WORKING PAPER 109

SSI Working Paper 1

Smallholder System Innovations in Integrated Watershed Management (SSI)

Strategies of Water for Food and Environmental Security in Drought-Prone Tropical and Subtropical Agro-Ecosystems

Yogesh Bhatt, Deborah Bossio, Elin Enfors, Line Gordon,
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IWMI
International
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Summary

Rapidly increasing population in the dynamic semi-arid agro-ecosystems in sub-Saharan Africa (SSA) highlights the necessity to increase food production, while at the same time safe-guarding other ecological systems that support human development and well-being. In the past, increases in crop production to keep pace with population growth in this region were largely achieved through the expansion of cultivated area. Today, we must also consider ways of improving the productivity of already existing cropping systems.

To address the challenges of increasing food production and improving rural livelihoods, while safeguarding other critical ecological functions, a research program “Smallholder System Innovations in Integrated Watershed Management” (SSI) was launched in early 2003. The program takes an integrated approach to agricultural water management: analyzing the interactions between the adoption and adaptation of water system innovations (such as water harvesting, drip irrigation, conservation farming, etc.) in a participatory manner, increased water use in agriculture and water flows, to sustain ecological functions that deliver critical ecosystem services to humans. The research within SSI is carried out in the Pangani Basin in Tanzania and the Thukela Basin in South Africa. A nested scale approach is adopted, which enables the analysis of scale interactions between water management at the farm level, and cascading hydrological impacts at watershed and basin scale. The program aims to produce high-level science while also contributing to development on the ground.

This working paper frames the critical questions that must be addressed through development-oriented research and describes the integrated research approach of the SSI program, its interconnected research projects - their scope and methodologies.

THE CHALLENGES

Increasing pressure on water resources for food production

The dominant water resources management challenge in the coming generations will be how to secure water to cover food demands of a rapidly expanding world population, while at the same time sustaining other critical ecological functions in regions with highly unreliable and scarce water resources.

This applies especially to developing countries where 95% of the world's population growth occurs, and most particularly to Sub-Saharan Africa, hosting the largest proportion of water scarcity-prone areas as well as the highest levels of malnutrition (Rockstrom et al. 2003). The preconditions to sustainable livelihood improvements are dynamic. The world is continuously experiencing socio–ecological changes (vander Leeuw 2000; McIntosh et al. 2000) that can alter the capacity of ecosystems to generate goods (including food) and services on which society depends (Daily 1997). Furthermore, it is becoming increasingly clear that diverting more water for agriculture may have serious implications for other water users and water using activities and systems. As shown by Conway (1997) no less than a new green–Green Revolution is required, which not only (at least) doubles food production, particularly, among resource poor rural societies hosted in ecologically vulnerable landscapes, but also achieves large production increases in agriculture without compromising essential ecological functions.

Compared to the previous Green Revolution, which in the 1950s and 60s lifted large parts of Asia and Latin America from imminent risks of large scale food deficits, the challenges at present are even more daunting. Food production has to increase as fast or faster than the first Green Revolution, and this time the production increase has to occur among poor farming communities often depending on highly unreliable crop water supply (generally rainfall in semi-arid and dry sub-humid savanna agro-ecosystems is very variable) (Falkenmark and Rockstrom 2004). As shown by Rockstrom (2003,) present food production requires some 7000km^3/yr of consumptive freshwater (of which 1800km^3/yr originates from blue water use—i.e., runoff water—in irrigation and the remaining 5200 km^3/yr from direct green water use in rainfed agriculture). Two hot-spot regions of the world emerge, in terms of water needs for food and livelihoods, namely sub-Saharan Africa (SSA) and Asia. For sub-Saharan Africa indications suggest a tripling of agricultural water demand by 2025, and an almost five-fold increase by 2050 (Falkenmark and Rockstrom 2004).

Growth of food production in sub-Saharan Africa has during the last decades primarily been achieved through expansion of agricultural land and an increase in water use. Land degradation and desiccation have in many areas resulted in diminishing crop yields, with average yields oscillating in the range of one ton of grain per hectare. Furthermore, 95% of the agricultural land use in sub-Saharan Africa is rainfed agriculture. Conventionally, the focus of attention for water management has been on blue water (river, lake or groundwater flow used for irrigation, industry and domestic uses), but the predominance of rainfed agriculture necessitates a shift in focus towards direct use of productive green water.

'One-ton-agriculture' in sub-Saharan Africa

It is becoming increasingly clear that smallholder farming systems in SSA are in a transient evolutionary stage, today, characterized in large by an agrarian crisis.

Only a century ago (and in some parts even today), land productivity was sustained through shifting cultivation practices dependent on highly extensive farming practices. The population-driven abandonment of this strategy for soil fertility recycling and soil and water productivity maintenance (long fallows) has not been compensated for by the introduction of a new management strategy, particularly to sustain soil fertility and soil structure (a key for soil water availability and water holding capacity). Fertiliser use in sub-Saharan Africa is on average below 10 kg/ha (FAO 2002) and studies in Eastern and Southern Africa show that the farming systems suffer from extensive nutrient mining. The farming systems have dropped down to a new, lower agro-ecological climax, adapted to the “new” situation of extremely low soil fertility and low organic matter contents, resulting in a “one-ton-agriculture”. As shown, by Rockstrom and Falkenmark (2000), there seems to be no hydrological limitations, even in semi-arid regions, to attain a maximum climax 5–10 times higher than the yields experienced at present (0.5–1 ton/ha yields). The adoption of plough tillage practices which have a highly detrimental effect on soil structure and fertility in tropical soils has further speeded up the process towards extremely low on-farm yields. The result is a dramatic loss of ecological resilience, related both to quick biophysical cycles, manifested as low levels of soil moisture available to plants, and slow cycles related to soil biology, soil crusting and plant cover.

Over the last 50-70 years many efforts have been made by farmers, extension workers, researchers and donor agencies to address this agrarian crisis. All ingredients of the industrial farming systems (fertilisers, mechanization, and pesticides) have been promoted. This has been done together with “old” indigenous elements in “new” disguise, such as improved manure management, stalled livestock in zero grazing systems, composting, green manures, and short fallows.

Today, as opposed to twenty years ago, there is a firm understanding that technology transfer of temperate zone successes alone will not work. Instead, tailor made, site-specific adaptations, building on indigenous knowledge are required. But the magnitude of the agrarian crisis is so large that development and refinement of indigenous knowledge alone will not be enough. Instead, innovations—often alien innovations that go through a participatory process of local adaptation—are required in all fields of land-use management such as the handling of crop choice, of water, soil, livestock, and forests. Small-holder System Innovations in agricultural water management are important cornerstones in sustainable agricultural development—not in isolation—but as an integral part of a participatory development process, following, the approaches to innovations in land management experienced by the Regional Land Management Unit (RELMA) of Sida in East Africa (RELMA 2002), and the recent developments of the national catchment approach in Kenya (Lundgren 1993).

The Adoption Dilemma

Water system innovations are still predominantly found as small islands of success.

There is ample evidence to show that rainfed agriculture in water scarcity-prone tropical savannah environments, at present, is carried out below its realistically achievable potential. Moreover, it is becoming increasingly clear that water *per se* is not necessarily the limitation, but rather it is the lack of management strategies available to the farmer in order to mitigate periods of dry spells and droughts, caused by the high variability of rainfall over time and in space.

There is furthermore a very rich knowledge base of promising water management innovations systems for rainfed agriculture, including a broad spectrum of water-harvesting practices, conservation farming systems, water conservation techniques, integrated soil fertility management, and response farming**.** These have often been developed from indigenous knowledge in one location, but when transferred to neighboring communities (even in the same country), constitute innovations in water management. Other systems are completely new to a region or community, e.g., watershed management practices from semi-arid watersheds in India, introduced in sub-Saharan Africa. All these form part of water system innovations, which aim at improving rainfall productivity and reducing risk for crop failure due to poor distribution of rainfall. They can never be adopted as blanket solutions, but need to go through a process of adaptive adoption, which include moulding them to local bio-physical and socio-cultural conditions. Furthermore, water system innovations need to be addressed in an integrated fashion. Water is generally not the only limiting factor for agricultural productivity improvements, but generally forms the logical entry point for upgrading. Soil fertility, tillage, timing of operations, labor use, pest management, livestock interactions, land ownership and watershed stewardship, are other aspects that interact with the introduction of water system innovations in complex ways. These need to be addressed in conjunction with water management.

The frustration at present is that we know quite well what these water innovations are, and what they can do. We also have the tools to carry out adaptive adoption. However, water system innovations still are predominantely found only as small islands of success within isolated development projects. Very little is known about the actual reasons for non-adoption at larger scales, and the preconditions that need to be in place to enable adoption.

Furthermore, very little is known about the consequences of large-scale adoption of water innovations to downstream water-dependent ecosystems and human communities. Understanding downstream and larger scale impacts is fundamental to successful out-scaling if inequities, conflict and resource degradation are to be avoided.

THE SSI PROGRAM

In response to these challenges, in July 2003, WOTRO, the Dutch funding organization for research in tropical regions residing under NWO (the Netherlands organization for scientific research), the Development Agencies of Sweden (Sida) and the Netherlands (DGIS), the International Water Management Institute (IWMI) and UNESCO-IHE Institute for Water Education, supported the launch of an integrated and applied research program on how to balance water for food and nature (Smallholder System Innovations in Integrated Watershed Management (SSI)). Recently, the Stockholm Environment Institute (SEI) has joined in supporting the project. Particular focus in this program is given to research on opportunities to upgrade smallholder rainfed agriculture through water system innovations, while securing water to sustain critical ecological functions, in vulnerable semi-arid tropical and sub-tropical river basins.

Partners in the project include the above institutions as well as the Sokoine University of Agriculture (SUA) in Tanzania, the University of KwaZulu-Natal in South Africa, and two field-based organizations, the Farmer Support Group (FSG), a South African development organization based at the University of KwaZulu-Natal and a designated SADC centre of excellence, and the Soil-Water Management Research Group (SWMRG), based at the Sokoine University of Agriculture.

This working paper outlines the rationale for a new approach to integrated water resource management from the local field scale to the watershed and basin scale, which incorporates the balancing of green and blue water flows in agriculture with freshwater, to sustain ecosystems and downstream human use of water, and describes the scope of the SSI program, in Tanzania and South Africa.

A widened eco-hydrological freshwater approach in IWRM

There is a growing realization that the conventional approach to water resource management, which considers accessible blue water flow as the only freshwater involved in societal development, needs to be widened to involve functions of both green and blue water flows.

Irrigated agriculture will have to play an important role in contributing to the increase in food production required to keep pace with population growth and eradicate malnourishment in SSA. Similarly, virtual water, through increase in food trade, will certainly continue to fill a part of the increased demand for food. Despite these factors, indigenous small-holder farming systems will continue to contribute the bulk of food (Parr et al. 1990) over the next 20 years. Rainfed agriculture is today practiced on 97% of the agricultural land in SSA. Despite optimistic outlooks on the development of irrigated agriculture (FAO 2002), past trends indicate that it is precarious to rely too strongly on irrigation as the panacea for food security in SSA. Irrigation expansion has been much slower than expected over the last 20 years, and irrigation schemes have suffered from problems related to degradation of irrigated crop land, mismanagement of irrigation schemes, difficulties in maintaining and rehabilitating schemes, and problems of upstream/downstream sharing of water resources. However, water resource policy and management continues to focus largely on blue water supply for irrigation, domestic use in households, municipalities and for livestock, and water for industry. Among these direct blue water using sectors, irrigation dominates by far the most—withdrawing some 70% of the managed blue water resource.

The SSI program aims at applying an integrated approach to freshwater management that acknowledges the vital role played by both green and blue water flows in sustaining direct and indirect ecological functions and services benefiting human beings. Figure 1 shows a conceptual framework for such an integrated approach to water management. The water flow domain is divided into green (vapor) flows and blue (runoff) flows. The use domain is distinguished between direct

Figure 1. An integrated approach to freshwater management indicating the four freshwater use domains.

Water Flow Domain **Use Domain**	**GREEN**	**BLUE**
DIRECT	**ECONOMIC BIOMASS GROWTH** Rainfed food, timber, fibers, fuel wood, pastures, etc.	**ECONOMIC USE IN SOCIETY** Irrigation, Industry, Domestic/Municipal
INDIRECT	**ECOSYSTEM BIOMASS GROWTH** Plants and trees in wetlands, grasslands, forests and other biotopes. Biodiversity, resilience.	**ECOSYSTEM FUNCTIONS** Aquatic freshwater habitats. Biodiversity, resilience.

uses and indirect uses. Conventionally, our freshwater management focus has been on the direct blue water use sustaining irrigation, industry and domestic water uses. Green water sustains ecosystem services that directly benefit humans in rainfed food production, forests for timber, biomass for fuel wood and fibers, pastures for grazing, and other biomass growth directly used by humans (such as wild fruit). Indirect blue use includes water flows that sustain ecological functions in aquatic ecosystems, such as fish habitats in rivers, wetlands, and lakes. Indirect green water use includes vapour flow that sustains grasslands, natural forests, plant growth in wetlands, meadows etc., that constitute habitats for wildlife, and the vast biodiversity of flora and fauna.

Science for livelihood improvement

SSI is a research program that aims to produce high quality science. At the same time the program is applied and focuses on improving the livelihood of the rural poor in Savannah agro-ecosystems.

The program will investigate sustainable options to unlock the potential of smallholder farming systems. The SSI program thereby contributes to the UN endeavor of achieving the Millennium Development Goals (MDG) to halve poverty and malnourishment by 2015 in hot-spot regions such as water scarcity-prone rural communities in sub-Saharan Africa. It also focuses on an area in need of fundamental research e.g., the inter-linkage of how to use and balance water resources between food and environmental security at watershed and river basin scales.

The program operates at field, watershed and basin scale together with rural communities studying the potential and consequences of introducing water system innovations to upgrade rainfed agriculture. The program will generate knowledge on the extent to which rainfed farming can sustainably be upgraded and what capacities are required among local farmers, community institutions and formal watershed and basin authorities to make a process of sustainable agricultural water use possible.

The SSI program has a strong capacity building component. The program includes 8 PhD projects and 2 Post-Doc researchers, and will host numerous MSc students from the participating institutions and from the WaterNet regional Master program in IWRM.

Innovative aspects

Within SSI, both indigenous and novel water system innovations for upgrading of rainfed smallholder farming will be analysed from a broad spatial and temporal perspective in order to understand system impact at different spatial scales.

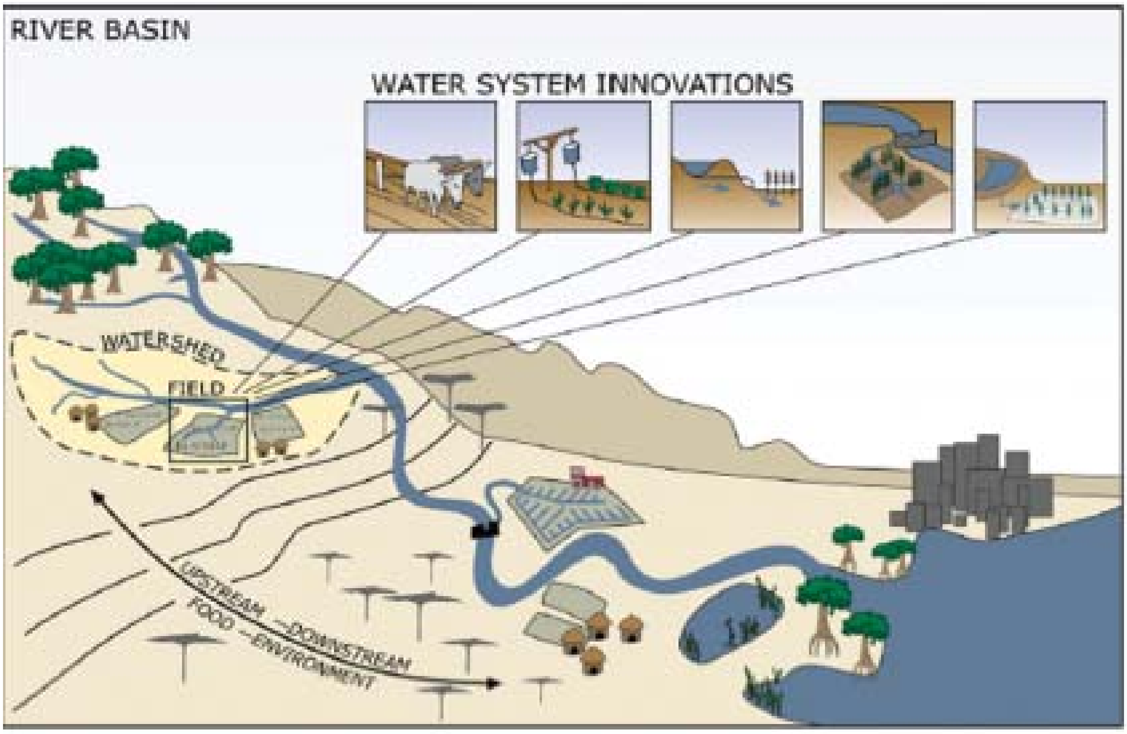
The program thereby addresses fundamental livelihood and environmental challenges in water scarcity prone agro-ecosystems and seeks to fill fundamental research gaps using a multi-disciplinary approach, and by feeding the results into planning and management of natural resources. Filling the research gaps will enable us to answer so-far unanswered questions regarding how far rainfed smallholder land management can go in securing human livelihoods in semi-arid tropical savannahs; what the upstream-downstream implications of upgrading of rainfed agriculture are; how scales interact from field to river basin; and what the trade-offs are between water for food and water for the environment at field, landscape and basin scales.

