CGIAR Challenge Program on
WATER & FOOD

2nd International Forum on Water and Food

Addis Ababa Ethiopia
November 10 -14 2008

Volume III

Water benefits sharing for poverty alleviation and conflict management

- Understanding impacts of water allocation, storage and use
- Agriculture, water and environment and payment for environmental services
- Benefits and costs of multiple use water systems

Drivers and processes of change

- Higher level institutions and policies
- Impact of water-for-food research on poverty alleviation
- Scaling up and out of food and water innovations

Co-hosted by: ILRI International Livestock Research Institute; IWMI International Water Management Institute

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CGIAR Challenge Program on Water and Food
2nd International Forum on Water and Food

Fighting Poverty Through Sustainable Water Use: Volumes I, II, III and IV.

Proceedings of the CGIAR Challenge Program on Water and Food 2nd International Forum on Water and Food, Addis Ababa, Ethiopia, November 10—14, 2008.

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Note on cover design:	The Amharic lettering in the lower right hand corner translates as "International Program and Water and Food". The colours in the keyline at the bottom of the page are those of the Ethiopian Flag, and the obelisk is a famous landmark of Axum – a historic city of Ethiopia and a world treasure. Their inclusion on the cover and use in other Forum print materials is recognition of the wonderful hospitality of the Ethiopian people and a thank you for being such a generous host country for the 2nd International Forum on Water and Food.

Foreword

Every two years the CGIAR Challenge Program on Water and Food holds an International Forum on Water and Food, during which we present our research results, debate these, and consider ways in which we can better deliver these into impact. Another important function of this second Forum is to consolidate CPWF research priorities for our second 5-year phase starting in 2009.

We are particularly glad to introduce these four volumes of papers and posters originating from CPWF phase one projects. All papers were peer-reviewed, and a total of 154 papers selected for publication in these proceedings. They include papers from all 9 Basin Focal Projects, 30 of the 1st competitive call projects, 3 of the Small Grants projects for innovation, and 2 Themes.

We wish to congratulate all of you who contributed papers to these proceedings, and thank you for the tremendous enthusiasm and cooperation enabling us to meet very tight publication deadlines so that all papers could be available, in hard copy, at the Forum. All this was achieved in less than 9 months, from the time of the call for Abstracts to release at the Forum.

We are also proud of the excellent teamwork of the CPWF Theme Leaders and Basin Focal Project Leadership teams, who worked very hard reviewing abstracts, reviewing and editing papers, checking revised papers, and who designed and selected the papers for the sessions, based on your submissions.

The publication of these proceedings is the result of a truly CPWF global community effort. We also thank Reg and Ida MacIntyre for their careful editing to tight deadlines.

The papers and posters are provided in 4 volumes as follows:

Volume I – 4 invited **Key Concept Papers** from the Phase 1 projects, and 1 invited **Keynote Paper** from Dr Carlos Sere, DG of ILRI entitled 'Swimming upstream' – the water and livestock nexus, and 36 papers on **Cross-cutting topics**: Agriculture, water and health; Governance: linking communities across boundaries; Innovative modelling tools; Participatory modelling and knowledge integration; and Resilience to climate change

Volume II – 44 papers from Phase 1 projects directly relevant to the CPWF Phase 2 Topic 1 **Increasing rainwater productivity** and 21 papers relevant to Topic 2 **Multi-purpose water systems**

Volume III –23 papers from Phase 1 projects directly relevant to CPWF Phase 2 Topic 3 **Water benefits sharing for poverty alleviation and conflict resolution,** and 25 papers relevant to Topic 4 **Drivers and processes of change**

Volume IV – 40 Project Posters by Phase 1 Projects of the Challenge Program on Water and Food

Five years is at the same time long from an outside perspective, but short for multi-disciplinary projects including partners from different horizons, backgrounds, and often river basins. These Proceedings present many, but not all, of the fine achievements and outcomes of the CPWF Phase 1 projects.

Dr. Jonathan Woolley
Program Coordinator

Dr. Alain Vidal, Cemagref
Forum Convener, Chair Organising Committee

CGIAR Challenge Program on Water and Food
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Understanding impacts of water allocation, storage and use

Small reservoirs, big impacts? Exploring alternate models of river basin development

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Abstract

Over the past century, a particular model of river basin development has dominated water resources planning and policymaking. This is the model of large, centralized storages in the form of a dam, connected to a network of constructed canals and hydraulic infrastructure to harness the runoff from catchment areas. This requires large investments of capital and high technical skills to construct and maintain, and is usually financed and managed by the state. In recent decades, however, certain water-scarce regions in India have witnessed an alternative model of river basin development, largely independent of the state, and involving a large number of decentralized and distributed storages across the river basin. These storages are created through numerous tiny check-dams built by communities, with or without technical and financial inputs from the State. This paper presents work-in-progress on understanding the impacts of small, distributed storages in river basins. The paper reviews the discussion, views, and counter-views about the downstream hydrological impacts of upstream water harvesting and recharge. In addition, it views the socioeconomic impacts of such an intervention by exploring potential impacts on the total value created in a river basin. Further, the paper discusses various governance implications of such a distributed storage model. The paper ends with ways forward and outlines an agenda for in-depth research and analyses on the issue.

Media grab

Small reservoirs can have big impacts on a basin's hydrology and governance systems and therefore should not be neglected by policymakers.

Introduction

Historically, civilizations have developed around rivers and river basins. In the past century, a particular model of river basin development has tended to dominate planning and policymaking. This is the model of developing river basins through large, centralized storages in the form of a dam, connected to a network of constructed canals and hydraulic infrastructure to harness the runoff from catchment areas. Such a model requires large investments of capital and high technical skills to construct and maintain, and is usually financed and managed by the state. Users of such centralized systems (mostly farmers, but also other stakeholders such as domestic users and industrial users) are often passive recipients of the benefits (or dis-benefits) of the project (Gupta and Van der Zaag, 2007).

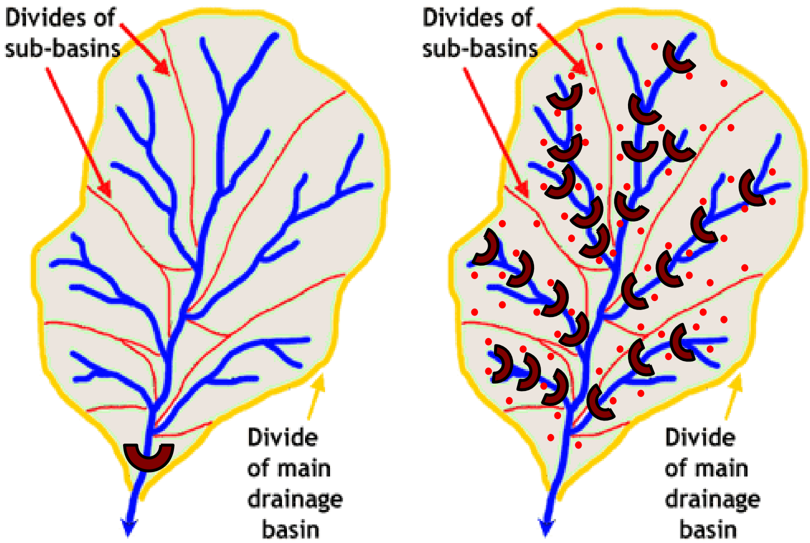

Figure 1: Two alternate models of river basin development–Centralized (left) and Decentralized (right) water harvesting.
Source: Modified version of original figure in Gupta and Van der Zaag (2007)

In recent decades, however, certain water-scarce regions in India (as well as some parts of Africa) have witnessed an alternative model of river basin development that occurred autonomously and largely independent of the state, and involves a large number of decentralized and distributed storages all across the river basin. These storages are created through numerous tiny check-dams that are built by communities themselves, with or without technical and financial inputs from the state. The water captured in these tiny storages is used for supplemental irrigation. The greatest benefit of these storages, however, is argued to be the groundwater recharge that they facilitate. The model is thus largely privately financed and involves much simpler technical inputs from the local communities themselves.

The efficacy of this alternate, decentralized and distributed model has been an issue of debate within academic and policy circles. Scientists have argued that large-scale and unplanned harvesting of water by catchment communities leads to negative consequences downstream. On the other hand, proponents of this decentralized model have argued that these decentralized structures, being small, have little or no impact on the large reservoirs downstream. They have further argued that these structures benefit poor people, require less investment, improve the groundwater situation, cause less environmental damage, are demand-driven, and managed by the local communities.

Decentralized water harvesting and storages in India

There already exist instances of decentralized water harvesting in many parts of India. These have often emerged as a response to water scarcity and the resultant hardships faced by farmers in arid and semiarid regions. In fact, intensive decentralized water harvesting and groundwater recharge is suggested as an alternative to the Government of India's massive plan to link rivers to facilitate inter-basin water transfers under the National River Linking Program (NRLP).

While there has been a lot of debate on the merits and demerits of decentralized water harvesting and recharge at the local level, especially in western India (Agarwal and Narain, 1997; Badiger et al. 2002; Kumar, 2000; Shah, 2002; Sharma, 2002; Athawale, 2003), formal studies to assess the hydrological and socioeconomic benefits of these at the basin level are scarce (Kumar et al. 2006). The basin level impacts of such harvesting have appeared in policy debates, though largely through anecdotal evidence. The Government of Rajasthan, for instance, took strong exception to Tarun Bharat Sangh's Laava ka Baas dam, arguing that it was basically capturing the water that would normally have flowed down to Bharatpur. (Tarun Bharat Sangh (TBS) is an NGO led by Magsaysay award winner Rajendra Singh which works with rural communities in Alwar district of Rajasthan.) There are also reports about how 'indiscriminate' rainwater harvesting in the upper catchment is preventing the Jayakwadi reservoir in Maharashtra from filling. Even in Saurashtra–home to what is perhaps the largest people's movement of its kind in the world–doubts have been raised that the popular water harvesting and groundwater recharge movement might have affected the storage in reservoirs downstream (Verma and Phansalkar, 2007).

The following excerpt from Shah (2005) sums up the conflict and confusion about the people's movement in Saurashtra:

'It is difficult to assess the social value of this movement partly because 'formal hydrology' and 'popular hydrology' have failed to find a meeting ground. Scientists want check dams sited near recharge zones; villagers want them close to their wells. Scientists recommend recharge tubewells to counter the silt layer impeding recharge; farmers just direct floodwaters into their wells after filtering. Scientists worry about upstream-downstream externalities; farmers say everyone lives downstream. Scientists say the hard-rock aquifers have too little storage to justify the prolific growth in recharge structures; people say a check dam is worthwhile if their wells provide even 1000 m^3 of life-saving irrigation/ha in times of delayed rain. Hydrologists keep writing the obituary of recharge movement; but the movement has spread from eastern Rajasthan to Gujarat, thence to Madhya Pradesh and Andhra Pradesh. Protagonists think that with better planning and larger coverage, decentralized recharge movement can be a major response to India's groundwater depletion because it can ensure that water tables in pockets of intensive use rebound to predevelopment levels at the end of the monsoon season every year they have a good monsoon.'

Stages of river basin and irrigation development

A river basin goes through various stages of development over time. Experience from India suggests that until the 1830s, most irrigation was restricted to riverine irrigation through diversions and dryland farming away from streams. In this stage, the community acts as the unit of irrigation management and there is little role for individuals or the state. The period of state-controlled irrigation (1830-1970) was marked by large-scale construction of big dams and canals that were centrally planned and had defined command areas, meant for full-irrigation. Post 1970, India saw the rapid expansion of pump irrigation, within, as well as outside command areas of centralized irrigation systems. This is largely privately financed and allows farmers greater 'water control' for managing a distributed, on-demand, atomistic irrigation system (Shah, 2008).

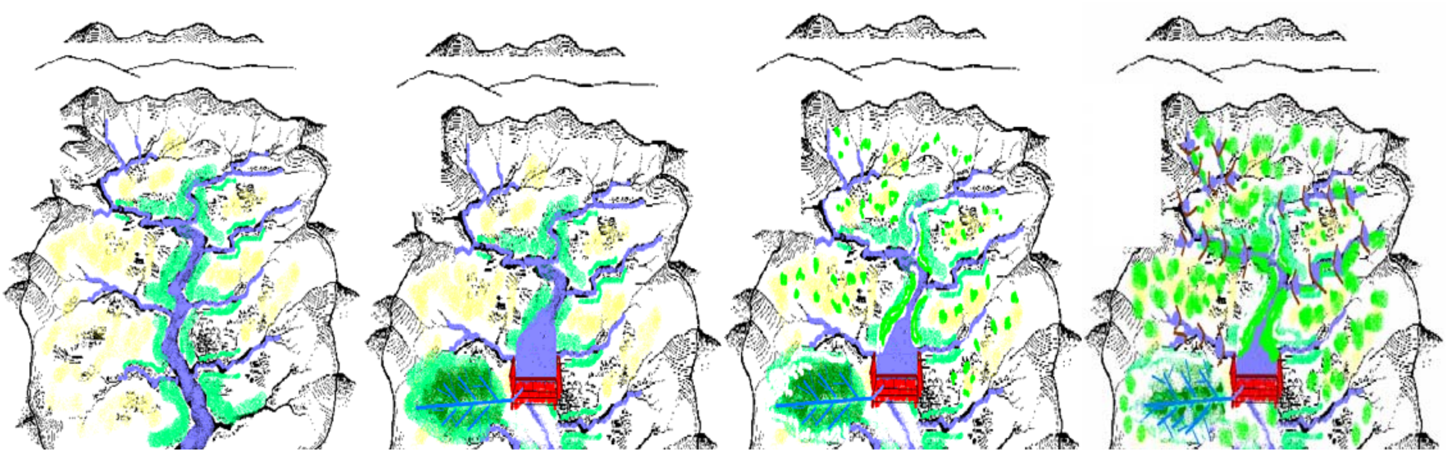

Figure 2. Stages of river basin development.
Source: Shah (2008).

As mentioned above, the past few decades have seen a spontaneous reconfiguration of river basins by the communities through creation of tiny decentralized storages. Such an intervention has changed the irrigation configuration of river basins from 'full or no irrigation' to 'supplemental irrigation.' Various aspects of this spontaneous reconfiguration, however, are still poorly understood.

Basin hydrology

The first question to be addressed is: 'which water is harvested by these small reservoirs and to what effect?' This can be done with the help of a study of Basin Water Accounts.

Each basin or sub-basin potentially has some so-called *unutilizable* (due to spatial and temporal variability in precipitation) and some *unutilized* or *uncommitted* water resources. As long as the decentralized storages tap uncommitted flows, there does not seem to be any reason for negative downstream impacts. In fact, water harvesting in the upper catchments may reduce siltation downstream and may lead to improved groundwater regimes, since the water that gets recharged upstream might be available for use downstream in the form of groundwater. In closing or closed basins, however, where there are little or no uncommitted flows, harvesting and recharge upstream might impact flows downstream.

Can distributed storages tap the unutilizable resources in a basin? Can they do this without negatively impacting the large storages and ecology downstream? Can the optimal/potential size of distributed storages be known from such a water accounting exercise? A lot depends on the reliability and frequency of rainfall, the rainfall runoff relationship, the already established uses in the valleys downstream, and the stage of basin development (Molden et al., 2001; Kumar et al., 2006). Furthermore, the impact of intensive decentralized water harvesting on lean season flows and its environmental impact needs to be studied.

As well, the impact of a highly variable and unpredictable rainfall regime needs to be understood properly. Most of these semiarid regions receive very little rainfall, much of which falls in a very few days, often causing flash-floods in an otherwise drought-prone area. Large reservoirs built downstream are designed to capture dependable runoff while the distributed reservoirs can capture the runoff in extreme events.

Socioeconomic impacts

It has been argued that in regions facing high inter-year rainfall variability and low reliability, decentralized water harvesting might be prohibitively costly in terms of cost per cubic meter of water (vis-à-vis centralized storage systems), and may produce limited benefits (Moench and Kumar, 1993). At the same time, Anil Agarwal, one of the key proponents of the Rainwater Harvesting Movement in India, argued that scientific evidence from the Negev Desert in Israel suggests that decentralized water harvesting can capture as much as five times more water vis-à-vis centralized storages, rendering the centralized storage system highly cost-ineffective (Agarwal, 2001).

The efficiency of large-scale surface irrigation systems in India is very low. The average efficiency of surface irrigation systems has been estimated to be less than 40%! Considering that, on an average, large irrigation systems are only able to deliver 40% of the water stored, does it make more sense to store the water upstream in decentralized storages? The distributed storages are likely to be planned for supplemental irrigation, thereby creating more direct economic value per drop. On the other hand, large-irrigation projects have strong multiplier effects within and outside the command areas. This research proposes to compare the efficiencies of large-scale irrigation projects vis-à-vis distributed storages. The comparison would include water storages, evaporation losses, conveyance, distribution and application efficiency, in addition to a study of the economic value generated by the water use under the two models of development.

Most upstream communities in Indian river basins are poor and politically marginalized, deprived of irrigation under the centralized river basin development models. Since the decentralized river basin development model offers catchment communities greater access and control over their water resources, the social equity impact of such interventions can be significant. It has been argued that even at the cost of losses downstream, it might make sense to promote upstream storages given that upstream communities are poorer. In addition, there exist possibilities of exchange mechanisms between upstream and downstream communities on the lines of 'Payments for Environmental Services' (PES).

Let us assume, hypothetically, that upstream harvesting results in benefits to the tune of Rs. X for upstream communities while at the same time causing losses downstream to the tune of Rs. Y. If Y > X, and if we assume that upstream communities have rights to use the water flowing through their lands, downstream communities can reimburse Rs. X to upstream communities in exchange for allowing the water to flow uninterrupted. Such an arrangement would ensure that upstream communities do not lose out on the potential benefits from decentralized harvesting while at the same time, the centralized storages created downstream can also continue to operate without any conflicts.

Can objectives of social equity in themselves justify reconfiguration of river basins in favor of distributed storages? Can the economic efficiency comparisons above be redone by assigning higher weights to value generated upstream on equity grounds? Is there scope for development of an exchange mechanism between upstream and downstream communities on the lines of PES?

River basin governance

A distributed storage model will require special governance structures to ensure coordination and to avoid conflicts at the watershed/river basin level. This might involve the need for river basin/sub-basin level institutions to check and control the amounts of water being harvested at different scales. It would also involve ensuring that the decentralized storages do not compete with each other for the same flow–through proper citing, capacities and allocations–in above normal, normal, and below normal rainfall years. Do we have the institutional capacities for this? What institutional design may best work to manage this? How does this institutional complexity compare with the institutional complexity required to manage large centralized surface irrigation projects?

Discussion

Data from a small sub-basin in Saurashtra in western India suggests that in drought years, flows to downstream reservoirs indeed get affected by increased water harvesting in the catchment areas. In good rainfall years, however, the total amount of water harvested in the basin would increase with little or no negative impacts downstream. Thus, for the basin as a whole, the impact of additional decentralized harvesting would be positive. Even in drought years, where additional water gets harvested upstream at the cost of downstream reservoirs, if the water-use efficiency in upstream areas is greater than or equal to the water-use efficiency in the command areas of centralized reservoirs, the net impact at the basin level would be positive.

Furthermore, given the high evaporation rates and low rainfall-runoff coefficients, the amount of water captured for economic use in drought years would increase as a result of decentralized water harvesting. These results however, need to be backed up with proper hydrologic monitoring and analysis, in addition to socioeconomic surveys to estimate the value created by water-use by upstream as well as downstream communities. The governance of such *hybrid* basins, with centralized as well as decentralized reservoirs, presents new challenges and opportunities for water managers and policymakers. What is clear is that these small reservoirs can no longer be ignored in water policy discussions, and their hydrologic and socioeconomic impacts must be incorporated in future river basin development discussions.

Acknowledgments

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The paper was prepared as part of ongoing doctoral research work of Shilp Verma at UNESCO-IHE, Delft, The Netherlands, and stems from a research grant from PN48 that partly supports the candidate's field research in India in 2008.

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Evaluation of water availability and allocation in the Blue Nile Basin

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Abstract

The Blue Nile River is the principal tributary of the Nile River, providing about 62% of the flow reaching Aswan Dam (48-52.5 km3/y) in Egypt. Ethiopia currently utilizes very little of the water, less than 1 km^3. In contrast, Sudan and Egypt use significant volumes for irrigation, hydropower, and other uses. There remains considerable potential for additional exploitation, and the three countries have plans to further develop of the water resources. In Ethiopia, major irrigation schemes with a total area of approximately 164,000 ha are planned for completion by 2010, and 815,000 ha in longer term. In addition, several hydropower dams, including four located on the main stem of the river, are being contemplated. In Sudan, it is planned to develop 889,000 ha of additional irrigation by 2025. This paper provides an overview of the basin characteristics, hydrology of the Blue Nile, and a brief evaluation of the current and future status of water resource development. The future development in Ethiopia for consumptive water use, limited by land potential, is an order of magnitude of 5-6 km^3, net water, about 10% of its runoff contribution. Similar analysis for Sudan shows possible use of 9 km^3. The analysis helps policymakers reach informed decisions.

Media grab

Current water use of Ethiopia in the Blue Nile Basin is less than 2%, and increasing the level to 10% can contribute to socioeconomic development of the country without adversely affecting downstream flows.

Introduction

The need for improved water resources management to alleviate poverty, food insecurity, and increase socioeconomic development in Africa is immense. Recent strides in sustainable resource management have recognized the need for a broad-based, integrated approach that coordinates the activities of people dependent on a common resource base to achieve resource-use efficiency, equity, and sustainability. In the Nile Basin, water from the Ethiopian Highlands, particularly from the Blue Nile (Abay in Ethiopia), has historically benefited downstream people in Sudan and Egypt in different ways: agriculture, livestock, industry, and electrical power (Awulachew et al., 2008). The sustainability of such use, in terms of water quantity and quality, is heavily affected by dramatic changes in population growth and the pressing needs of socioeconomic development. These factors have resulted in great changes in land, water, and livestock management upstream in the Ethiopian part of the catchment. It is widely recognized that understanding the potential and investment to improve water management in the Abay catchment could significantly increase water availability for various upstream and downstream users. Better water management could help to alleviate the impacts of natural hydrological variability (i.e. droughts and floods), enhance development, and reduce water-related conflict. The objectives of this paper are: (1) to characterize the hydrology and its variability; (2) identify existing developments and future plans; and (3) apply a modeling tool that helps to evaluate scenarios of development and their impacts on hydrology and water resources availability. The information generated could contribute to decision-making on future water use and development in the basin.

Methods

The data related to the Blue Nile Basin (BNB) are scanty and not available in a single database. We tried to develop the basin map under Arc GIS environment and 90m resolution digital elevation model (DEM), from which various sub-basins have been delineated. The result of this provides a useful platform for various studies. One of the results generated is shown in Figure 1, which is useful as source of input for this study. For the current study, in addition to the physical characteristics, hydro-meteorological data have been compiled from a number of secondary sources. Geo-referenced location information (e.g. of rain gauges and flow stations) has been mapped using GIS. Analysis of these data using simple statistics, graphs, and plots related to rainfall, runoff, and evapotranspiration provides information that can be used to enhance understanding of the spatial and temporal variation of hydro-meteorological parameters. The actual runoff measured and derived from hydrological models provides information on water availability at various locations. Scenarios of current and future water use are established based on information available in documents such as master plan studies. The water demand for various uses is quantified using simple methods of quantifying water duty per hectare. The benefit of our approach is that it analyzes the Blue Nile as one system inventory.

Results and discussion

Based on analysis of DEM, the BNB is characterized by highly rugged topography and considerable variation in altitude (350 m at Khartoum to over 4250 m in the Ethiopian highlands). The 90 m DEM based derivation of area shows that the total area of the basin is 311,437km^2, of which approximately 63% is in Ethiopia and 37% is in Sudan, similar to data in Hydrosult et al. (2006). Rainfall varies significantly with altitude and is considerably greater in the Ethiopian highlands than on the plains of Sudan (Figure 1). Within Sudan, the average annual rainfall over much of the basin is less than 500 mm. In Ethiopia, the average annual rainfall is about 1,600 mm and at some points exceeds 2000 mm. The temporal distribution of rainfall is governed to a large extent by the movement of air masses associated with the Inter-Tropical Convergence Zone (ITCZ). The main rains occur in the summer, between June and September, when the ITCZ moves north, and the southwest airstream extends over the entire Ethiopian highlands. This is also the main rainy season in Sudan. Inter-annual variability in rainfall is considerable, and several consecutive years with below average rainfall is not uncommon. The physiographic features of the 16 sub-basins of the BNB and other parameters (e.g. temperature, potential evapotranspiration) are analyzed and presented in Awulachew et al. (2008), which also provides a wider analysis related to this study. The total volume of water falling in the Abay is approximately 320 billion cubic meters (BCM), from which about 16% is converted to runoff as Blue water.

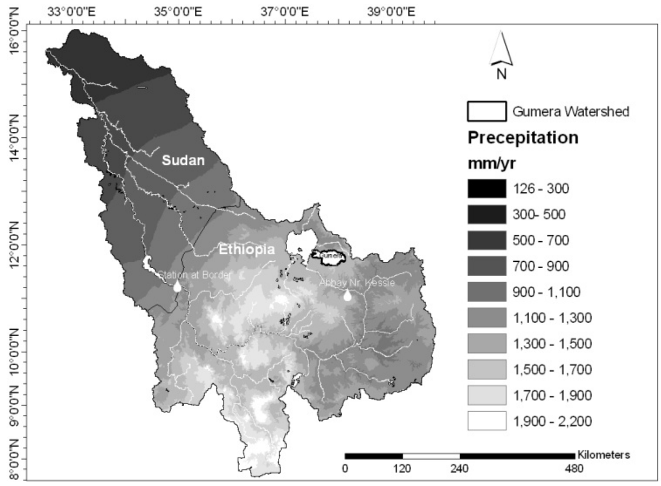


Figure 1. Mean annual rainfall across the Blue Nile Basin.

Throughout the BNB, flow data are generally limited because of the remoteness of many of the catchments, and the lack of economic resources and infrastructure to build and maintain monitoring stations. In Ethiopia, there are over 100 flow gauging stations in the basin; most of these are located on relatively small tributaries and/or are near the headwaters of the main rivers. Very few gauging stations are located on the main-stem of the river or on the major tributaries close to their confluence with the BN. Summary statistics and flow estimates for each of the major tributaries, the network of the tributaries, and schematization of water allocation are presented in Table 1 and Figure 2. As with rainfall, there is considerable inter-annual (Figure 3) and seasonal variability in flow. Typically, 80-85% of discharge occurs in the four months July to October (see Figure 4a).

The average annual flow of the Blue Nile at the Sudan border is 52 km^3. Despite inflows from the Dinder and Rahad, the two major tributaries in Sudan, the mean annual flow of the Blue Nile at Khartoum is 48.2 km^3 (i.e. less than at the border). The reduction in flows between the border and Khartoum is a consequence of both water abstractions (primarily for irrigation) and high transmission losses. It is estimated that annual transmission losses (i.e. both evaporation and percolation) between the border and Khartoum are about 2 km^3, with an additional 0.5 km^3 of evaporation from the two major reservoirs, Sennar and Roseires (Sutcliffe and Parks, 1999). The revised estimate of evaporation is 0.91 km^3. Ethiopia currently utilizes about 0.3 km^3 of water of the Blue Nile for consumptive uses. To date only two relatively minor hydraulic structures have been constructed in the BNB of Ethiopia. These are at Chara Chara (i.e. at the outlet of Lake Tana) and Finchaa. These dams are used mainly for hydropower generation, with a total capacity of 218 MW (i.e. 30% of the total electricity generating capacity of Ethiopia). The total irrigation development in the BNB of Ethiopia is estimated to be 32,000 ha. The current irrigation development in the BNB of Sudan amounts to 1,305,000 ha, mostly in the huge Geizera scheme. The total hydropower development in the BNB of Sudan is 295 MW (i.e 25% of total electricity generating capacity of Sudan) at the Rosieres and Sennar dams. The Roseires and Sennar reservoirs have suffered extensively from sedimentation. It is estimated that sediment loads to both dams are approximately 140 million t/year (Hydrosult et al., 2006), and reservoir volumes have declined significantly as a result (Awulachew et al., 2008). There is no binding agreement that hinders Ethiopia’s development of the water, but Sudan and Egypt have a 1959 agreement that apportions the Nile flow among the two countries, with negligible amounts generating from Sudan and zero from Egypt.

Table 1. Summary statistics for the major sub-basins of the Blue Nile.

Sub-basin	Catchment area (km^2)	Mean annual rainfall (mm)	Mean annual potential evapotranspiration (mm)	Mean annual runoff (mm)	Mean annual flow (Mm^3)	Coefficient of runoff
Ethiopia						
Guder	7,011	910	1,307	312	2,187	0.34
Dabus	21,030	2276	1,112	297	6,246	0.13
Finchaa	4,089	1766	1,290	438	1,719	0.25
South Gojam	16,762	1633	1,183	299	5,012	0.18
Anger	7,901	1813	1,318	298	2,355	0.16
Beles	14,200	1655	1,274	306	4,345	0.18
Didessa	19,630	1816	1,308	289	5,673	0.16
Muger	8,188	1347	1,210	298	2,440	0.22
North Gojam	14,389	1336	1,242	305	4,389	0.23
Jemma	15,782	1105	1,059	304	4,798	0.28
Lake Tana	15,054	1313	1,136	253	3,809	0.19
Welaka	6,415	1072	1,263	323	2,072	0.30
Beshilo	13,242	982	1,140	296	3,920	0.30
Wombera	12,957	1660	N/A	299	3,874	0.18
Sudan						
Dinder	14,891	N/A	N/A	188	2,797	N/A
Rihad	8,269	N/A	N/A	133	1,102	N/A

Source: Ethiopia data from Tadesse, T (2006). Sudan data from Sutcliffe and Parks (1999). N/A not available.

