki Abdallah	Research assistant project 2 and 4	2007-2008	Tanzania
Kapombe	Research assistant project 3	2004-2008	Tanzania
Gevaronge Myombe	Outreach & research assistant project 1	2007-2008	Tanzania