The program is multi-disciplinary in that it links a broad set of disciplinary sciences, and inter-disciplinary in that it has the ambition of advancing the knowledge on eco-hydrology, integrated water resources management, ecological-economics, and integrated land management. It links recently developed stakeholder oriented and integrated research methodologies and applied research, with a clear development orientation. Local adaptation needs, adoption constraints, policies to enable upgrading of rainfed agriculture, institutions and capacity needs are areas of research that form an integral part of the program.

The objective is to deliver results that are directly useful for regional and district rural development planners in the region of research, and that which contribute to improved livelihood among rural poor.

Systems innovations in Integrated Watershed Management

Figure 2. Water System Innovations in Watershed Management.



SSI research projects

The SSI program consists of six research projects, which form an integrated entity, with mutual inter-dependence and synergies. Together, they are designed to yield integrated research outputs, which can guide sustainable upgrading of rainfed smallholder farming within the context of watershed and river basin management (table 1).

Table 1. SSI projects.

Project	Title	Researcher	Host Institution	Summary Focus
Project 1	Adaptive development of system innovations	1 PhD 1 PD	SUA, Tanzania	Participatory research on sharing exogenous and indigenous knowledge on system innovations. Deliver methodology for adaptive development of system innovations at farm and community level. Co-management strategies for watershed management at community level
Project 2	Upgrading rainfed agriculture through system innovations	2 PhD	UNESCO-IHE BEEH, RSA	Agro-hydrological research at sub-watershed scale analysing soil, crop, water and atmosphere interactions of innovative production systems. Green and blue water interactions, shifts between productive and non-productive water flows, soil and water interactions, fertiliser and water productivity impacts. The field research will be supported by crop water modeling and distributed hydrological modeling at the sub-watershed scale. Cost-benefit and analyses of system options.
Project 3	Building resilience of the eco-hydrological landscape: Dynamics of ecosystems and farming systems under intensification of rainfed agriculture	1 PhD 1 PD	SU, Sweden	Mapping of ecosystem functions and service generation, quantifying water impact and water dependence of ecological functions and services. Research on vulnerability and resilience of ecosystem functions to agricultural dynamics. Ecological economic and socio-economic analyses of management strategies. Development of conceptual framework for integrated eco-hydrological landscape management
Project 4	Balancing water for food and ecosystems at watershed and river basin scale: Integrated hydrological and remote sensing modeling	2 PhD	UNESCO-IHE BEEH, RSA	Distributed and conceptual modeling of biophysical implications of upscaling of system innovations at watershed and river basin scale. Develop tool for zonal mapping of system opportunities (identification of geographical units where water innovations would fit) based on biophysical and socio-economic criteria.
Project 5	Watershed planning of system innovations: Spatial mapping of environmental and hydrological determinants	1 PD	IWMI UNESCO-IHE SEI	Research on water dependence and water impact of different land use types at watershed scale. Use of remote sensing to assess hydrological determinants. Develop the geographic component of the spatial zoning tool for assessment of technological fit.
Project 6	Enabling environment for innovation adoption–Institutions, economics and policy	1 PhD	IWMI UNESCO-IHE	Research on institutional arrangements, support systems and policy requirements at different scales to enable adoption and sustainability of system innovations and achieving better livelihoods for poor people.

SSI Pilot watersheds

The SSI research is carried out in two river basins in Southern Africa; the Pangani basin in Tanzania, and the Thukela basin in South Africa. The Pangani river, the third largest river basin in Tanzania covering some 56,000km^2, has its head waters in Kilimanjaro and Meru mountains, passes through large tracts of low-lying semi-arid savannahs hosting rural communities, before discharging in the Indian Ocean. Field research is focused in the Makanya watershed (approximately 200km^2) located in the South Pare Mountains in the mid/upper reaches of the Pangani basin. The Thukela basin covers approximately 29,000km^2, and flows from Drakensberg mountains in KwaZulu-Natal, eastwards and joins the Indian Ocean in Durban. Thukela is a highly diverse basin with valuable aquatic and terrestrial ecosystems, mixed with subsistence and commercial farming activities. The research is focused on the Emmaus watershed located in the western upstream parts of the Thukela basin.

Criteria for selecting SSI pilot watersheds

A core focus of the SSI program is to investigate innovative options—which integrated green and blue water flows—to upgrade rainfed smallholder farming systems in water scarcity-prone agro-ecosystems. This, in practical management terms, means adding irrigation components/ thinking, into rainfed farming systems, through improved moisture management, supplemental irrigation, off-season small-scale irrigation using water harvesting systems, drip irrigation etc. The SSI research, further, addresses the biophysical, socio-economic and institutional sustainability of upgrading rainfed farming systems, which requires a multi-scale methodology, where experiences at the smallest scale (i.e., location or field scale) is cascaded through scales (field to watershed, watershed to sub-basin, sub-basin to basin) in order to understand consequences (e.g., upstream-downstream water trade-offs between water depending ecosystems) of upscaling smallholder system innovations.

The criteria for selecting SSI pilot research watersheds was discussed and while it was decided that there was no need to force similarities between two pilot watersheds, certain conditions should be met that included:

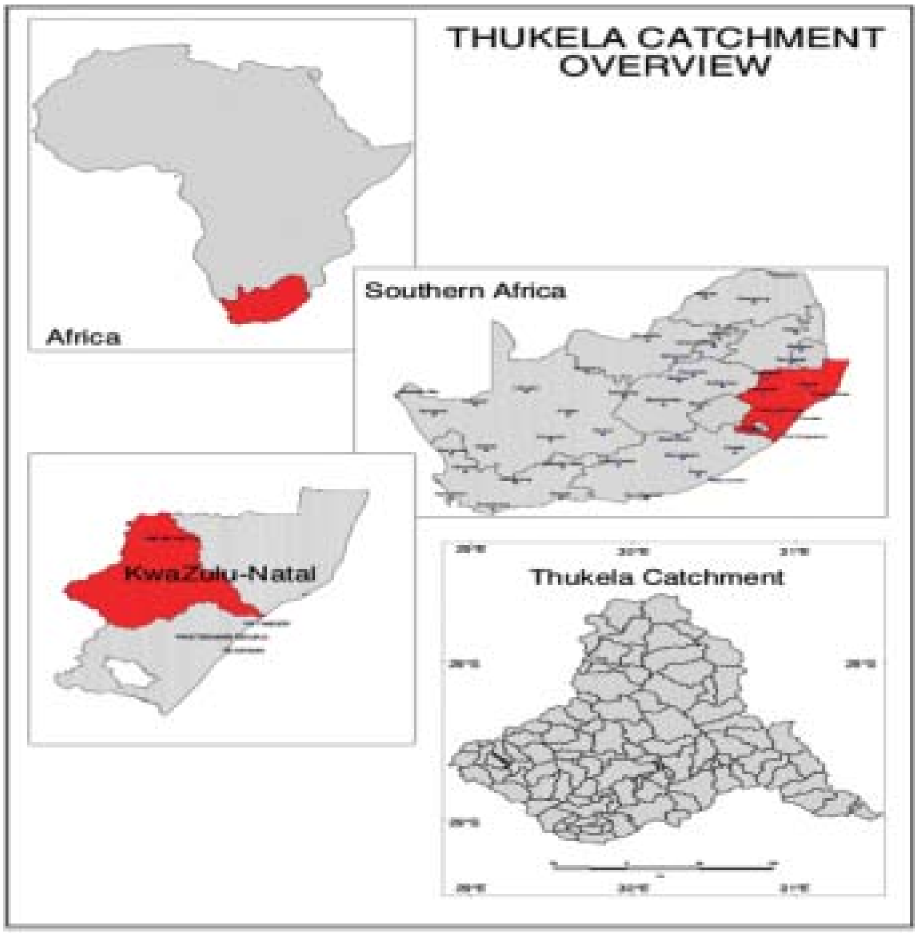
- Smallholder farming must play an important role in livelihood security.
- Water scarcity should be a critical limiting factor for improvements in agriculture—this does not necessarily focus on annual rainfall totals, but can be linked to evaporative demand and seasonality.
- Pilot watershed must allow the possibility of studying and understanding scale links. It is important to be able to link land use changes at the small scale with impacts at the larger scale, e.g., it is favorable if runoff from upstream areas of the pilot watershed are a function of land use, and not a function of regulations from a dam or runoff generated from high rainfall areas without human manipulated land use (e.g., the slopes of Kilimanjaro).

River basin baseline reports were prepared and formed the basis of pilot watershed selection.

Thukela River Basin, South Africa

The Thukela River is a principal river of KwaZulu-Natal province in South Africa and is ranked as the largest river by volume in the country. It is a physiographically, climatologically, hydrologically and socio-economically diverse watershed on the east coast of South Africa. It is bounded in the west by the Ukhahlamba-Drakensberg Park, a declared World Heritage Site, with altitudes of over 3000 m, and in the east by its estuary discharging into the Indian Ocean. It is hydrologically complex with high spatial and temporal variability and unpredictable seasonal climate, and with streams contaminated by high sediment concentrations and acid mine drainage. The watershed is characterised by a juxtapositioning of “first world” commercial agriculture and industrial economies and “third world” impoverished communities dependent upon subsistence farming in degraded areas.

Figure 3.Thukela River Basin.



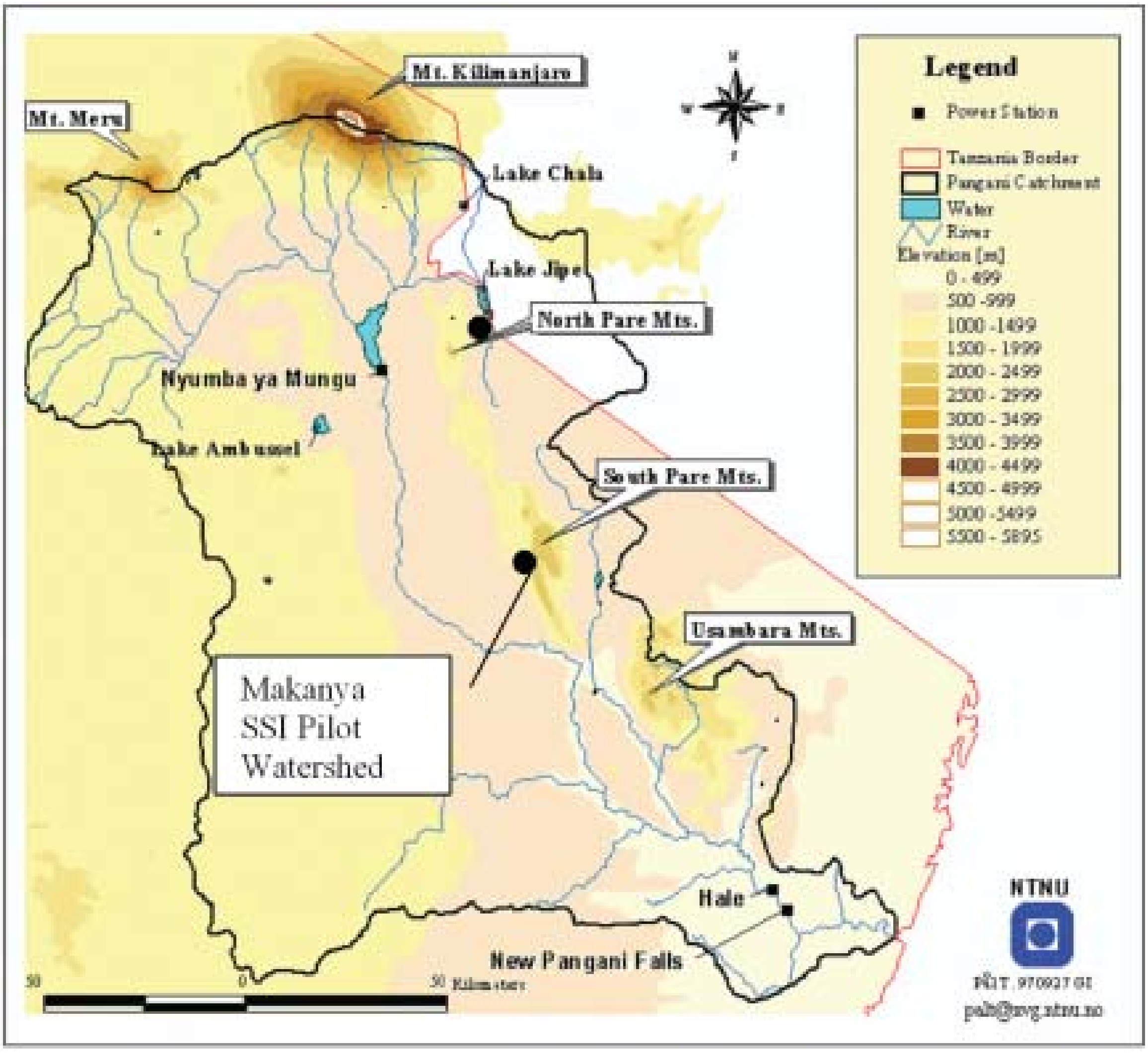
The Emmaus/Mpotsheni research is hosted by the University of KwaZulu-Natal and will be carried out in close collaboration with the ARC (Agricultural Research Council) Mpotsheni Land Care Initiative. This initiative has set up an experimental demonstration farm (Mpotsheni Exp Site) where trials are carried out together with farmers on soil BMP–best managed practices-for dry land agriculture including soil fertility management, inter-cropping, conservation farming and liming. The objective is primarily crop productivity improvements and soil erosion control. The SSI partnership adds the element of water management and research.

The farming system in Emmaus/Mpotsheni pilot watershed has a strong element of livestock/grazing, which will have to be incorporated in the SSI research. There is ongoing grassland research in Emmaus, which is an opportunity for SSI. Tillage is mainly based on animal drawn traction, and implements (planters and ploughs) are generally 80 yrs old.

Pangani River Basin, Tanzania

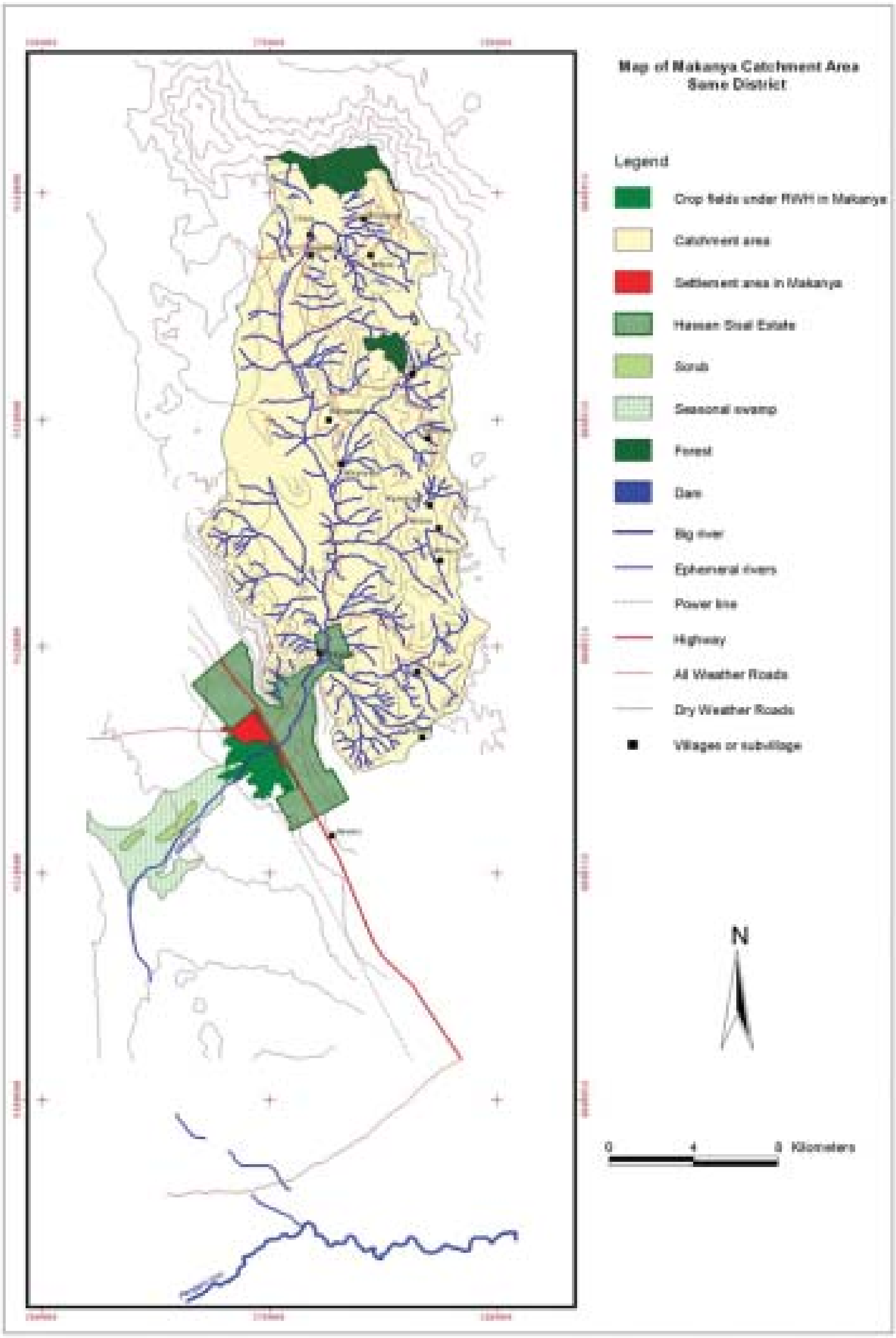
The Pangani River Basin (PRB) is one of nine drainage basins in Tanzania. It extends from the northern highlands to the north-eastern coast of the country and lies between latitude 03º 05' 00" and 06º 06' 00" South and longitude 36º 45' 36" and 39º 36' 00" East. The PRB covers an area of about 56,300km^2, of which 4,880 km^2 lies in Kenya.