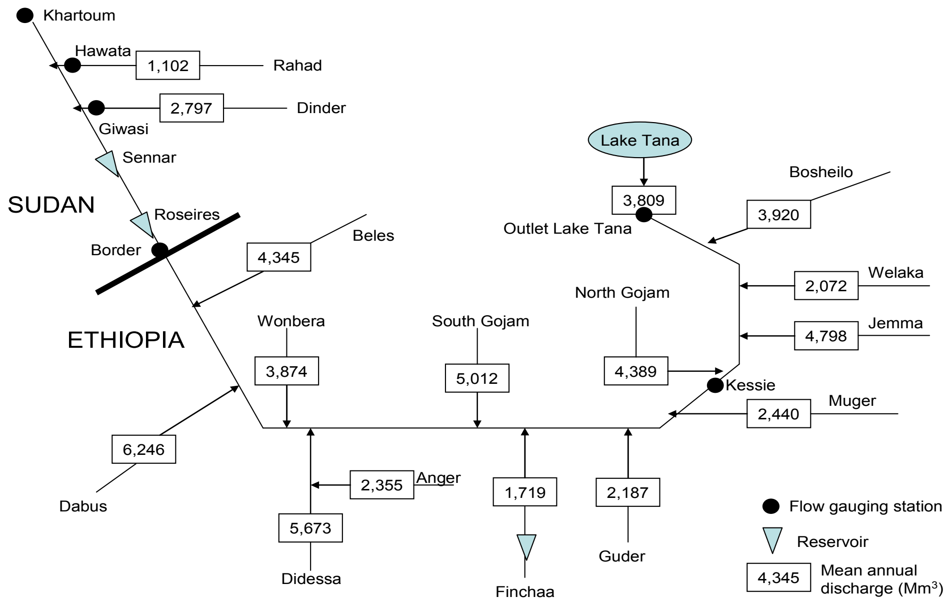
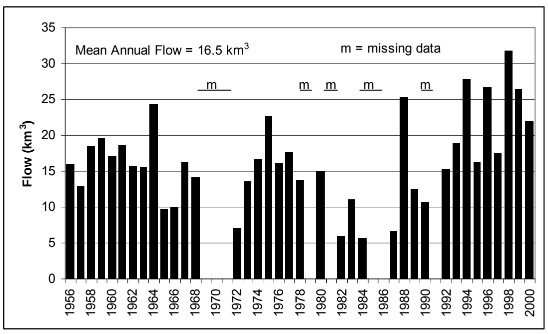
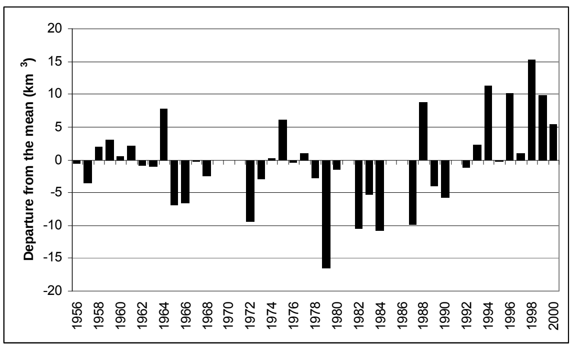


Figure 2. Mean annual discharge figures and schematic showing the proposed configuration of the water allocation model under use for this study.

a)





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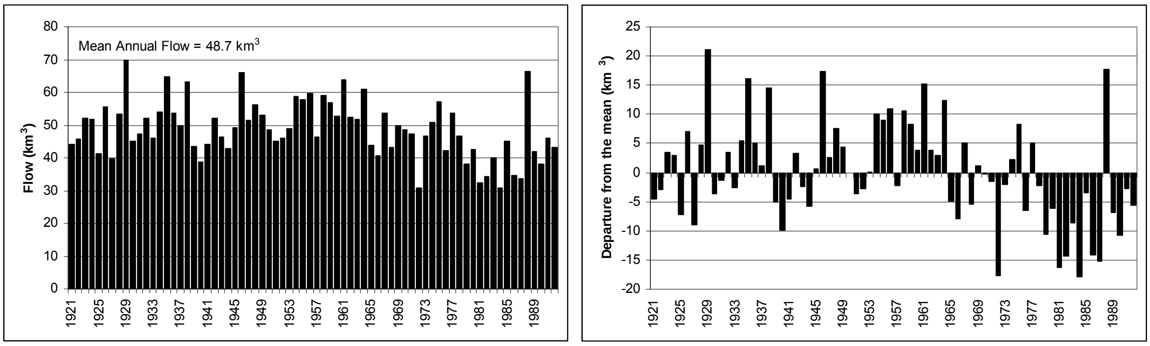
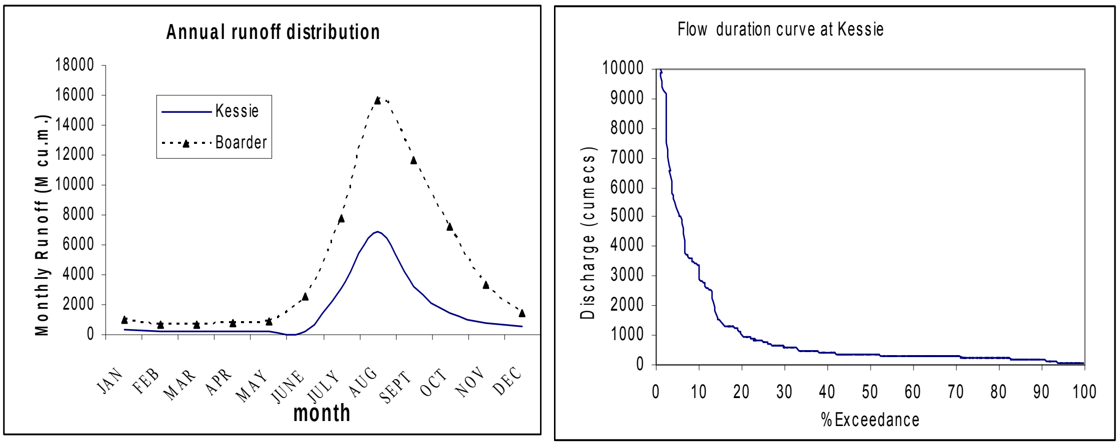


Figure 3. Flow and departure from the mean as measured on the Blue Nile River at two locations: a) Kessie in Ethiopia; and b) El Diem in Sudan. Locations of stations shown in Figure 1.



a) b)

Figure 4. a) Variations of runoff of Blue Nile (notice periods of large volume of flow); b) flow duration curve.

Under the auspices of the Nile Basin Initiative, which was established in 1999, with the exception of Eritrea all the riparian countries of the Nile have agreed to collaborate in the development of the Nile water resources to achieve sustainable socioeconomic development. Ethiopia and Sudan plan to further develop the water resources of the Blue Nile. Similarly Egypt is developing new irrigation development areas. In Ethiopia possible irrigation projects have been investigated over a number of years (e.g. USBR, 1964; BCEOM, 1998). Currently envisaged irrigation projects will cover a total of more than 164,000 ha, which represents 20% of the total 815,581 ha of potential irrigation estimated in the basin (BCEOM, 1998). As it is reflected in its master plans, Ethiopia has also a long-term interest to develop its land, mainly as supplementary irrigation. Sudan is also planning to increase the area irrigated in the BNB. Additional new projects and extension of existing schemes are anticipated to add an additional 889,340 ha by 2025. The water required to develop the high priority irrigation of 220,416 ha in Ethiopia is estimated to be between 2.2 km^3 and 3.83 km^3 (Endale, 2006), which appears to be an overestimation. We estimated that water requirement to develop the 816,000 ha at about 5 km^3 to develop the full potential in the Blue Nile part of Ethiopia. Based on current irrigation efficiencies in the Gezira and other schemes, the additional development in Sudan will require an average of 9.3 km^3 more water than is abstracted at present. In the BNB of Ethiopia more than 120 potential hydropower sites have been identified. Out of these, 26 were investigated in detail during the preparation of the Abay River Basin Master Plan (BCEOM, 1998). The major hydropower projects currently being contemplated in Ethiopia have a combined installed capacity of between 3634 MW and 7629 MW, mostly with storage reservoir. Storage reservoir is mandatory for any meaningful development in upper Blue Nile, since the temporal variation of the flow is significant as shown in Figure 4b, the dependable flow at 95% reliability being extremely low. There is no planned hydropower development in the BNB of Sudan. Hydropower is a nonconsumptive use of water and has no expected impact in the water budget. The immediate impact is the redistribution or even-out effect of temporal variation, but with added benefits of storing spilling water from Aswan during high water years, storage at high altitude and low evaporation sites, and more water-saving for beneficial use.

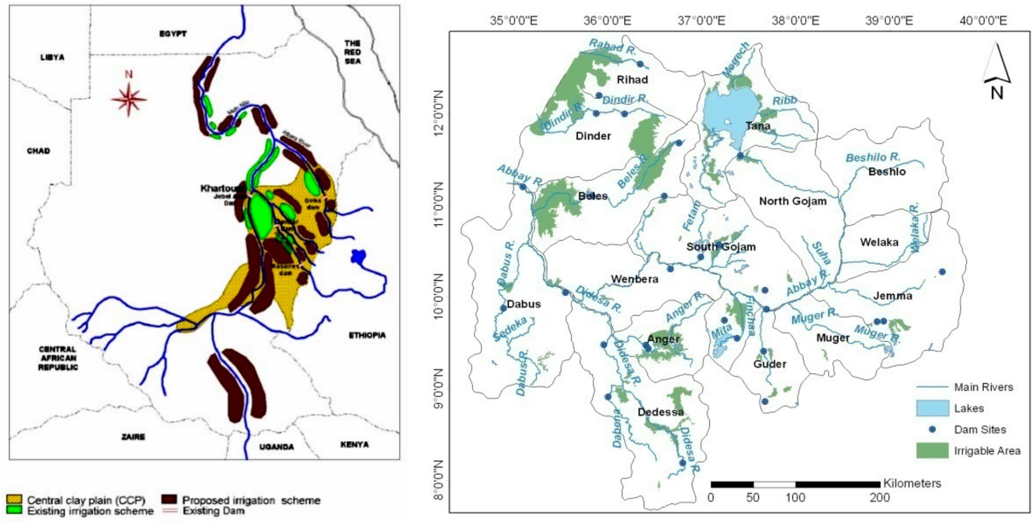


Figure 4. Current and future potential of irrigation of Sudan (L) future potential of Ethiopia (R).

Conclusion

Pressure on water resources in the BNB is likely to increase in the near future due to high population growth and increasing development-related water needs. In spite of the national and international importance of the region, however, only a relatively few studies have been conducted and there is limited understanding of the basin's detailed climatic, hydrologic, topographic, and hydraulic characteristics as well as earnest quantification of potential development scenarios. Our results show that the Blue Nile, despite its significant flow volume, has large time variation of flow and almost exclusively runoff is generated from the Ethiopian highlands. Any meaningful development of the river requires storage infrastructure. The current irrigation development in Ethiopia is insignificant, and future development to the full potential of the Blue Nile may lead to only 5-6 km^3 of water abstraction, which is at most 10% of its contribution to the flow. The use of the water for further development in the Sudan may lead to an additional water withdrawal of 9.5 km^3 in the Blue Nile Basin. Countries can use such analyses to avoid conflicts, to understand the needs, to establish agreed extent of development, and to rapidly harness the available resources for beneficial use and accelerated socioeconomic transformation of the region.

Acknowledgments

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Application of WEAP in the Volta Basin to model water allocation to the Akosombo hydropower scheme under different scenarios

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Abstract

This paper presents a first version of a decision-tool for the management of the transboundary water resource of the Volta Basin. We used the hydrological model of Kirby et al. to provide inputs to the WEAP allocation model. Both models were parameterized to reproduce observed river flows and water stored in Lake Volta. As an application, we considered the consequences of climate change and development of upstream small reservoirs scenarios on the downstream Akosombo hydropower scheme. Water levels in Lake Volta were highly sensitive to the inter-annual rainfall variations and simulated climate changes, which affect operations of the Akosombo dam. Comparatively, the scenario of development of small reservoirs had a negligible impact on the Akosombo scheme during the span of the scenario. At the end of the scenario, however, the mean inflow to Lake Volta is reduced by about 3%, which is subtracted to hydropower production. The model is multipurpose and may be further applied to other development issues, provided that the necessary data become available.

Media grab

An application of the model WEAP is being developed to assist managers of the transboundary water resource of the Volta Basin.

Introduction

The Volta Basin is a transboundary basin of 394,100 km^2, which lies mainly in Ghana (42%) and Burkina Faso (42%), while Benin, Togo, Côte-d'Ivoire and Mali share the remaining 16%. This work will focus on the upstream Burkinabe and the downstream Ghanaian parts of the basin. The upper part of the Volta Basin lies in semiarid Burkina Faso and the rivers flow toward the more humid Ghana. Priority in Burkina Faso is to develop water conservation, with numerous small dams and some medium-size reservoirs, while the Akosombo/Kpong hydroelectric compound lies in the lower part of the basin, a high priority for Ghana. These different uses of water set the grounds for consultative water allocation, in a context of climate change, and a population increase of 2.5-3 % per year (Andah et al., 2004).

The objective of this work was to apply the Water Evaluation and Planning (WEAP) of the Stockholm Environment Institute (Yates et al., 2005) to the Volta Basin, and provide insight into possible consequences of climate change and development of upstream small reservoirs on water allocated to the downstream Akosombo hydropower scheme. For that, the hydrologic model of Kirby et al. (2006) was coupled with WEAP.

Methods

Hydrologic modeling
River flows were calculated with the hydrologic model of Kirby et al. (2006). Inputs were the land use, the digital elevation model (DEM), and meteorological data (from the Climate Research Unit). Groundwater behavior has not been taken into account due to scarcity of hydrogeologic data.

Flows were calculated at the outlet of 19 sub-basins (Figure 1). We calibrated the hydrologic model with available observed river flows between 1951 and 2000, taken from Bodo (2001) and provided by the project Volta HYCOS. Please refer to Kirby et al. (2006) for a detailed description of the model and its utilization. The data set covers a variable part of the whole 1951-2000 period, and thus allows for more or less satisfactory calibrations according to the importance of the data set.

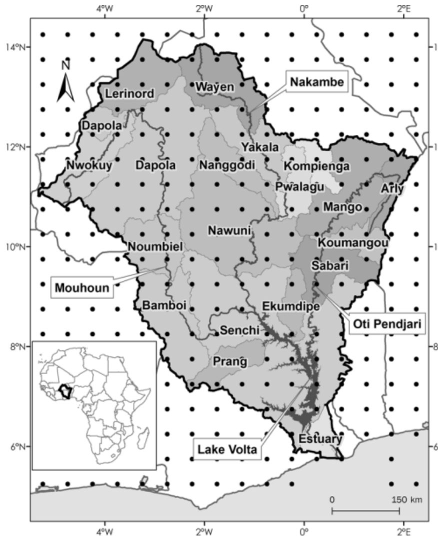

Figure 1. The three main river systems and the 19 sub-basins of the Volta Basin.

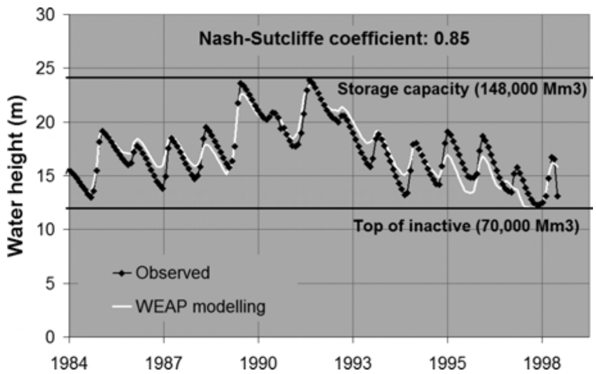

Figure 2. Storage of Lake Volta: observed vs. simulation.

Water allocation modeling

Parameterization

Calculated river flows have been used as inputs to the modeling of water allocation with the software WEAP. We imported the 19 sub-basins in WEAP as spatial background modeling entities. The next steps were: (1) to estimate the water uses and their demands in the 19 sub-basins; (2) to prioritize these demands; and (3) to test the parameterization of WEAP. In the first step, four types of water uses were identified:

- Small reservoirs that are mostly informal/private arrangements and mainly located in Burkina Faso (data sources: the CPWF *Small Reservoir Project*, Liebe, 2002; and Liebe et al., 2005),
- Large irrigation reservoirs that are formal/state arrangements (data sources: Direction Générale de l'Hydraulique, 2000; Liebe et al., 2005).
- The large hydroelectric reservoirs Bagre and Kompienga in Burkina Faso and Akosombo in Ghana (data sources: Société Nationale d'Electricité du Burkina (SONABEL), van de Giesen et al., 2001; and Obeng-Asiedu, 2004).
- Remaining irrigation schemes plus domestic and livestock drinking water (data sources: Ministry of Works and Housing, 1998; Direction Générale de l'Hydraulique, 2000; Barry et al., 2005; and Nii Consult, 2007).

In the second step, we chose allocation priorities of the water demands taking the assumption that there is no upstream-downstream cooperation in management of the Basin water resource. Consequently, water allocation was based on a 'first come, first served,' with priority decreasing from upstream to downstream. The last step tested the parameterization in WEAP by comparing simulated and observed water storage in Lake Volta. We calculated the Nash coefficient and matching is satisfactory (Figure 2).

Scenarios

We developed scenarios for 20 years, with the year 2000 as initial condition. Three types of scenarios have been considered: (1) reference, where no change occurs; (2) climate change with a drier and wetter climate; and (3) development of small reservoirs, denoted SRs. So as to simulate yearly climatic fluctuations, we considered in the scenario of reference the CRU meteorological data for the period 1980 to 2000. In all scenarios, we kept the water demands constant; target for turbined-water at Akosombo was taken equal to the average value observed during the period 1985-1998, i.e., 31.6 km^3/year (Obeng-Asiedu, 2004).

Referring to the reduction in rainfall that occurred in the basin around 1970 (L'Hôte et al., 2002; Lemoalle, 2007), we simulated climate change scenarios by shifting the CRU meteorological grids of the reference scenario (grids of the period 1980-2000) by (1) 1 degree southward for a drier period; and (2) 1 degree northward for a wetter period. We defined a scenario of rapid increase in number of SRs that we expressed as a growth of 10% per year in water demand from SRs. This is equivalent to an increase of about 4 times in irrigated areas in Burkina Faso, which may appear ambitious but is required to improve the resilience of food production to rainfall variability.

Results

Climate change

The fluctuation in annual meteorological data in each scenario produced inter-annual storage variations that were of the same magnitude as effects of climate change (Figure 3). The ten first years of the scenarios were dry, leading to low storage (Figure 3) and water releases below the target (31.6 km^3/year), especially in the drier scenario (Figure 4). After these initial years, differences between the scenarios became significant with a situation: (1) comfortable in the wetter scenario (target always met and high storage); (2) vulnerable in the reference scenario (target always met but storage close to the inactive zone); and (3) critical in the drier scenario (target hardly met and storage reaching the inactive zone).

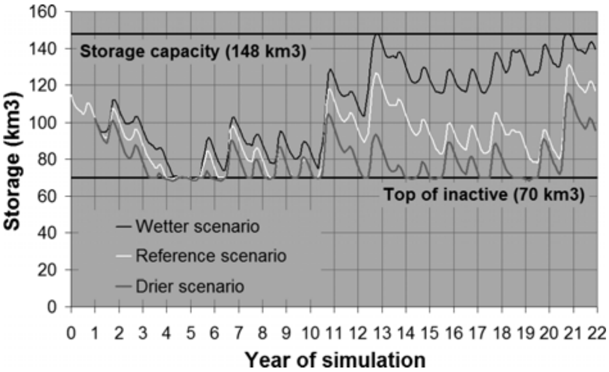

Figure 3. Simulation of the water stored in Lake Volta for the climate change scenarios.

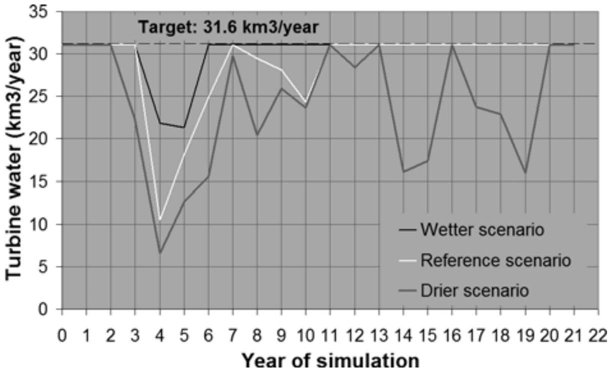

Figure 4. Simulation of annual water used for hydropower in Akosombo for the climate change scenarios.

Development of small reservoirs

There was a slight impact on Lake Volta during the span of the scenario (Figure 5). These results were strongly influenced by our assumption of a constant value for the turbine water target (31.6 km^3/year). In reality the operational rules of the Akosombo dam are dynamic and adapt the target to the observed situation. The departure from the inflows simulated in the reference scenario increased with time, reaching about 0.8 km^3/year after 20 years (Figure 6). This is about 3% of the mean inflow simulated in the reference scenario (29.1 km^3/year) not available for hydropower production, a small but noteworthy impact.

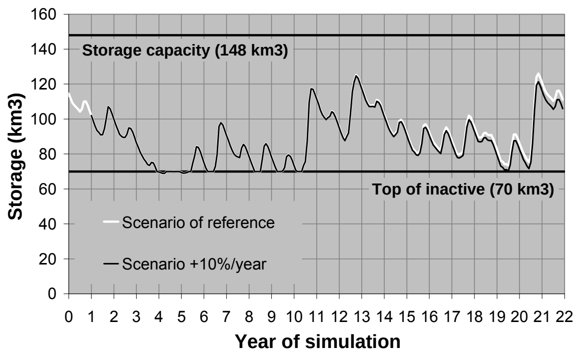

Figure 5. Simulation of the water stored in Lake Volta for the scenario of development of small reservoirs (+10%/year).

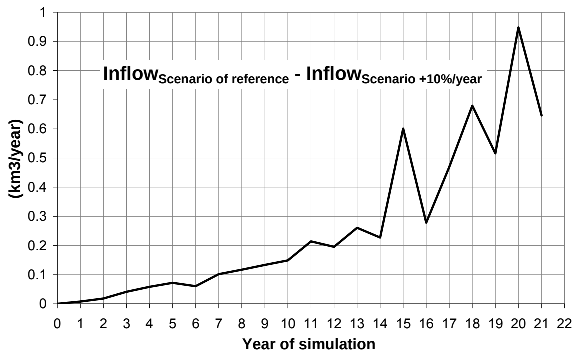

Figure 6. Difference between the inflows in the reference scenario and in the SRs development scenario (+10%/year).

Outcomes and prospects

The aim of this work was to apply WEAP to the Volta Basin and provide insight into possible consequences of climate changes and development of upstream small reservoirs on the downstream Akosombo hydropower scheme. We coupled two models: the hydrological model of Kirby et al. (2006) and the software WEAP. Both models were parameterized to reproduce observed river flows and storages in Lake Volta.

The first outcome of this work is that, with respect to all our limitations/assumptions, climate changes similar to that which had been observed in the recent past have a critical impact on the hydropower generation at Akosombo. The second conclusion is that, compared to consequences of climate change, a growth of 10%/year in water demand from SRs has a negligible impact during the span of the scenario. After 20 years of this growth, however, the mean inflow to Lake Volta is reduced by about 0.8 km^3/year, that is about 3% of the mean inflow that is subtracted to hydropower production.

Our work will be handed to the Volta Basin Authority. The Authority is a platform for consultation at the basin scale and needs this kind of tool to illustrate situations the Basin is very likely to face soon. As a final caveat, it must be kept in mind that the tool was parameterized and calibrated for the Basin with limited data on river flows and water uses, hence its utilization for a particular scenario may require further tuning with specific data (e.g., dam operational rules). Other scenarios could include:

- Impact of small reservoir development on hydropower reservoirs in Burkina Faso (i.e. Bagre and Kompienga) as it is foreseen to be significant.
- Trends for other water demands, such as urban use and population growth.
- Development of groundwater exploitation.

Acknowledgments

This paper presents findings from PN55 'Basin Focal Project: Volta Basin,' a project of the CGIAR Challenge Program on Water and Food. Observed river flows were partly provided by the project 'Volta HYCOS.'

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Modeling upstream-downstream interactions using a spreadsheet-based water balance model: two case studies from the Limpopo Basin

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Abstract

Sharing scarce surface water resources requires tools for water allocation. Water balance modeling can be used to analyze upstream-downstream interactions, dam management options, and water allocation and development options. The spreadsheet-based model WAFLEX provides such a modeling tool. In this study, the lower Mzingwane and Thuli river basins, Limpopo Basin, Zimbabwe, are modeled in WAFLEX in order to assess existing upstream-downstream interactions and future development and allocation options. The lower Mzingwane River is managed through releases from Zhovhe Dam. The downstream river reaches, via an alluvial aquifer, supply water to an important agro-industry (growing and processing citrus and other crops) and to the border town of Beitbridge. The WAFLEX model shows how, through management of the dam and planning of releases, these water resources can be better shared to also provide irrigation water for smallholder farmers in the communal lands along the river, where soils are poor and rainfall low and erratic. The Thuli river basin is dominated by the Thuli-Makwe Dam, which supplies water for smallholder irrigation, and the Mtshabezi dams, that provide urban water supply. An inter-basin water transfer is proposed from Mtshabezi Dam to Bulawayo, the second largest city in Zimbabwe. The WAFLEX model shows how the water can be equitably shared with minimal negative impacts.

Media grab

Spreadsheets can be powerful tools for water allocation and the spreadsheet-based model WAFLEX can provide a simple approach to analyzing water availability and allocation scenarios. Two case studies show its utility in identifying under-utilized resources and demonstrating where trade-offs can be evaluated in a water-scarce basin.

Introduction

Water balance modeling can be used to analyze upstream-downstream interactions, dam management options, and water allocation and development options. The spreadsheet-based model WAFLEX provides such a modeling tool (Savenije, 2005). WAFLEX has been applied extensively in southern Africa for the modeling of water allocation: between Swaziland, South Africa, and Mozambique on the transboundary Inkomati River (Nkomo and van der Zaag, 2004; Juízo and Líden, 2008), environmental flow requirements of the Odzi River in Zimbabwe (Symphorian et al., 2003) and water quality and mass balance of the Kafue River in Zambia (Mutale, 1994).

In this study, two subcatchments in the northern Limpopo Basin, Zimbabwe, are modeled in WAFLEX to assess existing upstream-downstream interactions and future development and allocation options.

Methods

Study area

The northern Limpopo Basin is a semi-arid area, with rainfall varying from 630 mm/year in the north to 360 mm/year in the south. Rainfall is seasonal, controlled by the Inter Tropical Convergence Zone and falling between October/November and March/April (Makarau and Jury, 1997). Rainfall occurs over a limited period of time, and often a large portion of the annual rainfall can fall in a small number of events (De Groen and Savenije, 2006). The two study subcatchments are the lower Mzingwane and Thuli (Figure 1). The lower Mzingwane Subcatchment (downstream of hydrological gauge B62) is 5479 km^2, downstream of the 9740 km^2 Upper Mzingwane Subcatchment. Mean annual runoff is 345 Mm^3. The Thuli Subcatchment covers 7670 km^2 and has a mean annual runoff of 285 Mm^3. Major dams in the two subcatchments are shown in Table 1.

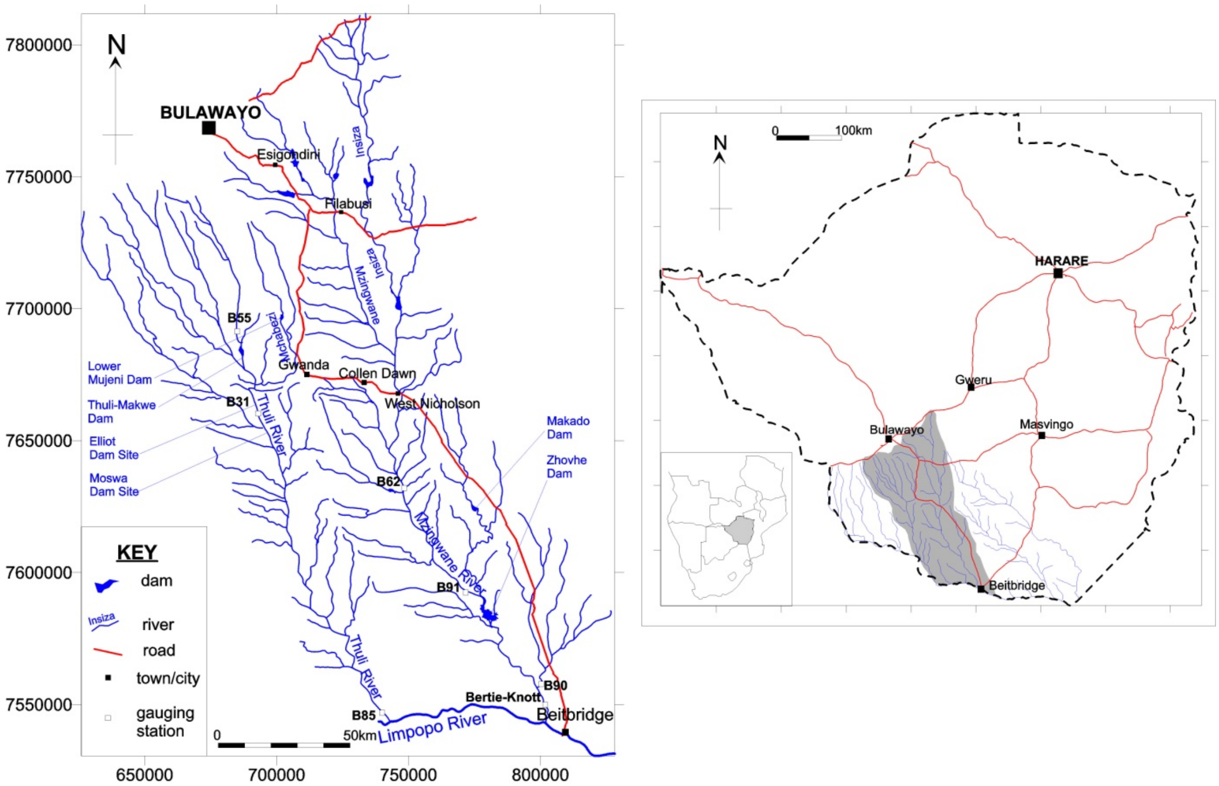

Figure 1. The study area: (left) map of the Thuli and Lower Mzingwane subcatchments, showing locations of principal dams and gauging stations; (right) location (shaded) within Zimbabwe and southern Africa. Base map after Love et al. (2006).