Figure 4. Pangani river basin.



The Makanya watershed, located in the South Pare Mountains in mid-reaches of the Pangani river basin 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, where land use changes upstream are affecting hydrology and erosion downstream.

Figure 5. The Makanya watershed.



At the downstream part of the Makanya watershed there is a large Sisal estate. The river passes under the Moshi-Dar highway and the main railway line, and then fans out in a vast lowland area before eventually reaching the main stem of the Pangani. The SUA team has a long track-record of research in the Makanya watershed, focusing on soil and water management and participatory rural development.

The SWRMG at SUA(Soikoine University of Agriculture) has a research field station in the vicinity of the watershed. Farmers have developed interesting indigenous river diversion water harvesting for maize at the lower part of the Makanya watershed, just before it fans out in the lowland (locally defined as *Tifutifu*).

SSI Program Integration

Integration at Program level

The SSI program is very clear that in order to address the set objectives 'Integration by Stapling' is not going to work. SSI needs a true inter-disciplinary research approach, where different disciplines interact as close teams in the field in order to deliver the expected outputs. SSI is an integrated research program, which incorporates integration in three dimensions:

- scientific integration
- scale integration
- outreach integration

Scientific integration: The SSI research projects gather multiple disciplines within the same program, where research in hydrology, geography, ecology, agronomy and social sciences will integrate at program level. At the same time, each individual project research is systems-oriented and interdisciplinary in approach, i.e., each disciplinary project will expand the boundaries of the research field, into adjacent fields (e.g., in eco-hydrology, agro-hydrology, socio-ecology). The program will achieve integration at program level, through a concerted effort to generate synthesis outputs, where the outcome of the individual inputs is larger than the individual components in themselves (i.e., the sum of the whole will be larger that the sum of the parts). This is not only a "boost" for the SSI program, but a real concrete challenge, because despite the well recognized need for a multi-disciplinary and inter-disciplinary approach to livelihood improvements among smallholder rural communities in drought-prone environments, no-one has so-far addressed the interactions between agricultural development, livelihoods, hydrology and ecological functions at scales from field to basin.

Scale integration occurs both in the scientific research—in upscaling the consequences—social and biophysical—of adoption of WSIs—and in upscaling and out-scaling experiences of the research. We know, for e.g., that many existing techniques do not necessarily require more research, and are basically ready for out-scaling, and focus is therefore on institutional arrangements, action research on co-management, and methodologies for outreach. There is also a wide set of technologies in need of fine tuning, or local adaptation, and then there are exiting emerging technologies that require additional action research in close partnership with local communities.

Outreach integration poses the challenge to connect SSI research with development efforts, where science is directly used to support capacity building, policy development and dissemination of knowledge within an outreach or learning framework. To address this challenge, SSI has specially designed an outreach and learning component.

Integration at Project level

SSI projects have different levels and dimensions of integration. The first dimension is geographical—between basins (some projects focus only on one basin but have 2 PhD students, one per basin, i.e., Project 2 and 4 – while Projects 1,3, 5, and 6 focus on both basins).

The other integration dimension is between disciplines/research topics. A matrix (*figure 6*) outlines the anticipated levels of disciplinary/topic integration between projects.

Figure 6. Project Integration Matrix.

	Projects					
	1	2	3	4	5	6
1		■				▨
2	■		▨	▨	▨	
3		▨		▨	▨	▨
4		▨	▨		■	
5		▨	▨	■		▨
6	▨		▨		▨	

	Category of Project Integration
■	Joint field research
▨	Sharing of methodology and/or data

Program-level methodological considerations

Approaches and methodologies for specific project research are discussed in the following sections. There are, in addition, several program-level elements that are essential to support synthesis activities and individual research projects.

SSI Database

The SSI program will have a common terminology that cuts across disciplines, in order to enable integration and synthesis. SSI data stores will include baseline assessment information for the basins, and common indicators that will be developed for evaluation of success of water system innovations. These indicators will cover both social and biophysical parameters.

Nested catchment approach

Integration of scales is a major research challenge in the SSI research program. A nested catchment approach will be used to scale analyses, both in terms of social and institutional constraints for upscaling and in terms of biophysical assessment of scaling influence of shifts in hydrological determinants caused by land use change. Ecological functions and ecosystem services are considered across all these scales.

Hydrological modeling will be used to enable the continuum study of scale interactions from the farm-level (hectare scale using point scale modeling, project 2), to the small watershed (generally < 10 km2 using small-scale distributed hydrological modeling, projects 1, 2 and 3), to the watershed (generally < 100 km2, using distributed hydrological modeling) and finally out to the river basin (> 1000 km2 distributed hydrological modeling). These scales are represented within each of the SSI pilot watersheds (figures 3,4 and 5).

Integrated systems research

Each project will have a systems approach, and thus cross-disciplinary borders in order to interlink with other projects. It is a common understanding among SSI project researchers that each core disciplinary research will have a "scientific outlook" which links to others projects, where for e.g., the social adaptation and adoption research in Project 1 will address environmental constraints (project 3), soil and water management issues (project 2) in order to fully analyse adoption and adaptation research. Systems research will also characterise the "within project" research, where ecological functions will be studied not only for conventional ecological values (e.g., diversity) but also in terms of ecological parameters determining productivity and resilience of farming systems (e.g., organic matter).

Adaptive management action research

The SSI research will build on the most recent advances in socio-ecological and participatory research. Dynamics of social and ecological resilience and the co-management aspects of building resilience will be at the forefront of the eco-hydrological research. Similarly action research, adaptive management and co-learning will be applied in all field based research through projects 1–3. The SSI outreach component sets the tone for the action research of the SSI program.

RESEARCH PROJECTS

The following pages discuss the different SSI research projects.

Project 1A

Adaptive Development of Water Systems Innovations: Conditions for Sustainable Adoption at Farm-Level in Pangani River Basin in Tanzania

Kenneth Masuki[1]

This project will investigate and study constraints and opportunities that determine adoption of rainwater systems innovations and conditions and approaches for farmers-led adoption of the innovations.

Its focus is the Pangani River Basin, Tanzania, and aims to develop a framework for participatory knowledge sharing, that can contribute to faster and higher adoption rates of rainwater systems innovations. It is expected that the contribution of this study will improve the understanding of on-farm, off-farm, farmer, and non-farmer factors influencing farmer decision-making and driving or hindering adoption of water systems innovations at farm level.

Introduction

Water System Innovations (WSI) are understood in a wide sense, to include all indigenous and novel technologies and methodologies for improved agricultural water management, covering both crop and livestock production. System innovations, including water harvesting, drip irrigation, precision agriculture and conservation farming technologies (green and blue water interactions), that aim at improving water productivity (increasing water use efficiencies) while conserving resources, have been developed and tested often with success in several tropical savannahs of the World. The sustainability of such innovations has been receiving growing attention in recent years, with an emphasis on participatory identification and adaptation of techniques.

The greatest challenge for improving rainwater management in the semi-arid areas, is not so much technical innovations, but rather innovative approaches that facilitate adoption of well-tested techniques. Realisation of potential of indigenous knowledge development among smallholder farmers has resulted in very promising initiatives to promote farmer innovations through, e.g., farmer-to-farmer extension. Therefore, adoption or non-adoption of rainwater management innovations has a much wider impact on integrated watershed management.

In the case of water system innovations, their adoption will determine the sustainability of the small-scale rain-fed production system. Adoption of technologies is an exogenous scenario that affects production, consumption and marketing decisions. It is a slow process and distance from the source affect adoption. Analysis of adoption studies shows that time and location, are two important factors in designing adoption studies.

Several studies reported promising developments of water system innovations but experience shows that they are adopted at very low rates, and understanding of cause-effect relationships determining the adoption remains very limited. In general, factors influencing decisions by farmers in relation to adoption or non-adoption of technology are not well understood. Related to this is a lack of understanding of how indigenous knowledge can be integrated or developed in successful water system innovation within farm scale. Currently, internal capacity may also be lacking to design, implement and manage water system innovations that use run-off water flow for productive purposes at hill slope and sub-watershed scale.

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[1] Institute: Sokoine University of Agriculture; Supervisory Team: Prof. A. Z. Matee and Prof. F. B. R wehumbiza, SUA.

Objective

The objective of this study is to develop a framework for partnership-based sharing, for promotion and adaptation of water systems innovations, that can contribute to faster and higher adoption rates in target communities.

Research questions

The research will answer the following questions:

- What are the key water systems innovations already being practised in the target areas, their potential for improving rural livelihoods and beneficiaries of WSIs in primarily rain-fed farming systems at watershed scale?
- Under what biophysical and socio-economic conditions various practices or technologies have been highly adopted with significant socio-economic benefits to the farmer?
- What are the cause-effect relationships between adoption and influencing factors such as tenure arrangements, asset and capital endowments (social, economic & biophysical) at household level?
- What are the local perceptions of novel technologies and household's determinants for decision and willingness to adopt/adapt and what approach can be used to promote such innovations?
- What are appropriate tools and methodologies for dissemination of new WSIs in the study area?
- To what extent is access to markets and commercialisation improve the rate and sustainability of adoptions?

Materials and method

The study will be conducted in the Pangani River Basin in Tanzania. The focus watershed identified is Mwembe-Makanya in the western lowlands of the South Pare Mountains. Pangani Basin was chosen because it represents typical semi-arid to dry sub-humid rain-fed agrarian conditions. In this study multi-level sampling process will be use to draw the study sites and respondents. The levels are:

1. Targeted choice of the study basins, watersheds and landscape positions
2. Reductive choice of the study villages
3. Random probability sampling of respondents and
4. Non-probability sampling of respondents in exploratory case studies and theory construction.

Secondary data will be collected from relevant sources such as literature, monographs and several reports on the study areas. These will provide a triangulation with household surveys and pave the way for interview planning.

Primary data will be collected in the field with a focus on farm-household level, using various participatory methods such as Participatory Learning and Action Research (PLAR), Participatory Agro-ecosystem Analysis and Management (PAAM), and Rapid Rural Appraisals (RRA). Conventional ways of data collection such as household surveys will be conducted.

Explorative (descriptive, correlation and non-parametric) analysis will be employed for all quantitative data sets. Confirmative analysis will also be employed to show relationship among variables. Such models as cluster analysis (CA), Linear regression (LR), multi-dimensional scaling (MDS) and logistic regression analysis (LRA) will be employed at times where necessary.

Adaptive research based on participatory learning and action research (PLAR) methods will be used to investigate the indigenous knowledge about innovations and their adoption under different conditions. Various participatory tools will be employed such as: community meeting for entry point, key informants/historical trend/time lines, group discussions, visual observations.

Specific data will be collected on the following topics:

- Farm-household characteristics (resources, resource changes, resource use, external institutional factors, personal factors and attitudes).
- Farmers' awareness and indigenous knowledge on key water system innovations under practice (farmer-initiated practices) .
- All key water system innovations under practice and their adoption mechanisms. Evaluation of the performance and conditions for adoption of each practice.
- Farmer-perceived socio-economic benefits of highly adopted technologies and factors that provide significant socio-economic benefits.
- Availability of and access to markets, and existence of marketing and commercialisation systems/policies.

Analysis will:

- Categorize farmers/household based on assets and capital endowments (financial, physical, social and human)
- Assess relationships amongst these assets and tenure arrangements on adoption of water system innovations and practices for each category of farmer/household
- Assessment of both positive and negative influence of various factors (social, economic and biophysical) on investment decision-making.
- Determine the level/rate of adoption of each innovation as affected by their awareness and indigenous knowledge of such innovations.
- Determine relationships between adoption rates and access to markets and commercialisation systems/policies.

GPS referenced transect walks and mapping and focus group interviews will be used to collect longitudinal data sets in chosen sites. GIS tools (GPS and GIS software) will be used to map areas with high adoption rates and explore cause-effect relationships in the adoption of different water systems innovations.

The project will thereby develop a decision aid that farmers with the assistance of experts can use to "experiment" with alternative practices or innovations. This would be achieved by adopting existing models such as PARCHED-THIRST (Young and Gowing 1996, Gowing et al., 1999).

In addition, at the community level, surveys will be carried out to map existing and required human capacities to enable the dissemination of water system innovations which require joint management at above farm-level (e.g., run-off collecting storage reservoirs for supplemental irrigation or full small-scale irrigation of cash crops).

On-farm experimentation on the promising SSIs for adoption and adaptation will be conducted, substantiated with exploratory case studies formulated, to pursue some special cases that will come forth in the course of implementing this project.

Farmer field school in Pangani Basin.

Project 1B

Method for adaptive development of water system innovations for improved adoption at watershed and community scale

Siza D. Tumbo[2]

This project will develop a framework for improved adoption and adaptation of water system innovations at community level based on work in the Pangani basin.

Introduction

The role of watershed or community level actions, on the rate and level of adoption of water systems innovations (WSI) is crucial but not very well understood. Planning and carrying out water management for small-holder farming at community scale is complex and requires a combination of biophysical knowledge, management skill, favorable legal framework, institutional capacity and socio-economic power. Local institutional capacity to share management of common freshwater and the land tenure aspects of upstream harvesting of run-off water for downstream use are examples of two critical aspects for sustainable watershed management in large parts of sub-Saharan Africa.

Although many WSIs have been devised by researchers or farmers, adoption rates remains relatively low. For example, a study of the extent of adoption of the excavated bunded basins locally known as "*Majaluba*" system in Tanzania showed that the extent of adoption is only 49% of households where the technology has been practiced for over 80 years in Shinyanga and in Central Northern Tanzania (SWMRG 2001).

At the heart of the matter is to develop knowledge and understanding of the crucial conditions and constraints that determine decisions by smallholders to adapt or not adopt a certain innovation. Past research has shown that, the driving force behind adoption of techniques and innovations is the socio-economic returns to the farmer (Hatibu et al., 2002). Furthermore, improved or new approaches are needed where changing biophysical, socio-economic and environmental conditions/requirements are such that "indigenous" systems fail to provide satisfactory returns to the farmer. Therefore, to be successful, innovations made through research require an integration or development from the indigenous knowledge. The question is, how? This will be one of the critical questions to be investigated under this project.

Therefore, the greatest challenge for improving water management especially in the semi-arid areas is not so much technical innovations, but rather innovations in the approaches that facilitate adoption of well tested techniques (Due and Gladwin 1991; Pretty 1995). These techniques, despite being well tested in one area, are still often novel to the communities where they are promoted. Site adaptation of such technologies is generally required.

Objectives:

- To identify exogenous and indigenous water system innovations at watershed and community level.
- To determine the extent of diffusion of indigenous and exogenous water system innovations.

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[2] Institute: Sokoine University of Agriculture; Supervisory Team: Prof. Henry Mahoo, and Prof. F.B. Rwehumbiza, SUA.

- To explore factors that influence the rate and extent of diffusion of exogenous and indigenous water system innovations.
- To develop methodology for diffusion of water system innovations at watershed and community levels.

Materials and methods

Data collection

Participatory Rural Appraisal(PRA) : This will include transect walks, open-ended interviews of key informants, and focus group discussions. Group meetings will be held in each community sharing a common water system innovation. A list of about 30% of different communities randomly selected from the watershed will be used for the study. Focus group discussions based on gender and wealth will be used in the answering research questions listed above. Furthermore, semi-structured interviews and focus group discussions will be used.

Questionnaire survey: In order to quantify the data collected during the PRA exercise, a questionnaire will be administered at the household level. The intended respondents will be heads of households but the possibility for including other knowledgeable family members will be explored during the exercise, particularly for the questions that require recalling up.

Data analysis

The data collected will first be summarized and a database template containing the collected information will be made in Statistical Package for Social Science (SPSS) computer software. Descriptive statistics such as frequencies, means and cross-tabulations will be used to decode the attached messages in the data collected. Content analysis will be employed on qualitative data collected during the PRA sessions.

Activities

1. Identification of communities for focus group discussions and questionnaires
2. Inventory taking for existing water system innovations in the watershed
3. Preparation of a checklist for rapid rural appraisal
4. Questionnaire design and testing to collect supplementary information
5. Conduct the participatory rural appraisal
6. Administering of questionnaires
7. Perform qualitative and quantitative data analysis
8. Design of the diffusion/scaling-out framework for water system innovations
9. Writing of reports
10. Writing of papers

Project 2A

Water Productivity for Rainfed Agriculture

Hodson Makurira[3]

This project aims to improve smallholder rainfed crop water productivity in arid and semi-arid tropics through a better understanding of hydrological processes at smallholder farm scale.

Introduction

This research focuses on smallholder rainfed farmers in the Makanya catchment of Tanzania. The Makanya catchment receives an average rainfall of between 500mm/a and 800 mm/a. Given that the catchment also experiences a bimodal pattern of rainfall, it means that the net annual rainfall received is split between two growing seasons. If other losses[4] such as evaporation, deep percolation and interception, are taken into account there is hardly enough water to support a crop productivity in any given season. Maize is the most popular crop grown in the study area and it provides the staple food for the region.

The contribution of this research towards improved food security is through understanding the rainwater use systems that are being implemented for smallholder agriculture. The hypothesis is that these water use techniques are not efficient for the present day scenario. However, there is a need to better understand the hydrological processes involved at field scale in order to identify unproductive water use processes at field scale. It is only through a better understanding of water partitioning processes at field scale that improved technologies can be scientifically advanced for improved water productivity.

This research acknowledges that extensive research has gone into improving water productivity through soil and water conservation techniques. But there is still the need to bridge the gap that still exists in linking understanding field-scale hydrology to the work that has been conducted in the field of soil and water conservation.

Objective

To contribute towards food security through obtaining a better insight into the hydrological processes at smallholder farming scale in arid and semi-arid zones.

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[3] Institute: UNESCO-IHE; Supervisors: Prof. H.H.G. Savenije, Prof. S. Uhlenbrook, Prof. J. Rockstrom and Prof. A. Senzanje.

[4] In hydrological terms, water cannot be described as lost. It changes from one form to another but still remains part of the hydrological cycle.

Approach

Water is assumed to be the limiting factor to crop productivity. It is noted that other processes such as soil structure, fertility and farm management practices also contribute to overall yields.

The research is based on the general water balance equation:

$$\frac{dS}{dt} = P - E - Q$$

where

$\frac{dS}{dt}$	is the rate of change of storage within the system being considered;
P	is the rainfall received in the system;
E	is the total evaporation from the system which includes interception, transpiration, and from surface storage;
Q	is the discharge from the system, including from groundwater.

A system, in this case, is defined as the boundaries of a farmer's field plot. A portion of the field will be selected for detailed water balance analysis. The sources of water measured are rainfall, run-off and sub-surface inflow while run-off, interception, open soil evaporation and deep percolation are losses. Moisture available in the root zone which is eventually translated to transpiration is considered the water available for productive use.

Study plots have been selected from representative farmers in the up-slope, mid-slope and down-slope farms within the program study area. Both, efficiencies of the existing farming techniques and potential to enhance water productivity through improved practices, will be evaluated. A participatory action approach is taken whereby the research is carried out in farmers' fields with their full involvement and assistance.

The research aims to optimize water transition process which contribute to increased productivity through increased run-on, infiltration and transpiration while minimizing unproductive processes such as run-off, evaporation and deep percolation. By noting that water is the limiting factor to productivity, new innovations have been introduced at plot scale which aim to alter the hydrological cycle at plot scale through soil and water conservation techniques. Run-off diversion is also being studied as a method of concentrating water onto the plot.

Field data, collected over 3-4 years will be used to set up and calibrate the models. Different scenarios will be assumed and simulated to predict the impacts of various human interventions and climatic conditions on the performance of the studied plots, both hydrologically, and towards overall water productivity in agriculture.

Methodology

Data collection

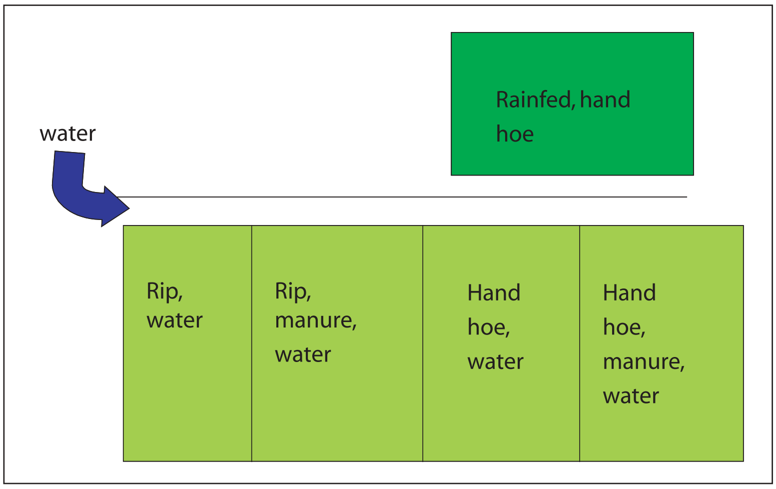
Six farmers have been selected for detailed study. A typical experimental layout is shown below in figure 7.

A number of existing and new rainwater use technologies are being studied. The techniques that are being studied include:

- supplementary irrigation from micro dam,
- deep tillage,

- gully and run-off diversion,
- ridging, and trenching (*fanya juu*)

Figure 7. Typical experimental layout.



At each of these sites water balance assessments will be conducted after measuring the parameters listed in table 2 below:

Table 2. Parameters being measured.

Parameter	Equipment	No. of stations available	Frequency of measurement
Temperature(^{o}C) Humidity (%) Rainfall (mm) Radiation (J/m^{2}/hr) Wind speed (m/s) Wind direction	Weather station	1	hourly
Evaporation (mm)	Evaporation pan	2	daily
Rainfall (mm)	Rain gauges	At every experimental plot	daily
Run-on/ Run-off (litres)	Tipping buckets	At every experimental plot	Continuous (automatic)
Geographic coordinates and slope	GPS		
Moisture (%)	TDR tubes	At every experimental plot	daily
Soil resistivity (W)	Resistivity meter	At representative experimental plots	daily
Plant moisture uptake (g/hour)	Sap flow meter	At representativ experimental plots	hourly
Evaporation (mm)	Lysimeter	At every experimental plot	hourly
Leaf area index	Leaf area	At every experimental plot	Per growth stage
Dry mass of stem and leaves (g)		At every experimental plot	Per growth stage
Evaporation from interception by mulch and soil (mm)	Interception meter		daily (especially after rainfall event)

Analytical tools

The following modeling approaches are to be applied:

A. System water productivity analysis

A simple spreadsheet model will be developed which will simulate the general water balance of the system.

B. Two-dimensional modeling

The Hydrus 2D model will be applied to simulate soil moisture transition in the vertical and horizontal directions. The simulation results will serve as input to the one-dimensional modeling.

C. One-dimensional modeling

The APSIM model will be applied to analyse the performance of a maize crop. This model will simulate maize crop growth at a point from given soil and moisture conditions up to harvest stage.

Expected outputs

The general output from the research is to contribute towards food security to climatically vulnerable communities through scientifically determining water partitioning processes at smallholder farm levels. The research will bridge the communication gap between scientists and farmers through on-farm experimentation and quantification of water transition processes at field scale, when different soil and water-use techniques are applied. A better understanding of water partitioning processes will also lead to easier identification of sources of inefficiencies in water utilization for crop production and, hence, it would be easier to advance more efficient water-use innovations at smallholder farm scale.

Project 2B

Upgrading Smallholder Rainfed Agriculture in Drought-prone Agro-ecosystems through Rainwater Harvesting Technologies: Seeking new hydrological flow paths in the Thukela River basin, South Africa

Job Rotich Kosgei[5]

This research project intends to contribute to the creation and dissemination of knowledge and skills that enable improved water productivity, and hence, an enhanced food security of smallholder rainfed farmers through a better understanding of hydrological flow paths at field and sub-watershed scales in Thukela River basin. Ways will be sought to transform the current dynamics of fluxes to favor more moisture retention (in the soil and/or in storage facilities) and its effective use by beneficial plants through transpiration.

Introduction

Increased demand for food has necessitated more water to be diverted from the environment for food production. This has often precipitated into conflicts with other water users and uses (Kosgei 2000). The current water requirement to produce adequate diets for humans is anticipated to increase due to the growing populations and the desire to eradicate the current under-nourishment (Falkenmark and Rockström 2005; Droogers et al. 2001). Much of this increase in water use will be required in regions of the world characterised by:

(i) The largest proportion of water scarcity-prone agricultural lands;

(ii) The highest levels of poverty; and

(iii) A high degree of present human-induced land degradation, further deteriorating the capacity of the land to produce food.

The Thukela catchment typifies this situation. Dryland subsistence agriculture and pastoralism are the dominant land uses in the rural areas since few of the rural communities have access to irrigation water. Subsistence farming and overgrazing has resulted in large tracts of degraded land. Per capita income levels in the catchment are generally low, with the average at R5500 per annum compared to the national average of R9520 (Taylor et al. quoting DWAF 2001). The lowest average incomes are in rural areas where large numbers of subsistence farmers have many dependents. The situation of smallholder farmers is worsened by poorly distributed rainfall. In spite of the annual rainfall total exceeding the crop water requirements in most of the years, part of the growing season (December-January) is characterised by inadequate rainfall that leads to loss of vigor in maize and

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[5] Institute: School of Bio-resources Engineering & Environmental Hydrology (BEEH); University of KwaZulu-Natal; Supervisory Team: Prof. Graham Jewitt and Prof. Simon Lorentz, (BEEH).

hence an impact in yields or in extreme cases total crop failure. All farmers in Potshini rely on rainfall for crop production and thus cultivate only one crop (maize) annually whereas the neighboring large-scale farmers manage two cash crops. This may be a result of inadequate knowledge of alternative water sources such as groundwater or water harvesting techniques. Water resources management is also of great concern in this area since part of the catchment has been declared a World Heritage site.

Objectives

i) To investigate the possible causes (biophysical, socio-economic, cultural, etc.) of the existing wide gap between achievable and potential crop yields in the Thukela River basin;

ii) To explore the potential of new and existing approaches and technologies for improving crop production in the study area through comprehensive analyses and modeling techniques of the key factors of crop production;

iii) To identify, appraise, design and implement appropriate water harvesting storage facilities for use in supplemental or total irrigation;

iv) To develop decision-support tools for use in water harvesting practices in semi-arid environments; and

v) To carry out a cost-benefit analysis (livelihood and ecosystem) at field scale of existing and adopted water harvesting technologies.

Materials and methods

This field-scale research will be carried out in Potshini catchment in the Thukela River basin.

i) Water productivity studies

Approach

- A weather station has been established within the catchment to enable collection of meteorological parameters. Its data will be supplemented with that from a nearby station established five years ago by the ARC-Landcare project. Long term data is also available at Bergville weather station, 10 km away.

- Four sites have been identified and a total of seventeen run-off plots set-up. Except one (main trial site), the remaining sites are farmer-managed. Each plot is 10 m by 2.45 m (Kongo and Jewitt 2005). Each plot is equipped with an Time-Domain Reflectometry (TDR) access tube in which weekly soil moisture measurements are taken at intervals of 30 cm to a depth of 150 cm. Granular matrix sensors (GMS, Watermark Soil Moisture Sensors Model 200SS, Irrometer Co., Riverside, CA) will also be installed that will monitor the wetting front at three depths (30 cm, 75 cm and 120 cm) in each of these plots.

- Farmer-managed trials will test maize yield impacts of conservation tillage with and without fertilizer and supplemental irrigation treatments. Researcher-managed trials (community plot) will measure yield impacts of conservation tillage with and without winter or summer inter-cropping, mulching, and grazing treatments.

- Transpiration will be measured through movement of sap in the maize plants under the different treatments using heat balance gauges to compare their level of moisture abstraction from the soil. This will be supplemented by indirect measurements using lysimeters.

- Shallow ground water wells will be sunk in the four sites to monitor variability of shallow ground water levels and its role in crop production.

To allow for a wider use of the results and scenario analyses, several development and analytical tools will be used in an agro-hydrological modeling exercise. The Penman-Monteith model (Allen et al. 1998) and SAPWAT (van Heerden and Crosby 2002) will be instrumental tools in computing the crop water requirements and hence planning of water allocation by water users' associations. The Apsim model (McCown et al. 1996) and the Parched-Thirst model (Young et al. 2000) will be the principal analytical tools.

ii) Investigation of appropriate water harvesting storage facilities and water utilization methods

Approach

Two systems of rainwater harvesting are seen to be practical in the study area: those that capture and store rain water before it falls onto the ground surface and those that collect and store run-off water. Efficiency of rainfall capture depends on the nature and surface area of the material the rain falls on, and the rainfall intensity. Both, corrugated iron sheet roof and thatch roof materials will be studied for efficiency. Efficient run-off capture depends largely on properly designed storage facilities. Thus, design of suitable storage facilities forms the thrust of this work, and has the following components:

- Sizing the storage tanks for run-off water harvesting, based on knowledge of the catchment supply and the crop water demand.
    - Storm flow depth will be calculated from the SCS model (Schmidt et al. 2004)
    - The FAO-56 Penman-Monteith (Allen et al. 1998) will be used to compute the reference evapotranspiration which is then used to estimate the water demand.
    - The total amount of water required for vegetables, to be established every winter, will then be determined.

- Design of tanks including location, shape, and material(s) of construction.
    - Uniformly distributed load as a function of radial displacement at any height will be calculated based on the method suggested by Godbout et al. (2003) citing Timoshenko and Woinowski-Krieger (1959).
- Low-water-use application methods, such as bucket/drip systems will be investigated for efficacy and cost-effectiveness.

Rooftop run-off harvesting, setting up run-off plots, TDR access tubes and rain gauges.

Project 3A

Building resilience and intensifying farming: the potential of small-scale water system innovations in semi-arid agro-ecosystems

Elin Enfors[6]

Semi-arid agro-ecosystems provide the resource base for some of the fastest growing human populations today, and are inhabited primarily by poor people who are dependent on the productivity of these systems for their livelihood security. The main function of these systems is normally defined as the generation of agricultural products. For a smallholder agro-ecosystem however, this definition would also include the generation of other ecosystem goods and services, such as firewood, livestock, wild herbs and fruits etc., on which local people depend. Over the past decades, more and more alarming trends of land and resource degradation are reported from these regions. To ensure the future production of food and other ecosystem services resilience, the capacity of social-ecological systems to cope with change without losing essential functions, needs to be increased in these systems.

Overall objective

The overall aim of this research project is to determine if the use of small-scale water system innovations (e.g. rainwater harvesting, conservation farming) can increase the resilience in semi-arid agro-ecosystems. The study is based on the assumption that water system innovations will lead to stabilized and even increased yields under rain-fed 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.

- This alters conditions for ecosystem functioning and for the generation of ecosystem goods and services.

In this project the relations between the intensification of agriculture (achieved through small-scale water system innovations), the generation of ecosystem services, and the management of natural resources, are analyzed, at both field and agro-ecosystem scales. Biophysical as well as social factors are studied. The effort includes identification of key variables in the agro-ecosystem that determine the capability of the system to maintain its functions when faced with change, i.e. variables that are especially important for maintaining the system's resilience. The objectives of this project will be met by answering the research questions listed below, and the results will be presented in five scientific papers. Fieldwork is carried out in the Makanya catchment, Pangani River Basin, Tanzania.

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[6] Institute: Department of Systems Ecology, Stockholm University; Supervisors: Dr. Line Gordon, Prof. Carl Folke, Dr. Johan Rockström, Dr. Siza Tumbo, and Dr. Graham Jewitt.