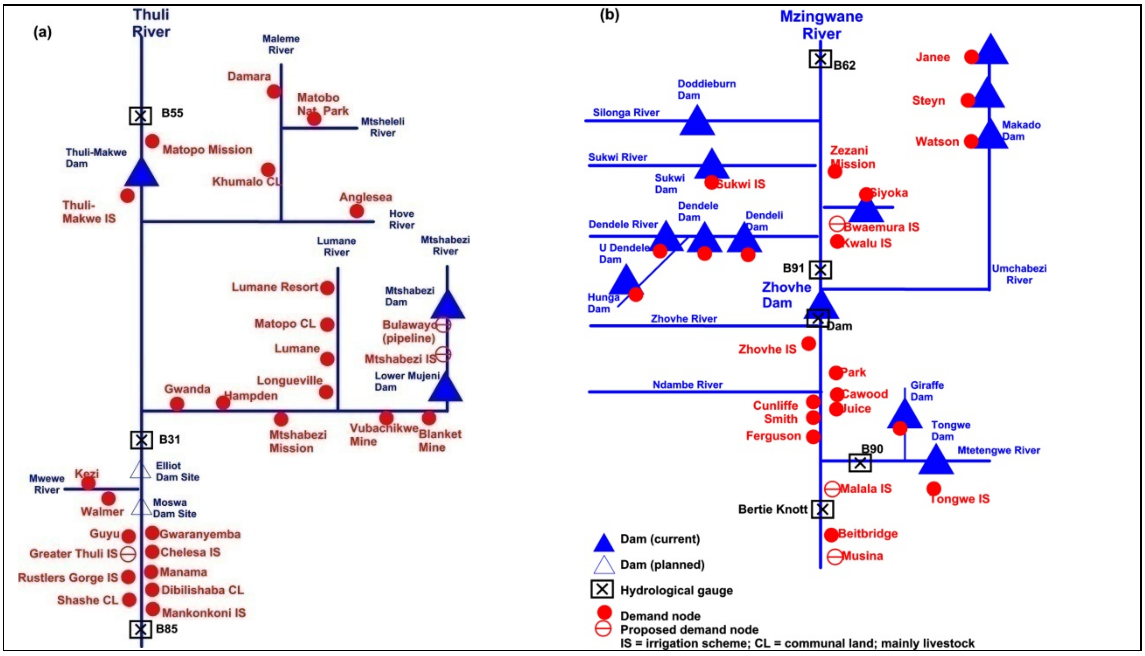

Figure 2. Network diagrams of the Thuli Subcatchment (a) and the Lower Mzingwane Subcatchment (b), showing major tributaries, dams, demand nodes, and gauging stations.

Table 1. Dams in the selected subcatchments. For locations, see Figure 1.

Dam	River	Dam capacity (Mm^3)	Constructed
Lower Mzingwane Subcatchment			
Zhovhe	Mzingwane	133.0	1995
Makado	Umchabezi	12.3	1980s
Thuli Subcatchment			
Thuli-Makwe	Thuli	8.3	1967
Lower Mujeni (Blanket)	Mtshabezi	10.5	1961
Mtshabezi	Mtshabezi	52.2	2001
Moswa	Thuli	419	proposed
Elliot (Manyange)	Thuli	33	proposed

WAFLEX model

For each subcatchment, a network was schematized, containing all major tributaries, dams and demand nodes (Figure 2). In WAFLEX each river reach, demand node, or reservoir is a cell. In supply mode, each cell contains a simple formula to add water flowing into it from adjacent cells, and to subtract any demand connected to that cell. The demand mode is a 'mirror-image' to the supply mode, and computes the required flow in an upstream direction, starting with the demand located furthest downstream (usually outflow). Visual basic macros used the formulas in the networks and input data (see Table 2) to model each time step and generate simulated discharge at specific river reaches, and time series of abstractions, shortages, and dam levels. The demand nodes are detailed in Tables 3 and 4. WAFLEX can work at a variety of time steps: for the Thuli Subcatchment a monthly time step was chosen; for the Lower Mzingwane Subcatchment a 10-day time step was chosen due to the shorter time series available.

Table 2. Data used in the models.

Type of data	Source
Rainfall	Field measurements
Evaporation	Hargreaves formula (Allen et al., 1998), meteorological data from West Nicholson
Inflows	Zimbabwe National Water Authority; water balance of Zhovhe Dam (Love et al., 2008, this volume)
Demand: irrigation	Interview with farmers and district authorities to establish crop patterns and extent. Crop water requirements modeled using CROPWAT for Windows 4.2 (Clarke, 1998)
Demand: livestock	Considering the distribution of cattle in the area (World Resource Institute, 2000; Thornton et al., 2002) neither the estimated livestock water requirements for Zimbabwe (e.g. De Hamer et al., 2008) nor the more generous ones for South Africa (KwaZulu-Natal Department of Agriculture and Environmental Affairs, 2008) constitute an annual livestock water demand equivalent to 2% of the capacity of any of the livestock supply dams. This demand was therefore discounted.
Demand: urban	For Zimbabwe: Chibi et al., 2006. For South Africa: Basson and Roussouw, 2003; Musina Municipality, 2004.
Dam depth/volume/ area relationships	Zimbabwe National Water Authority rating table for Zhovhe Dam. Relationships in smaller dams estimated from known maximum capacity and surface area.

Table 3. Demand nodes in the Lower Mzingwane Subcatchment.

Water user	Purpose	Demand (10^6m^3/year)	Connected in scenario numbers				
			A	B	C	D	E
Sukwi irrigation scheme	Agriculture	0.410	X	X	X	X	X
Zezani business centre	Urban	0.003	X	X	X	X	X
Bwaemura irrigation scheme	Agriculture	2.049		X	X		X
Kwalu irrigation scheme	Agriculture	2.561	X	X	X	X	X
Janee	Tourism	0	X	X	X	X	X
Steyn	Tourism	0	X	X	X	X	X
Watson	Agriculture	1.076	X	X	X	X	X
Zhovhe irrigation scheme	Agriculture	0.041	X	X	X	X	X
Park	Agriculture	7.140	X	X	X	X	X
Cawood	Agriculture	1.510	X	X	X	X	X
Cunliffe	Agriculture	1.376	X	X	X	X	X
Smith	Agriculture	0.688	X	X	X	X	X
Ferguson	Agriculture	1.544	X	X	X	X	X
Tongwe irrigation scheme	Agriculture	1.025	X	X	X	X	X
Malala irrigation scheme	Agriculture	1.885		X	X		X
Mtetengwe irrigation scheme	Agriculture	8.708			X		X
Beitbridge	Urban	2.493	X	X	X	X	X

Musina	Urban	4.317				X	X
Makhado, South Africa	Urban	2.400				X	X

Table 4. Demand nodes in the Thuli Subcatchment.

Water user	Purpose	Demand ($10^3 m^3$/year)	Connected in scenario numbers				
			1	5	6	7	9
Anglesea	Agriculture	140	X	X	X	X	X
Damara	Agriculture	8,800	X	X	X	X	X
Khumalo communal land	Domestic	840	X	X	X	X	X
Matopo National Park	Park	4,840	X	X	X	X	X
Bulawayo	Urban	7,100				X	X
Mtshabezi Irrigation scheme	Agriculture	4,200		X			X
Blanket mine	Mining	1,120	X	X	X	X	X
Vubachikwe mine	Mining	650	X	X	X	X	X
Gwanda	Urban	1,100	X	X	X	X	X
Hampden	Agriculture	700	X	X	X	X	X
Mtshabezi mission	Domestic	36	X	X	X	X	X
Matopo communal land	Domestic	48	X	X	X	X	X
Lumane resort	Domestic	1,400	X	X	X	X	X
Lumane communal land	Domestic	24	X	X	X	X	X
Longville	Agriculture	1,980	X	X	X	X	X
Kezi	Domestic	140	X	X	X	X	X
Walmer	Agriculture	140	X	X	X	X	X
Matopo mission	Domestic	72	X	X	X	X	X
Thuli-Makwe Irrigation scheme	Agriculture	1,500	X	X	X	X	X
Gwaranyemba	Domestic	1,940	X	X	X	X	X
Guyu	Domestic	60	X	X	X	X	X
Chelesa irrigation scheme	Agriculture	300	X	X	X	X	X
Manama	Domestic	40	X	X	X	X	X
Great Thuli Irrigation	Agriculture	42,000			X		X
Mankokoni irrigation scheme	Agriculture	200	X	X	X	X	X
Rustlers Gorge irrigation scheme	Agriculture	1,310	X	X	X	X	X
Shashe communal land	Domestic	110	X	X	X	X	X
Dibilishaba communal land	Domestic	1,240	X	X	X	X	X

For each of the two subcatchments, WAFLEX models were set up to evaluate a range of scenarios (Tables 3-6). In the base scenarios (A and 1) water is allocated to the existing demand nodes, starting with the most downstream node. Additional scenarios are simulated by connecting additional demand nodes, representing abstraction by proposed future demands. For the Thuli Subcatchment, simulated flows were validated against observed flows at gauging stations B55, B31, and B85. This process still has to be done for the Lower Mzingwane Subcatchment, where currently there are insufficient available observed flow data.

Table 5. Scenarios modeled in WAFLEX, Lower Mzingwane Subcatchment.

Model	Scenario
A	Existing water users, water allocated based on downstream demand with no restrictions on releases from Zhovhe Dam
B	A plus connection of Malala and Bwaemura Irrigation Schemes
C	B plus connection of Mtetengwe Irrigation Scheme
D	A plus intra-basin transfer Musina (and export)
E	C plus D

Table 6. Scenarios modeled in WAFLEX, Thuli Subcatchment.

Model	Scenario
1	Existing water users, water allocated based on downstream demand
5	1 plus connection of Mtshabezi Irrigation Scheme
6	1 plus connection of Greater Thuli Irrigation Scheme
7	1 plus connection of inter-basin transfer to Bulawayo
9	1 plus connection of Mchabezi and Greater Thuli Irrigation Schemes plus inter-basin transfer to Bulawayo and construction of Elliot Dam and Moswa Dam

Results and discussion

In the Lower Mzingwane Subcatchment, it is apparent that the water available in Zhovhe Dam is underutilized, as under each scenario shortages only occur on tributaries: Sukwi, Tongwe, and Umchabezi (Watson farm); this suggests that irrigation along these smaller rivers may have been planned without reference to the potential yield of the catchments. Demand added along the main

Mzingwane River is met, including the new schemes. The maximum expansion of irrigation proposed by government can readily be met, and even provide for exports of water to South Africa.

Table 7. Results of scenario E modeled in WAFLEX, Lower Mzingwane Subcatchment: demand compared with shortage based on simulated abstractions. The same shortages are simulated for all five scenarios.

Water user	Purpose	Demand (10^6 m^3/year)	Shortage (10^6 m^3/year)
Sukwi irrigation scheme	Agriculture	0.410	0.188
Zezani business centre	Urban	0.003	0
Bwaemura irrigation scheme	Agriculture	2.049	0
Kwalu irrigation scheme	Agriculture	2.561	0
Janee	Tourism	0	0
Steyn	Tourism	0	0
Watson	Agriculture	1.076	1.040
Zhovhe irrigation scheme	Agriculture	0.041	0
Park	Agriculture	7.140	0
Cawood	Agriculture	1.502	0
Cunliffe	Agriculture	1.376	0
Smith	Agriculture	0.688	0
Ferguson	Agriculture	1.544	0
Tongwe irrigation scheme	Agriculture	1.025	0.484
Malala irrigation scheme	Agriculture	1.885	0
Mtetengwe irrigation scheme	Agriculture	8.708	0
Beitbridge	Urban	2.493	0
Musina	Urban	4.317	0
Makhado, South Africa	Urban	2.400	0

Currently water is only released from Zhovhe Dam two or three times during the dry season, based on the dam operation plan and requests from the downstream users. Increasing the frequency of these releases (all scenarios require releases whenever demand is not met, which has meant every 10 days) will improve demand satisfaction downstream. The annual evaporation losses of 28 Mm^3/year are nearly four times the annual demand of the largest downstream user (Park irrigation: 7.1 Mm^3/year) and slightly more than the total demand of the South African urban areas of Polokowane, Louis Trichardt and Musina (24 Mm^3/year: Basson and Roussow, 2003).

In the Thuli Subcatchment (Table 8), it is clear that the Mtshabezi River is already heavily committed, as connecting additional demand nodes results in decrease of supply to the city of Gwanda and neighboring mines, which are currently supplied from this river. The addition of the Mchabezi Irrigation Scheme and Bulawayo inter-basin transfer nodes in scenarios 5 and 7 result in substantially decreased supply to Gwanda and the two mines, which are downstream on the Mchabezi River. The large Greater Thuli Irrigation Scheme (connected in scenario 6) is not feasible without the construction of Elliot and Moswa dams. In the event that this is done (scenario 9), demand throughout the subcatchment can be met adequately, except for the city of Gwanda and neighboring mines.

Table 8. Results of scenarios modeled in WAFLEX, Thuli Subcatchment, demand compared with shortage based on simulated abstractions.

Water user	Purpose	Demand ($10^3 m^3$/year)	Shortage (% by volume) under scenario				
			1	5	6	7	9
Anglesea	Agriculture	140	2.5	2.5	2.5	2.5	2.5
Damara	Agriculture	8,800	3.0	3.0	3.0	3.0	3.0
Khumalo communal land	Domestic	840	1.7	1.7	0.7	1.7	1.7
Matopo National Park	Park	4,840	62.7	62.7	62.7	62.7	62.7
Bulawayo *	Urban	7,100				0.0	3.1
Mtshabezi Irrigation scheme *	Agriculture	4,200		0.0			12.8
Blanket mine *	Mining	1,120	0.0	15.9	0.0	62.9	62.9
Vubachikwe mine *	Mining	650	0.0	17.6	0.0	62.6	62.6
Gwanda *	Urban	1,100	0.2	16.8	0.0	35.9	35.9
Hampden *	Agriculture	700	16.4	21.5	15.3	42.2	42.2
Mtshabezi mission *	Domestic	36	30.0	37.2	5.1	50.6	50.6
Matopo communal land	Domestic	48	0.0	0.0	0.0	0.0	0.0
Lumane resort	Domestic	1,400	0.0	0.0	0.0	0.0	0.0
Lumane communal land	Domestic	24	0.0	0.0	0.0	0.0	0.0
Longville	Agriculture	1,980	4.3	4.3	4.3	4.3	4.3
Kezi	Domestic	140	0.0	0.0	0.0	0.0	0.0
Walmer	Agriculture	140	6.6	6.6	6.6	6.6	6.6
Matopo mission	Domestic	72	1.3	1.3	1.3	1.3	1.3
Thuli-Makwe Irrigation scheme	Agriculture	1,500	3.1	3.1	44.9	3.1	0.0

Water user	Purpose	Demand (10^3m^3/year)	Shortage (% by volume) under scenario				
			1	5	6	7	9
Gwaranyemba	Domestic	1,940	2.6	3.3	20.0	3.3	0.0
Guyu	Domestic	60	3.3	3.3	30.0	3.3	0.0
Chelesa irrigation scheme	Agriculture	300	3.2	3.2	7.9	3.2	0.0
Manama	Domestic	40	3.3	3.3	30.0	3.3	0.0
Great Thuli Irrigation	Agriculture	42,000			51.6		0.0
Mankokoni irrigation scheme	Agriculture	200	3.5	3.5	2.4	3.5	0.0
Rustlers Gorge irrigation scheme	Agriculture	1,310	3.3	3.3	50.9	3.3	0.0
Shashe communal land	Domestic	110	3.3	3.3	55.4	3.3	0.0
Dibilishaba communal land	Domestic	1,240	3.3	3.3	55.8	3.3	0.0

*Demand nodes on the Mchabezi River

Conclusions and recommendations

The lower Mzingwane subcatchment is managed through releases from the heavily underutilized Zhovhe Dam. The downstream river reaches supply water to an important agro-industry (primarily citrus) and to the border town of Beitbridge. WAFLEX modeling suggests that there is surplus water in the subcatchment, and thus no water allocation problems. Through more frequent timing of releases from the dam, the water resources can be better shared to also provide irrigation water for smallholder farmers in the highly resource-poor communal lands along the river.

In the Thuli Subcatchment, the construction of the Moswa and Elliot dams are essential for the Greater Thuli Irrigation Scheme, and can provide sufficient storage for this scheme to operate at design capacity. In the light of these findings, however, and the fact that construction of the inter-basin water transfer to Bulawayo has already commenced, it may be necessary for the Ministry of Agriculture and the Zimbabwe National Water Authority to reconsider the scale of the proposed scheme, as its full design capacity cannot be met without compromising water supply for Bulawayo, Gwanda, and the mines. In the event that development of the Greater Thuli Irrigation Scheme is pursued, stakeholders at local and national levels will have to consider the trade-offs that will be necessary between the scheme and the large upstream users of Bulawayo and the city of Gwanda and neighboring mines, on the Mchabezi River. Since the Greater Thuli Irrigation Scheme and the upstream users on the Mchabezi River would be competing for the same water (the former requires outflow from the Mchabezi River into the Thuli River to meet its demand), demand would have to be reduced by some or all users in order for all of them to be satisfied. This could involve any of the following options: scaling down the Greater Thuli Irrigation Scheme or the inter-basin transfer to Bulawayo, decreasing proposed irrigation water demand through use of drip irrigation, water demand management at Gwanda and the mines. Attempting to further decrease Bulawayo's water demand is unlikely, given the extensive existing water demand measures in place in that city (Gumbo, 2004).

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Adapting the soil and water assessment tool (SWAT) for the Nile Basin

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Abstract

The Soil and Water Assessment Tool (SWAT) is a watershed model widely used to predict water quantity and quality under varying land and water use regimes. To determine the respective amounts of infiltration and surface run off, SWAT uses the popular Curve Number (CN) method. While appropriate for engineering design in temperate climates, the CN is less than ideal when used in monsoonal regions. The CN methodology is based on the assumption that moisture content distribution in the watershed is similar for each run off event, a questionable assumption in many regions where rainfall is concentrated into distinct time periods. In monsoonal climates water balance models generally capture the run off generation processes and thus the flux of water or transport of chemicals and sediments better than CN-based models. In order to use SWAT in monsoonal climates, the CN routine to predict run off was replaced with a simple water balance routine in the code base. To compare this new water balance-based SWAT (SWAT-WB) to the original CN-based SWAT (SWAT-CN), several watersheds in the headwaters of the Blue Nile in Ethiopia were modeled at a daily time step. While long term, daily data are largely nonexistent for portions of the Blue Nile, data were available for one 1270 km^2 sub-basin of the Lake Tana watershed, northeast of Bahir Dar, Ethiopia, which was used to initialize both versions of SWAT. Prior to any calibration of the models, daily Nash-Sutcliffe model efficiencies improved from 0.03 with SWAT-CN to 0.33 with SWAT-WB. These initial results indicate that replacement of the CN with a water balance routine in SWAT significantly improves model predictions in monsoonal climates.

Media grab

The popular USDA-SWAT watershed model was modified for the Blue Nile, greatly improving the ability to predict stream flow and sediment and nutrient loadings in tropical watersheds with monsoonal climates.

Introduction

Hydrologic models are used primarily to predict water quantity, peak flows, and export of water quality constituents from watersheds. One common method to determine the run off volume in these models is the Natural Resource Conservation Service Curve Number (CN) technique. This method was initially designed for determining run off volume for engineering design purposes, but has since been adapted, in a less than ideal manner, for use as a tool in many temporal watershed models, including SWAT (Garen and Moore, 2005). Under Ethiopian conditions, run off is mainly generated by saturation excess mechanisms and run off from a given amount of rain is less in the beginning of the rainfall season than at the end (Liu et al., 2008). Although the CN method can be adapted to predict saturation excess such as this, it inaccurately assumes that similar rainfall patterns produce the same amount of run off independent of the time of the year. This is well illustrated in Figure 1, where we applied the standard CN approach to the Anjeni watershed in the Ethiopian Highlands that has 16 years of rainfall-run off data. It is obvious that when we calibrate the method to the storms at the end of the rainfall season, the storms at the beginning of the rainy season with less than 500 mm of cumulative precipitation are under-predicted. Therefore, in order to apply SWAT to Ethiopian conditions, the original CN method has to be replaced by a more mechanistic approach that uses soil water balances to calculate when the soil is saturated and consequently produces run off.

Methods

To adjust the SWAT program to account for saturation excess run off, a new subroutine was created in the code that circumvented the original CN calculations and used water balances to calculate saturation. The new, saturation-driven SWAT model results were then compared to the original CN-based SWAT results for a simulated period from January 1996 to December 2005.

Original SWAT Curve Number Approach

The CN procedure lumps land use and soil characteristics into a single parameter, CN, relates the watershed's run off response to some theoretical storage capacity, and is obtained from tabulated values. An initial Curve Number is assigned for each specific land use/soil combination (commonly called a Hydrologic Response Unit, HRU) in the watershed, and these values are read into the SWAT program before any daily simulations are run. SWAT then calculates upper and lower limits for each Curve Number following a probability function described by the NRCS to account for varying antecedent moisture conditions (CN-AMC) (USDA-NRCS, 2004). SWAT determines an appropriate CN for each simulated day by using this CN-AMC distribution in conjunction with daily soil moisture values determined by the model. This daily CN is then used to determine a theoretical storage capacity, *S*, of the watershed for each day (via eq. 1).

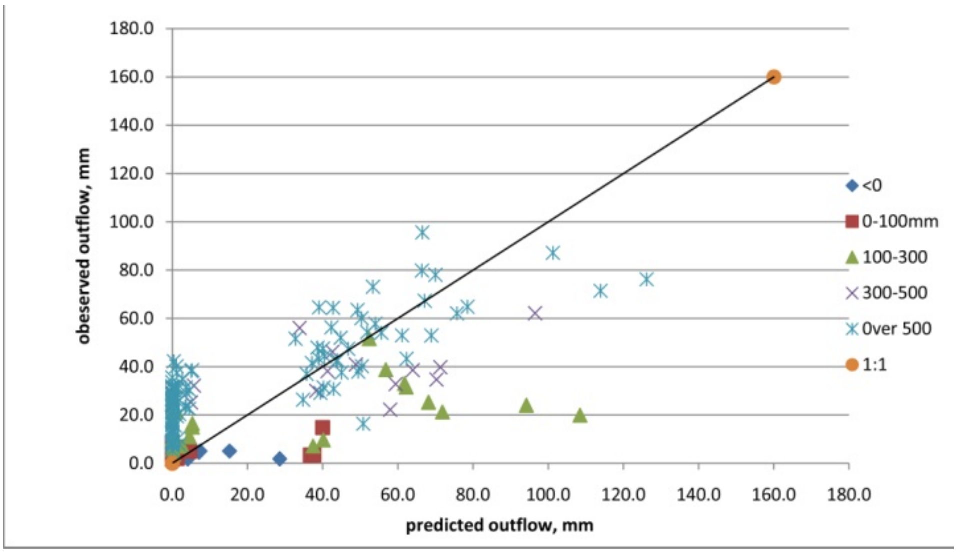

Figure 1. Observed vs. Curve-number-predicted streamflows for the Anjeni watershed showing cumulative rainfall values for each rainy season.

$$CN = \frac{1000}{10 + \frac{S}{25.4}} \qquad (1)$$

This derived storage capacity is then used to determine the run off volume, Q created from a precipitation event, *P (*eq. 2*)*. By convention, the initial abstraction, I_a, is assumed to be equal to 0.2**S*.

$$Q = \frac{(P - I_a)^2}{(P - I_a) + S} \qquad (2)$$

While a theoretical storage capacity is assigned and adjusted for antecedent moisture for each land use/soil combination, the storage is not used to directly determine the amount of water allowed to enter the soil profile. Since this storage is a function of the land parcel's infiltration properties, as quantified by the CN-AMC, SWAT indirectly assumes only infiltration excess run off. Prior to any water infiltrating, the exact portion of the rainfall that will run off is calculated via these infiltration properties. This determination of run off volume before soil water volume is an inappropriate approach for all but the most intense rain events, and particularly in monsoonal climates where saturation plays an important role in run off generation.

SWAT-WB saturation excess approach

The modified SWAT uses a water balance for each HRU. Based on this calculation, run off, interflow, and infiltration volumes are calculated. The modified model is therefore called SWAT-Water Balance or SWAT-WB for short. While this model simplifies the processes that govern water movement through porous media (in particular, partly saturated regions), for a daily model, the water balance model has been shown to be proficient (Guswa et al., 2002). Additionally, for Ethiopia, water balance models outperform models that are developed in temperate regions (Liu et al., 2008; Collick et al., 2008). In SWAT-WB, HRUs are formed based on land use, soil information, and a topographic index. For each HRU a water balance is kept that is adjusted daily for plant uptake, evaporation, and thus rather than determining the daily CN for determining the amount of run off from a given event in SWAT-WB the HRUs, run off is equal to the amount rainfall minus the amount of water that can be stored in the soil before it saturates. This amount of storage is called available soil storage, τ:

$$\tau = D(\varepsilon - \theta) \qquad (3)$$

Where *D* is the effective depth of the soil profile, ε is the total soil porosity, and θ is the volumetric soil moisture of the HRU. The porosity is a constant value for each soil type and can be found as $1-\rho_b/\rho_s$, whereas θ varies by the day depending upon plant uptake of water, evaporation, and precipitation. For any HRU, a precipitation event that has a smaller volume than the available storage will not contribute any run off to the channel (i.e. all the rain will infiltrate as soil water). Surface run off will be generated for an HRU when an event has a higher volume of rain than it will take to saturate the soil profile. The volume of this saturation excess generated run off will simply be the portion of the rainfall, P, that exceeds the τ value for the HRU (eq 4).

$$Q = P - \tau \qquad (4)$$

Note that since this model generates run off when the soil is above saturation, total rainfall volume, not intensity, determines the amount of run off. Therefore, when results are presented on a daily basis, rainfall intensity is inconsequential. We recognize that storms with a very high intensity may result in under-predicted amounts of run off, but this is the exception rather than the rule (Liu et al., 2008).

Watershed description

The new SWAT-WB was initially tested on a watershed in the Blue Nile River Basin in Ethiopia. The Gumera watershed, located northeast of Bahir Dar, is a 1270 km^2, heavily (~95%) cultivated, watershed in the Lake Tana Basin. Elevation of the Gumera watershed ranges from 1797 to 3708 m and predominant soils are generally characterized as chromic and haplic luvisols (24% and 63%, respectively) (FAO-AGL, 2003). Daily precipitation and temperature data for the period 1996-2005 were used, while other historic climate data (relative humidity, wind speed, solar radiation) were gathered from the United States' National Climatic Data Center for the nearest station, Bahir Dar, (NCDC, 2007). SWAT-WB and SWAT-CN output was then compared to daily stream flow data for the Gumera basin outlet for 1998 and 1999.

Results

As seen in Figure 2, initial results obtained with SWAT-WB indicate that a complex watershed model can be run with adequate results for predicting peak flows in monsoonal climates at a daily time step if the CN approach is replaced. Prior to any calibration or validation, SWAT-WB returned more accurate results than SWAT-CN. When comparing modeled stream flow to observed values, SWAT-WB returned a Nash-Sutcliffe model efficiency (NSE) of 0.33. This is quite an improvement over the SWAT-CN result (NSE=0.03). An efficiency of zero would indicate that the model performed no better than simply taking the long-term mean of the stream flow. Similar to the model efficiency results, SWAT-WB also returned a higher coefficient of determination, r^2, than SWAT-CN; 0.38 and 0.25, respectively.

An area that the SWAT-WB can be improved is that the run off is under-predicted in the middle of the 1999 rainy season (Figure 2). This situation should be improved by improving the soil properties data used as an input to SWAT. By improving the values used for the portion of the soil profile that is available for saturation (effective depth, *D,* in eq. 1) and drainage due to gravity will improve simulations as the rainy season progresses. This will lead also to more accurate base flow recession at the end of the rainy season. In addition to gathering better soil data, a soil topographic index for each HRU is to be used for calibration of SWAT-WB. As discussed in the following, this will lead to a realistic model of the spatial variation of runoff-generating areas. Even with these preliminary, uncalibrated simulations, several advantages of the SWAT-WB over the original SWAT-CN program can be seen.

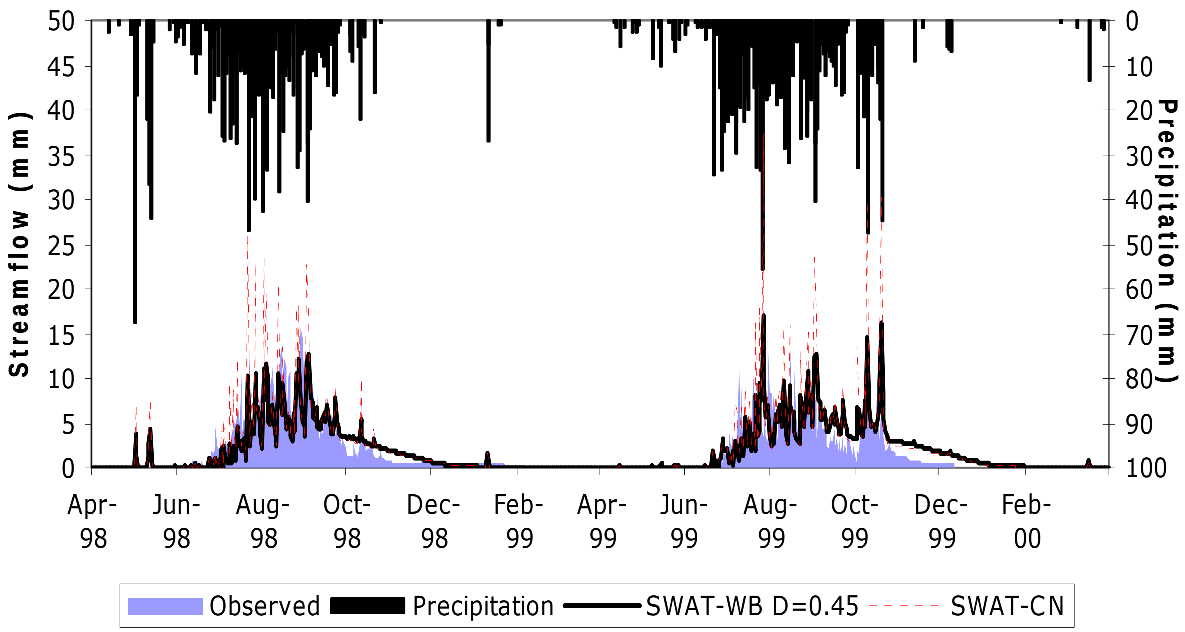

Figure 2. Observed and modeled daily stream flows for Gumera for two rainy seasons: 1998 and 1999.