Research questions

1. What are the main ecosystem services, generated in this agro-ecosystem? How do they sustain the livelihoods of the farmers in the area?
2. What major changes has this socio-ecological system gone through in the past, what were the main driving forces behind them, and how has this affected the resilience of the system?
3. What would be a desirable state(s) of this system? What main factors (conditions) support this state, i.e., what are the sources of resilience in this environment?
4. Which soil variables have important effects on the long-term productivity and the resilience to dry-spells at farm level? What impact will water system innovations have on these variables? Can certain slowly changing soil variables be used as indicators of resilience of the farming system?
5. Will the use of water system innovations affect the farmers' possibilities / willingness to invest in other on-farm improvements and thereby affect the management of the farming land?
6. What are the potential effects on key ecosystem services (other than food production) in the catchment from changes in water-flows brought about by increased use of water system innovations?
7. Will stabilized harvests, achieved through water system innovations, lead to changes in the use of other local natural resources? How would this affect the functioning of the surrounding support systems?

Research methodologies

Base-line study

A base-line study has been made in order to map the current state of the system, including its historical profile, and to outline future desirable states of the system—what has been referred to as establishing "resilience of what to what". The study addressed research questions 1, 2 and 3. To assess land cover changes in the Makanya catchment, an interpretation of aerial photos from 1953 and 1983, and of satellite images from 2002, has been made. Further, daily rainfall data from the Same Meteorological Station for the period 1957-2004, has been analyzed. The analysis focused on possible changes in rainfall amounts, number of days with rain, and dry-spell occurrence for Vuli and Masika seasons in the study area over this period. To gain an understanding of the local people's views on the agro-ecological changes in the area, and the perceived drivers behind these changes, interviews were made with elderly farmers in the study villages, with extensionists and with local authorities. To supplement the interview data, time-lines over the area's social, political and ecological history were created during focus group discussions. The local stakeholders' narratives on agro-ecological changes were compared to the land cover change analysis, and rainfall dynamics, institutional changes and poulation growth were analyzed as potential driving forces behind observed changes.

Field-scale study

The second part of this project is a field-scale study aiming at investigating how water system innovations affect the on-farm resilience. Both, the potential effects on intrinsic soil qualities of SWSIs (small scale water system innovations) and how the harvest-stabilizing effect of them affect the farmers' management of their farming land, are studied. This part of the project responds to research questions 4 and 5. The effects of SWSIs on overall management of the farming land will be addressed in an interview study, mapping the investment preferences among farmers who are using water system innovations (in this case Ndiva-irrigation), and comparing these with investments made by farmers cultivating under purely rain-fed conditions.

The focus of the biophysical part of the field-scale study is on the potential effects of water system innovations on slowly changing soil variables, that influence its resilience to dry-spells. The SWSIs are hypothesized to affect these variables e.g. through altered soil structure, increased plant density, and more frequent wetting of the soil. To investigate this, an on-farm experiment that will run over seven rainy seasons (short rains 2004–short rains 2007) has been set up in collaboration with local farmers. The innovation that is tested, an in-situ water harvesting system combining deep tillage with mulching and application of manure, is compared with the farmers' conventional tillage and land management in the experiment. The farmers themselves carry out all farming operations, and measurements conducted on the fields are done together with them. In addition to the scientific advantage of this approach (outside researchers benefiting from the farmers' local system knowledge) the aim of the approach is to strengthen the farmers' capacities to experiment in agriculture, evaluate the results and plan the management of their farming systems thereafter.

The experiment is set up as a split-plot "semi-randomized" block design, with four treatment plots (10x10m) in each block. In total three farmers are involved in the experiment, and six experimental blocks have been set up on their fields. Three of these blocks are located on the same field and seen as replicates of each other. The other blocks enable a comparison of the effects over a set of realistic on-farm conditions. The treatments that are applied is: a) deep tillage with ripper, b) deep tillage + mulch + manure (5 ton/ha), c) hand hoe (used as control), and d) hand hoe + mulch + manure (5 ton/ha). To produce mulch, a cover crop is grown (lablab beans during the long rains, and cowpeas during the short rains). In addition to these six blocks, one experimental block is run in collaboration with SSI Project 2A. On this site the treatments also include supplemental irrigation. Before starting the experiment, a detailed soil sampling was conducted to generate information about the soil type, and its chemical and physical properties in all the plots. The same sampling will be conducted after the last experimental season to evaluate the effects of the treatments on the slowly changing variables. All standard physical and chemical properties are monitored, but focus is put on soil structure, organic matter and water holding capacity. On the site co-run with Project 2A, data will also include a complete water balance. Further, a nutrient balance for each plot is made every season, by analyzing nutrient content in inputs and outputs. This will be used for modeling long-term effects of the treatments on soil productivity.

Agro-ecosystem-scale study

In the third component of this project, effects on key ecosystem services in the catchment from changes in water flows brought about by up-scaled use of SWSIs, and effects on resource use patterns among the farmers in response to stabilized harvests, will be examined. The study responds to research questions 6 and 7. For the first part of the study, scenarios suggesting/describing future potential states of the system will be developed in collaboration with local stakeholders, and conditions/ecosystem services necessary to sustain these states will be analyzed. Furthermore, modeled results from SSI Projects 2A and 4A, of alterations in field water balances and in hydrological regimes as a consequence of use/up-scaling of water system innovations will be used for an assessment of water availability for different terrestrial sub-systems in the catchment. Relating these assessments to the scenarios will provide indications of the effects of SWSIs on catchment scale. A detailed methodology for this study however still needs to be developed. In addition to this, patterns of resource use (crop complementing resources) and views on environmental management will be compared between farmers who use and who do not use water system innovations (in this case Ndiva-irrigation), and reasons behind possible differences will be traced. This will be investigated through in-depth farmer interviews and special focus will be on periods when yields would be reduced due to water deficits for those not using SWSIs.

Ripped plot in the on-farm experiment taken when planting for Vuli (2004/05).

Project 3B

Building socio-ecological resilience in semi-arid environments - the potential of small-scale water system innovations and adaptive co-management

Line Gordon[7]

The world is continuously experiencing socio-ecological changes (van der Leeuw 2000; McIntosh et al. 2000) that can alter capacity of ecosystems to generate goods (including food) and services on which society depends (Daily 1997; Millennium Ecosystem Assessment 2005). These changes can be fruitful for development, but have during history also led to collapse of societies (Redman 1999). In several regions the capacity of ecosystems to sustain the flow of goods and services are decreasing, while the demand in society of ecosystem goods and services is growing. Human alterations of freshwater quality and quantity are serious threats to a sustained capacity of ecosystems to maintain these services (FAO 2000).

In a human dominated environment, such as in most places on earth today, people are inherent part of socio-ecological systems, and their actions can enhance or erode the resilience of their system. In many regions people have found ways to adapt, learn and shape change in ways that build resilience and keep socio-ecological systems on sustainable trajectories (Berkes et al. 2003). During the last years, new theories are also forming about the ability of people to make systems transform from unwanted and unsustainable stability domains to more desired trajectories of development. These new theories, together with an in-depth understanding of the local context of the study area, including its historical development, can be of help to understand whether small-scale system innovations in semi-arid agro-ecosystems can help the local societies to move out of a negative spiral of land degradation to a more sustainable pathway of development.

Objectives and focus

The aim of this project is to determine whether progress in the development of new technologies for stabilized and increased yields can help in reversing negative environmental trends and build resilience of linked socio-ecological systems in a larger catchment perspective. In addition, this project would like to identify with farmers a set of plausible pathways of development, to build a shared vision for enhancing the capacity of adaptive co-management of their natural resource base. Work will focus particularly on the capacity to cope with disturbances such as droughts and dry spells in the catchment, as well as periods of rapid change that have taken place in the area.

The project will build on recent theories on resilience of socio-ecological systems as well as on theories on adaptive co-management as a potential way of building socio-ecological resilience. As such it addresses the question of whether the regions have the capacity to cope with change, or the

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[7] Institution: Stockholm University; Supervisory Team: Prof. Carl Folke, Stockholm University, Prof. Graham Jewitt, University KwaZulu-Natal, and Prof. Johan Rockström, Stockholm Environment Institute.

capacity to transform from an undesirable situation to a more desirable one. The overarching question is whether resilience can be built through upscaling of small-scale agricultural innovations, and the work is subdivided into three different parts:

- A baseline study to make a historical profiling of the system and analyse this through a 'resilience lens' to understand how the system resilience has changed.
- An analysis of the links between water, ecosystem services and the impacts of SSI's in the region and for the livelihoods of the farmers; focusing on the ecological systems that are nested to the agricultural fields and their capacity to generate welfare supporting services will be studied.
- Anticipating the future and building shared visions through scenario development.

The project will have both a biophysical and a social perspective. The biophysical part will primarily build on the work within project 3A for Makanya catchment, although since the focus of 3B will be in the Mpotsheni catchment it will be complemented by data from this catchments.

1) Baseline study

The first part relates to the "state" of the system. The aim is to find out the current "trajectory" of the system, with an approximately 100-year perspective. Is it going down a negative development pathway or is the resilience of the system being built up? This is similar to the Project 3B study, done in Makanya, and the methodology will build on (Walker et al. 2002 and Carpenter et al. 2005). This study will also develop a theoretical framework for analyzing changes in resilience of semi-arid agro-ecosystems.

Both catchments in the SSI program seems to be experiencing rapid socio-ecological changes. In the Makanya, the catchment seems to be drier in terms of access to water for crop production, erosion has increased and population pressure is larger today. In the Mpotsheni catchment there seems to be accelerated erosion and high-pressure on the natural resource base in general (e.g. grazing). In both of the catchments there are small-scale water system innovations used by the farmers in order to increase or stabilize yields. In the Mpotsheni catchment there is also a recently started Land Care program that focuses on increasing yields of small-scale farmers, capacity building, development of policy and legislation, and research and evaluation.

Hypothesis:

- There have been a couple of distinct events that have triggered changes in this system.
- These have occurred at different scales and been biophysical, but maybe primarily social in character. They are all manifested locally.
- The capacity of the ecosystems in the catchments to generate ecosystem services has decreased through time, but the production in terms of goods (crops mainly) has been increased.

Methodologies used:

- GIS - Mapping of the area today and in the past. Aerial photos will be used to see whether the system has gone through biophysical changes.
- Individual interviews with different groups/individuals at different levels in society (e.g. farmers, extension workers, and regional level officials).
- Focus group discussions to produce timelines to get an understanding of the system development.

2) Linkages among water, ecosystem services and SSI's

This part of the study will focus on the links between water, ecosystem services and the impacts of SSI's in the region and for the livelihoods of the farmers. The role of local ecosystem services for sustaining the livelihoods of the farmers will be analyzed in relation to current changes taking place in society.

Hypothesis for understanding how SSI's affects the preconditions in downstream systems:

- Farming in the area has already changed the hydrology of the region, and thus already changed preconditions for downstream systems
- SSIs can be done in a way that "mimic" the hydrology of "natural" ecosystems so that the effects for downstream systems can also be positive
- Synergistic effects between SSIs and other land cover and water management changes (like forestry and water schemes) can contribute to reduction in streamflow that affect downstream systems.

Hypothesis for understanding the role of ecosystem services for livelihoods in relation to the use of SSI's:

- The use of ecosystem goods and services from surrounding systems by farmers/stakeholders differ in times of crop failure/serious crop reduction from "normal" years. Stabilised and increased yields will thus affect the management and pressure on other ecosystems.
- The importance of both ecological and social diversification as an "insurance mechanism" will decrease. This is also decreasing as a result of new livelihood options opening up recently (including urbanization).
- The dependence on ecosystems further away from the catchment might increase (as the local dependence decrease) if farmers to a larger extent grow cash crops when the potential for increased yields is higher. This changes the key variables that determine farmers' risks, resilience and vulnerability.

Methodologies:

- GIS mapping of the landscape
- Hydrological modeling (mainly through interaction with Projects 2 and 4

    - Focus group discussions
    - Participatory walks with farmers in the landscape

Scenario-building and potential for an adaptive management process across scales

This part is not yet well developed, but will build on methodologies drawn from previous studies on scenario building at regional scales (e.g. Peterson et al. 2003), and adaptive co-management (Olsson et al. 2005). Below follows some very general hypotheses.

Hypothesis:

- Ecosystem management that today sustains the capacity to generate ecosystem services in this catchment depends to a larger extent on informal institutions and management practices than on formal rules. Diversity and redundancy of functional groups of species (“biological”), as well as of ‘knowledge reservoirs’ and institutions (“social”) are important for coping with changes and surprises.

- Strengthening, building or restoring strong and flexible local and nested institutions can help build resilience so that this change can be reduced, softened or filtered.

- Responses to change that reflect multiple spatial scales and consider multiple time scales lead to higher resilience than responses restricted to single scales. Also, biological and social information that flows across scale builds resilience. Polycentric and hierarchically nested institutions that are able to respond at different spatial scales promote resilience.

- Scenario building can help create a common vision and facilitate the move towards adaptive co-management.

Expected outputs

The theoretical outputs can hopefully help contributing to:

a) the emerging theories of resilience in socio-ecological systems, and maybe more specifically on how participatory introduction of small scale technologies can help systems transform from undesirable to more desirable trajectories of development

b) the understanding of effects of SSIs on things other than crop yield, i.e. on other ecosystem services, and on the more institutional dimensions of ecosystem management.

Project 4A

Balancing water for crop production and ecosystems at sub-catchment and catchment scale: Integrated hydrological modeling - Special focus on the Pangani river basin, Tanzania

Marloes Mul[8]

This study aims to increase the understanding of hydrological processes in semi-arid catchments at different scales, through the development of a physically based process-oriented model, TAC^D (Tracer Aided Catchment model, Distributed), run-off source tracer techniques and SEBAL monitoring of evaporation. This work will help identify the trade-offs between water used in smallholder farms in the upper areas of the Makanya catchment and downstream users, including farmers and ecosystems, and provide essential information to local resource users and planners.

Introduction

This research is located in the South Pare Mountains in northern Tanzania, in the Makanya catchment. Due to increasingly erratic rainfall patterns and steady population growth in the catchment, water availability has decreased. The study looks at the hydrological impact of smallholder water use in this catchment. The scale of the study ranges from a few square kilometres to about 260 km^2. It specifically looks at upstream-downstream water availability and the impacts for the water users in those areas.

The main water users in the area are smallholder farmers, who, depending on their location in the catchment are dependent on rainfall and supplementary irrigation through run-off and river diversions. In both the upper areas (>1500 m elevation), and lower areas (800 to 1500 m elevation) rainfall is generally not enough during the rainy season to realise crop production with seasonal rainfall ranging between 150-500 mm/season in upper zones, and 50-300mm/season in lower areas. Soil and water conservation techniques and groundwater help to increase soil moisture availability until crop maturity. Due to intra-seasonal rainfall variability and dry spells the need arises for supplementary irrigation.

To cope with these climatological conditions the villagers in the area have set up a system of canals that divert water from the main stream into the farm plots for supplementary irrigation. Several small reservoirs (locally called *ndivas*) act as temporary storage structures to facilitate distribution of water among the beneficiary farmers. Since independence (1961) the number of diversions has increased tremendously and the capacity of the storage structures has increased with the help of donor money. Another trend is the increased use of soil and water conservation techniques that promote soil moisture retention. These developments have not gone unnoticed downstream (catchment area +/- 260 km^2), where a perennial stream slowly turned into an intermittent stream and finally today only large flood events pass. Even at a smaller scale (catchment area +/- 24 km^2) the impacts are noticeable, where especially during dry spells there is not enough water in the streams to divert to the farm plots in the lower areas, due to upstream abstractions.

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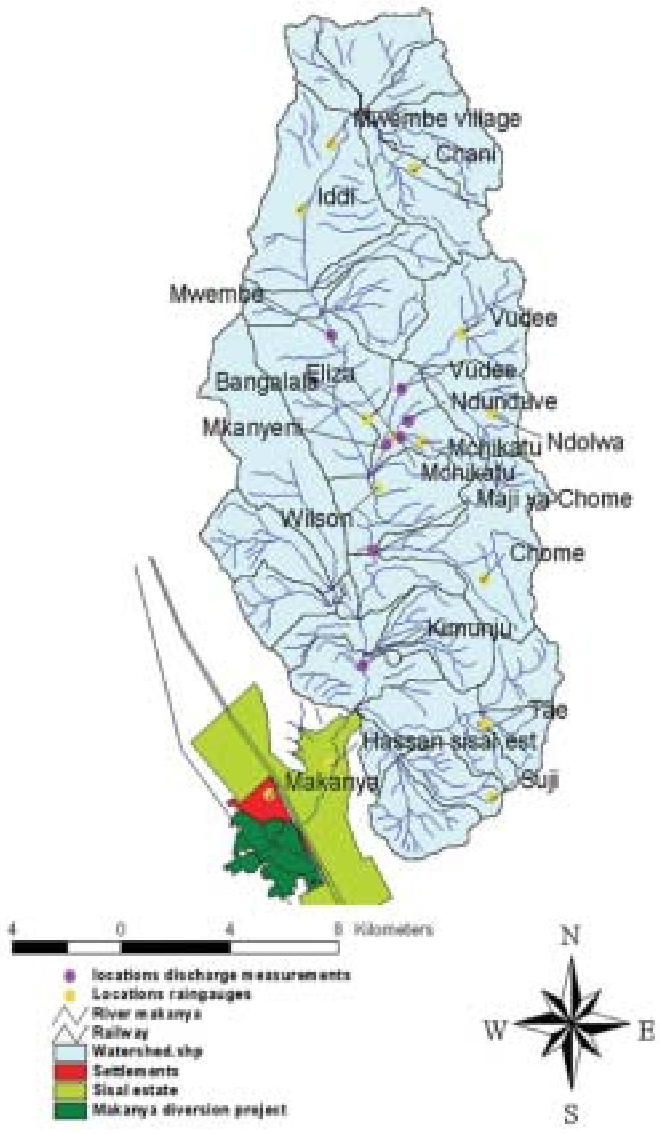
[8] Institute: UNESCO-IHE; Supervisory Team: Prof. H.H.G. Savenije, UNESCO-IHE; Prof. S. Uhlenbrook, UNESCO-IHE and Prof. J. Ngana, IRA, UDSM.

Approach

Data to be collected for this research range from physical parameters needed for the TAC^D modeling, primary data that will be collected in the Makanya catchment and will consist of discharge measurements, climate monitoring using rain gauges and a meteorological station, water user inventory and the monitoring of one of the small storage structures. Secondary data in the form of remote sensing images and GIS maps, and existing climate information will also be used.

Distributed hydrological modeling using TAC^D will be used to assess the impacts of soil and water conservation techniques and abstractions on the flows in the river. Different soil and water conservation techniques will have their own parameterisation for e.g. infiltration, transpiration rates, based on the work to be done by SSI project 2A. Diversions and storage structures will be integrated into the hydrological model, through sink and source cells. The impact will be estimated from small scale (0.5-4 km^2) to the Makanya catchment scale. The catchment response at different scales will be analyzed in dominant hydrological processes and the links between the different scales.

Figure 8. Monitoring network.



The aim of the hydrological model is to increase the hydrological understanding of this semi-arid catchment. Increased understanding and an improved hydrological model can predict the hydrological response of soil and water conservation techniques and diversions. Based on these strategies water managers can include this additional information to make catchment management plans more sustainable, taking into account the impact of upstream users on downstream users. This information is also essential for policy makers when drafting new policies to ensure soil and water conservation techniques are promoted in an integrated and sustainable manner.

Methodologies

Data collection

The Makanya catchment is a relatively hydrologically ungauged catchment, thus, a measuring network had to be installed. The existing network of three rain gauges (with data for more than ten years), were supplemented with eleven additional rain gauges, distributed according to topography. A full meteorological station was installed near the experimental sites, because the nearest meteorological station, Same, is located in the lower and arid areas, west of the Pare Mountain range, does not represent the climatalogical conditions of the study area. A run-off measuring network, set up with the nested catchment approach (figure 8), complements the monitoring network. Run-off measurements will be taken at two springs (catchment area +/- 0.5 and 4 km^2), a medium scale catchment (+/- 24 km^2) and at the outlet of the Makanya catchment (+/- 260 km^2).

Distributed hydrological modeling

The distributed conceptual hydrological model that will be used in this study is TAC^D, developed by Uhlenbrook et al. (2002b), which is a process based distributed model. Models will be developed at different scales; each model will analyse the catchment response at that scale. Different hydrological determinants and land use changes are 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. Different models have different catchment sizes, and also different grid cell sizes and different time steps (table 3). The smallest headwater catchment is Ndunduve catchment, with an area of about 0.5 km^2 and Mchikatu is also a headwater catchment with a slightly larger area of about 4 km^2. Both catchments are nested within the Vudee catchment. The largest catchment is the Makanya catchment just before the confluence with the Tae River, draining an area of about 260 km^2. Data on soils, land use and land cover with this resolution can be collected from the Internet. The two smallest scales will have to collect primary data with contribution from other SSI projects. While specific modeling spatial and temporal scales are indicated, the research has the flexibility to adjust the scales where and when necessary.

Table 3. Modeling scales.

	Small scale		Medium scale	Large scale
Catchment	Mchikatu	Ndunduve	Vudee	Makanya
Catchment area [km^2]	4	0.5	24	260
Modeling grid cell size	20*20-50*50 m^2	20*20-50*50 m^2	100*100 m^2	1*1 km^2
Modeling timestep	1 hour	1 hour	1 hour	1 day/ 10 days/ 1 month

SEBAL

The Surface Energy Balance Algorithm for Land (SEBAL) method computes actual evaporation for a large area, based on remote sensing images (Bastiaanssen et al. 1998). The algorithm is based on the surface energy balance, which reads:

$$R_n = G_0 + \rho\lambda E$$

where

R_n is the net radiation [W m^{-2}],

G_0 is the soil heat flux [W m^{-2}],

H is the sensible heat flux [W m^{-2}], and

$\rho\lambda E$ is the latent heat flux associate with total evaporation. [W m^{-2}]

The resulting evaporation maps will be used to calibrate the distributed hydrological model. Maps can also identify crop performance. Together with the database on water use in the catchment, water efficiency can be estimated, which will be a valuable addition to the study on the most beneficial balancing of water for crop production and ecosystems.

Isotope and tracer studies

The study will be complemented by a tracer study that will assist in identifying the governing processes of run-off generation. Usually, studies of this type are performed on a small catchment (< 5 km^2), to distinguish between run-off generated from event water, such as Horton overland flow, water from shallow groundwater and from deep groundwater (Uhlenbrook et al. 2002a). Each of these run-off sources; has a specific signature in terms of a tracer or isotope composition. In general the isotopic composition of the total run-off consist of the contribution from the three run-off sources, knowing the composition from each source, the contribution can be derived with the formula for tracer:

$$c_T Q_T = c_E Q_E + c_S Q_S + c_D Q_D$$

where

c_T = concentration total runoff [mg l^{-1}]

Q_T = total run-off [m^3 s^{-1}]

c_E = concentration event water [mg l^{-1}]

Q_E = run-off from event water [m^3 s^{-1}]

c_S = concentration shallow groundwater [mg l^{-1}]

Q_S = run-off from shallow groundwater [m^3 s^{-1}]

c_D = concentration deep groundwater [mg l^{-1}]

Q_D = run-off from deep groundwater [m^3 s^{-1}]

Suitable tracers or isotopes will be identified at the beginning of the research in this catchment. This technique will add to the knowledge on the processes within the catchment. It will complement the study on the conceptual models and will add to the analysis of the impact of new technologies in smallholder system on the hydrology.

Project 4B

Balancing Water for food and ecosystems at watershed and river basin scale: Integrated hydrological modeling in the Thukela river basin, South Africa

Victor Kongo[9]

This project aims to provide in-depth understanding of the hydrological regime of the Potshini 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 study will generate useful information to aid decision-making on policy development and reforms in the agricultural and water sectors particularly, with regard to hydrological impacts associated with adaptation and adoption of rainwater harvesting techniques.

Introduction

To fulfil some of the objectives of the SSI project in Thukela river basin, it was imperative to establish a catchment hydrology monitoring network. The Potshini catchment monitoring network comprises gauging structures and instruments, most of them automated, for measuring and monitoring stream flows, sediment load, run-off generated from run-off plots, shallow ground water table, volumetric soil moisture content, soil moisture wetting front, soil infiltration rates and meteorological parameters. Detailed description and methodologies applied in establishing the Potshini catchment monitoring network are highlighted in Kongo et al., (2005). The Potshini catchment monitoring network was established to fulfil a threefold mission aimed at:

- Monitoring the hydro-climatological regime of the Potshini catchment in an effort to have an in-depth understanding the hydrological processes in the catchment.
- Establish a capacity to assess, monitor, and manage water and environmental resources in the Potshini catchment especially within the local community in collaboration with the extension officers through training on the basic methodologies of catchment monitoring.
- Provide an opportunity for future and further research with a potential for upscaling and integrating into other networks.

The catchment monitoring network at Potshini has the potential to become an integral part of the decision making process, from farm to national level, on water and agricultural policy development.

Collaboration with other stakeholders and engaging the local community

The SSI research project collaborates with the Agricultural Research Council (ARC)-Bergville Landcare Project (Smith et al., 2004) at Potshini in Emmaus ward where Farmer-to-Farmer extension has proved

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[9] Institution: University of KwaZulu-Natal; Supervisory Team: Prof. Graham Jewitt, Prof. Roland Schulze and Prof. Simon Lorentz.

to be successful in adaptation of conservation tillage and other land management practices. The ARC-Landcare project uses a participatory action research approach which was incorporated in the SSI project. The SSI project has also established collaboration links with the Department of Water Affairs and Forestry (DWAF), especially, in establishing water user forums in the region covering the Potshini catchment. Good progress has so far been achieved in this exercise with the formation of emerging farmers' water user forums in 3 villages (wards) in the Bergville district, which brings together smallholder farmers who share a common objective of managing water resources in a sustainable manner.

It is important to note that, the culture and practices of the Potshini community were respected at all times by the SSI research team during any installation or research activities in the area. Such an approach is useful in perpetuating a conducive environment for interacting with the local community and hence the goodwill of the community to safeguard any installations in the area. Several farmers in the Potshini community are voluntarily participating in the following activities:

- Recording of daily rainfall
- Monitoring of soil moisture under different land management practices
- Monitoring of discharge from run-off plots on their farms
- Enabling a conducive environment for interacting with other members of the community

Measurement of meteorological parameters

The ARC-Landcare project has a telemetric weather station at the nearby De Boers farm since November 2002, and SSI has installed a second weather station in the catchment. Eight manual rain gauges for monitoring the spatial variation of daily rainfall events have been installed under the care and goodwill of some of the smallholder farmers in Potshini (figure 9). The recording of daily rainfall is done twice a day, i.e at 09h00 and 17h00, from which the daily average rainfall is calculated.

Figure 9. A smallholder farmer taking a reading from a manual rain gauge in Potshin.

Stream flow monitoring

Monitoring and measurement of stream flows is being done at two locations using a pressure transducer and a H-flume coinciding with nested catchments of 10km^2 and 1.2 km,^{2} respectively. Stream peak discharge (design flow) at different return periods was estimated using the Soil Conservation Service-South African version method, SCS-SA, (Schulze et al. 1992). The H-flume has a flow capacity of 3.34 m^3/s, and is equipped with an ISCO sampler, with a capacity of 24 sampling bottles, and controlled by an MCS data logger. Suspended sediment and flow variation are monitored.

Monitoring isotope compositions of run-off and groundwater

To understand rainfall partitioning, and as an input to hydrologic modeling, isotope composition (^{18}O, deuterium and chloride) will be measured on water samples taken from five sites (the H-flume, (1.2 km^2 catchment), the Pressure transducer (10km^2), two shallow groundwater wells and from a raingauge) at fortnightly intervals. This activity will add value to the ongoing monitoring of isotopic composition in the Thukela river basin.

Run-off plots

Eleven run-off plots (10m by 2.45m) have been installed in the catchment, an effort to investigate the influence and impact of conservation agriculture practices i.e., water use innovations, on surface run-off generating characteristics. The recording of run-off intensities in all run-off plots is facilitated by use of tipping buckets and HOBO-event data loggers. A sampling scheme has been established in five run-off plots to monitor sediment load in the overland flow from different tillage practices.

Soil Moisture Profiling

Soil volumetric moisture monitoring is being done using the Time Domain Reflectometry (TDR). A total of 16 access tubes of different lengths ranging from 1.2m to 1.5m have been inserted in various sites in the 1.2 km^2 Potshini catchment, most of them being in farms belonging to smallholder farmers and under different land management practices (conservation and conventional tillage practices). TDR readings are taken weekly at different soil depths.

Monitoring of shallow groundwater

The fluctuation of the ground water table at the Potshini sub-catchment is being monitored by use of 12 shallow groundwater observation wells. Two transects are monitored, one on each side of the 1.2km^2 catchment, and running more or less perpendicular to the general slope of the catchment. The wells were bored to bedrock and are monitored both using manual and automatic recording.

Electical resistivity sounding survey

Electrical resistivity sounding will be used to interpret and analyze linkages between surface and shallow ground water in areas where water-use innovations are being practiced, and to investigate whether such water use innovations have any significant influence on the occurrence of shallow ground water. Resistivity measurements will be done along several transects in the catchment. With this method the occurrence of geological formations, e.g. groundwater is mapped by “injecting” direct current through metal electrodes installed in the ground and measuring resistivity of the material through which the current moves (Lashkaripour 2003).

Monitoring of total evaporation ("Green Water Flows")

The Surface Energy Balance Algorithm for land (SEBAL) (Bastiaanssen et al. 1998a; Bastiaanssen et al. 1998b; Bastiaanssen et al. 2000) has been tried and applied to estimate actual evapotranspiration in the Potshini catchment and the surrounding region. A subset of cloud free 7-band satellite Landsat-ETM image (path 160, row 080) was used in this analysis as highlighted in Kongo and Jewitt, (2005). It is the expectation of this study to apply the SEBAL algorithm in real time situations and use the freely available NOAA/AVHRR and MODIS images (with spatial resolution of 1.1 km and 500m respectively) which has the advantage of almost daily scene coverage. The measurement of total evaporation from the Potshini catchment using scintillation techniques (Kite et al. 2000; Meijninger and Bruin 2000) will also be done.

Figure 10. Scintillometer at the Potshini catchment.

A Scintillometer measures sensible heat flux along a transect (typically less than 10km) from which the latent heat flux (total evaporation) can be computed as a residual in the surface energy balance equation after measuring the soil heat flux. The surface energy balance equation is given as:

$$LE = R_n - H - G$$

where:

LE = latent heat flux (W.m^{-2}), which is readily converted to total evaporation (mm)

R_n = net radiation (W.m^{-2})

H = sensible heat flux (W.m^{-2})

G = soil heat flux (W.m^{-2}).

The scintillation technique and SEBAL share a common background of exploring and trying to solve the energy balance equation on the earths' surface and linking the energy balance with the hydrological water balance through the evapotranspiration (total evaporation) process. The scintillation technique forms an intermediate scale of measurement and calibration of total evaporation between field (point measurement e.g weather station) and the large-area remote sensing SEBAL estimates with no instrument calibration requirement.

Hydrological modeling

The ACRU hydrological model (Schulze et al. 1995, 1998) will be configured for nested spatial scales (catchments) from 1.2 km^2 catchment to the larger 10 km^2 catchment. The measured run-off data will be used to calibrate and verify the ACRU modeling system at these scales. The ability of the ACRU model to represent physical processes explicitly and simulate impacts of land-use changes makes it a handy modeling tool in this research study, especially in assessing the hydrological impacts of upscaling water use innovations (rainwater harvesting) in the Potshini catchment and the Quaternary Catchments (operational catchments) in the Thukela river basin. The benefit of this configuration set-up is that the spatial extent of each land use category and the parameters associated with different land use management practices can be altered accordingly within the configuration, when the hydrology of different land-use scenarios is simulated in hydrological modeling using the ACRU model.

Project 5

Watershed Planning of System Innovations: Spatial Mapping of Environmental and Hydrological Determinants

IWMI, UNESCO-IHE, SEI: Position, to be filled[10]

This project will investigate water dependence and water impact of different land use types at watershed scale. It will use remote sensing to assess hydrological determinants, and develop the geographic component of the spatial zoning tool for assessment of technological fit.

Introduction

Water-related problems in rainfed agriculture in the water scarce Semi-arid Savannah Environment (SASE) are often related to high-intensity short-duration of rainfall with large spatial and temporal variability, rather than to low cumulative amount of rainfall. This rainfall pattern results in a high risk for meteorological droughts and intra-seasonal dry spells that lead to low crop yields and sometimes total crop failure. The major challenge therefore, is how to reduce the impact of such climatic disparities and cushion farmers against their effects on rainfed agriculture. Mitigation of intra-seasonal dry spells is a prerequisite for improving water productivity in rainfed agriculture in the SASE. This could be achieved by identifying and adopting agricultural and water systems innovations (WSIs) such as rain water harvesting, conservation farming, drip irrigation and precision irrigation so as to achieve more output per unit of water consumed, and hence ensuring food security. Water system innovations (WSIs) such as rainwater harvesting (RWH) are nowadays receiving a renewed attention because it is environmentally sound, and can easily be integrated with indigenous and traditional knowledge (Boers and Ben-Asher 1982).

The Research Context

This project will be conducted in two pilot Basins (Thukela in South Africa and Pangani in Tanzania) at three different scales. A suitable Spatial Decision Support System (SDSS) will be adopted to facilitate the identification of potential sites for various appropriate WSIs at watershed scale using a Multi-Criteria Evaluation (MCE) approach in which biophysical, hydrological and socio-economic characteristics of the area under investigation will be incorporated within a GIS environment. This procedure will then be applied to the basin scales in which spatial distribution of these WSIs will be obtained.