Discussion

SWAT CN and most other watershed models have been developed for temperate climates where rainfall is generally well distributed throughout the year. Running models developed in the temperate climate for Ethiopian conditions with a monsoonal climate is problematic. Temperate models assume that there is a nearly unique relationship between precipitation amounts or intensity and run off generated. This is not the case for Ethiopia as demonstrated by the results of Liu et al. (2008), where for three watersheds with more than 16 years of data, the rainfall relationship was far from unique. The first rains after the dry season all infiltrate and nearly no run off is generated. As the rainfall season progresses more and more rainfall becomes run off. For each of the watersheds, after approximately 500 mm of effective rainfall (i.e., precipitation minus potential evaporation) a constant fraction (approximately 50%) becomes run off. The only possible explanation for this phenomenon is that more and more of the watershed starts generating runoff as the season progresses (Liu et al., 2008). Since the intensity of the rain did not affect the runoff amounts for a given storm, the runoff mechanism is saturation excess run off. This is in accordance with unpublished infiltration measurements made in the Lenche Dima and Yeku watersheds (McHugh et al., 2007) that indicates that the infiltration rate of most soils exceeds the rainfall intensity of most storms.

Water balance models are consistent with saturation excess run off process because the run off is related to the available watershed storage capacity and the amount of precipitation. The implementation of a water balance in run off calculations in the Blue Nile Basin is not a novel concept, and often performs better than more complicated models in Ethiopia-type landscapes (Johnson and Curtis, 1994; Conway, 1997; Kebede et al., 2006; Liu et al., 2008; Ayenew and Gebreegziabher, 2006). These water balance models are typically computed with monthly or yearly values because the models are generally not capable of separating base-, inter-, and surface runoff flow. To truly model erosion and sediment transport, however, large events must be captured by the model and simulations with a daily time step are needed do so. Thus SWAT-WB not only maintains a water balance but in addition calculates the interflow and the base flow component, and as Figure 2 shows, gives a reasonable prediction of peak flows. SWAT-WB is therefore more likely to capture sediment transport than either SWAT-CN or water budget models with monthly time steps. Note that by choosing to run models on a daily time step, the model performance always is significantly worse than for monthly or yearly time steps.

SWAT-WB is more in tune with the run off processes that occur in the Ethiopian highlands than other models that base their run off prediction on the NRCS curve number method (Liu et al., 2008; Collick et al., 2008; Steenhuis et al., 2008). The calculations that serve as a foundation for NRCS curve number technique assume that the moisture condition in the soil can be determined by taking into account the five day previous rainfall events. As indicated above the moisture content in monsoonal climates is changing during the first 500 mm effective precipitation or approximately 1-2 months. SWAT-WB, on the other hand, determines run off volume simply by calculating the available storage in each soil profile. This value is not dependent only upon the five previous days' rainfall (as the CN method is), but instead allows for progressive saturation as the rainy season continues.

Although the SWAT-CN predicts the stream flow except for peak flows reasonably well, using SWAT-CN does not mean that the spatial distribution of run off areas is predicted correctly. This issue has been studied in the past, and numerous CN-based models have been adjusted to correct for the method's shortcomings. By making simple modifications to the CN approach, the percentage of a watershed that contributes run off can be determined, but not the explicit locations of these runoff-producing areas (Steenhuis et al., 1995). These modifications, among others, have been implemented into watershed models in an attempt to pinpoint the location of run off production. This CN modification coupled to a topographic index was used by Lyon et al. (2004) and by Schneiderman et al. (2007) in the General Watershed Loading Function (GWLF) model to capture spatial variation controlled by topographic features. Easton et al. (2008) used these same modifications to create a version of SWAT that could determine the location of run off producing areas more accurately than the traditional SWAT-CN. While these model modifications show that the CN method can be adjusted to overcome its inherent shortcomings, and are appropriate for many regions, SWAT-WB goes one step further and eliminates the CN completely from run off calculations in monsoonal climates.

Conclusions and recommendations

Daily modeling of peak stream flow and surface run off was improved by replacement of the CN method with a WB routine in the SWAT model. In addition to improving model efficiencies, it is also predicted that the new WB-based SWAT will be a better predictor of the location of runoff-generating (and therefore sediment and chemical generating) areas of a watershed. To aid in this determination of locale, SWAT-WB should be calibrated utilizing the soil topographic index, resulting in a watershed model where surface runoff is modeled as a function of topography, soil characteristics, and soil moisture. Additionally, improved soil properties data should aid in accurately determining flows during the middle of the rainy season, as well as aid in the accurate modeling of base flow recession after rains end.

In general SWAT-WB should be more widely applicable than SWAT-CN. Water balance models have been found to work in nearly all climates, therefore incorporation of these procedures into SWAT provides a more robust model and is potentially applicable in watersheds (such as in Ethiopia) where it has been determined that run off generation is driven by saturation excess processes.

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Assessing the hydrological impact of ensembles of small reservoirs

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Abstract

Small reservoirs (<100 ha) are an important instrument for the development of water resources in rural areas in semiarid areas throughout the world. Because small reservoirs induce decentralized development, impact assessment of reservoir ensembles is more difficult than that of large dams or irrigation schemes. To be able to assess the impact of existing and future ensembles of small reservoirs, a stochastic framework is presented. This framework takes into account the most relevant statistical properties and relations of reservoir properties and fluxes. A subtle problem is the fact that ensembles follow different pathways when filling up and emptying out, which is called hysteresis. The hysteresis necessitates that the history of all individual reservoirs in the ensemble need to be tracked. The main statistics needed for the analysis are the size distribution of the reservoirs, which can be obtained through remote sensing, and the area-volume relation, which can be obtained through a limited bathymetric survey. In addition, some analysis is needed of inflows and outflows. Once these relations are determined, the hydrological impact of ensembles of any size can be estimated statistically. A case study for the Upper East Region of Ghana, in the Volta Basin, is used to illustrate the method.

Media grab

One small reservoir will not affect the hydrology of a large river. But how about a thousand or ten thousand reservoirs? Find the answer here.

Introduction

Small reservoirs supply rural local populations with water for irrigation, cattle, household, fisheries, and recreation. These reservoirs can be found in semiarid areas around the world. Small reservoirs are defined here as reservoirs with a surface area between 1 ha and 100 ha. Typically, such reservoirs are sited on the headwater of an ephemeral stream where they catch water during the wet season, to be made available during the dry season. Important advantages of small reservoirs are that they drive a geographically more diffuse development process, and they tend to have fewer governance problems because local institutions (villages) are already in place.

In many semiarid areas in developing countries, small reservoirs are an integral part of improved rural water management strategies. The central question of this study is: what hydrological impact do a large number of small reservoirs, or an ensemble of reservoirs, have at the level of a river basin? A convenient way to think of an ensemble of small reservoirs would be as one larger reservoir, perhaps situated at a higher order stream downstream from all these headwater streams. Unfortunately, there is a little snag. An ensemble of differently sized reservoirs fills and empties along different trajectories (such a phenomenon is called hysteresis). This subtlety is illustrated in Figures 1A and B.

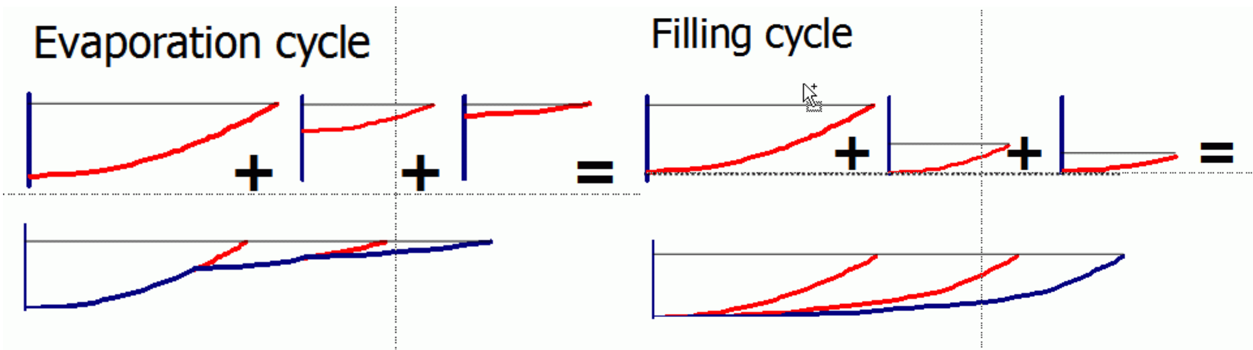

Figure 1. Left: Evaporative cycle of three differently sized reservoirs, starting with completely full reservoirs. Right: Filling cycle of three differently sized reservoirs, starting with completely empty reservoirs.

The consequence is that the complete filling and emptying history of the individual reservoirs has to be taken into account. It would be impossible, or extremely tedious at best, to enter each individual ensemble member to simulate the overall impact. Instead, a number of stochastic relations will be developed here that allow for the hydrological impact assessment of a large number of reservoirs. The impact assessment comprises evaporative losses, spillage, water used for irrigation, and irrigation excess drainage.

The research presented here is part of the Small Reservoirs Project (www.smallreservoirs.org), which is part of the CGIAR's Challenge Program on Water for Food (www.waterforfood.org).

Methods

The basic idea is that an ensemble of small reservoirs has certain statistical and stochastic properties (such as size probability distributions and area/volume relations) that are relatively constant, even when the number of reservoirs is increased. By randomly drawing from these distributions, one can increase the number of reservoirs and simulate the total impact of the (enlarged) ensemble. The scaling laws of ensemble impacts are governed by these statistics. The reason to go this roundabout way is that the alternative would be to site and design individual new reservoirs and simulate their behavior. This would be acceptable for a handful of dams but not if, say, the government of Burkina Faso would like to know what the impact would be of doubling the number of small reservoirs from 2000 to 4000.

A handful of stochastic relations have to be established empirically. Here, we use relations as found in the Upper East Region of Ghana. It is important to realize that the analytical framework presented here does not depend on the exact shape or parameterization of the relations. In other areas, other parameters may be found but the framework remains valid. The two most important stochastic functions that need to be known are the distribution of reservoir sizes and the relation between reservoir areas and volumes. Here, we start with the distribution of reservoir areas because these can easily be determined on the basis of remote sensing (Liebe et al., 2005; Mialhe et al., 2008). For Ghana's Upper East Region, the cumulative distribution of reservoir areas takes the form of a Pareto distribution, as shown in Figure 2.

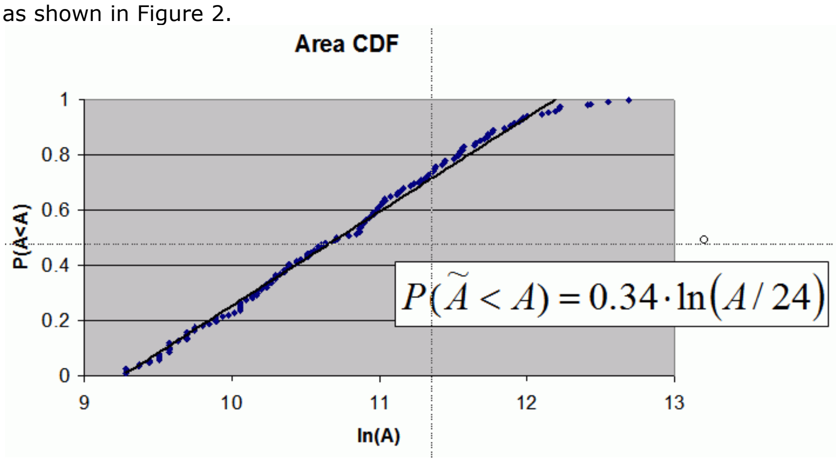

Figure 2. Cumulative distribution.

An important finding is that there is a strong relation between surface areas, which can readily be determined with remote sensing (Liebe et al., 2008a), and the stored volume. The parameters need to be established in the field through a limited bathymetric survey. The method has been repeated in the Upper East Region and yielded similar results (Annor, 2007). Application of this method in Zimbabwe also showed a power relation between area and volume but with different parameters (Sawunyama et al., 2006).

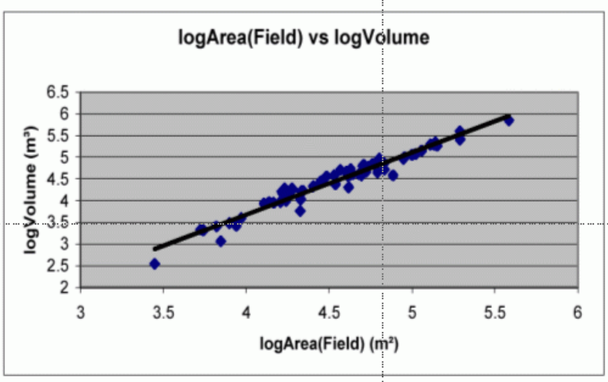

Figure 3. Correlation between reservoir areas and volumes

With the graphs shown here, one already has important information concerning the statistical properties of reservoir ensembles. Total storage capacity of the ensemble and of planned ensemble expansions can, for example, now be estimated reliably.

To determine the dynamics of the ensemble, we will have to estimate inflows and outflows over time. The water balance can be written as:

$$\Delta S / \Delta t = RO + P - S - Irr - E \qquad \text{Eq. 1}$$

in which ΔS (m^3) is the change in storage, Δt (s) the time period over which the water balance is determined, *RO* (m^3/s) the average surface runoff into the reservoir, *P* (m^3/s) the precipitation on the reservoir, *S* (m^3/s) the seepage from the reservoir (negative if groundwater flows into the reservoir), *Irr* (m^3/s) water use for irrigation (other uses are negligibly small but could be included here), and *E* (m^3/s) the evaporation from the reservoir. Each term in the water balance needs to be determined, whereby a reasonable time step seems to be one month. Rainfall and evaporation can be determined on the basis of readily available climate data such as the CRU dataset (New et al., 1999, 2000). With respect to evaporation from the reservoir, one can take potential evaporation. It has been suggested that evaporation of a reservoir in a dry environment may be as high as twice the potential evaporation due to advection of energy from the warm environment to the reservoir. Measurements in Ghana's Upper East suggest that for most of the year, evaporation from the small reservoirs is less than potential, probably due to the buildup of a stable (inverted) internal boundary layer.

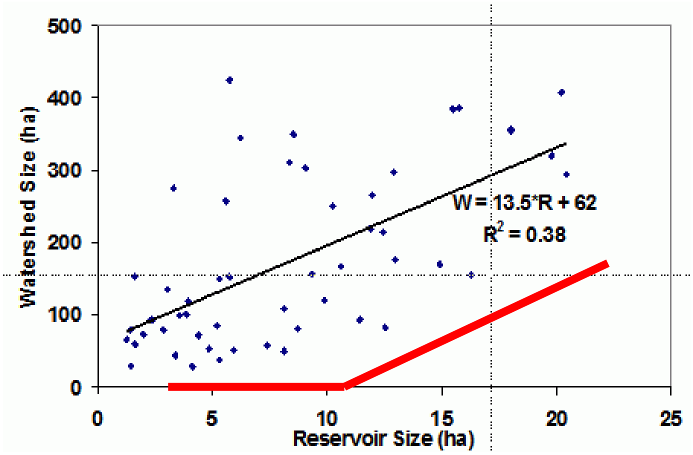

Figure 4. Correlation between reservoir size and watershed size for Ghana's Upper East Region. The thick red line represents a lower envelope under which no reservoirs are found.

RO depends on the size of the watershed that drains into the reservoir. The correlation between reservoir area size and watershed size is shown in Figure 4. The correlation found is relatively weak (R^2=0.38). A closer look reveals the logic behind the siting of small reservoirs, which depends on many factors, of which total available water, or watershed size, is only one. Proximity to a village, availability of roads and building material, and a natural 'bottle neck' in the stream are all relevant. It does make sense to build a relatively small reservoir at the bottom of a relatively large watershed (Figure 4.). Such a reservoir may fill up quickly and spill most of the wet season but still provide extra water during the dry season. It does not seem to make sense, however, to build a large reservoir in a small watershed. The costs of such a reservoir would be high but the yield would still be low. We model the stochastic dependence by defining a lower envelope below which no reservoirs are found (Figure 4). The distance between this envelope and the individual data points can be fitted accurately with a Gamma distribution. To determine the watershed size for a given reservoir size, one draws from the Gamma distribution and adds the value of the envelope. With the watershed size, a suitable rainfall-runoff model, and regional rainfall data, the inflow into the reservoir can be calculated. Interestingly, it is also possible to calibrate models by observing the filling of reservoirs through satellites (Liebe et al., 2008b).

The remaining term is the water used for irrigation, which is the most difficult to estimate. Ideally, one would observe with satellites the irrigated areas. By measuring or estimating an irrigation efficiency, one could then readily calculate water use for a given cropping calendar. In West Africa, this has not been possible due to the fact that irrigation schemes are typically found in valley bottoms and wetlands that have the same spectral properties irrespective of the presence of irrigation. The alternative chosen here is to include a simple learning algorithm that expands the irrigated area from one year to the next as long as a (significant) amount of water is still available at the end of the dry season. Irrigation efficiency is assumed to be low given direct measurements in the Upper East Region (Faulkner et al., 2008). This procedure remains relatively weak and, given the high uncertainty in efficiency levels, this term will in most cases remain likely to contain the largest estimation error. Regional surveys may help reduce the uncertainty.

All information is now in place to integrate Eq. 1 numerically. The available climatic data series has a length of 98 years, so almost a full century can simulated. These simulations are repeated for a large number of reservoirs, say 1000, drawn from the determined statistical distributions. The average storages and fluxes now represent an ensemble of reservoirs that can readily be varied in size. The MatLab code that performs this task is available through the authors.

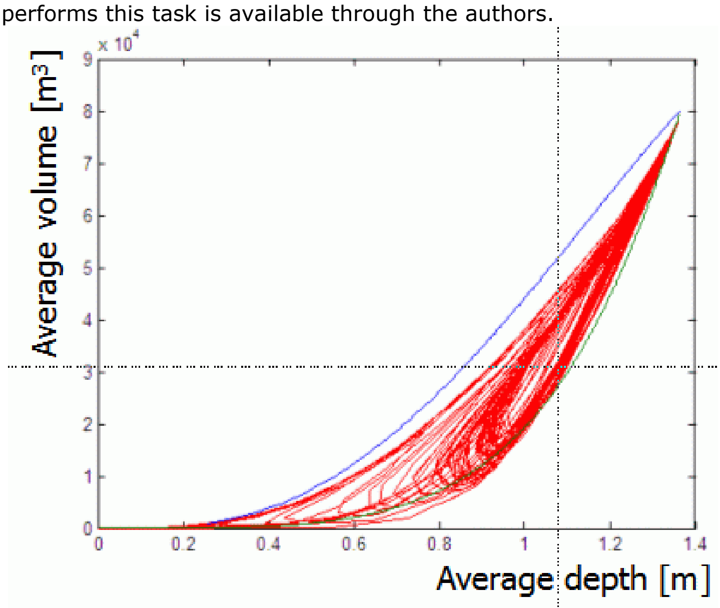

Figure 5. Thin red line shows development of average volume stored in an ensemble of 1000 reservoirs over a 98-year period as a function of average depth.

Results and discussion

The results of a typical simulation are shown in Figure 5. The original expectation, and hope, was that hysteresis would be negligible and that the storage/depth evolution over time would closely follow a single line. This line could then be used to represent a single reservoir, the size of which could then be adjusted to represent larger or smaller ensembles. As can be seen in Figure 5, hysteresis cannot be neglected. For an average depth of 1 m, for example, the stored volume varies between 1.5 and 3.8 m.

The good news is that even the simulation of 1000 reservoirs over a period of 100 years, does not take more than a few seconds on a standard computer. The method is not difficult to apply in other regions but the stochastic relations found for the Upper East Region of Ghana cannot be assumed to be valid elsewhere. The core relations that need to be established are the area distribution and the area volume relation. Sawunyama et al. (2006) have shown that for parts of the Limpopo Basin in Zimbabwe, similar distributions can be determined be it, as expected, with different parameters.

Conclusions and recommendations

To determine the impact of diffuse water resource development projects, such as through small reservoirs, a stochastic approach is logical. An analytical framework was presented that allows for the assessment of the hydrological impact of present and future ensembles of small reservoirs. Hysteresis is a subtle but relevant issue that can be taken into account by keeping track of volumes, areas, and main fluxes for a large set of reservoirs. The main statistics that need to be established can be obtained with relatively little field work. Most relations are relatively robust. The main remaining uncertainty is the link between reservoir size, irrigated areas, and irrigation efficiencies.

It is difficult to verify the results but there is promise in satellite observations that are capable of mapping reservoir areas over large areas. It is recommended that some of the key relations, especially the area distribution and the area-volume relations, are measured in different semiarid areas around the world.

Acknowledgments

This paper presents findings from PN46 'Planning and evaluating ensembles of small, multi-purpose reservoirs,' a project of the CGIAR Challenge Program on Water and Food. Support from the GLOWA Volta Project (www.glowa-volta.de) and ESA's Tiger Project 2871 (http://tiger2871.shorturl.com) is also gratefully acknowledged.

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Overview of streamflow variability and water accounts for the Karkheh Basin, Iran

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Abstract

This paper provides an overview of the streamflow variability in the semiarid to arid Karkheh River Basin of Iran, using daily data for the period 1961-2001 at seven key locations. It also provides a snapshot of the basin level water accounting for 1993-94, which is considered the reference year for the future water resource planning for the Karkheh Basin. The study showed that the streamflows of the Karkheh River and its tributaries exhibit large inter- and intra-annual variability. The study concluded that the Karkheh Basin appears to be an open basin during the period of investigation. Considering the water availability and the current and ongoing water resources development planning, however, the basin will very likely approach a critical stage during the first quarter of this century, and meeting the demands of all users will be an extremely challenging task.

Media grab

The Karkheh River and its tributaries exhibits large inter- and intra-annual variability, and inclusion of this information into water resources allocation planning will help to develop a sustainable management regime.

Introduction

Assessment of the spatio-temporal variability of water resources provides essential scientific information that in turn could be used for making water resources policies, for instance, regarding sustaining the food production, ecosystem health, and socioeconomic benefits from the use of water. This is extremely important for water-limited environments, such as the semiarid to arid Karkheh Basin of Iran, where scarcity and variable distribution of water and nutrients makes these environments highly vulnerable and sensitive to change. The Karkheh Basin (Figure 1) is subjected to a fragile balance between environment and human uses of natural resources. The demands for water are increasing and sustainable management of water resources has become an important issue. In this river basin, massive irrigation development is under way, but the knowledge and understanding of basin hydrology (including the water balance variations in space and time) and impacts of these developments on other users and water uses across the basin are patchy (Qureshi et al., 2005).

This paper provides an overview of the surface water hydrology of the Karkheh Basin and details on the nature of its spatial and temporal variability. The basin level water accounts are also provided for 1993-94. This study is part of the Basin Focal Project for the Karkheh (CPWF, 2006), and is expected to guide further water resources research and development planning by the Challenge Program on Water and Food and Iranian stakeholders such as the Ministry of Energy and Ministry of Jihad-e-Agriculture.

The Karkheh River Basin has a drainage area of 50,764 km^2, of which 80% is part of the Zagros mountain ranges of Iran. The climate is semiarid in the mountainous parts and arid in the lower plains. The mean annual precipitation in the basin is about 450 mm, ranging from 150 mm in the lower arid plains to 750 mm in upper mountainous parts. The annual renewable water resources of the basin are about 8.5×10^9 m^3 (JAMAB, 1999).The details on the study area can be found in Sutcliffe and Carpenter (1967), JAMAB (1999), CPWF (2006), and Ahmad et al. (2008).

Methods

For this study, seven river gauging stations (Figure 1) were selected on the basis of their geographical importance, availability of consistent length of records, and longer time series. The data on the surface water withdrawals was not available, therefore the analysis accounts for the abstractions for various uses such as irrigation and domestic. The naturalization of streamflows can be made if the withdrawals are known or estimated through indirect means, if the information on daily crop water demand, cropping pattern, and cropped area and irrigation efficiencies are available (Masih et al., 2008). A streamflow naturalization approach for agricultural withdrawals in the Karkheh Basin has been devised by Masih et al. (2008) for the period 1987-1997. It was not possible, however, to carry out naturalization of streamflows over the 40 years of the study period 1961-2001, because the required information was not available.

The analysis included: (1) basic statistics and trend detection; (2) flow duration curve; and (3) water accounting. Daily stream flow data for the period 1961-2001 were acquired, quality controlled, and used. The trend analysis was carried out on the monthly and annual time series of streamflows using Spearman rank test (e.g Yue et al., 2002). We attempted to attribute the trends and patterns by analyzing available (limited) information on climate, irrigation developments, reservoir construction, and land use changes. We analyzed the precipitation data of three climatic stations, Kermanshah and Khorramabad (data from 1951-2003) and Ahwaz (data from 1957-2003), each representing the upper, middle, and lower parts of the basin, respectively. We used 90% confidence interval (one tailed) for evaluating presence or absence of trends, as in the semiarid to arid environment of the Karkheh Basin changes that are significant at this level could have quite serious implications. The annual data series was used to derive Flow Duration Curve (FDC) for the Q_{1}, Q_{5}, Q_{10}, Q_{25}, Q_{50}, Q_{75}, Q_{90}, Q_{95} percentiles. FDC is a cumulative distribution of flows at a site showing the flow assurance that how often any flow is equalled or exceeded (see Linsley et al., 1982).

The IWMI water accounting framework (Molden and Sakthivadivel, 1999), which provides a unique way of distinguishing different water use categories (e.g. net inflow, depletion, committed and uncommitted outflows), was applied for the basin level water accounting for the water year 1993-94, as most of the required information was available for this period from the study of JAMAB (1999), and also because this year is considered as the reference year for the future water resource planning for the Karkheh Basin. Although the similar exercise for an extended period, i.e., for one decade or more, and for dry, medium, and wet years could be much more helpful, but was not possible due to unavailability of the required data . A brief description on the estimation of water accounting components is provided here, and details can be found in JAMAB (1999). The estimates were based on the observations on climate (e.g., precipitation, evaporation), streamflows, water uses, and other water balance components. For the purpose of detailed water balance analysis, they divided the basin into 47 subcatchments, and their water balance results were aggregated at the basin level. The inflow components of the water accounting were composed of precipitation, inflow from outside of the basin, and changes in surface and subsurface storage (Figure 3). The precipitation data were based on the 61 climatic stations spanning the basin. Changes in subsurface storage were estimated based on the groundwater measurements related to water level changes, specific yield, and domain area. Since there was no major storage dam in the basin during 1993-94, the surface storage was considered as zero. The actual evapotranspiration was estimated through empirical equations calibrated for selected locations in the basin where detailed data on climate and water balance were available. The actual evapotranspiration from diversions for agricultural purposes was estimated as the difference of total abstraction and return flows. The subsurface outflow was regarded as zero, whereas outflow from rivers and drains were based on the observed records. The data on committed and uncommitted water were not available through the study of JAMAB and, therefore, we estimated these values in order to complete the water accounting exercise. The committed water was estimated in the range of 10-50% of the available streamflows, based on Tennant (1976), who suggested that allocating 50% of the available streamflows to riverine ecosystems can maintain healthy ecosystems, whereas the minimum flows should be at least 10%, although the ecosystem degradation will be inevitable at this level. It should be noted that this method is simple to apply but has the potential for inadvertent misuse, because it does not account for specific species/life phase habitat requirements, short-long-term changes in flow rates, seasonal variability, or channel geometry.

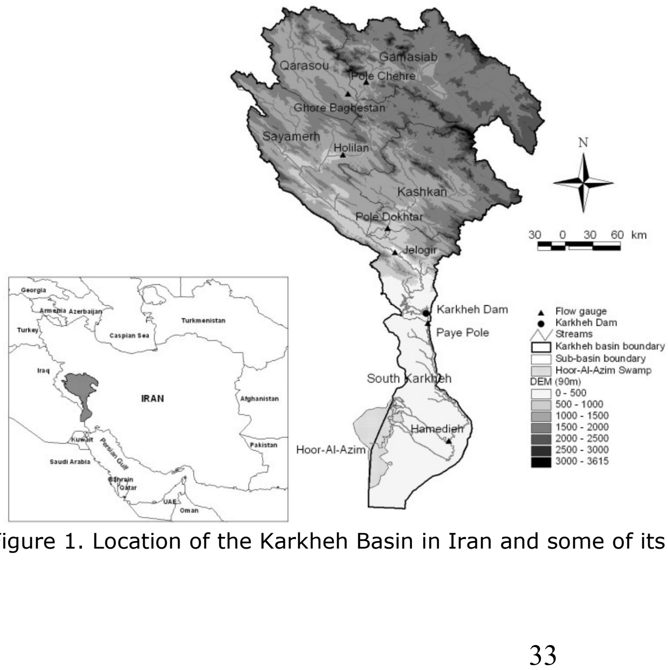

Figure 1. Location of the Karkheh Basin in Iran and some of its salient features.