Impacts of upscaling and outscaling of these WSIs at basin level will be assessed with collaboration of Project 4 (balancing water for food and nature), and include agent-based modeling to incorporate spatially disaggregated social data in collaboration with Project 6 (institutions). The research will put more emphasis in the Pangani Basin. The research outputs would be used by decision makers and planners in drawing suitable and appropriate recommendations for improving watershed planning and management.

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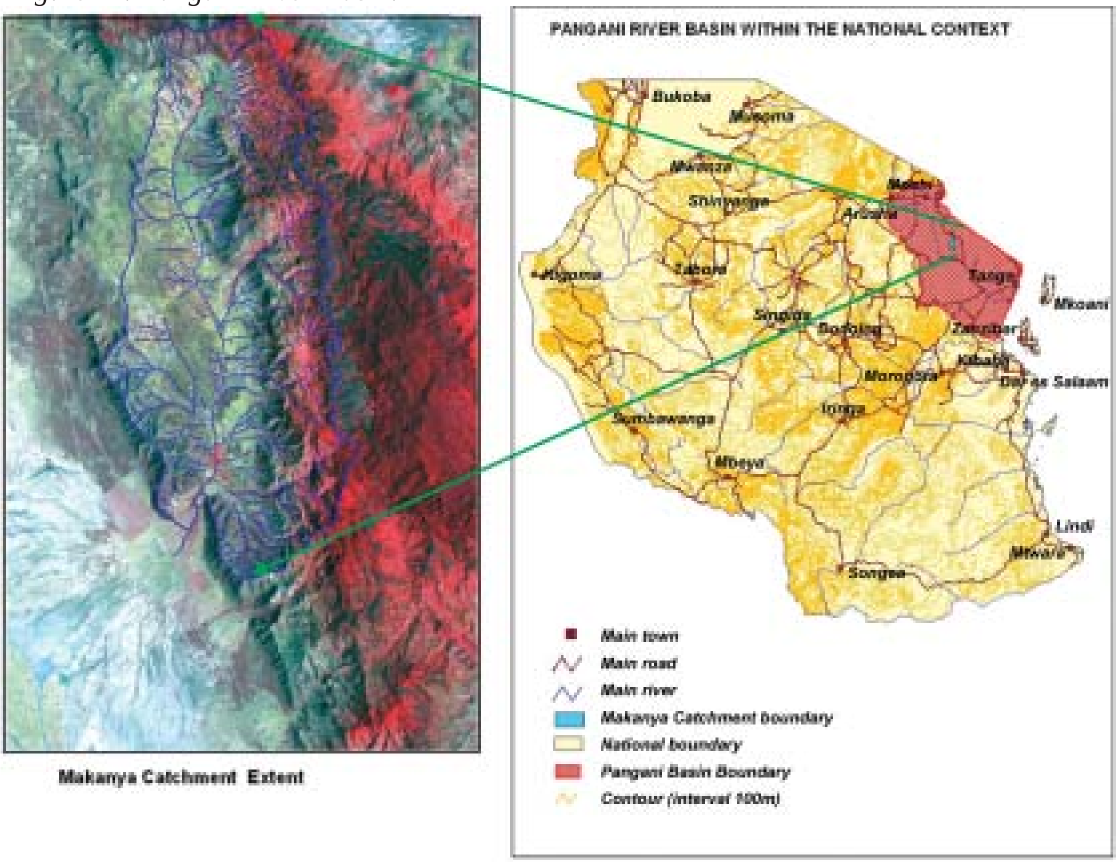
[10] Institute: IWMI, UNESCO-IHE, SEI; Supervisors: Dr. Hilmy Sally, IWMI, Dr. Peter van der Zaag, UNESCO-IHE, Dr. Tom Downing, SEI and Dr. Deborah Bossio, IWMI.

Figure 11. Pangani River Basin.



Project Goal

This research project aims at developing and implementing a spatial decision support system tool (SDSS) also referred here as the Multi-Criteria Evaluation (MCE). This tool would assist decision makers and planners in a multi-criteria selection of appropriate and suitable water resource management strategies geared towards the improvement of water resource management, and at the same time ensure equitable sharing of the resource between upstream and downstream users in nature and society. To achieve this goal, the study will apply a holistic and participatory research approach in which all stakeholders (farmers, pastoralists, water user groups, decision makers, GOs, NGOs, other interest groups) in water resource use and management will be involved in designing and implementation of a suitable SDSS. This system is intended to generate practical and field-based recommendations on institutions and policy arrangements that would enable the adoption of water system innovations (WSIs) and ensure sustainable watershed management.

For the above project goal to be achieved, the following specific objectives will be addressed:

- Identify potential and suitable sites for WSIs at watershed scale using a MCE
- Apply agent-based modeling to integrate farmer decision-making criteria with biophysical conditions in collaboration with Project 6.

- Develop a Spatial Decision Support System (SDSS) tool to facilitate planning and management of the water resource with capabilities of building alternatives such as “what if” scenarios.

- Evaluate the impacts of outscaling of different system innovations at watershed scale with the use of SDDS in collaboration with Project 4.

Project 6

Policy and Institutional Dimensions of Smallholder Systems Innovations in Integrated Watershed Management

IWMI, Unesco-IHE: Position to be filled [11]

This project will develop institutional and policy models that can be used as a guide to viable basin management for the attainment of sustainable water resources management and improved livelihood systems in the pilot basin in Tanzania and beyond.

Problem statement

Over the last decade, prompted by shifts in international thinking about natural resources management by donor conditionalities, and by fiscal crises, many developing countries have instituted sweeping reforms of their natural resource base, including new water, land and irrigation laws and policies. Closer analysis indicates that most water sector reforms are generally focused on management of blue water and exclude green water. On the other hand, agricultural policy is generally focused on modernisation of agriculture through extension services promoting soil and water conservation, crop management, and animal husbandry at the farm level. At the same time, local indigenous institutions for resource management have been eroded or stressed by factors such as population growth, resettlement, national policies and globalisation pressures. With the intention of modernizing agricultural processes and activities, governments have been interfering with the agricultural strategies of people at local levels. This has tended to disturb local institutions and may have led to increased dependence of local people on formal state institutions.

There is growing evidence that when rainfall is inadequate or unreliable and water shortages limit crop production, the uptake of resource conserving technologies can bring about sustainable agriculture for local communities. But despite the increasing number of such initiatives in many parts of the world, most of them remain localized success stories. It is felt that this is partly because smallholder system innovations, and the interactions between water for food and ecosystem services, are not properly addressed in terms of policy and regional and local institutional development.

It is also becoming increasingly clear that to increase productivity and resilience to climatic changes at the community level, there is a general need for new institutional arrangements that support rather than suffocate local initiatives.

Moreover, in cases where such innovations are being widely adopted, there is a need for strengthening water management institutions that will ensure equitable access to blue water resources, among the variety of users in the various parts of catchment areas and the river basin as a whole.

The *first* challenge of this research is to identify institutional arrangements and approaches that allow such innovations to be scaled up so that they spread beyond their small localities in both space and time.

The *second* challenge of this research is to analyze the institutional requirements of upscaling of smallholder systems innovations for water management.

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[11] Institution: IWMI, Unesco-IHE. Supervisors: Prof. Pieter van der Zaag (Unesco-IHE/University of Zimbabwe) and Dr. Barbara Van Koppen (IWMI, Pretoria, South Africa).

The hydrological impact of many farmers adopting system innovations in the upper catchments is increasingly being understood (e.g. by SSI Project 4). It is also emerging that the water management institutions that exist at the local level and which have evolved over time, need to enlarge their spatial span/ command area and interconnect. Institutional arrangements that used to govern water flows between members of the same community jointly owning a shared infrastructure (e.g. a furrow, a small dam (*ndiva*)), now also have to include water sharing arrangements with neighboring communities. It is expected that similar arrangements with more distant villagers have to be established in order to ensure equitable access to blue water. The complexity of such institutional arrangements increases with increasing spatial scale.

One of the questions to explore is how the existing hydrosolidarity (Falkenmark and Folke 2002) can be spatially upscaled by creating institutional linkages that reciprocate and mirror the water flows (for instance through so-called payment schemes for environmental services in watersheds, see e.g. Hermans and Hellegers 2005).

This research project will focus on institutional arrangements, support systems and policy requirements at different scales to enable adoption and sustainability of systems innovations like water harvesting, drip irrigation, and conservation farming. In particular, the necessary institutional and policy conditions to enable significant expansion in the use of these innovations will be examined, as well as the necessary institutional framework to monitor and manage the impacts at an appropriate aggregate level.

The innovation of this research project is that it will combine theories to understand the dynamics of adoption and use of systems innovations (including actor-network theory,[12] and theories on hydraulic property creation and entitlements[13]), with theories to understand collective action that is required as a result of the increased blue-water interdependencies in the catchment (game theory, theories of cooperation and competition, actor and agent-based approaches, intervention analysis[14]).

The research questions and methodology still have to be finalised. A preliminary outline is presented.

Research questions

1. *Farmers, system innovations and their linkages*

- How do farmers adopt and combine assemblages of technologies (“system innovations”) in order to secure crop yields and enhance the resilience of their farming systems? *[links with SSI projects 1 and 3]*

- From where do farmers draw the required resources (especially knowledge, labor, capital and social)? What is the implication of investing in land and water technologies for (perceptions of) entitlements?

- Into which web of relationships are innovative farmers drawn, including fellow farmers, businessmen, markets, NGOs and government support organisations?

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[12] E.g. Law (1994); for applications to water see Kortelainen (1999) and Van der Zaag et al. (2001).

[13] See Coward (1986a, 1986b); for entitlements, see Leach et al. (1999).

[14] See Axelrod (1997), Baland and Platteau (1999), Pahl-Wostl (2002), Long and Van der Ploeg (1989).

2. *Farmer institutions*

- What farmer institutions are in place at various scales to enhance agricultural production and water resources management. How have these institutions evolved over time?

- How do local institutions that govern shared blue water resources deal with competition and cooperation? What factors influence their effectiveness (or lack thereof)?

3. *Support organizations*

- Do farmer organizations link to formal governmental agricultural and water institutions, such as the extension service and river basin organizations; if so, what characterises these relationships?

- What internal and external support requirements are necessary to the successful upscaling and sustainability of the identified innovations? What specific roles can government, donors and development banks play (if any) that would lead to sustainable and dynamic scaling-up of improved water and land management technologies?

- If, as expected, improved land and water management leads to higher productivity, what is the potential market for the crops that may be grown? Will the markets be able to absorb the increased production, either locally, or regionally?

Enabling environment for sustainability

- How are global policies on water and agriculture understood at national level and implemented at the local level? What are the impacts of existing or new policies, legislation and institutions on existing farming, and water management practices?

- In what ways can characteristics of successful local level institutions be upscaled at catchment level, so as to address the increased interdependence between upstream and downstream blue water users?

- How do meso-level institutions maintain linkages with local level institutions, on the one hand, and with macro level institutions, on the other?

- What are the best modalities for monitoring, reporting and acting on the observed impacts on livelihoods, the local rural economy and socio-economic conflicts or synergies?

- What are the requirements for investment in terms of staffing, skills and operational resources, whether by government, civil society and/or the private sector, including smallholder farmers and their service providers, development banks, and donors?

Methodology

A semi-longitudinal case study methodology will be utilized focusing on the Pangani basin. The study is longitudinal, in that, while actual field data collection will take place over three years, effort will be made to dig deeper into the past and gain a detailed understanding of institutional arrangements that focus on the control and use of green and blue water. As a result, elements of the historical analytical profiling approach will inevitably be incorporated. This will come in the form of a review of the policies and institutions that have historically determined the nature of water management and agricultural productivity in Tanzania. Historical profiling will also be extended to the exploration of remarkable smallholder systems innovations that have been adopted in the study sites in the past up to the present.

The research will use methods primarily developed from social sciences, and will combine theoretical research with field surveys and data collection. The following methods will be used:

- Review of literature and experiences in each country
- Field surveys and structured interviews at various levels
- Detailed case studies of farmer innovations, farmer institutions and formal support organisations; at local, meso and macro scales, including "biographies" of selected technologies (see for example Van der Zaag 2003)
- Quantitative and qualitative observation and analysis
- Stakeholder meetings, consultation and key informant interviews

While the empirical field research will be designed at the basin level, focusing on specific innovations and their development paths, the literature review will be extended to national level to enhance an assessment of the role of specific policy variables. Also, data and information (both technical and sociological) generated by other researchers of the SSI program will be used in order to take advantage of the multidisciplinary nature of the SSI program.

Outreach, Action Research and Learning for improved development and policy impact of SSI Research

Yogesh Bhatt[15]

The outreach component of SSI is designed to address three important contemporary concerns when conducting applied research in the context of water, food and the environment. Firstly, how to ensure that the research is integrated–both between scientific disciplines, between stakeholders and scales–and driven by real needs on the ground. This requires a participatory action research approach, where learning and reflection forms an integral part of the research. Secondly, to ensure that the results of the research are fed into policy and development, not only in the locations of study, but also to other locations and stakeholder arenas. Thirdly, what is an effective approach to systematically learn from initiatives on the ground, such as the SSI program?

The outreach, action research and learning program contribute to improving the integrated research output, and ensure that there is a continuous reflection on the relevance and demand for SSI knowledge outputs, and gives SSI a channel to share lessons learnt through other international forums.

The outreach and learning component of SSI Program is coordinated by IWMI in partnership with two field-based organisations, viz. the Farmer Support Group (FSG), a South African development organization based at the University of KwaZulu-Natal and a designated SADC centre of excellence, and the Soil-Water Management Research Group (SWMRG), based at the Sokoine University of Agriculture, which has long term experience in Participatory Action Research and Learning. These organizations also provide support to the researchers during their field work and ensure the continuous presence of the SSI program in the two basins.

The goal of the SSI Outreach and learning strategy is:-

1. To strengthen the SSI program with an action research and outreach component that operationalizes and contextualises lessons learned from the SSI research, and extends this knowledge beyond the pilot catchments.

2. To disseminate knowledge and research methodologies from SSI within Sida-supported water initiatives in Southern Africa, through partnerships with other water initiatives, and development of appropriate capacity building materials.

3. To develop a framework for enhanced learning within SSI and for sharing lessons learnt from the SSI program, and thereby contribute meaningfully to the global water, food and environment agenda.

The outreach and learning activities of SSI will be very closely linked to - among others - the following projects:

- The Comprehensive Assessment of Water in Agriculture.
- CGIAR Challenge Program on Water and Food.
- UNESCO-HELP
- Millennium Ecosystem Assessment

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[15] Researcher/ Outreach and Learning Coordinator, International Water Management Institute- Southern Africa.

- IWMI, particularly the projects in Africa Region and KM Initiative
- SIDA funded projects focused on water management in Southern Africa.
- WaterNet – the capacity building network on integrated water resource management in Southern Africa, which is an important knowledge building and disseminating institution in Southern Africa (coordinated by UNESCO-IHE in Delft, a core partner of SSI).
- IWMI/Gender and Water Alliance/Dialogue activities in Tanzania and South Africa.

Implementation strategy

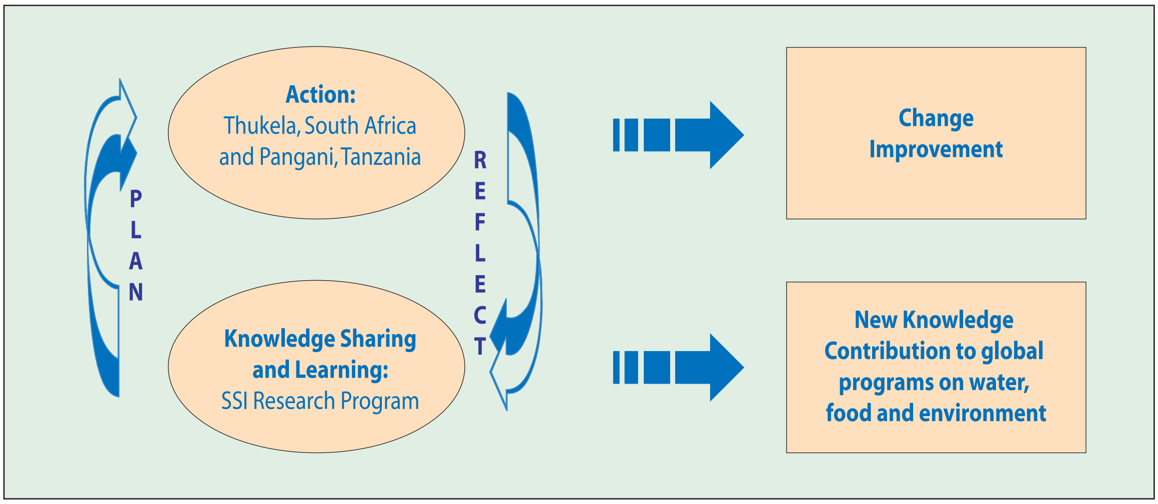
1. *Strengthening participatory research within the SSI program*

The key to success of the SSI outreach is that the SSI researchers have strong foundations on Participatory Action Research (PAR) and hence the first and foremost task being implemented in the program is to build the capacity of SSI researchers in Participatory Action Research, and application of participatory approaches in the life cycle of the project. Two in-depth training programs have so far been organized.