Results and discussion

Spatial and temporal variability of the streamflow regimes

The streamflows show large variability within a year and between years. The general temporal pattern of streamflows, however, is quite synchronized when different streams or flow behavior at different locations on a single river are compared (Figure 2). This is indicated by the similar timings of the high- and low-flow months. The high-flow events are mainly concentrated during November to May, with peak flows mainly in March-April. The duration of these events varies depending on the precipitation timing and snow melt dynamics. Generally high-flow events of small duration (i.e. 1-5 days) occur due to high rainfall events; but the high flows prevailing for 1 or 2 months, mainly observed during February-May, are caused by the snow melt and combined effect of snow melt and rainfall. The low flows are observed during June-September. The maximum values of CV are observed for November ranging from 0.96 to 1.77, and the minimum values of CV are observed in February ranging from 0.44 to 0.53. In spatial terms, highest variability is observed for Pole Chehre and Ghore Baghest, located in the upper parts of the basin. The annual values of CV fluctuate around 0.47, with the range of 0.41-0.54 (Table 1). These high inter- and intra-annual variations are mainly governed by the variability of precipitation, topography, soils, land use, and geology. The high variability in autumn streamflows and precipitation has implications for the management of rainfed and irrigated lands. This adds to the uncertainty of the water availability through surface flows as well as through precipitation. As a result, the decisions related to cropped area and agronomic operations (e.g. sowing operations for wheat and barley) remain at risk. Improved forecasts and their use by farmers could greatly help in getting ensured and better agricultural outputs from the land.

The results of the trend analysis show that declining patterns were observed during May at all stations. Generally decline during May-September were observed in upper parts of the basin, though trends were significant only for May at Ghore Baghestan and Holilan. December and March show increasing patterns all across the basin, with December streamflows significant at Holilan, Pole Dokhtar and Jelogir. Increasing trends were observed during October at Pole Dokhtar and Hamedieh. Decreasing trends were observed for August at Ghore Baghestan and Holilan, whereas Hamedieh station showed increasing trends in August and September. The decline in flow during May was mainly attributed to the decline in precipitation during April and May, whereas increase in December flow was not clearly attributed to climate alone but was likely to be triggered by the combined effect of climate and land-use changes. These would include increasing patterns of precipitation in December, though not significant, and the watershed degradation due to a decline in the forest cover and a deterioration of rangelands (Mirqasemi and Pauw, 2007). Increasing trends at Hamedieh, particularly during July-September, were mainly attributed to the operations of the Hamedieh reservoir. This analysis has highlighted the need of further (modelling) studies on the linkages of streamflows with climate, land use, and reservoir operations.

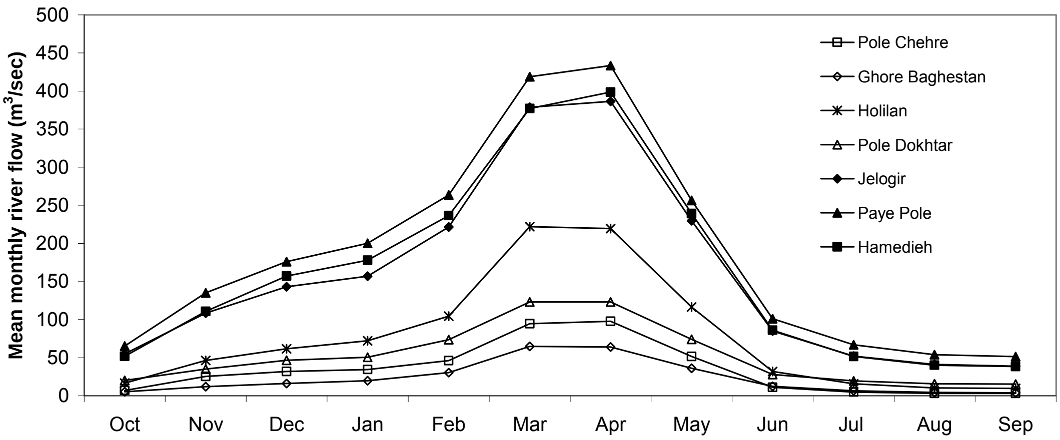

Figure 2. Mean monthly discharge at the selected locations in the Karkheh Basin, Iran.

The comparison of mean and median annual surface water availability indicates that the mean values are 0-7% higher than the median estimates. This exhibits the classic arid and semiarid hydrology characteristic that the mean is greater than the median, but, in this case, not by a big margin at an annual scale (only 4% on average). Further examination of annual surface water availability (Table 1) shows that maximum flow of 12.59×10^9 m^3 occurred in the wet year 1968-69, whereas the minimum flows of 1.92×10^9 m^3 correspond to the drought year 2000-01, at Paye Pole station. In the time period of this analysis, 1961 to 2001, a drought persisted from 1999 to 2001, though the longer term time series do depict high- and low-flow years throughout the study period. These large temporal variations indicate high levels of supply insecurity for current and further withdrawals for human uses.

The analysis of flow duration curves (Table 1) provide further insights into the annual availability of surface water along with the corresponding level of assurance. For instance the value of Q_{75} at Paye Pole station at the Karkheh River is 4.082×10^9 m^3, which shows that this much volume of surface water could be available for 75% of the time, i.e. 30 out of 40 years. Further examination was done to see the assurance levels associated with mean annual water availability. For this, FDC plots were generated, using annual data (not shown in the paper), and the exceeding level of means were noted for each station. This analysis indicated that mean annual surface water availability has an assurance level of about 45% at the basin scale, ranging from 40% for Pole Chehre to 52% for Pole Dokhtar. This shows that the annual mean is biased toward water years with high values for Pole Chehre (and also for Ghore Baghestan) and, therefore, the median is a better measure of central tendency for these stations. Furthermore, due to the construction of the Karkheh dam in 2001 and ongoing irrigation schemes in downstream parts, one can anticipate that during the below average/low-flow years, the most serious conflict would concern retention of water in Karkheh dam for hydropower generation and reduced supplies to the downstream agricultural users, whose situation will be exacerbated by soil salinity problems. This would also be accompanied by the diminished flows to riverine ecosystem and floodplains as well as to the Hoor-Al-Azim swamp further downstream.

Table 1. Some basic statistics and flow duration characteristics showing annual variability in streamflows.

	Units M^3/year	Pole Chehre	Ghore Bagestan	Holilan	Pole Dokhtar	Jelogir	Paye Pole	***Hamedia***
Mean	10^6 m^3/	1080	722	2431	1639	4974	5827	5153
CV	-	0.50	0.54	0.53	0.41	0.43	0.43	0.48
Minimum	10^6 m^3/	198	104	607	645	1790	1916	1068
Maximum	10^6 m^3/	2851	1914	6193	3206	10773	12594	11324
Median	10^6 m^3/	1003	712	2292	1637	4692	5590	4852
Q_5	10^6 m^3/	2416	1844	6042	3081	8958	10755	9280
Q_{10}	10^6 m^3/	1684	1183	4250	2455	8227	9280	8641
Q_{25}	10^6 m^3/	1303	957	2977	2064	6193	7756	7555
Q_{50}	10^6 m^3/	1022	716	2343	1645	4836	5651	4873
Q_{75}	10^6 m^3/	766	419	1499	1113	3562	4082	3447
Q_{90}	10^6 m^3/	549	353	1168	854	2601	3020	2254
Q_{95}	10^6 m^3/	294	268	871	778	2230	2404	1648

Overview of the basin level water accounting

Basin level water accounts are given in Figure 3. The annual gross inflow, net inflow, and total depletion were 24.96×10^9 m^3, 25.08×10^9 m^3, and 19.94×10^9 m^3, respectively. Direct depletion from precipitation constituted 82% (or 16.39×10^9 m^3) of the total depleted water (19.94×10^9 m^3). This water was mainly depleted through cropped areas, pasture, forests, and bare lands. The quantified data on these uses were not available for the study period; however, the estimates could be seen in a recent remote sensing-based study of Muthuwatta et al. (2008) who has estimated actual evapotranspiration for the different land uses in the basin for 2002-03. The portion of irrigation diversions, during 1993-94, depleted as evapotranspiration from irrigated areas was estimated as 3.21×10^9 m^3. The annual depletion of water in municipal and industrial sectors was very small (only about 0.05×10^9 m^3), as most of the water diverted to these sectors generates return flows (about 76%). The total annual outflow from the basin during 1993-94 was 5.09 ×10^9 m^3, which is composed of outflow from the Karkheh River (3.99×10^9 m^3) and from the drainage network (1.10×10^9 m^3). The annual outflow from the Karkheh River is 54% or 3.99×10^9 m^3 of the total annual streamflows volume of 7.37×10^9 m^3 available in 1993-94.

We estimated committed water required to support riverine ecosystem functions in the range of 0.74×10^9 to 3.69×10^9 m^3. It should be understood that most of the environmental flow assessment studies recommend that in order to keep healthy, resilient, and productive riverine ecosystems, water management policies should aim to restore the natural flow regime of the rivers, including flow variability, as much as possible (Poff et al., 1997). Based on these simple assumptions, however, uncommitted outflow from rivers (i.e. Total outflow minus committed outflow), in a year like 1993-94 available for further allocation to various uses, would be in the range 1.070×10^9 to 4.02×10^9 m^3.

Considering the water accounting analysis for 1993-94 and long-term streamflows measured at the last gauging station of the basin (Hamediah during 1961-2001), the Karkheh Basin appears to be an open basin. A river basin is termed closed when additional water commitments for domestic, industrial, agricultural, or environmental uses cannot be met during all or part of a year, while in an open basin more water can be allocated and diverted (Falkenmark and Molden, 2008). But when we view the Karkheh Basin in terms of surface water variability and long-term water availability with the ongoing and future water allocation planning, then it is likely to attain the basin closure stage in the near future. For instance the annual water allocation to different sectors for 2001 was 4.95 ×10^9 m^3 (JAMAB, 2006), which is about 60% of the total renewable water resources available during the reference year 1993-94. The allocation to different sectors will be 8.90×10^9 m^3 by the year 2025, among them the irrigation share will be the biggest (7.42×10^9 m^3), almost equal to the renewable water supplies in an average year.

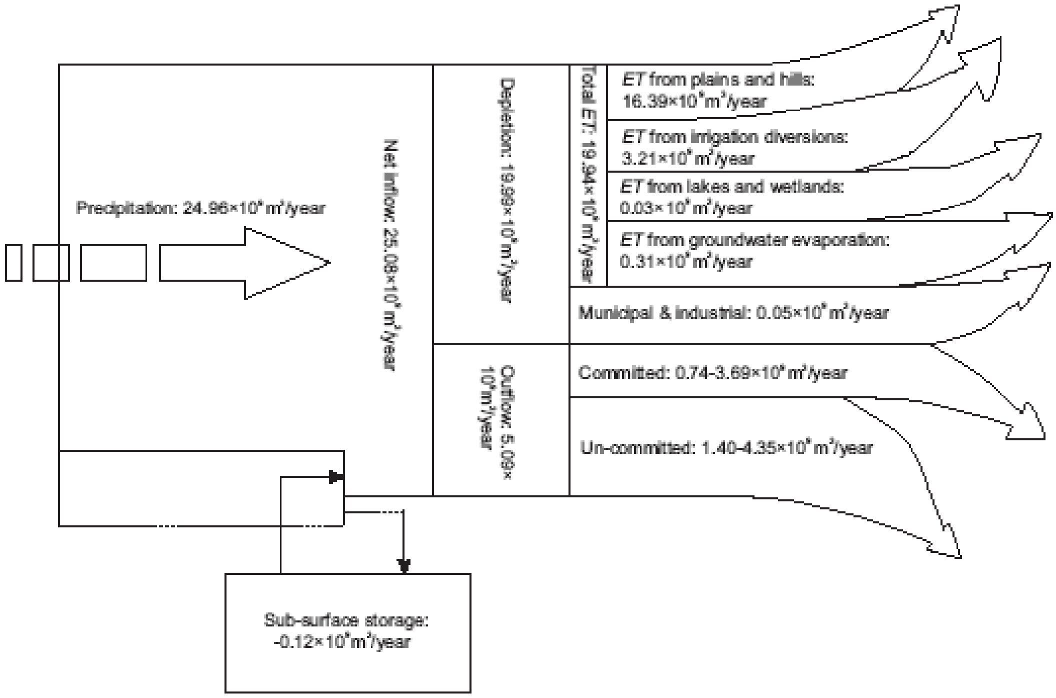

Figure 3. Schematic representation of the basin level water accounting of the Karkheh Basin (1993-94).

Conclusions

The study shows that the streamflows of the Karkheh River and its tributaries exhibit large inter- and intra-annual variability, inclusion of which into water resources planning is pivotal for sustainable management of the available water resources. The Karkheh Basin appears to be an open basin and the competition among various uses of water was not alarming during the study period. This was exemplified, for instance, by the fact that about half of the total renewable streamflows were flowing out of the basin during 1993-94, the amount which is generally considered sufficient to maintain healthy ecosystems. This was further supported by the records at Hamedieh station indicating no decline in the streamflows over the study period 1961-2001. Considering the water availability and current and ongoing water resources development plans, however, the basin will very likely approach closure stage during the first quarter of this century. Meeting the demands of all users will then be an extremely challenging task, particularly during dry years. The analysis conducted in this study is helpful in gaining further insights into the hydrological variability of surface water resources, and in turn could be instructive for the (re)formulation of a sustainable water resources development and management regime for the Karkheh Basin. For instance, this study has shown that streamflows in the upper two sub-basins are more variable compared to the middle parts, indicating a declining trend during low-flow periods, most notably in upper parts and during May. This means that contributions from the upper two sub-basins toward the Karkheh River would likely be reduced during low-flow periods, and additional irrigation developments may exacerbate this. Furthermore, the water accounting exercise has generated useful information about the availability of water, and different pathways by which water resources were depleted or moved out of the basin. The estimation of committed and uncommitted outflows provided practical insights about the degree to which water resources can be further developed. The analysis also highlighted trade-offs between different uses of water. For example, increasing allocations to irrigation will increase the depleted portion of the water accounting and consequently reduce outflow from the basin that will likely have a negative impact on the environment. Further studies are recommended on the linkages of streamflows with climate and land uses, management of the flow regime close to the natural variability, estimation of environmental flow requirements in terms of temporal and spatial dimensions, and setting up river/reservoir management targets that can minimize the negative impacts for the environment while ensuring the food security and economic gains from the use of water.

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Agriculture, water and environment and payment for environmental services

Wetland uses and livelihood strategies in the Limpopo River Basin: the case of Ga-Mampa wetland, South Africa

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Abstract

Wetland ecosystems provide a wide range of goods and services that are important in supporting the livelihoods of many rural communities in Africa. Despite their importance these ecosystems are being degraded and lost through human activities. As part of an effort to improve management of wetlands, the present study assessed the socioeconomic determinants of household use of wetland resources in the Limpopo River Basin. A household survey was conducted using a structured questionnaire to solicit for data on household socioeconomic characteristics and wetland use patterns. A stratified random sampling technique was used to select 143 households for the interviews. An econometric model was used to analyze the factors that influence household choices on use of wetland resources. Results indicated that household socioeconomic characteristics influence household use of wetland resources. The results also showed that poor households are more likely to use the wetland for crop production and natural products than the non-poor, suggesting that wetland resources provide a safety net for the poor. Efforts to improve management of wetlands should integrate awareness with poverty alleviation (incentives) through support to alternative income-generating activities.

Media grab

The poor people are more dependent on wetlands for their households and there is need to support incentives in the form of alternative livelihood opportunities to ensure effectiveness of wetland management programs**.**

Introduction

It is now widely recognized that communities with livelihood strategies that combine subsistence agriculture with utilization of wetland resources constitute a significant proportion of the population in southern Africa (Turpie et al., 1999; Taylor et al., 1995; Roggeri et al., 1995; Frenken and Mharapara, 2002; Mmopelwa, 2006; Seyam et al., 1992). Wetlands provide a great variety of services that support human welfare. Examples include their role as hydrological buffers and the provision of food, livestock grazing, domestic water, construction materials, and many other products.

In spite of their importance in supporting human welfare, wetlands in southern Africa are increasingly degraded and lost mainly through overexploitation of wetland products and conversion to intensive agriculture, fuelled by socioeconomic, political, and environmental factors (e.g. decline in soil fertility in drylands, and droughts) (Biggs et al., 2004; Matiza and Chabwela, 1992). Given their importance to the livelihood of many rural households in southern Africa sustainable management of wetland ecosystems is essential.

One of the major constraints to sustainable management of wetlands in Africa is that there is lack of understanding of the factors influencing people’s access and decisions on use of wetland resources (McCartney and van Koppen, 2004). Very little empirical work has been done to understand the factors influencing rural household decisions on use of wetland resources in southern Africa. The objective of this study is to examine the socioeconomic determinants of household use of wetland resources in the Limpopo Basin using a case study of Ga-Mampa wetland, South Africa.

Methods

Data collection

To understand the determinants of household use of wetland resources, primary data on household livelihood activities and patterns of wetland utilization by communities in the Ga-Mampa area was collected using a combination of key informant interviews, focus group discussions, and a household survey. The information collected through the key informant interviews and focus group discussions was mainly qualitative information aimed at understanding livelihood activities in the study area and uses of the wetland, rules and regulations governing access, and use of wetland resources and general perceptions on the importance of the wetland as a source of livelihood to the community. Key informant interviews were held with members of the community and external stakeholders well versed on issues regarding the utilization of wetland resources in the area.

A household survey of 143 households was carried out to collect household data. A structured household questionnaire was used to elicit data on household demographics, asset endowments (physical, natural, financial), main livelihood activities and their contribution to the household economy, uses of wetland products, income sources, household food security status, access to markets, and household perceptions on the importance of the wetland for their livelihood

Data analysis

Multiple correspondence analysis (MCA) and cluster analysis were performed to determine the main combinations of wetland uses for the households. Principle component analysis was used to construct an asset-based wealth index. This enables analysis of the influence of wealth status on household wetland resource use choices. Cross tabulations were used to relate household wetland uses with household characteristics such as wealth class, gender of household head, and access to off-farm income.

A Multinomial logit model was used to estimate the socioeconomic determinants of wetland resource use choices. The dependent variable in the model was the wetland categories generated from MCA and cluster analysis. Independent variables in the model include household demographics (family size, sex of head, age of head, education of head), asset endowments (wealth index), access to irrigation plot, household cash income, and access to off-farm income.

Results and discussion

Poor households are more likely to engage in wetland cropping and collection of natural products (reeds, sedges, edible plants, and domestic water) than the rich households. Rich households have access to productive assets that serve as buffers against income shocks and are therefore less dependent on wetland products. There is also evidence of gender dimension in use of wetlands. Our results show that female-headed households are more likely to engage in wetland cultivation than male-headed households. This finding could be explained by the fact the women have fewer opportunities for off-farm employment compared to men, and their livelihoods rely to a larger extent on crop production. As such, female-headed households try to mitigate risks of yield losses in drought years by cultivating the wetland, whereas male-headed households can cushion themselves from such calamities through off-farm income. Households with access to income from paid jobs are less likely to engage in collection of natural products, partly because they have a more lucrative source of livelihood, and because they can afford to buy substitutes for wetland products (the substitution effect). Our results also show a positive relationship between wetland cultivation and access to irrigation plots suggesting that households are spreading risks by using both the wetland and irrigation plots for crop production.

Conclusion and recommendations

Our findings indicate that households in the study area are mostly poor, and that wetland products are more important to the poor than the less poor. We conclude that wetland products provide a safety net, preventing households from slipping even further into poverty. This has two implications. First, poverty alleviation is a prerequisite for improving management of wetland ecosystems. Second, environmental protection policies based on drastic limitation of access to and use of wetland resources increase inequality in the local rural populations and deepen poverty, because poorer households suffer disproportionately from the deprivation of wetland products.

Moreover, a potentially important side effect is that increased inequality and poverty may hamper environmental protection since social cohesion is a key factor in emergence of efficient institutions for environmental management. This shows that increased agricultural productivity through improved agricultural practices, crop diversification, and establishment of irrigation technologies and creating alternative livelihoods for the people through small-scale nonagricultural income generating projects, could foster wetland environmental security.

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Seasonality dynamics for investigating wetland-agriculture nexus and its ecosystems service values in Chibuto, Mozambique

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Abstract

This study is a subsection of CPWF-30 (Challenge Program on Water and Food) that centers on investigating the wetland, agriculture, and livelihoods interactions. Chibuto, the floodplain of Changane River in Mozambique is a representative downstream site for the Limpopo sub-catchment. It largely serves as an agro-ecosystem with agricultural, grazing, and fiber collection as the prominent set of ecosystem services. Additionally, the freshwater springs in the wetland are valuable for local irrigation and domestic use; largely supporting the subsistence livelihood in the poverty-stricken zone. Given this background, the present analysis is a three-tier framework conceptualized to develop a synoptic overview of spatial, social, and economic elements that governs the system dynamics. The first tier describes the seasonal dynamics and wetland-agriculture interactions based on temporal earth observation data (2001-2007), wherein thematic layers on changing land cover are derived. The second tier investigates the social dynamics serving a dual role: to validate the spatial analysis based on the anecdotal information, and decipher the local people's perception of the ecosystems services. The concluding component is an interactive platform that quantifies the spatial and the social attributes based on the coefficients value by Costanza et al. (1997), to derive value changes in ecosystem services and rank their contribution. Furthermore, the sensitivity analysis validates the veracity of the coefficients value. The preliminary findings present visual representation of the wetland dynamics, ecosystem service value transfer to explain trade-offs, and identify 'integrated stress indicators.' Summarizing, the multiple analyses supply a knowledge base that can help improve wetland management while addressing core issues related to local livelihoods.

Media grab

Estimating the numerical value of the ecosystem services for the resource systems helps to understand the benefit we have lost and cost we might have to pay in future.

Introduction

This project is concerned with the use of Limpopo's wetlands for the livelihood support of local communities. The study area resembles a typical landscape in lower Limpopo, where wetlands are associated with river bank overflows and sand dunes drainage. These also constitute the main cropping area and a source of food security to local communities. The communities themselves have a protracted experience of managing these resources for their livelihood. The increasing impact of population pressures upon the natural resource base, however, and an increasing need for the system to provide more resources and more food for an increasing population, strongly suggest a more scientific and well planned management approach. Such a well planned framework would facilitate better livelihoods of the beneficiaries and environmental protection of the system. The present project relies on the local population knowledge combined with spatial inputs to improve existing management options using a cross-disciplinary integrated framework. The area in question experiences different uses of its resources, hence it enables the application of the trade-off analysis for striking the balance in use and management of the resource systems.

Chibuto is a flood plain wetland of the Changane River in Mozambique. It primarily serves as an agroecosystem. It is one of the representative sites of the Limpopo floodplain. Agricultural activities are predominantly a mix of vegetables, banana, maize, and rice (seasonal), whilst cattle grazing and fiber (reeds/grass) collection add another set of ecosystem services. Interestingly, the freshwater spring in the eastern zone of the wetland is of high value for local irrigation and domestic purposes, considering the fact that the adjoining Changane River is brackish and the salinity gradient of the river changes with the hydrological inflow and outflow. Synoptically, the major portion of the Chibuto wetland is cultivated with a few small and isolated patches of native wetland vegetation such as grass and reeds. The wetland bears a pertinent value for the subsistence livelihood of the adjoining village with 50% of the population living below the poverty line

The present analysis is a multitiered analysis conceptualized with the objective of developing a synoptical overview of spatial, social, and economic transitions that impact on the system dynamics. The first tier of the analysis reflects the seasonal dynamics describing the wetland-agriculture interactions on a temporal scale. Multispectral geospatial data are analyzed to derive thematic information on land cover/use change. The socioeconomic component serves a dual role; first to fine tune, verify, and validate the spatial analysis based on the anecdotal information derived from focal group discussion and household survey analysis on wetland resource consumption, and second it views what the local people perceive as threats to the wetlands and their current usage, as well as the pattern of change. The third component is an interactive analysis that economically quantifies the derivatives from the above two. The value coefficients method by Costanza et al. (1997) was used as a framework to derive the valued changes in ecosystem services delivered by each land category.

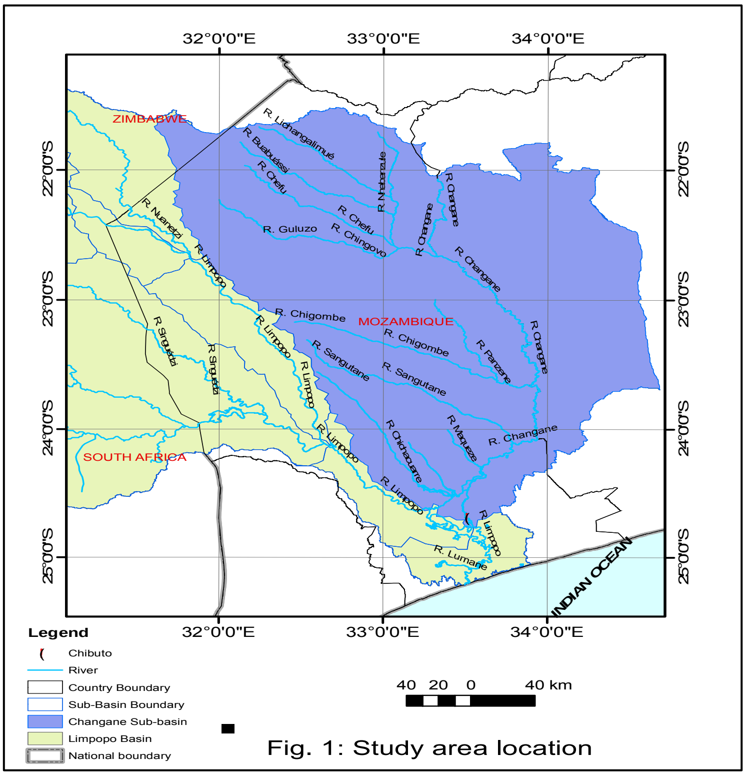


Fig. 1: Study area location

Methods

The study area

Mozambique is one of the world's poorest countries. Approximately 59.2% of the Mozambican population live below the poverty line (<US$2/day) (INE, 2004), and around 20% of the catchment area is on Mozambican territory. It contributes around 20% of the Limpopo River and finally enters the sea at Xai-Xai province. Changane sub-basin on the northern side of the catchment and immediately adjacent to the Limpopo River, is a low-lying region forming the Changane marsh and floodplains wetlands (INGC, FEWS NET MIND, EMU, 2003). This region serves as an important resource base for crop production and livelihood sustenance for the adjoining communities. The present study focuses on these interactions in the representative wetlands near Chibuto City along the Changane River (Figure 1). The wetlands in the sub-catchment with semi-deep soils offer great potential for agriculture, hence they play an important role in the livelihood of the local people. These ecosystems are productive throughout the whole year. The changing environment of wetlands, however, is driven by the conversion to cultivation, which has potential negative impacts. Prevalence of poverty in the Mozambican portion of the Limpopo Basin is comparatively lower and in Chibuto meeting the basic needs of households in that district is not necessarily easy. It is estimated that approximately 83.7% of people in Gaza Province practice agriculture, solely depending on the surrounding natural resources. In terms of cultivation, the temporary or permanent wetlands and areas adjacent to the river provide wet soil for subsistence agriculture in the cold and dry season from April to September (average rainfall 171-225 mm). The seasonal rainfall in the hot and humid season (October and March) ranges on average between 541 and 600 mm, stimulating the production of pasture to feed the livestock and rainfed crops (INGC, FEWS NET MIND, EMU, 2003). The district of Chibuto has a total population of 197,214 inhabitants (INE, 2008, http://www.ine.gov.mz/censo2007/rp/pop07prov/gaza) and average family size of 4.3 (INE, 1997). Wetland-based agriculture is practiced within community-defined boundaries. Many lakes and wetland zones in the sub-catchment 'wetlands based agriculture' zone serve as a refuge for the communities particularly during the dry season. Against a background of social (unemployment) and natural (irregular rainfall pattern) uncertainties, regulating the conversion of wetlands for agriculture remains uncertain. It is important, however, to ensure that this conversion will not compromise environmental sustainability.

Data	Year	Resolution
Wet		
Landsat TM		28.5 m
Aster	May, 2001	15 m
Aster	May , 2003	15 m
Aster	May , 2005	15 m
	May , 2007	15 m
Dry		
Aster	Sept, 2005	15 m
AlOS	Aug, 2007	10 m

Table 1. Tabulation of data used.

Assignment of ecosystem services values

To estimate the value of ecosystem services, the land-use categories derived form the spatial analysis were compared with the 16 biomes identified in the ecosystem services valuation model of Constanza et al. (1997). A coefficient for each land-use class corresponding to one of the biomes (Table 2) and the total value of ecosystem services was calculated using the given equation (Kreuter et al., 2001):

$$ESV = \sum(A_k \times VC_k)$$

Where ESV is the estimative of ecosystem services value, A_k is the area (ha) and VC_k is the value coefficient (US$/ha year) for the land-use category *k*. The change of ecosystem services values was estimated by the difference of the estimated seasonal values for each land-use category between dry seasons and wet seasons (ranging from 2001-07).

Table 2. The Constanza's et al. (1997) biome equivalent for the six land-use-classes, and the corresponding ecosystem values.

Land-use class	Equivalent Constanza´s et al. biomes	(US$/ha/year) Land-use coefficient
Cultivated wetland (maize, rice, other)	Cropland	92,00
Waterbody/lakes/open water/waterlogged areas	Lakes/rivers	8.498,00
Seasonally cultivated vegetables	Cropland	92,00
Reeds/sedges	Swamps/floodplains	19.680,00
Marshlands with shrubs	Tidal marsh/mangroves	9.990,00
Fallow, grazing land	Grass/rangeland	232,00

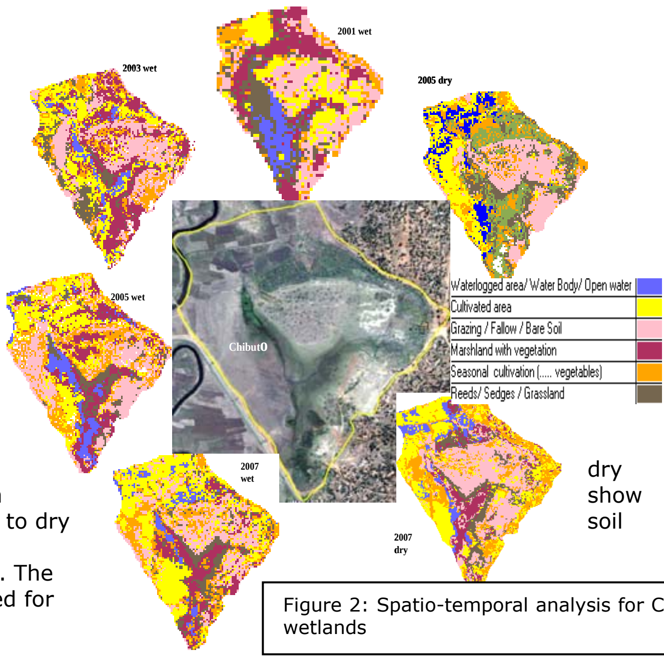
Socioeconomic analysis

A focus group discussion held in July 2005 involved 45 stakeholders, including the project team. Seven groups were created; agricultural and commercialization group, cattle producers, reeds and grass collectors, fishers, hunters, local government officials and Corridor Sands Mining Company. These closely corresponded with the spatial pattern of land-use units. The discussion focused on their perceptions, problems, vision on the future, and proposed solution of the existing environmental concerns. Participatory rural appraisal techniques such as community mapping, role playing, etc. was used to collect qualitative data that was later related with changes observed from the spatial analysis and some of the results are presented below to explain the land-use and ecosystem services changes.

Results and discussion

Land-use changes

The land-use/cover maps for the wet season (2001, 2003, 2005 and 2007) and dry season (2005 and 2007) produced from a variety of earth resource data shows that most of the shrubby marshlands have been slowly and gradually converted for cultivation both in dry and in wet season, although the extent and area varies. For the wet season it was observed that the cultivation zone has increased from 30.1 ha in 2001 to 57.1 ha in 2007 as depicted in Figure 2. Also the conversion of wetland area to seasonal vegetable cultivation shows a similar trend. In the season the marshland and reed vegetation shrinkage. This can probably be attributed to dry conditions, whilst the cultivated area has significantly risen between 2005 and 2007. The spatial statistics are graphically represented for the wet and dry season in Figure 3a, c.



dry
show
soil

Figure 2: Spatio-temporal analysis for Chibuto wetlands

Socioeconomic results

The main outcomes from the socioeconomic analysis have been listed here to support the spatial assessment of changes in land-use pattern. Notably, the stakeholder discussion with farmers highlighted the reduced water availability from the spring, especially during the dry season. This can be explained by the reduction in swamp areas that feed these springs in dry periods. Cattle owners highlighted socioeconomic impacts of the shrinkage in grazing area, which was also confirmed by the spatio-temporal analysis. They also feel that the proportion of cattle population and the extent of shared grazing area are not in equilibrium: for instance, the number of cattle has significantly risen over time. A point of interest raised by the reed collectors was the agriculture intrusion in these zones.

These people mentioned that the farmers' encroachment on the reeds area is destroying the reeds, because they burn them to clear the soil for agricultural production. This will gradually lead to widespread negative environmental impacts.

Changes in ecosystem services

The economic valuation of ecosystems services for both seasons reflects that the flooded area (reeds/sedges and marsh) contribute more than 80% to wetland service value (Figure 3a, b). The cultivated area is increasing while the rest of the land-use classes are shrinking. The most impacted are the reeds and marshlands areas that provide important ecosystem services (Figure 3c, d). The analysis of annual change for the wet season shows that the conversion of wetland area for cultivation has grown by >2% yearly between 2001 and 2007 (Table 3). Dry season analysis shows similar results. The matrix was used as the base frame for the estimated ecosystem services values and its changing trend over the given time period for both seasons is provided in Annex I. For the wet season, total ecosystem value losses between 2001 and 2007 are estimated at US$350,082. Assuming a linear decrease in ecosystem services, the annual decrease is estimated at US$59,746 for the dry season during the period 2005-2007, ecosystem value decreases are estimated at US$47,195/year.

Figure 3. Area (a, c) and value contribution (b, d) contribution of the ecosystem services in Chibuto during wet and dry season.

Table 3. Land-use change from 2001 to 2007 in study area during wet season.

Land-use classes	2001-2003			2003-2005			2005-2007		
	ha	%	%/year	ha	%	%/year	ha	%	%/year
Cultivated wetland (rice, maize)	8.2	4.1	2.1	9.3	4.7	2.3	8.8	4.4	2.2
Waterbody/lake/open water/waterlogged	-1.9	-0.9	-0.5	1.9	0.9	0.5	-2.8	-1.4	-0.7
Seasonally cultivated vegetables	8.2	4.1	2.1	7.2	3.6	1.8	2.1	1.0	0.5
Reeds/sedges	-8.5	-4.3	-2.1	-4.0	-2.0	-1.0	2.6	1.3	0.7
Marshy lands with shrubs	2.6	1.3	0.7	-8.2	-4.1	-2.1	-7.5	-3.7	-1.9
Fallowland, grasslands/grazing area	-8.6	-4.3	-2.2	-6.1	-3.1	-1.5	-3.1	-1.6	-0.8

Conclusion

Based on preliminary results, it was concluded that the major provisioning services of the floodplain are derived from cropping. While considering how these services can be maintained and extended locally, it is important to assess potential impacts on the hydrological functioning of the river and its landscape interactions. Geospatial tools provided the base frame to trace biophysical and livelihood dynamics as discussed in this section. Along with the importance of economic values of ecosystems, goods and services have to be taken into account for informed environmental decision-making that provides a quantitative analysis of the varied wetland services. This has to be based on a cross-disciplinary framework, and calls for greater collaboration between multiple stakeholders involved with the management, conservation, and use of the wetland and its adjoining resources at the landscape level. We recommend that monitoring and measuring changes in resource patterns and evaluation of trade-off between goods/services delivered can contribute a way forward to address some of the uncertainties affecting the sustainable management of such complex systems.

Acknowledgment

This paper presents findings from PN- 30 titled 'Wetland Mapping and Spatial Modeling for Change Detection and Study of Landscape Interactions in the Challenge Program Wetland sites in Africa,' a project of the CGIAR Challenge Program on Water and Food.

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Annex I. Estimated ecosystem services values changes in study area in dry and wet season (ESV in US$/year).

Land-use classes (dry)	2005 ESV	2005 %	2005 rank	2007 ESV	2007 %	2007 rank	Overall rank	Trend
Reeds/sedges	558,764.40	58.0	1	487,839.7	57.3	1	1	⇩
Marshy lands with shrubs	293,568.51	30.5	2	246,244.6	28.9	2	2	⇩
Waterbody/lake/open water/waterlogged areas	92,410.04	9.6	3	99,280.4	11.7	3	3	↑
Fallowland, grasslands/grazing area	11,280.39	1.2	4	9,956.6	1.2	4	4	-
Cultivated wetland (rice, maize)	4,160.57	0.4	5	4,956.7	0.6	5	5	↑
Seasonally cultivated vegetables	3,379.19	0.4	6	3,797.0	0.4	6	6	↑
	963563.095	100	-	852074.92	100	-	-	⇩

Land-use classes (wet)	2001 ESV	2001 %	2001 rank	2003 ESV	2003 %	2003 rank	2005 ESV	2005 %	2005 rank	2007 ESV	2007 %	2007 rank	Overall rank	Trend
Reeds/sedges	593,754	51.33	1	426,093.91	42.67	2	#######	40.67	2	#####	49.38	1	1	↑
Marshy lands with shrubs	427,322	36.94	2	453,218.86	45.39	1	#######	43.50	1	#####	36.80	2	2	⇩
Waterbody/lake /open water/waterlogged areas	116,913	10.11	3	100,948.83	10.11	3	#######	13.68	3	#####	11.51	3	3	⇩
Fallowland, grasslands/grazing area	13,884	1.20	4	11,891.71	1.19	4	#######	1.23	4	#####	1.21	4	4	⇩
Cultivated wetland (rice, maize)	2,840	0.25	5	3,591.96	0.36	5	#######	0.52	5	#####	0.65	5	5	↑
Seasonally cultivated vegetables	2,001	0.17	6	2,757.14	0.28	6	#######	0.40	6	#####	0.45	6	6	↑
	1,156,713	100	-	998,502.41	100	-	#######	100	-	#####	100	-	-	⇩

##signs refer to the estimated values with more than nine natural numbers that have been symbolically represented using hash sign.

Impact of the Zhovhe Dam on the lower Mzingwane River channel

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Abstract

The lower Mzingwane River in Zimbabwe was dammed in 1995 by the large (133 Mm^3) Zhovhe Dam. Managed releases from the dam supply commercial agrobusiness and Beitbridge town, downstream. A substantial change in the flow regime of the Mzingwane River occurs downstream of Zhovhe Dam, with the capture of all flows early in the rainy season, most low flows, many larger flows, and the reduction in magnitude of some floods. This change in flow regime could be the cause of observed changes in the channel morphology, where the active riverbed has declined in width and portions of the river channel on either side have been abandoned. These abandoned parts of the river channel are being colonized by vegetation, which represents competition for water with the established riparian vegetation as well as with the water users. The ongoing noninundation and abandonments of portions of the river channel and the apparent loss in aquifer material indicate that the extent of the alluvial aquifer is likely to decrease. The change in grain size from a coarse sand to a fine gravel (if substantiated, further sampling is required) could result in a decline in specific yield. Such changes would negatively impact the water storage and water supply potential of the Lower Mzingwane alluvial aquifer, and thus the current and potential water users. It is widely acknowledged that indigenous vegetation has evolved to prevailing water balance and soil moisture conditions. The riparian ecosystem, notably an important stand of acacia woodland, is also likely to suffer.

Media grab

The operation of Zhovhe Dam, whilst beneficial to downstream water users, has altered the Mzingwane River flow and channel, potentially threatening the same water users.

Introduction

The construction and management regime of dams change the downstream flow regime of river. For example, in Southern Africa, concerns have been expressed about the impacts of the two largest dams on the Zambezi River, Kariba and Cabora Bassa (Guy, 1981; Davies et al., 2000). Disruption of the natural flow of the river through changes in the fluvio-geomorphic processes can lead to either siltation or erosion of riparian zones (World Commission on Dams, 2000).

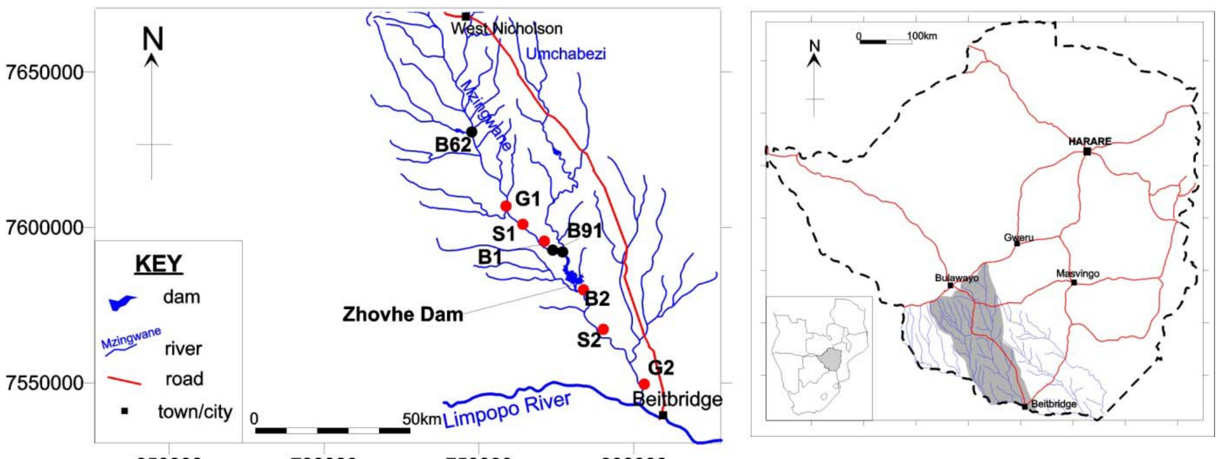


Figure 1. The Mzingwane River Valley, showing the location of Zhovhe Dam, the study sites (red dots), gauging stations (black dots) and settlements (black squares). (right) location within Zimbabwe and southern Africa.

The Lower Mzingwane, a sub-basin of the Limpopo Basin (Figure 1), is an ephemeral river, flowing on average 191 days per year (Love et al., in prep.). Zhovhe Dam (133 Mm^3) was constructed in 1995-96 to provide a secure water supply for Beitbridge town and for irrigation. Releases of water from Zhovhe Dam recharge an alluvial aquifer in the lower Mzingwane River, and the water is abstracted from boreholes and well-points in the river and on the banks (Love et al, 2007). The dam provides significant economic benefits through commercial agrobusinesses that use the water for production of export crops, mainly citrus. These agrobusinesses represent the main source of employment in the area. The Lower Mzingwane also has the potential for benefitting a greater breadth of the local communities, through supporting the development of smallholder irrigation schemes (Moyce et al., 2006). These current and potential economic activities are dependent on the operation of Zhovhe Dam. The purpose of this study is to assess some of the downstream biophysical impacts of the operation of Zhovhe Dam.

Methods

Using a daily water balance of Zhovhe Dam, the flow regime upstream and downstream of Zhovhe Dam was determined and compared. To study the geomorphology and vegetation, six sites were selected based on regional geological mapping (Mineral Resources Centre, 2007), confirmed by ground truthing. The sites covered three distinct types of bedrock, one site upstream and one downstream for each of the three types (Figure 1). At each site, a cross-section was surveyed and the vegetation along the cross-section identified. At site S2, 30 km downstream of the dam, a grain size analysis of the channel material was available from before the construction of Zhovhe Dam. A grain size analysis was carried out in 2008 with material sampled from the same locality.

Results and discussion

Flow regime

Four effects of the dam on the flow regime can be seen in Figure 2: Firstly, all upstream flows are retained by Zhovhe Dam in the earliest part of the rainy season (October/November). This is typical of large dams in the northern Limpopo Basin (Love et al., in prep.). Sometimes the late rainy season flows (April/May) are also retained, e.g. April 2008. All upstream flows are retained by the dam during drier years. For example, the only downstream flows in the 2006-07 climatic season were planned releases for irrigation–this was a drought year with a moderate El Niño recorded during that season (Logan et al., 2008).

Secondly, there are no downstream low flows during the rainy season: the only downstream flows are the larger floods when the dam spills. The loss of low flows has important ecological significance, for example, low flows are thought to sustain herbaceous riparian vegetation (King et al., 2003). Such changes in flow regime can also be associated with loss of habitat and biodiversity (Brown and King, 2003).

Thirdly, the dam releases only a limited number of large floods from upstream. The magnitude of these floods is often decreased, including for some of the extreme events such as Cyclone Japhet. This contrasts with the operation of some other large dams in Zimbabwe, such as Insiza and Rusape, where an increase in size or number of large floods is observed downstream (Kileshye-Onema et al., 2006; Love et al., 2006).

Fourthly, there are small managed releases made during June/July and August/September for irrigation and other water users; this is during the dry season when there are no natural (upstream) flows.

Geomorphology and vegetation

On sandstone and basalt, the downstream cross-sections show increased channelization (Figure 3). At the downstream sandstone site Mazunga Drift (site S2) part of the sand bed on each bank has now been abandoned by the river, and the active channel width is reduced from nearly 200 m at Bwaemura School (site S1) to 150 m. The abandoned parts of the channel have been colonized by shrubs. At the downstream basalt site Zhovhe Irrigation Scheme (site B2) the active channel is now confined to an incised bed of under 30 m along the left bank, with a sloping flood channel of some 150 m, compared to an active bed width of 250 m upstream (Kwalu, site B1). The bulk of the sand bed is now apparently being colonized by trees and shrubs.

The change is less apparent on the granitoids, although the channel is narrower at G2 than G1. It is likely that the observed channelization is due to the regular system of managed releases, and the decline in larger floods and decline in magnitude of floods. This results in only partial inundation of the river channel.

Sedimentology

Comparison of grain size analyses (Figure 4) carried out at Mazunga Drift (site S2) immediately before (1995) and thirteen years after (2008) the construction of Zhovhe Dam show a substantial decline in the finer sediments, and an increase in the larger particle fraction. A X^2 test confirmed that the sample from site S2 in 2008 is statistically distinct from that of site S2 in 1995 at 95 % probability. The 2008 samples from sites S2 and B2 were confirmed as statistically similar, however.

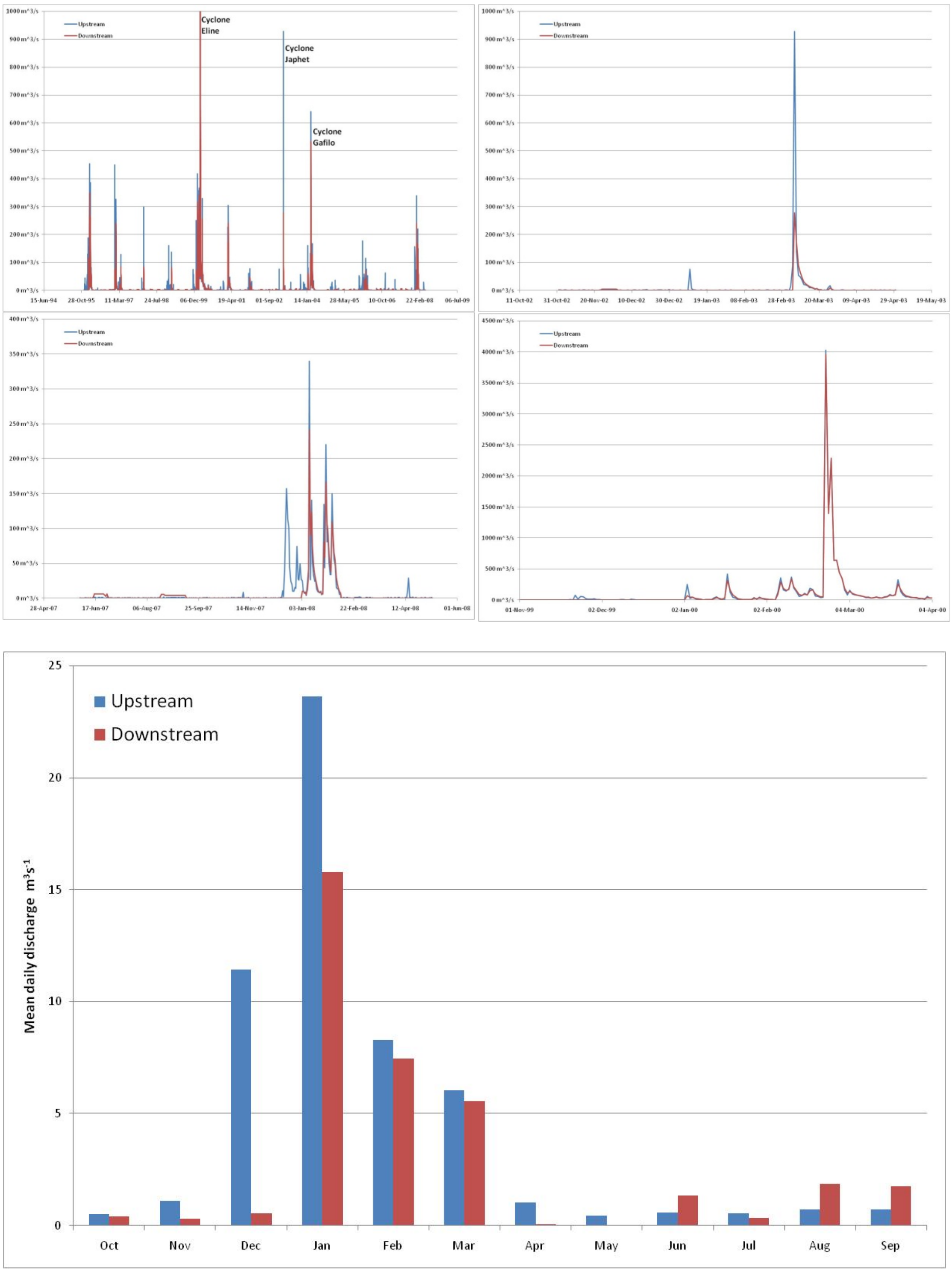
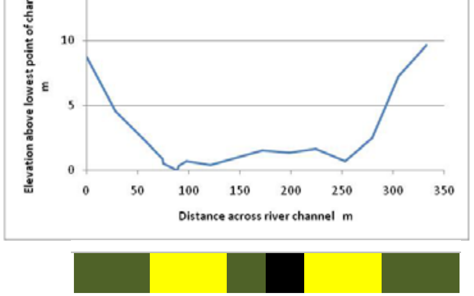
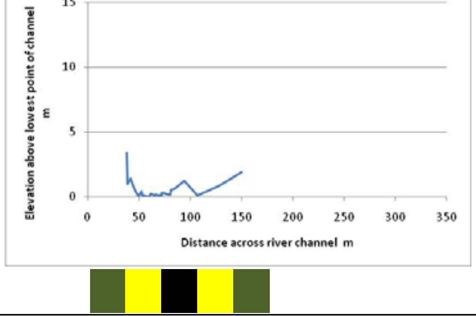
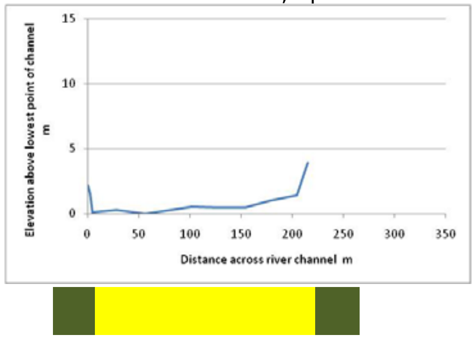


Figure 2. Flow regime of the lower Mzingwane River upstream and downstream of Zhovhe Dam, all data are daily m^3/s. Full time series (top left) since the construction of Zhovhe Dam in 1995. The three large cyclones are indicated. In most years, upstream discharge increases from late November/early December but is retained by Zhovhe Dam. Spilling occurs leading to downstream discharge in late December/early January. Small managed releases are made during June/July and August/September. One example is the 2007-08 season (top right). This is also apparent in the monthly mean data (lower graph). Cyclone Japhet occurred during a season with low rainfall (centre left) and some of the inflowing water was retained by the dam. Cyclone Eline occurred half way through a season with normal rainfall, after Zhovhe Dam had already filled (centre right). Thus the bulk of the water was discharged downstream.

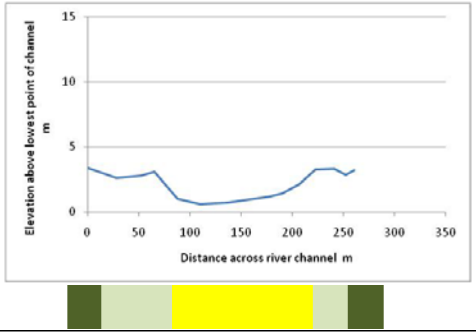




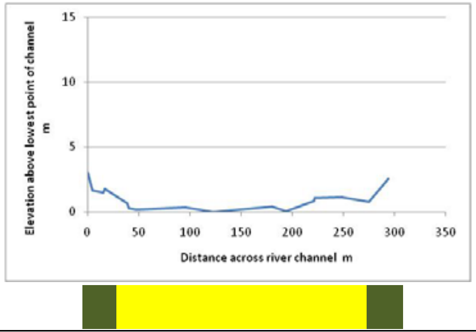
Site S1 Bwaemura School, upstream site on sandstone



Site S2 Mazunga Drift, downstream site on sandstone



Site B1 Kwalu Irrigation Scheme, upstream site on basalt



Site B2 Zhovhe Irrigation Scheme, downstream site on basalt

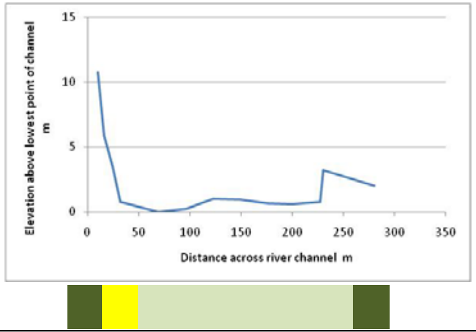


Figure 3. Variation of geomorphology and vegetation in the lower Mzingwane River channel for sites with similar geology, upstream and downstream of Zhovhe Dam. For each site: (left) surveyed cross-section at study site, with vegetation along cross-section below. (right) photo from study site. Key to vegetation: green = trees/shrubs, yellow = clear riverbed (no vegetation), light green = sandbank with trees/shrubs, black = bare rock. The narrowing of the active (bare) river channel and the colonization of abandoned parts of the channel can be clearly seen at sites S2 and B2.

This change at site S2 from 1995 to 2008 is from a mainly coarse sand sediment to a fine pebble/very coarse sand sediment, and a substantial change in grain size distribution. There are two possible explanations for this observation: The first explanation is that the 2008 sediment represents material from a different provenance: neither the spillway nor the managed release system at Zhovhe Dam allow for significant downstream release of sediments, thus more recent (post-1995) sediments in the riverbed will have been carried down into the Mzingwane River by tributaries. There are two right-bank tributaries that join the Mzingwane River downstream of Zhovhe Dam (Figure 1). Thus although erosion and removal of the existing (and pre-dam) downstream sediments continues, their replacement is from a different source and appears to favor the larger coarse sand/fine gravel particles.

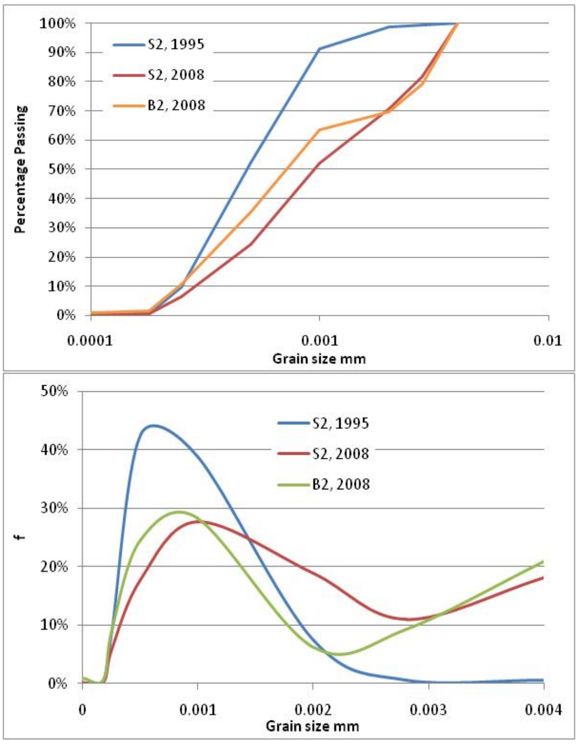


Figure 4. Grain size analysis of channel bed (alluvial aquifer) material at Mazunga Drift (site S2), immediately before (1995) and 13 years after (2008) the construction of Zhovhe Dam. 1995 data after Ekström et al. (1996). Material from site B2 (2008) is presented for comparison. Note that the composition of material sampled from site S2 in 2008 is much closer in composition to that sampled from site B2 on the same date, than to that sampled from site S2 at the earlier date (1995).

The alternative explanation is that the 2008 sediment represents material from a different depositionary environment: The sample might have been collected from a slightly different point than the 1995 sample, or the alignment of the river channel could have changed in the intervening period. In either case, the 2008 sample could represent a different depositionary environment, thus different sedimentary facies. If this explanation is true, then no useful interpretations can be made from the observed differences. The similarity in composition between the material from sites S2 and B2 in 2008 favors explanation (i). However, the two explanations are not mutually exclusive.

Conclusions and recommendations

A substantial change in the flow regime of the Mzingwane River occurs downstream of Zhovhe Dam, with the capture by the dam of all upstream flows early in the rainy season, most low flows, many larger flows and the reduction in magnitude of some floods that are released downstream. This change in flow regime could be the cause of observed changes in the channel morphology, where (for a given lithotype) the active riverbed has declined in width and sections of the river channel have been abandoned. These abandoned parts of the river channel appear to be being colonized by vegetation, which represents competition for water with the established riparian vegetation as well as with the water users.

The ongoing noninundation and abandonments of portions of the river channel and the apparent loss in aquifer material (also supported by anecdotal reports of rock being visible in the downstream river channel that were previously covered by sand; P. Bristow, personnel communications, 2007) indicate that the extent of the alluvial aquifer is likely to decrease. The change in grain size from a coarse sand to a fine gravel (if substantiated, further sampling is required) could result in a decline in specific yield (the amount of water abstractable from the aquifer material under gravity drainage; Johnson, 1967). Such changes would negatively impact the water storage and water supply potential of the Lower

Mzingwane alluvial aquifer, and thus the current and potential water users. It is widely acknowledged that indigenous vegetation has evolved to prevailing water balance and soil moisture conditions (Farmer et al., 2003), the riparian ecosystem, notably an important stand of acacia woodland, is also likely to suffer.

Acknowledgments

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Environmental impact assessment follow-up in the Koga Irrigation Project, Ethiopia

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Abstract

In Ethiopia, environmental impact assessment (EIA) procedures are generally properly considered and result in well-formulated environmental impact statements and plans. The implementation of proposed mitigation measures and monitoring of actual environmental impacts, however, form a weak link in the EIA process. As a result projects still cause negative environmental impacts. We report on a study of the follow-up of EIA-recommended mitigation measures in the Koga irrigation and watershed management project. We found that the EIA documents, which were prepared during the feasibility study, were generally satisfactory. One weakness, however, in the EIA was the poor estimation of flow requirements downstream of the dam. The analyses conducted as part of the EIA neglected both the natural variability of flow and the livelihoods of people dependent on fisheries. Furthermore, many of the activities planned in the EIA were not implemented in a satisfactory manner. Lack of consultation and public participation was a major constraint to implementation of EIA recommendations. To improve the sustainability of the project, attention needs to be given to improving public participation, regulatory activities, and institutional arrangements.