2. *Facilitating learning processes*

The SSI uses the simple Action Research Framework where planning, action, reflection and learning are continuous parts of a learning spiral. It uses the processes of developing strategies to share the lessons learnt from action research in the SSI program within projects and across basins, with Sida-supported and other initiatives in Southern Africa, and other similar projects contributing to the global agenda on water, food and the environment.

Figure 12. Framework for Action Research in SSI program.



SSI will liaise with Global Knowledge sharing Initiatives like: Dialogue on Water for Food and Environment, the Comprehensive Assessment on Water Management in Agriculture, the Challenge Program on Water for Food, the HELP program of UNESCO and the Ecosystem Millennium Assessment. The purpose is not only to share SSI research outputs but also gain from research and knowledge produced elsewhere.

In addition, SSI will establish communities of practices around common interest themes for exchange of experiences, stimulate creative thinking and knowledge generation. The program will also set-up appropriate systems/platforms for monitoring, evaluation, learning and information exchange.

3. Exchange lessons from SSI with other programs and contribution to the global Water, Food and Environment agenda

In order to disseminate the knowledge emerging out of the SSI program, SSI will develop appropriate Knowledge Sharing Products and strategies for dissemination, to stakeholders at different levels, for improved awareness on the issue and stimulating creative thinking. The exchange and sharing of SSI knowledge products will be facilitated in the two basins in partnership with Farmer Support Group of the University of Kwazulu Natal and the Soil and Water Management Group at Sokoine University in Tanzania. Partnerships will also be sought with other relevant organizations and networks (e.g. SEARNET, RELMA, PROLINNOVA).

The Knowledge Sharing vehicles that SSI will use, at various levels, over the project period include:

Field level

Target group-Community and Farmers' groups, Village leaders, Village Councils, Extension Workers, Water Users' Associations, etc.

Means: Field experiments, open field days, trainings, workshops and feed-back meetings, exchange visits, producing brochures, posters, leaflets, and information dissemination through program partners through their communication tools and networks, etc.

District/watershed Level

Target group-District Councils, District planning Agencies, Catchment Management Agencies, NGOs, local MPs and other development agencies, etc.

Means: Promoting local multi-stakeholder dialogues, regular newsletters, material support in form of toolkits and guidelines to organizations involved in district and level planning and implementation, sharing results as they come.

National and Policy level

Target Group-Policy makers, Government departments, National and International NGOs, Research and Academic Institutions, Development Programs and implementing partners, etc.

Means: National level policy dialogues, policy briefs, research reports and synthesis documents, articles in national, regional and international magazines.

Scientific Community level

Target Group-Research and scientific community, students, etc.

Means: Publications, research reports, synthesis documents, capacity building material for post-graduate education and courses on IWRM, participation in scientific conferences, workshops, etc.

SSI also intends to extensively use the local, national and international media for sharing SSI research outputs and promoting awareness. In addition, the SSI researchers will participate and share generated knowledge in national, regional and international meetings and conferences and other stakeholder and scientific forums.

Expected outputs of SSI outreach

It is expected that the SSI outreach and learning component will strengthen the delivery of relevant and appropriate integrated research outputs from the SSI program. It will further improve the replicability of SSI research outputs in other similar multi-disciplinary action research programs. It is expected that the methods, tools, learning strategies and other products generated from SSI research will be widely used by development and policy initiatives in integrated water resource management. Since the program focus is Southern Africa, most of the policy briefs, fact sheets, and training materials will target mid to senior level water managers in Southern Africa. In addition, the program intends to synthesize the learning to develop capacity building materials for use in post-graduate education and short courses on IWRM. And finally, the lessons learnt from SSI research will shared with other global programs on water, food and environment and will be recognized as a key contribution to the global water, food and environment agenda.

Participatory Research in the Makanya catchment.

REFERENCES

Allen, R.G.; Pereira, L.S; Raes, D; and Smith, M. 1998. Crop evapo-transpiration: Guidelines for computing crop water requirements. FAO Irrig. and Drain. Paper 56. FAO, Rome.

Axelrod, R. 1997. The complexity of cooperation: Agent-based models of competition and collaboration. Princeton University Press, Princeton NJ; 232pp.

Baland, J.M.; Platteau, J.P. 1999. The ambiguous impact of inequality on local resource management. World Development 27(5): 773-788.

Barron, J. 2004. Dry spell mitigation to upgrade semi-arid rainfed agriculture: Water harvesting and soil nutrient management for smallholder maize cultivation in Machakos, Kenya. Doctoral thesis in Natural Resource Management; Department of Systems Ecology Stockholm University, Stockholm: Sweden.

Bastiaanssen, W. G. M. 2000. SEBAL-Based Sensible and latent heat fluxes in the irrigated Gediz Basin, Turkey, Journal of Hydrology 229: 87-100.

Bastiaanssen, W. G. M.; Menenti, M.; Feddes, R. A.; Holtslag, A.A.M. 1998a. A remote sensing Surface Energy Balance Algorithm for Land (SEBAL), Part 1: Formulation, Journal of Hydrology 212-213: 198-212.

Bastiaanssen, W.G.M.; Pelgrum, H.; Wang, J.; Ma, Y.; Moreno, J.; Roerink, G.J.; van der Wal, T. 1998b. The Surface Energy Balance Algorithm for Land (SEBAL), Part 2: Validation, Journal of Hydrology 212-213: 213-229.

Berkes, F.; Colding, J.; Folke, C. (editors). 2003. Navigating Social-Ecological Systems: Building Resilience for Complexity and Change. Cambridge University Press, Cambridge, UK.

Carpenter, S.R.; Westley, F; Turner, M.G. Surrogates for Resilience of Social–Ecological Systems. Ecosystems, 8(8): 941–944.

Conway, G. 1997. The Doubly Green Revolution: Food for All in the Twenty-First Century. Penguin Books, USA, p. 334.

Coward, W.E. 1986a. State and locality in Asian irrigation development: The property factor, in: K.C. Nobe and R. K. Sampath (eds.), Irrigation management in developing countries: current issues and approaches. Studies in water policy and management no. 8. Westview Press, Boulder and London; pp. 491-508.

Coward, W.E. 1986b. Direct or indirect alternatives for irrigation investment and the creation of property, in: K. William Easter (ed.), Irrigation investment, technology, and management strategies for development: Studies in water policy and management no.9. Westview Press, Boulder and London; pp. 225-244.

Daily, G. (ed.). 1997. Nature ̀s Services - Human Dependence on Natural Ecosystems. Island Press, Washington, DC, USA.

Droogers, P.; and Kite,G. 2001. Estimating productivity of water at different spatial scales using simulation modeling. Research Report 53. Colombo, Sri Lanka: International Water Management Institute.

Falkenmark, M.; and Folke, C. 2002. The ethics of socio-ecological catchment management: towards hydrosolidarity. Hydrology and Earth System Sciences 6(1): 1-9.

Falkenmark, M.; Rockstro¨m, J. 2004. Balancing Water for Man and Nature: The new approach to ecohydrology. EarthScan, UK.

Falkenmark, M.; Rockström, J. 2005. Rain: The Neglected Resource. Swedish Water House Policy Brief Nr. 2. SIWI.

FAO. 2002. Agriculture: Towards 2015/30. Technical Interim Report, FAO, Rome. Available from: *http://www.fao.org/es/esd/at2015/toc-e.htm*>.

Fox, P.; Rockström, J.; Barron, J. 2005. Risk analysis and economic viability of water harvesting for supplemental irrigation in semi-arid Burkina Faso and Kenya. Agricultural Systems 83. p231–250.

Hermans, L.; Hellegers, P. 2005. A “new economy” for water for food and ecosystems; synthesis report of E-forum results. FAO/Netherlands International Conference Water for Food and Ecosystems, The Hague 13 January. URL: *ttp://www.fao.org/ag/wfe2005/*

Kite, G. W. ; Droogers, P. 2000. Comparing evapotranspiration estimates from satellites, hydrological models and field data; Journal of Hydrology 229: 3-18.

Kongo, V.M.; Jewitt, G.P.W. 2005. Preliminary investigation of catchment hydrology in response to agricultural water use innovations: a case study of the Potshini catchment-S. Africa, paper submitted to the 12th SANCIAHS symposium, Eskom convention center, Midrand, South Africa.

Kongo, V.M.; Jewitt, G.W.P; Lorentz, S. 2005. Establishment of a catchment monitoring network through a participatory approach in the Potshini catchment in Thukela river basin. Manual. Smallholder System Innovations (SSI) research program. School of Bio-resources Engineering and Environmental Hydrology, University of KwaZulu-Natal, S.Africa.

Kortelainen, J. 1999. The river as an actor-network: the Finnish forest industry utilization of lake and river systems. Geoforum 30: 235-247.

Kosgei, J. R. 2000. Impact Assessment of Irrigation Water Abstraction on River Flow Systems in Usangu Plains, Tanzania. Unpublished MSc thesis. University of Dar-Es-Salaam, Tanzania.

Lashkaripour, G.R. 2003. An investigation of groundwater condition by geoelectrical resistivity method: A case study in Korin aquifer, southeast Iran. Journal of Spatial Hydrology, Vol.3, No.1.

Leach; Mearns; and Scoones. 1999. Environmental Entitlements: Dynamics and institutions in community-based natural resources management. World Development, Vol. 27. No. 2 pp 225-247.

Long, N.; and van der Ploeg, J.D. 1989. Demythologizing planned intervention: an actor perspective. Sociologia Ruralis 29(3/4): 226-249.

Lundgren, L. 1993. Twenty years of soil conservation in Eastern Africa. RSCU/Sida, Report No. 9, Nairobi, Kenya, p. 47.

McCown, R.L.; Hammer, G.L.; Hargreaves, J.N.G.; Holzworth, D.P.; and Freebairn, D.M. 1996. APSIM: A novel software system for model development, model testing, and simulation in agricultural research. Agricultural Systems 50: 255-271.

McIntosh, R.J.; Tainter, J.A.; McIntosh, S.K. 2000. The way the wind blows: climate, history, and human action. Columbia University Press: New York.

Meijninger, W.M.L.; and Bruin, H.R.A. 2000. The sensible heat fluxes over irrigated areas in western Turkey determined with large aperture scintillometer. Journal of Hydrology, 229: 42-49.

Ngigi, S. N.; Savenije, H.H.G.; Thome, J. N.; Rockström, J.; Penning de Vries, F.W.T. 2005. Agro-hydrological evaluation of on-farm rainwater storage systems for supplemental irrigation in Laikipia district, Kenya. Agricultural Water Management 73, 21–41.

Olsson, P.; Folke, C.; Berkes, F. 2005. Adaptive Co-management for Building Resilience in Social–Ecological Systems. Environmental Management, 34: 75–90.

Pahl-Wostl, K. 2002,.Towards sustainability in the water sector–the importance of human actors and processes of social learning. Aquatic Sciences 64: 394-411.

Parr, J.F.; Stewart, B.A.; Hornick, S.B.; Singh, R.P. 1990. Improving the sustainability of dryland farming systems: A global perspective, in: Singh, R.P.; Parr, J.F.; Stewart, B.A. (Eds.), Dryland Agriculture Strategies for Sustainability. Advances in Soil Science, vol. 13. New York, USA, pp. 1–8.

Peterson, G.D.; Beard, D.; Beisner, B.; Bennett, E.; Carpenter, S.; Cumming, G.; Dent, L.; and Havlicek,T. 2003. Assessing future ecosystem services: A case study of the northern highland lake district, Wisconsin. Conservation Ecology 7(3): 1. [online] URL: *http://www.consecol.org/vol7/iss3/art1*

Redman, C.L. 1999. Human impact on ancient environments. The University of Arizona Press, Tucson, Arizona, USA.

RELMA. 2002. Annual Report of the Regional Land Management Unit (RELMA). RELMA, Nairobi, Kenya.

Rockstro¨m, J. 2003. Water for food and nature in the tropics: vapour shift in rainfed agriculture. Invited paper to the special issue 2003 of Royal Society Transactions B Biology, Theme Water Cycle as Life Support Provider.

Rockstro¨m, J.; Barron, J.; Fox, P. 2003. Water productivity in rainfed agriculture: challenges and opportunities for smallholder farmers in drought-prone tropical agro-ecosystems. In: Kijne, W.J., Barker, R., Molden, D. (Eds.), Water Productivity in Agriculture: Limits and Opportunities for Improvement, Comprehensive Assessment of Water Management in Agriculture, No. 1. CABI Publishing, Wallingford, UK, pp. 145–163.

Rockstro¨m, J.; Falkenmark, M. 2000. Semi-arid crop production from a hydrological perspective – Gap between potential and actual yields. Critical Review of Plant Science 19 (4), 319–346.

Rockstro¨m, 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 (2004) 1109-1118.

Rockström, J. 2003. Resilience building and water demand management for drought mitigation. Physics and Chemistry of the Earth 28, 869-877.

Schmidt, E.J.; Schulze, R.E.; Dent, M.C. 1987. Flood Volume and Peak Discharge from Small Catchments in Southern Africa, based on the SCS technique: Appendices. WRC report No. 155 (TT 32/87).

Schulze, R.E. 1995. Hydrology and agrohydrology, a text book to accompany the ACRU 3.00 Agrohydrological Modelling System; Water Research Commission, Pretoria RSA Report TT69/95.

Schulze, R.E.; Schmidt, E J.; Smithers, J. C. 1992. PC-based SCS design flood estimates for small catchments in Southern Africa. Department of Agricultural Engineering, University of Natal.

Schulze, R.E. 1998. Modeling hydrological response to land use and climate change: A South African perspective. Report 27, University of Natal, Pitermaritzburg, RSA, ACRUcons p. 30.

Smith, H.J.; Trytsman, G.; Bloem, J.F.; Everson, T.; Mthethwa, S. 2004. Development and implementation of sustainable land management practices in the Bergville district of the KwaZulu-Natal Province. Fourth progress report, Bergville/Emmaus Landcare project 2003/2004.

Taylor, V.; Schulze, R.E.; Jewitt, G.P.W.; Pike, A.; Horan, M.J.C. 2001. Practical issues of HELP: Examples from the Thukela Basin in South Africa. Proceedings of the AWRA/University of Dundee International Specialty Conference on Globalization and Water Management. *http://www.awra/org*

Uhlenbrook, S.; Frey, M.; Leibundgut, C.; Maloszewski, P.; 2002a. Hydrograph Separations in a Mesoscale Mountainous Basin at Event and Seasonal Timescales. Water Resources Research, Vol. 38 (6), 31 1-13.

Uhlenbrook, S.; Leibundgut, C. 2002b. Process-oriented catchment modeling and multi-response validation. Hydrol. Process. 16, 423-440.

Van der Leeuw, S.E. 2000. Land degradation as a socionatural process. In: McIntosh, R.J.; Tainter, J.A.; McIntosh, S.K. (Eds.) 357-383. The Way the Wind Blows: Climate, History and Human Action. Columbia University Press, New York.

Van der Zaag, P. 2003. The bench terrace between invention and intervention; physical and political aspects of a conservation technology. In: A. Bolding, J. Mutimba & P. van der Zaag (eds.), Agricultural intervention in Zimbabwe: new perspectives on extension. University of Zimbabwe Publications, Harare; pp. 184-205.

Van der Zaag, P.; Bolding, A; and Manzungu, E. 2001. Water-networks and the actor: The case of the Save River Catchment, Zimbabwe. In: P. Hebinck & G. Verschoor (eds.), Resonances and dissonances in development; actors, networks and cultural repertoires. Van Gorcum, Assen; pp. 257-279.

Van Heerden, P.; Crosby, C. 2002. A computer program for the estimation of crop irrigation requirements and for the planning of water requirements by Water User Associations.

Walker, B.; Carpenter, S.; Anderies, J.; Abel, N.; Cumming, G.; Janssen, M.; Lebel, L.; Norberg, J.; Peterson, G.D.; and Pritchard, R. 2002. Resilience management in social-ecological systems: a working hypothesis for a participatory approach. Conservation Ecology 6(1): 14.

Young, M.D.B.; Gowing, J.W.; Wyseure, G.C.L.; Hatibu, N. 2002. Parched-Thirst: Development and validation of a process-based model of rainwater harvesting. Agricultural Water Management 55; 121–140.

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