Media grab

The utility of environmental impact assessments conducted in Ethiopia could be greatly improved by enhancing public participation and developing mechanisms to ensure full implementation of recommendations.

Introduction

Environmental impact assessment is a process that attempts to identify, predict, and mitigate ecological and social impacts of development proposals and activities. It also helps to assist decision-making and to achieve sustainable development. The effectiveness of EIA depends on several factors. The quality of EIA guidelines, EIA reports, and implementation and follow-up of EIA recommendations are of particular importance (Arebo, 2005). According to the Australian Environmental Protection Agency (EPA Australia, 1995), EIA follow-up is needed because relatively little attention is paid to the actual effects arising from project construction and operation. Without some form of systematic follow-up to decision-making, EIA can simply become a paper chase to secure a development permit, rather than a meaningful exercise in environmental management to bring about real environmental benefits. This is a recognized problem not only in developing countries, but also in many industrial countries: implementation of EIA recommendations is frequently not done well (Noble and Storey, 2004). Successful implementation of EIA recommendations requires that policies and institutions be strengthened to facilitate adequate follow-up.

The aim of this study was to determine the critical factors affecting the successful implementation of EIA mitigation measures, developed to minimize environmental and social impacts of the Koga irrigation and watershed management project in the district of Mecha, Amhara National Regional State, Ethiopia. The research questions addressed were:

- To what extent have EIA-recommended mitigation measures been implemented by the project proponent?
- How do regulatory bodies ensure implementation of EIA-recommended mitigation measures?
- How and to what extent did the public participate in the EIA process?
- What are the likely downstream impacts of the project and to what extent where they considered?

Methods

The research method comprised a literature review and fieldwork. The literature review centered on issues of sustainability and links to EIA and the Millennium Development Goals (MDGs) as well as EIA experiences in Ethiopia and other countries. In addition, project-specific reports (i.e. the Environmental Management Plan (EMP), accomplishment reports, monitoring reports and permit conditions) were reviewed. In the fieldwork, semistructured and structured questionnaires were used. This enabled the perceptions and opinions of specialists (from the project and the Ethiopian Environmental Protection Agency, EPA, the communities (located upstream and downstream of the dam), and management bodies (from the project, EPA, and other groups) to be gathered. The extent of public participation in the project was assessed using the Aarhus practice evaluation criteria for public participation, adopted from the European convention on public participation (Hartley and Wood, 2004). Finally, observations were made by visiting the site to independently assess the accomplishments of the EIA-recommendations. Analyses conducted included comparison of the perceptions of different stakeholders on the accomplishment of the project with the EMP and the accomplishment reports.

Results

Most of the documents (Acres and Shawel, 1995; WAPCO and WWDSE, 2005; KIWMaP, 2006; EPLAUA, 2006; MacDonald, 2004a, b, c, d; ADF, 2000, 2001) fulfill requirements and provide satisfactory information on the probable impacts of the scheme, as well as mitigation measures to minimize environmental problems. Predicted impacts considered in the EMP include impacts on: water resources, water quality, air, noise, land, ecology, command area development or induced development, and demographics and socioeconomics. The Q95 method was used (WAPCO and WWDSE, 2005). This method does not address the variable nature of the hydrological regime. There is no mention of likely impacts of the dam on downstream flooding, fisheries, and riparian vegetation. Review of the EMP indicates some limitations in the planning process, including:

- No process of public consultation.
- No evaluation of different project scenarios and possible alternatives.
- No monitoring plan for erosion and siltation.

A review of the project progress reports indicates that of the 20 major plans identified in the EMP for implementation, only two activities (planting forest seedlings and livestock development) have progressed satisfactorily. Three activities (watershed management measures, public health, and resettlement/compensation payments) were progressing unsatisfactorily. The remaining 15 activities were either moribund or not reported.

The community (farmers)
Interviews conducted with farmers focused on public participation and implementation of mitigation measures. Farmers were asked to comment on the likely impacts of the scheme, what they knew about the EIA, and more generally how decisions relating to the scheme were communicated to them. Farmers were asked if project material was presented in a way that was understandable to them. We found that many farmers recognize the possible environmental impacts that could affect their livelihoods. Downstream communities expressed concerns about adverse impacts on drinking water, fisheries, traditional irrigation, forestry products, and firewood. We also found that 19% of the interviewees agreed that communication criteria for the project were completely fulfilled, 14% nearly fulfilled, and 26% partially fulfilled. The remaining 41% said that the project did not provide project materials in a clear format, implying that communication criteria were not fulfilled. Thus nearly half of the interviewed people living in the catchment do not have a clear understanding of the project documents or the project itself, based on the materials provided by the project team. Moreover, neither downstream nor upstream farmers felt that they had participated in decision-making related to the project. These findings confirm those of a stakeholder analysis indicating that decisions pertaining to the construction of the dam have been made with little public consultation and with insufficient explanation of intended project objectives (Gebre et al., 2007).

Specialists
The interviews conducted with specialists focused on implementation of EIA recommendations and the EMP. The results obtained from the interviews indicated that 70% of the specialists thought that the environmental mitigation measures recommended in the EIA were not being adequately implemented. In addition, 90% of the specialists thought that the EMP was constrained by weaknesses in institutional arrangements, time schedules, finance, limited integration of the EMP within the overall project schedule and limited capacity of project staff.

Management bodies
The interviews with staff from the management bodies focused on the institutional arrangements and regulations to ensure that EIA recommended activities are undertaken. We found that the Koga project has no official permit, as officially required by national environmental legislation. Instead, the African Development Bank (the donor funding the scheme) required that an EIA be undertaken and then approved the EIA documents. The African Development Bank also prepared its own EIA summary (ADF, 2000). There are several national institutions involved with the scheme:

- The Amhara Regional Water Resources Bureau is responsible for hosting the project management unit that coordinates the construction and implementation of the project.
- The Amhara Regional Agriculture Bureau is responsible for implementing the watershed management component.
- The Environmental Protection, Land Administration and Use Authority (EPLAUA) is responsible for overseeing environmental aspects of the project and is also responsible for land redistribution and compensation.

Staff interviewed in these institutions, either knew nothing or stated that they had 'no opinion' about the lack of an official permit. There were no environmental specialists in either the scheme management team or the various consultants employed by them. Consequently, the project has not undertaken any formal monitoring of environmental impacts. Furthermore, the EPLAUA has only undertaken surveillance/monitoring once in the four years since the project commenced. There is no regular monitoring of any environmental impacts, and recommendations for monitoring made in the EIA are not being followed. For various reasons, including lack of capacity and financial constraints, the institutions tasked with ensuring that the EIA recommendations be implemented be not fulfilling their responsibilities.

Conclusion and recommendations

The primary objective of EIA follow-up activities should be to ensure that project managers are able to realize intended project outcomes. As this study has shown, the effectiveness of the follow-up in the Koga scheme is limited with weaknesses in several key areas (Figure 1). Constraints arise for technical reasons as well as limitations in human, financial, and technical capacity. Key limitations are:

- Lack of monitoring, which means that managers are unable to make informed decisions.
- Lack of relevant expertise in the project management team.
- A weak regulatory and institutional framework.
- Lack of public participation and the absence of a strong civil society to ensure that EIA recommendations are implemented.

As a result of these limitations, it is not possible to determine the long-term consequences of cumulative environmental impacts, and it is possible that the sustainability of the scheme could be undermined.

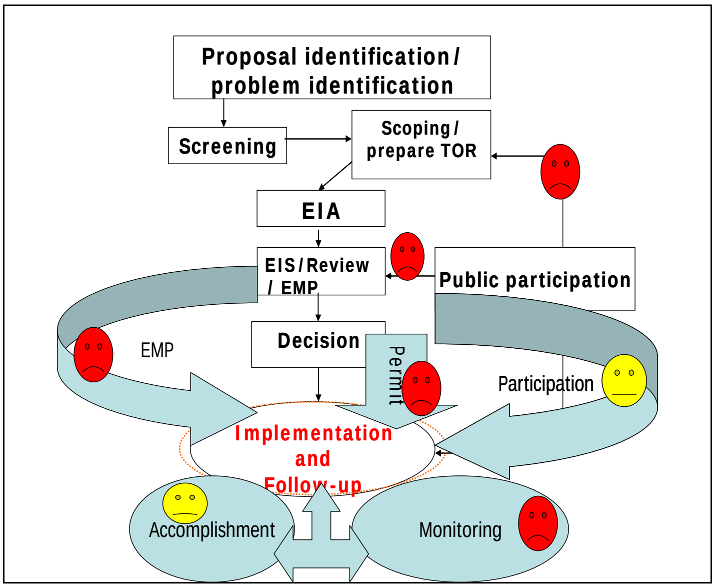

Figure 1. Schematic illustrating points of weakness in the EIA process undertaken for the Koga Irrigation and Watershed Management Project.

It is recognized that all development projects have adverse biophysical consequences. Ideally, these will be kept to a minimum through the proper implementation of recommendations from EIAs. Based on the study findings, the following recommendations are made to improve EIA follow-up in development projects in Ethiopia:

- Enforcing certification mechanisms provides a critical first step in the EIA follow-up process, and is essential if project proponents are to take their environmental responsibilities seriously.
- Implementation of EIA follow-up measures would be greatly improved by clearly defining and dividing tasks and responsibilities between those organizations that are supposed to implement them.
- Mechanisms are required to strengthen public participation in project decision-making processes. This is essential to ensure cooperation and consensus building between different stakeholders.
- Project management teams need to take environmental concerns seriously. It should be mandatory that they include staff with relevant environmental expertise and the knowledge required to implement EIA recommendations and monitoring requirements.
- The finances required to implement EIA recommendations should be identified and ring-fenced at the commencement of projects. This should include funds required by the relevant regulatory bodies to monitor compliance.

- Appropriate incentives and legal mechanisms need to be developed to encourage compliance with EIA recommendations.

The Koga scheme is the first in Ethiopia to combine irrigation and watershed management, within a project that will ultimately be managed by local farmers. Consequently, it is widely perceived to be a learning experience that can be used to inform future irrigation development in the country. To this end, the lessons learned in relation to EIA follow-up have been communicated to government representatives in various forums, including one workshop attended by the Minister of Water Resources. To maximize the benefits to be gained from future development projects (not only irrigation schemes) it is essential that the lessons learned be acted upon.

Acknowledgments

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Prospects for Payment for Environmental Services: the Case of Blue Nile

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Abstract

Environmental conservation is pursued as an investment to create the necessary conditions for sustainable development. Payments for Environmental Services (PES) are a component of a new and more direct conservation paradigm and an emerging concept to finance conservation programs by fostering dialogue between upstream and downstream land users. Those kinds of approach are particularly useful if applied in basins where irrigation schemes are emerging and the service life of reservoir and irrigation canals, in downstream areas, are threatened by the sediments moved and floods from upstream regions. Here we report the results of our study on the determinants of willingness to pay (WTP) and willingness to compensate (WTC) for improved watershed conservation practice in the Blue Nile Basin (Gumera and Koga watersheds). We selected 325 sample households using a multi-stage sampling technique and a structured and pre-tested questionnaire was used to collect data. We applied Contingent Valuation Method (CVM) to elicit WTP and WTC using monetary and material payment vehicles. Our results show that more households are willing to pay/compensate in labor than cash, and there is significant difference in mean WTP between upstream and downstream users. There is significant difference between MWTP and MWTC. Household characteristics, asset holdings, and access to services have significant effects on the amount of WTP and likelihood of WTC. In view of the results we concluded that PES has a potential to internalize the cost and benefits of environmental services in the Blue Nile Basin while concerted engagement of the public is still called for in effective land and water management.

Media grab

Sharing the costs and benefits of environmental conservation, on an equitable basis among all stakeholders, improves the prospects of sustainable land and water management in the Blue Nile Basin.

Introduction

There is real evidence suggesting that ecosystem regulation services, in the Blue Nile Basin, are threatened. Land degradation has serious on-site and off-site impacts for upstream and downstream users in the study area. The on-site effects lead to significant reductions in crop yield, in terms of grain yield and biomass. The off-site damage of erosion consists of deterioration in the quality of water (due to the suspended load), heavy floods destroy lives, property, and irrigation infrastructure, and cause downstream sediment deposition on reservoirs. Hence, in addition to water resources, the Blue Nile Basin countries are linked by the problems of soil erosion in upstream areas and sedimentation in downstream areas. PES is a new and more direct conservation paradigm to finance conservation programs. The principle of PES is that those who provide environmental services should be compensated for doing so, and those who receive the services should pay. This also applies at a watershed scale and means upstream communities produce watershed protection services at an opportunity cost, while the downstream communities are consumers of these services with no payment. Such benefits are positive externalities, and PES aims at internalizing these benefits and channel it to the upstream communities as an incentive to pursue their watershed conservation practices. Upstream users are not mere service providers. They also accrue benefits for undertaking land and water management measures in terms of reduced erosion, increased soil fertility, and crop yield. Hence they may well be willing to pay for improved land and water management.

To date little attention has been paid to the use of PES as a tool for improved land and water management. This study was undertaken in Gumara and Koga watersheds of the Blue Nile Basin (Ethiopia). Large-scale irrigation schemes are under construction in the downstream parts of these watersheds. In both watersheds, high rates of sedimentation are anticipated, and mechanisms to mitigate the impacts on the reservoir and irrigation canals are a concern. We investigated the willingness of the downstream users to compensate (WTC) and the upstream users to pay (WTP) to cover the cost of land management in the upstream areas. We also explored socioeconomic and institutional drivers of WTC. We found upstream users willing to pay for land and water conservation, and they rarely expect compensation for what they do. We also explored the determinants of WTP. (only two respondents from upstream were willing to accept compensation; we focus on their WTP).

Methods

Description of the study area and sampling technique

Gumera (lat 110. 83'; long 370 63') and Koga (lat 11037'; long 37005') watersheds are located in Tana subbasin. There is considerable variation of climate (e.g. temperature) across the landscape of the two watersheds. This is associated with the wide range of altitudes: between 1782 and 3704 m. Frequent flooding and severe erosion (1643 Mg/km2/year) are major problems in the downstream and upstream of Gumera watersheds, respectively. In Koga watershed, erosion rate as high as 1.66 Mg/km2/year are reported. Currently, in Gumera and Koga, dams are under construction to irrigate 23,000 and 7000 ha, respectively. In this study, we stratified each watershed into upstream and downstream. We followed a systematic-random sampling technique to select communities and then sample farm households. A total of 175 (from upstream users) and 150 (from downstream users) households were randomly selected. Using a structured contingent valuation questionnaire, data on individual and socioeconomic characteristics of farm households as well as policy and institutional characteristics of the watersheds were collected.

Analytical models

Contingent Valuation Method (CVM)

CVM can estimate the value that a person places on a good that has no market price. Many applications of CVM deal with public goods such as measuring WTP for environmental services and in policy formulation, and for evaluating investments (Alberini and Copper, 2000). In this study, we used the so-called double-bounded dichotomous-choice format to elicit users' WTC/WTP. A dichotomous choice payment question asks the respondent if she would pay B_i (initial Bid amount) to obtain the good. There are only two possible responses to a dichotomous choice payment question: 'yes' and 'no'. Then following the response, follow-up bids are presented (B_i^d and B_i^u, where $B_i^d \le B_i \le B_i^u$) depending on the response to the initial bid. The bid value (B_i) is varied across respondents. It is important to note that the dichotomous choice approach does not observe WTC/WTP directly: at best, we can infer that the respondent's WTC amount was greater than the bid value or less than the bid amount, and form broad intervals around the respondent's WTC/WTP amount. Mean WTC/WTP is estimated statistically from the data of responses obtained from respondents.

Econometric estimation

Double-bounded dichotomous choice payment questions typically require a different type of statistical analysis, based on the assumption that if the individual states she is willing to pay the bid amount, her WTP must be greater than the bid. If the individual declines to pay the stated amount, than her WTP must be less than the bid. In both cases, the respondent's actual WTP amount is not observed directly by the researcher. Let WTP* be unobserved willingness to pay, which is assumed to follow a distribution F (θ), where θ is a vector of parameters, and form an indicator, I, that takes on a value of one for 'yes' responses and 0 for 'no' responses. The probability of observing a 'yes' (or I =1) when the respondent has been offered a bid equal to Bi is:

$$\Pr(I_i = 1) = \Pr(WTP_i^* > B_i) = 1 - F(B_i;\theta), \qquad (1)$$

Whereas the probability of observing a 'no' (or I =0) is simply $F(B_i;\theta)$, i.e. the cumulative density function (CDF) of WTP evaluated at the bid value. The log likelihood function of the sample is:

$$\sum_{i=1}^{n} \left[I_i . \log(1 - F(B_i;\theta)) + (1 - I_i) . \log F(B_i;\theta) \right] \qquad (2)$$

If WTP is normally distributed, $F(.)$ is the standard normal cumulative distribution function, and $F(B_i;\theta) = \Phi(B_i;\sigma - \mu/\sigma)$, where the symbol Φ denotes the standard normal cdf, μ is mean WTP and σ is the standard deviation of the distribution. The parameters θ can be estimated directly by maximizing (2) using Maximum likelihood estimation technique.

Results and discussion

Households' willingness to pay or to compensate

We report first the downstream users' willingness to compensate the upstream users to continue doing land and water management. Upstream users were also willing to pay for land and water conservation, and in fact rarely expect compensation for what they do, as minimizing the on-site costs of land degradation is critical for their livelihood. Hence, we also report as part of this study households' WTP in cash or spent time for improved land and water management practices and the determinants thereof. Of all downstream sample farm households 83.6% showed willingness to compensate the upstream farmers in cash. The remaining 16.4% were not willing to compensate the upstream farmers in cash. More households were willing to compensate in labor but administering it is not trivial. The mean WTC is US$1.84. Of all sample farm households 64.9% showed willingness to pay in cash. The remaining 35.1% were not willing to pay in cash. In similar observation in upstream and downstream strata, our results revealed that 66.7% of the upstream and 53.1% of the downstream sample farm households WTP money for improved land and water management activities. Bane (2006) reported similar results on his study of valuating domestic uses of irrigation water in the upper Blue Nile Basin. Farmers' WTP in labor, for improved land and water management, showed stronger magnitude (97.2% of the total sample farm households). Our result was in good agreement with Asrat (2002) who reported farmers' perception on soil conservation and willingness to pay more in labor than in cash. Our result also showed a significantly higher Mean Willingness to Pay (MWTP) by downstream users. MWTP in cash was US$1.08 and 1.36/month for upstream and downstream farmers, respectively. While MWTP in labor was 3.3 and 3.9 person-days/month for upstream and downstream farmers, respectively, the average day labor wage rate in the study areas was US$1.60. Comparing the MWTP figure with estimated investment cost for land reclamation, it fails far short of covering the required amount. MoWR (2002) reported an estimated watershed management cost of US$760/ha (This is the estimated amount for establishment and maintenance costs.). Taking mean current landholding into account, a farm household may require about US$1365 to implement improved land and water management on its plots. The elicited MWTP values cannot cover this cost and may take as long as 19.7 years taking the labor contribution into account. The is even longer in the case of cash contribution by farmers. In general this suggests that land conservation will require the coordinated effort of all stakeholders (including the government, upstream, and downstream community).

It is very clear that those farmers' enthusiasm to invest in land and water conservation for sustainable water use and ecosystem services emanates mainly form maintenance of land conservation in upstream areas, and mitigation of siltation and flood damages downstream. Grasping those interests and designing strategies to address the problem at watershed and basin scales would be a good strategy in achieving sustainable land and water management in the Blue Nile Basin.

Determinants of downstream households' willingness to compensate upstream users

A total of 13 explanatory variables (10 continuous and 3 dummy) were included in a Probit model to analyze determinants of downstream farmers' WTC upstream users for improved land and water management (Table 1). The results showed that six explanatory variables are needed to have significant effect on the probability of downstream farmers to compensate upstream farmers. These are access to credit, total family size, ratio of irrigation to cultivated land, TLU, distance to agricultural office, and location dummy (for watershed). From the model results it was evident that downstream farmers' socioeconomic and livelihood status determines their WTC. This was clearly explained by the positive and significant relation between livestock holding and access to credit on their willingness to compensate. Keeping the ceteris paribus assumption, the probability of being willing to compensate increased by 1.9% and 11.4%, respectively, for additional increment in livestock ownership and access to credit service. The negative effect of ratio of irrigation to cultivated land is unexpected and could not be explained. It needs to be explored further. Besides, the model showed that total family size and distance to the agricultural office has a negative and significant effect on downstream farmers' WTC. Keeping the influences of other factors constant, downstream farmers' willingness to compensate upstream farmers decreases by 4% and 1%, respectively, as the total family size and distance to the agriculture office increases by 1 person and 1 kilometer, respectively. Though seven explanatory variables were not significant in explaining downstream farmers' WTC, clear trend of relation between the dependent and independent variables could be traced.

Table 1: Determinants of WTC.

Explanatory Variables	Coef.	dy/dx	Std. Err.	P>z
Start bid	0.013728	0.002388	0.012163	0.259
Age	-0.01751	-0.00305	0.011794	0.138
Educational level (dummy 1=illiterate and 0 otherwise)	-0.13372	-0.02349	0.325927	0.682
Access to credit	0.643803	0.114452	0.329956	0.051**
Sex	-1.02892	-0.28513	0.693857	0.138
Total family size	-0.23304	-0.04053	0.083337	0.005***
Adult male in the household	0.070711	0.012298	0.108249	0.514
Ratio of irrigated to cultivated land	-3.82163	-0.66466	1.936619	0.048**
Number of trees owned	6.58E-05	1.15E-05	0.000107	0.538
Off farm income	-9E-05	-1.6E-05	0.000163	0.579
Livestock owned in TLU	0.110001	0.019131	0.056892	0.053**
Distance to agricultural office	-0.05925	-0.01031	0.033094	0.073*
Watershed2 (1=Gumera and 2=Koga)	1.035345	0.181854	0.381166	0.007***
_cons	2.334752		1.051206	0.026
Number of observations = 146				
LR chi2 (24) = 32.34				
Prob > chi2 = 0.0021				
Log likelihood = -49.073538				
Pseudo R2 = 0.2478				

***, **, and * indicate significant level at 1%, 5%, and 10%, respectively.

Determinants of farmers' willingness to pay in cash

In this section, we report the determinants WTP for improved land conservation using the data for upstream and downstream users. A total of 23 explanatory variables (14 continuous and 9 dummy) were included in the model not reported here. The interval regression model results showed that 15 explanatory variables significantly determine farmers' WTP. The significant variables included access to education, technical assistance, access to credit, number of trees, distance to different services, age of household head, start bid and number of female adults.

From the model results it was also evident that farmers' economic status determines their WTP. This was clearly explained by the positive and significant relation between livestock, size of arable land, and number of trees owned by the sample farm households and their WTP. In line with this, Peden et al. (2007) indicated that more livestock and arable land ownership is considered as asset possession. Those in turn lead to farmers' investment decisions. It is also clear that when farmers own large numbers of livestock, they need to have land and water available to provide feed and drinking water. The size of cultivated land is often associated with more crop income and could also be a viable means to help ease the households' liquidity constraint. From field observations and discussions held with farmers, we also realized that the eucalyptus tree is becoming a major source of income for farmers in the two watersheds. This can explain the reason why farmers with more trees were willing to pay more. With the assumption of ceteris paribus, the probability of being willing increases by 0.74, 0.35, and 4.73 for livestock ownership, land ownership, and access to credit service increased by 1 unit, respectively. In addition to the household economic status, the model showed access to education, information, financial, and technical assistance as strong explanatory variables for farmers' WTP. Pender and Kerr (1996) reported that farmers' ability to acquire, process, and use information could be increased by education. According to those authors, education reflects acquired knowledge of environmental amenities. This was in good agreement with our results, and suggests that keeping the influences of other factors constant, compared to illiterate households, literate households are willing to pay by 6.29 units. Compared to illiterate heads, being literate increased the predicted farmers' WTP in cash by 6.29. Variables such as distance to the agriculture offices showed significant and negative relation with WTP. This means, as the time a household needs to walk to get the agricultural office increases, their WTP decreases as farmers would have less access to information and technical knowledge. From the model we realized that, keeping the influences of other factors constant, farmers' willingness to pay decreases by 0.77 as distance to the agriculture office increased by 1 km.

A stronger relation was observed for assistance to land and water management practices with WTP: farmers' willingness increased by 5.76 as they get additional assistance in land and water conservation practice, keeping other factors constant. Understanding and implementing policy instruments related to those explanatory variables is important to use PES as a tool for improved land and water management in the Blue Nile Basin. Though eight explanatory variables were not significant in explaining farmers' WTP, a clear trend of relation between the dependent and independent variables could be traced.

Conclusion and recommendations

This study aimed at investigating farmers' WTP/WTC and its determinants to help understand the prospects of PES as a tool for improved watershed conservation practices. In view of the result, we concluded that PES has a potential to internalize the cost and benefits of watershed protection and improved environmental services. This potential must be understood to bring about a win-win scenario upstream and downstream of the river basin. Our results show that most of households, in upstream and downstream, are willing to pay for improved land and water management. More interestingly, households downstream are also willing to compensate upstream service providers for their continued land and water management. But its effective realization will still require stronger engagement of all stakeholders, particularly the state, not least in contributing to cover the cost of land conservation. There is also a need for the coordination and harmonization of efforts among upstream and downstream stakeholders and institutions. Institutionalization of a watershed development organ is called for to tap the potentials available locally, and solicit external support for improved watershed management. Alleviating poverty is the most important way to conserve and protect the watersheds, thus, as means of improving farm households livelihood, development policies should target increasing farm households income through intensification. These approaches may include increased adoption of technologies that improves product and productivity of the crop and livestock production. Policymakers should also encourage and provide education, credit service, training, and technical advice to farmers to enhance their efforts.

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Contextualizing payment for environmental services potential in Mzingwane, Zimbabwe

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Abstract

Households in the semiarid Mzingwane Catchment of southwest Zimbabwe live in chronic poverty characterized by severe food insecurity. Rainfed agriculture is unproductive. Even in good rainfall years, there is usually an acute shortage of agricultural inputs and lack of extension support. Some households now engage in gold panning. Poor farming methods, gold panning, and overgrazing by upstream resource users have resulted in siltation of dams and rivers and pollution of water with mercury downstream. This study was carried out to assess the potential for implementing a PES-type scheme, and designing locally suited incentives for sustainable utilization of soil and water, while providing environmental services for the catchment and improving livelihoods. The study sought to understand the interactions amongst the different resource users within the catchment. Smallholder farmers downstream of the catchment are willing to pay upstream land users to adopt land uses or management practices that yield less sediment. Despite their willingness to pay, downstream smallholder farmers do not have the ability to pay. Plot level options that increase productivity seem to be the option.

Media grab

Locally designed incentives can induce improved land and water use interactions as well as environmental services such as sedimentation control and water quality maintenance in Mzingwane, Zimbabwe.

Introduction

Poverty among subsistent smallholder farmers in the Mzingwane Catchment is characterized by food insecurity and a high dependency on food aid. Food insecurity is exacerbated by poor soil fertility, dry spells, unreliable rainfall, poor incomes, lack of capital, and poor access to agricultural inputs (Twomlow and Bruneau, 2000; Mugabe, 2005; Nyagumbo and Rurinda, 2006). Farmers depend on rainfed agriculture, which is risky. Few have access to blue water. The challenge is to enhance land management practices that hydrologically benefit the environment for high yields of dryland crops. Current land uses threaten environmental services such as water quality maintenance, water table regulation, and erosion and sedimentation control. It is against this background that a feasibility study on Payment for Environmental Services (PES) potential in soil and water management was undertaken in the Limpopo Basin. The study sought an understanding of the interactions amongst land and water resource users within the catchment to design locally suited incentives in a participatory manner for improved livelihoods and sustainable utilization of resources providing environmental services for the catchment and people.

Objectives

- Characterize current socioeconomic and biophysical conditions of the area.
- Examine relationships amongst different land and water users and qualify relationships.
- Assess the magnitude of current environmental problems associated with inappropriate upstream, midstream, and downstream land, water management, and impact on livelihoods.
- Identify relevant institutional factors for design and implementation of PES, highlighting potential strategies and interventions for amelioration of identified environmental problems.

Methods

Research was carried out in Zhulube in the Insiza District of Matabeleland South within the Limpopo Basin of Zimbabwe. Zhulube has 18 wards and is in agroecological zone IV, characterized by low rainfall (≤600mm) and poor soils (Ashton et al., 2001). The study used qualitative and quantitative methods to gain an understanding of land and water use interactions and impacts. Qualitative methods used include land use mapping, seasonal calendars, wealth ranking, key informant interviews, observations, and participant observations among other Participatory Rural Appraisal (PRA) methods. PRA methods were used to ascertain social realities of processes and phenomena of interactions in land and water use, with observation methods helping to gain first-hand information. A questionnaire was administered to characterize current socioeconomic and biophysical conditions of the area. Fifty households (38.5%) were sampled, 30 were interviewed in February and 20 in June of 2008. The sample was derived from three strata based on relative location (upstream, midstream, and downstream) of homesteads in the catchment. Quantitative data were analyzed using Statistical Package for Social Scientists (SPSS) version 13.0, and qualitative data were analyzed by themes.

Results

Socioeconomics: human, financial, physica, and natural capital

The community is patriarchal with a majority of households headed by males (78%), while 22% are headed by females. Household size ranges between three and sixteen members with an average of 6.04. With such family sizes, the demand for food from plot level production is a challenge for households. Literacy levels are skewed toward males with 78% having received an education, compared to only 18% of the women who went through at least primary and secondary school. Most households have a diversified income portfolio and engage in on and off-farm activities to cushion themselves against risky rainfed agriculture. Their livelihoods portfolio includes gardening, poultry keeping, crop sales, informal trade, brick molding, gold panning, beer brewing, livestock sales, carpentry, and providing labor for a fee. Gardening and fruit sales are an important income source involving 64% of the households, mainly adult females. Thirty-two percent of households are involved in field crop sales, 26% in gold panning, and 10% in livestock sales. Although a greater number of households engage in gardening, male-dominated gold panning is a more lucrative year-round income generator, free from climatic stresses. Women and girls carry loads of ore and water during the dry season. A few women go to the site to sell food but are said to sometimes end up engaging in prostitution. About 18% of the farmers have access to contract loans from Agribank (2%) and Grain Marketing Board (GMB) (16%) for seed and fertilizer. The hyperinflationary economic climate discourages most farmers from taking loans. Land is under communal tenure. The majority of structures are owned (98%) and only 2% rented. There is a low possession and ownership of farm implements and livestock. There is, however, a significant positive correlation at 0.05 (2 tailed) confidence level between steers and plows owned.

Current land and water use

Current land uses are fragmented across the catchment. Most land is under arable farming with fields located on valley slopes. Open grazing and gold panning are practiced in the mountains. The main successful land use is irrigation on 15 ha downstream of the catchment, where each of the 40 members has three blocks of 0.1 ha. Wheat, maize, and beans are grown interchangeably throughout the year. Scheme members get assistance from World Vision, and in February 2008 a dairy project was introduced. A milking shed is currently under construction. Rainfed agriculture is practiced by all households growing mainly maize and sorghum. The farming practices are intercropping practiced by 64% of respondents, monocropping (44%), and crop rotation (30%). Intercropping and crop rotation are preferred to avoid pests and diseases, and as risk aversion against climatic shocks and stresses keeping yields high. A few households (6%) leave land fallow. Water for domestic use, farming, and panning is accessed from a number of sources, and 86% of the households have access to dam water. Some households access water from rivers (12%), shallow wells (10%), protected wells (4%), and boreholes (92%). Dam water is available perennially in good rainfall years and seasonally in bad rainfall years, while other sources are available seasonally. Dam water is used for irrigation by 6% of households, domestic purposes (26%), livestock (4%), domestic and livestock (36%), and domestic and irrigation (14%). Those that use the water for domestic purposes purported to drink water when boreholes are broken due to gold panning activities and overuse, especially during dry seasons. About 26% of sample households are involved in gold panning, but the figure could be conservative as key informants argued that most panners conceal their involvement since panning is regarded as illegal. Key informant interviews revealed that ‘panning is life for the village’ (interview with Mpumelelo Village Head, 10 June 2008), hence it is difficult for traditional institutions to control panning activities. The reported high dependence on gold panning makes community members less prepared to stop the activity as this threatens their livelihoods. Although gold panning is an issue, environmental impacts are ignored by the community as most households benefit from the activity directly and indirectly. Reports indicate negative impact of gold panning on forest resources, boreholes, river water quality, and quantity.

Social interactions, environmental problems, and willingness to pay

Social capital is high among Mpumelelo households and neighboring villages. It is inherent in sharing of risks, benefits, and profits among the gold panners, irrigation scheme members, gardeners, brewers, brick molders, and farmers. Social networks are common in exchange for goods and services, encouraging cooperation and collective action. Kinship ties especially of totems cement relationships resulting in reliability, trust, and norms and values that encourage some kinds of behavior such as gold panning. Although gold panning is illegal, the villagers protect gold panners and are reluctant to discuss it. Latent conflicts exist, however, over access and control of water and land. Major conflicts in the village are caused by gold panning activities as expressed by 38% of respondents. Reasons given are panners digging farmers' fields, livestock falling into gold mining pits, panners causing siltation of rivers and dams, as well as contested access to and use of water from the Zhulube dam and boreholes. Gold panning conflicts are also intergenerational as most of the panners are young adult males who view rainfed agriculture as unproductive. Other conflicts are over cattle plundering fields during the planting season and these are amicably resolved amongst the offending party, the offended, and village head’s panel. Perceptions of households on environmental problems are varied. Decreased pasture land has been observed by some while others have seen an improvement since the village head took the initiative to monitor cattle grazing areas. Water quality problems are highlighted by 38% of households with siltation of rivers and dams as the most worrying problem. Villagers fear that uncontrolled gold panning activities might lead to silting up of the new

Zhulube Dam like the old one. Environmental problems highlighted were attributed to gold panning activities by 50% of respondents. The community is aware of environmental problems and impact on their livelihoods in reduced water quality and quantity through siltation and sedimentation. Expression of willingness to pay for a change in upstream land uses is high at 78%, though financial capacity is low. Some respondents do not see the logic of rewarding wrong doers to stop their activities

Discussion: payment for environmental services potential in soil and water management

PES requires a voluntary transaction between at least one seller and one buyer of environmental services with the condition of payment for provision of services by provider (Wunder, 2005). Demand for quality water and soil erosion control is evident in the catchment. Expressed willingness to pay defines possible buyers of environmental services. Land uses are not determined by where households are located but by availability of resources and preferred livelihood sources by households and individuals. Potential providers of environmental services are gold panners and conservation farmers. Compensating gold panners for an illegal activity might complicate PES process, however. Gold panners have, 'real but not legal choices for how to use resources' (Ravnborg et al., 2007). The forest upstream is being degraded, water sources polluted, and water quantity reduced by panning activities. Panning is lucrative; though illegal, it has more benefits. PES can induce incentives through contractual agreements among policymakers, gold panners, and funding organizations. Contracts should ease certification and legalize land use by panners binding them to provide demanded environmental services. Plot level options that increase productivity seem to be the best option as evidenced by low productivity of crops. This may be achieved through upscaling conservation farming (Oldreive, 1993) and providing incentives like inputs, technical assistance, and capacity-building for the providers of services. Funding by intermediaries such as government and nongovernmental organizations is required. Incentives have to be agreed upon in a participatory way by stakeholders and a greater awareness of environmental services created.

Conclusions and recommendations

Environmental problems exist in Mzingwane that undermine the provision of environmental services such as water quality and quantity maintenance and land and soil conservation. PES can induce provision of environmental services through integrated catchment management. Coercive enforcement has failed to curb gold panning. Incentives for cleaner, organized, and legal production and markets for small-scale miners can induce provision of water quality and quantity maintenance as well as soil and land conservation. Unproductive rainfed agriculture reinforces adaptation to gold panning. Therefore, conservation farming at plot level at a larger scale is essential for soil erosion control, soil fertility improvements, and water retention to cushion crops against dry spells. Provision of inputs, timely planting, and conservation farming can result in high yields. Successful examples from the community can be used to highlight benefits of adopting technology. Rangelands can be restored through growing plants to stabilize the soil and monitoring livestock while revitalizing areas. Traditional institutional arrangements are already monitoring rangelands. Efforts need strengthening through clear incentives and benefits of activity for the people downstream. Strategic stock feed reserves can be built from irrigation the scheme. Improved marketing and marketing intelligence of on- and off-farm products can provide incentives for provision of environmental services. PES in soil and water conservation has potential to induce provision of water quality and quantity maintenance and soil conservation in Mzingwane. Contractual agreements strengthened by intermediaries such as government and nongovernmental organizations may be needed.

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PES in upper-catchments of Vietnam: expected differential impact for contrasted farmers

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Abstract

In most upper-catchments of the Northern provinces of Vietnam current land uses are producing negative externalities that affect downstream areas. Slash-and-burn is often blamed as the main cause for the problem.

Land uses that would bring about environmental benefits include tree-based land use alternatives and agroecological practices (e.g. direct-seeded mulching cropping systems). The environmental services these alternative land uses would provide, however, are unrewarded. Payments for Environmental Services (PES) schemes present a new approach that focuses on creating a conditional benefit transfer between the upland providers of environmental services and the downstream beneficiaries.

Agricultural households in upper-catchments have unequal access to natural resources, inducing contrasted farming practices and livelihood strategies. Our main objective was to evaluate the response of contrasted households to PES schemes that would reward them when they set aside some land for forestry projects. We looked at the specificity of PES schemes targeted at agricultural households of the upper-catchments in Northern Vietnam.

Based on farm typologies developed earlier, and using a simplified farm model, we analyzed how households with different endowments would respond to such PES schemes.

Media grab

Access to irrigated land is instrumental in reducing poverty and erosion for poor farmers in the northern provinces of Vietnam.

Introduction

In most upper-catchments of the northern provinces of Vietnam current land uses are producing negative externalities that affect downstream areas. Slash-and-burn is often blamed as the main cause for the problem. New land uses that would bring about environmental benefits include tree-based land use alternatives and agroecological practices (e.g. direct-seeded mulching cropping systems). The environmental services these alternative land uses would provide, however, are un-rewarded. Payments for Environmental Services (PES) schemes present a new approach that focuses on creating a conditional benefit transfer between the upland providers of environmental services and the downstream beneficiaries (Pagiola and Platais, 2002; Wunder, 2005).

The past few years have witnessed a surge of interest in the development of PES schemes in Asia. In Vietnam, while some projects using the conceptual framework of PES are being initiated in the central and southern part of the country (e.g. WWF, 2007), no PES schemes are currently being implemented in the upper catchment areas of northern Vietnam (Wunder et al., 2005). The Vietnamese government, however, expressed recently its interest in starting such a scheme to protect fragile upper-catchments whose degradations are causing problems, among others, on hydro-electric infrastructures.

Agricultural households in upper-catchments have unequal access to natural resources, inducing contrasted farming practices and livelihood strategies (Do Anh Tai et al., 2007). Our main objective was to evaluate the response of contrasted households to PES schemes that would reward them when they set aside some land for forestry projects. While some analytical work has already given general results (Zilberman et al., 2006), we looked at the specificity of PES schemes targeted at agricultural households of the upper-catchments in northern Vietnam.

A large diversity of situations in the upper-catchments of Vietnam

Mountainous provinces of Vietnam contain huge ecological and economic heterogeneity. In upper-catchments areas, household livelihoods are influenced by major driving forces such as the type of land they have access to, the amount of water they can capture for irrigation, and the markets they have access to. Household surveys conducted in Yen Bai Province in 2006 and 2007 were used to build a generic typology of upland farmers to relate the differences in resource endowments and their livelihood strategies.

The first and main differentiating factor was the combined access to land and water. Results showed that land well-suited for growing paddies was unevenly distributed between households. For the typology construction, two types of access to land and water were defined: (1) households with sloping rainfed land only; and (2) households with sloping rainfed land and access to water flows allowing the production of one or two paddy crops per year. The second differentiating factor is the household access to markets (inputs, outputs, and off-farm). Large differences were found between the communities access to markets. Distance to main markets gives one explanation. Many households were also excluded from markets because of previous bad experiences such as defaults on previous credits. On the latter, participation to input/output markets was also highly variable between households of the same community.

Based on these factors, we classified the households into four categories (Table 1). Of the four groups identified, types 1 and 3 households are the poorest in terms of income generation and also the most vulnerable over time. Both have limited access to markets, but they are contrasted by their access to irrigated land. Here we concentrate on the impact of the PES scheme on these two groups. Type 1 farmers do not have land suitable for growing paddy rice, so they cultivate only more fragile sloping lands for their food needs. Shifting-cultivation rice-based systems are used. With low availability of land per capita, shifting cultivation is practiced with short fallow periods, and the overall land fertility is progressively decreasing. Without access to input, output markets, food demand can only be met through traditional cultivation techniques (no fertilizers) and through food produced from their own land (no purchase of rice). Type 3 farmers have access to water for irrigation, but have limited access to markets. Most of the activities are concentrated on the production of paddy rice. Sloping areas are only cropped when the rice paddy production is not sufficient for household needs. In particular, when farmers can grow two rice crops per year, the remaining upland is usually left idle for soil fertility recovery. The fourth group does have access to water for irrigation and to markets.

Table 2. Simplified typology of households in upper-catchments.

		Access to land and water	
		Upland mainly (no water)	Paddy land mainly (water for 2 rice crops)
Access to markets	No	① Subsistence rainfed rice farming (18%)	③Subsistence paddy farming (21%)
	Yes	② Diversified upland growers (15%)	④ Diversified production (46%)

A simple model of type 1 and 3 production systems was developed and simulations were conducted to analyze their potential reactions to different types of PES schemes. Modeling shifting cultivators, however, is not straightforward since the model has to reproduce systems with discontinuous behavior over time, and cannot rely on the traditional hypotheses of income maximizing behavior and market integration.

Specificities of our modeling approach

Shifting cultivation systems are characterized by the use of long fallow periods alternating with short cultivation periods and the absence of use of external inputs. The rationale of discontinuing cultivation is double. First, fragile sloping soils are degrading fast and crop yields tend to fall rapidly. Second, invasion of weeds after a few years of cultivation is causing a sharp reduction of labor productivity. For these subsistence oriented shifting cultivation systems, we hypothesized that a field cultivated in the preceding season, is given up if two conditions are fulfilled: (1) the discounted projected benefit stream of continued cultivation is less than the one associated with the alternative options of concentrating efforts on the other opened fields, or by opening a new field; and (2) the expected food production stream will not fall below the household minimum requirements.

Since the two types of farmers modeled do not have access to markets, it was assumed that modeled farmers are only interested in basic consumption needs. When these are met they prefer more leisure to higher consumption. Hence, in the households' objective is to reach a food sufficiency target with the minimum of labor effort, implying that consumption beyond that level has no real value (e.g. Dvorak, 1992; Angelsen, 1999; Rasmussen and Møller-Jensen, 1999).

Most conservation decisions involve inter-temporal trade-offs. Nevertheless, most farmers with pressing subsistence needs have high discount rates resulting in very short planning horizons. Still, decisions taken at one point of time will influence future outputs and decisions. Hence, we used a recursive model, where households take decisions annually with short-term planning horizons, but have to bear the consequences of their previous choices.

Model structure and dynamics

The model simulates private decisions of a farmer who has been allocated a given area of sloping land for individual management. It focused on three interlinked mechanisms: nutrient dynamics, cropping and fallow periods, and labor allocation decisions. The model is recursive dynamic and deterministic. It is recursive dynamic because farmers make annual decisions based on expectations over their planning horizons and on the actual state of the system. The state of the system, however, depends only on the previous decisions. The following assumptions were also made: only one crop is grown, land available to the household is fixed, household population is constant over time, and fertility status of each field can be described by only one parameter.

Nutrient dynamics is influenced by household decisions at each period, i.e. cropping versus fallowing, and labor input in each cropped plot. In return, those decisions will be conditioned by the status of each available field, and household food requirements and labor constraints. Household land is divided into a fixed number of fields of equal size, among which a variable number is cultivated at any time. Fertility equations ensured that plot fertility increases at a decreasing rate during fallow periods, and decreases proportionally to yields during cultivation periods. Yield obtained in each plot will depend on its actual fertility and the labor investment. The production function ensured that yields increase at a decreasing rate with plot fertility and labor input. The modeled households have no access to markets, so it was assumed that households chose the number of fields cultivated or fallowed, and allocated labor among cultivated lands to produce enough food and minimize labor input. The household planning horizon is one year.

For each time step, we implemented the following decision process. Four strategies with respect to opening and abandonment of fields were defined: (1) no changes made compared to previous season; (2) one new field is opened and no fields abandoned; (3) one field is abandoned; and (4) one new field is opened, and one field is abandoned. If a field is to be opened, the field with the highest fertility is chosen. Besides, field clearing time is added to the labor needs of this plot. If a field is to be abandoned, the cultivated field with the lowest fertility value is chosen. For each strategy, a decision model, using nonlinear programming, is applied that minimizes household's labor input, while producing the required food and respecting the family labor constraints. If a strategy is impossible at a particular time, it is discarded during that loop. Farmers with access to water can also allocate labor to their paddy fields. Paddy fields are producing food according to a specific production function. The strategy giving the lowest forecasted value of household labor required is retained. State variables are recalculated for the next time step using the chosen strategy. This model was implemented using GAMS with the nonlinear programming solver CONOPT2 (Drud, 2006).

Simulations and discussion

Many of the mechanisms required by the model were difficult to extract from available empirical data. Hence, they are based on generalized empirical findings in terms of yields decrease over cultivation years in shifting cultivation systems, and are as far as possible based on a household survey done in the Van Chan district, Yen Bai Province in 2007.

We first ran the model for base scenarios (Scenarios 1 and 3 of Table 2) to reproduce the main phenomena observed over time in the shifting cultivation systems. In all cases, households were composed of three working adults that provided food for a total of five household members. The models were able to reproduce a cropping/fallow system quite realistically. The fertility index of one farm plots over the years under the different scenarios is shown in Figure 1. The upward sloping part of the curves correspond to fallow periods, the downward sloping part of the curves correspond to cultivation periods. Farms without access to irrigated land (scenario 1) have a shorter cropping/fallow period of around 16 years, with a cultivation period of 6-7 years. Farms with access to irrigated land (scenario 3) have a longer cropping/fallow cycle of 20 years, with around 5 years of cultivation and the remaining time for fallow. Given the high productivity of paddy fields, fertility can be maintained over time in the sloping land. Different coefficients taken for the yield and fertility equations provided slightly different cycle length, but the same fundamental cycle was obtained, which suggests that the most fundamental mechanisms are represented in the model, even though real empirical coefficients could not be obtained.

Table 3 : Land and water access under the different scenarios.

Scenarios	Paddy area (ha)	Upland area (ha)	Upldand area under cultivation after 15 years (ha)*
1 (Base, Group 1)	0	3.5	1.31
2 (Protected zone, Group 1)	0	2.62	1.31 (0%)
3 (Base, Group 3)	0.2	3.5	0.87
4 (Protected zone, Group 3)	0.2	2.62	0.82 (-6%)

** Results of the simulations*

For the simulated farms with access to water, the average land fertility is decreasing only slightly over time suggesting that shifting-cultivation systems could be sustainable over time since enough time is given for soil fertility recovery. Fertility is decreasing faster for the farm without access to irrigated land, since they have shorter fallow periods.

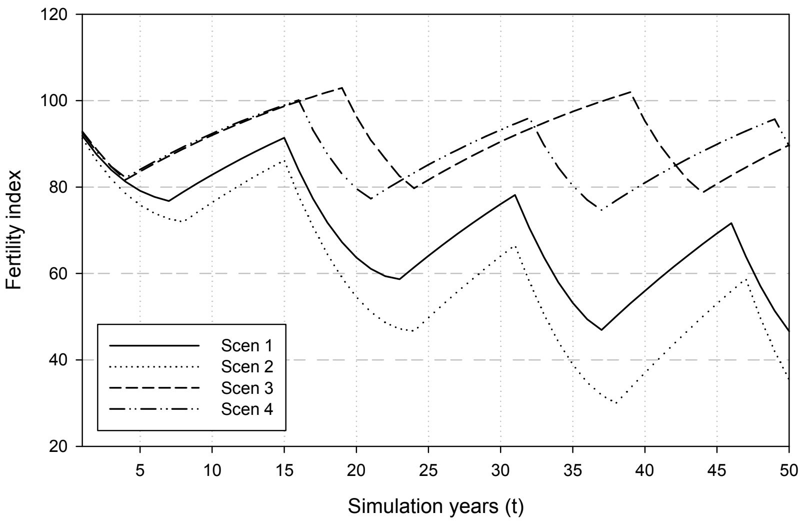

Figure 1: Fertility index over time of one selected plot. Scenarios 1 and 3 are base scenarios. Scenarios 2 and 4 correspond to a 25% reduction of cropping area in the sloping compartment of the farm.

We then simulated the effects of a hypothetical PES scheme, where participants would receive monetary compensation to set aside part of their cultivated land for reforestation (scenario 2 and 4). Given the high transaction costs these households are facing, however, monetary payments are unlikely to be easily translatable into real goods. Hence households have no other opportunities than to live with their new constraints, and can only reduce slightly the amount of food they expect from their agricultural land. To illustrate this, we simulated farmers that should reduce their cropping area by 25%, and that would receive monetary compensations that would reduce their food needs from agriculture by 10%. Other alternative PES schemes could be considered, such as monetary compensations for adopters of a set of sustainable farming practices and are likely to produce different results, but actual projects of the Vietnamese government in the northern part of Vietnam focused so far on forestry projects.

For households without irrigated land, a sharp soil fertility decrease was observed over time in the area left for agriculture (Scenario 2 of Figure 1). Although protected areas are recovering progressively, increased degradation took place on the remaining cultivated land. With less available land for agriculture, households were forced to reduce the fallow periods, and to cultivate their land for longer periods of time. Simulation results even show that the land under cultivation does not diminish the proposed PES scheme (Table 2). Therefore, the overall effects on erosion transmitted to downstream users and dams would depend on the relative sensitivity of protected and cultivated soils to erosion.

For households with irrigated land, the farmers are decreasing their fallowing period, but are also increasing the labor allocated to irrigated crop (Scenario 4) to be able to produce sufficient food for their needs. Cultivation area in the upland compartment is slightly reduced, and the fertility index in the remaining land is slightly increasing. Therefore, the reduction of available land to agriculture is likely to decrease the erosion created by those upstream farmers.

Conclusions

PES scheme designed to set aside land for forestry programs is likely to have very contrasted effects on farm households without access to markets depending on their access to irrigated land. Farmers with access to irrigation are more likely to participate in such PES schemes because they can compensate the reduction in land availability by increasing the productivity of the lowland compartment. In contrast, farmers without irrigated land are likely to suffer most from land set aside if only monetary compensations are given. For them, participation in the scheme can only be compensated by cropping more intensively the nonprotected zones, thereby increasing the likelihood of erosion on these zones.

For farmers without irrigation, having access to new irrigated areas to compensate for their loss in sloping land would be the most favorable reward. For communities that have difficult access to markets, funds transferred to communities in the form of irrigation infrastructure are likely to be more efficient both in terms of soil conservation and livelihood improvement than monetary transfers to individual farms for forestry projects. For example, building up concrete canals so that more households have access to irrigated land is likely to produce important environmental effects by reducing the pressure on sloping lands. This kind of reward would not be conditional, however.

The results of this simplified model confirm the information obtained during group discussions with farmers in the communities where this work was conducted. Farmers have often expressed the need for improvement of irrigation infrastructure as a mean to improve their livelihoods, and also tend to see set-aside programs for forestry projects as an additional constraint to their daily life more than an opportunity. In contrast they showed interest in projects that would increase land productivity whether by getting improved access to water or by new sustainable technologies on the sloping lands. In the latter case, new cropping systems such as direct seeded rice or maize with cover mulch are often reducing incomes in the first years of adoption (Affholder et al., 2008). Alternative PES schemes that would provide some compensations conditioned to the adoption of such technologies are also likely to interest from farmers.

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Relevance and feasibility of PES to combat soil erosion and solve catchment management issues in the Mekong Region

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Abstract

The possibility of developing a PES market in continental Southeast Asia (CSEA) to improve cachment management was addressed through three case studies in mountainous areas of northern Laos (L), northern Vietnam (V), and northern Thailand (T). The study sites encompass a wide array of environmental, social, and governance issues. Results showed that many key elements favorable to the emergence of a PES market already exist in CSEA, as follows: All stakeholders, including farmers and Governmental agencies (GoAs), have a clear perception of environmental issues (T, V, L). Farmers have even changed occasionally (T, V) their practices without compensation as the result of a conflict-solving process at village level. Potential buyers have been identified in the public and private sectors (T, V). Public effort is already addressing erosion issues (T), and could eventually be redirected to a PES scheme if proved economically efficient. Major impediments are, however, limiting the implementation of PES targeted to small stakeholders. Willingness to pay is consistently low (T, V, L) even where the environmental issues are the most severe (L), or the potential buyers are powerful agribusinesses (T) or GoAs (T, V). The number of potential buyers can be too small (L). The relationship between environmental service, user and provider is equivocal in a number of catchment management issues (T, L), especially when the communities of providers and receivers overlap. In conclusion, while many catchment management issues are clearly outside the scope of PES, a large potential exists in CSEA for implementing PES in the agricultural and rural development sector.

Media Grab

Clean water in Southeast Asian uplands is no longer granted for free. The concept of watershed service proved very useful in identifying bottlenecks, and elaborating solutions for a better management of the environment at the watershed scale.

Introduction

Environmental management policy in developing countries has characteristically oscillated between command and control limitations imposed upon local people and indirect integrated conservation and development projects (ICDPs) (Wunder, 2006). ICDPs proponents hypothesize that poverty alleviation programs will catalyze trickle down improvements in sustainable land use, based on the theory that raising incomes is a critical precursor to the adoption of sustainable production techniques (Wunder, 2006; Gillis and Vincent, 2000). These strategies have proven their inability to address 'urgent, priority (environmental) issues' Chape (2001). Moreover, Valentin et al. (2008) have shown in Southeast Asia (SEA) that the possible adoption of conservation practices was not correlated with household income. Payment for environment services (PES) offers an alternative ongoing funding source for sustainable agriculture amongst poor and subsistence farmers in SEA. It is especially advantageous in situations where conventional instruments have failed, either from a lack of institutional capacity or political will, or where willingness and/or capacity of private landowners to finance ecosystem conservation are low (Bracer et al., 2007).

Whether watershed services make good PES markets is a subject often debated. In a report prepared for CIDA, Robinson and Venema (2006) claim that hydrological watershed services are ‘ideal’ for PES because of the apparent ease in identifying direct and obvious users of water in a watershed, meaning buyers can be targeted. In many cases, this is the case with a clear delineation between the beneficiaries of ES (often downstream domestic water users) and the providers (upstream farmers who modify land use). Wunder et al. (2005) as well as Jack et al. (2007) or Tomich et al. (2004) highlight difficulties specific to the watershed approach when addressing poor stakeholders. Thus, the question of whether watershed services can support PES is pertinent to the foothills of continental SEA, where farmers are typically poor smallholders, although they produce strong externalities. Especially, preconditions such as education, local organization of farmers (Gutman, 2003; Rosales, 2003) and institutional context (Gillis and Vincent, 2000; Huang and Upadhyaya, 2007; Wunder, 2005; Pagiola, 2007; FAO and Latin American Network for Technical Cooperation in Watershed Management, 2004; Mayrand and Paquin, 2004) are highlighted.

In their review of PES in Asia, Huang and Upadhyaya (2007) argue that successful uptake of PES in Asia will depend upon the consideration of five factors specific to the Asian context. These include: (1) diverse governance structures and regulatory frameworks; (2) risk of high transaction costs from high population density and low land holdings per capita; (3) weak property rights for forest and agricultural land; (4) insufficient hydrological data and understanding of watershed services; and (5) low awareness of PES. There is a significant need for further research that explains the effect of these factors on PES uptake for watershed services in foothill communities, where upland and lowland communities are relatively poor and in some cases overlap.

The objective of this paper is to establish whether foothill communities in CSEA have a suitable structure to establish PES within the community, using data collected from two case studies in northern Thailand, Lao PDR, and Vietnam. The paper will contribute to the discussion of the following points, frequently raised in the literature: (1) legal land rights are critical to PES realization; (2) WTP is an efficient way to manage environmental services; (3) the ideal launching process for PES; and (4) the constraints of overlapping buyers and sellers and competing sources of environmental hazard to WTP.

The chosen case studies offer useful evidence to discuss these ideas because of their broadly representative biophysical and socioeconomic relations between the uplands and lowlands and predominance of poor small-scale farmers. The diverse governance structures and policies of the three countries are useful in addressing Huang and Upadhyaya’s (2007) warning against a one-size-fits-all solution for PES in Asia.

Thailand

The Mae Thang watershed is located in the province of Phrae in northern Thailand about 550 km northwest of Bangkok. The Town of Phrae lies in an alluvial plain surrounded by mountains. Between the plain and the mountains is a hilly area where the Thai people living in the plain are cropping corn. Irrigation users in the lowland include rice farmers, who are often poorer than the upland cash crop farmers. In many cases, a same household can own irrigated paddy fields in the lowland and corn fields in the uplands. Moreover, the constantly rising price of corn makes upland farmers unanimously perceived as wealthier than any others, with the result that lowland farmers will never accept to pay the corn growers for WS. This case study debunks the myth that watershed service (WS) buyers are downstream and rich while WS providers are upstream and poor.

The water flowing from the slopes is collected in a series of reservoirs devoted to irrigation. Among them is the Mae Thang reservoir, which began operating in 1997. The reservoir’s maximum capacity was 30 106 m3 at construction. Over 3.5 106 m3 of sediments have accumulated in eight years in the reservoir. The Royal Irrigation Department (RID) estimates the cost of dredging at 15 THB/m3 (0.5 USD). RID, however, has no WTP for WS for multiple reasons: (1) the watershed is not under their authority, but under the Royal Forest Department (RFD); (2) the perceived cause of siltation is landslides and heavy rainstorms, both visible without any equipment, while an echo-sonar would be needed to survey the cumulated sediment brought year after year by erosion from cultivated fields. Other Thai governmental organizations are the Tambons Administration Offices (TAOs), which are the district and sub-district authorities. TAOs are currently acting as intermediaries in a PES-like soil and water conservation project named check-dams project (CDP). CDP is a national project running since 1985. It consists of paying villagers for construction of small dams whose function can either be to do gully correction in the slopes, or to store water temporarily during the dry season. CDP has a number of technical and administrative flaws, but still demonstrates that TAOs can effectively work as an intermediary in a national market of WS. At the local scale, however, their administrative limits do not correspond to the watersheds, and their internal rules prevent them from spending their budget outside their own superscription, therefore making impossible for a TAO located downstream to buy WS from upstream users.

There is a significant level of formal organization between farmers. Farmers’ water needs are decided by water use management groups who regulate a dry season irrigation plan along two streams. Many farmers in the uplands and lowlands are organized through agricultural cooperatives or sahakons that coordinate their access to capital and sale of produce. Although water quality is steadily declining in the Mae Thang, a WS that guarantees stable water quantity through diminished erosion is more suitable for PES. Over 90% of surveyed upland farmers believe soil erosion affects production negatively. For example, one-third of farmers mentioned an increase in the rocky terrain making the land unsuitable for cultivation. A further 67% identified that runoff and erosion are leaching the soil of valuable nutrients, impacting productivity, and 33% stated an increase in expenditure on fertilizers in recent years. Most interestingly, a full 75% of farmers have noticed visible changes in the size of the gullies on their land, stating they can see an increase in width 'of centimeters' following each big rain.

Laos

The Houay Xon watershed is located in the Luang Prabang province, in northern Laos, south of the UNESCO World Heritage city of Luang Prabang. The studied watershed covers 22 km2 and includes seven villages located along the Houay Xon stream.

Upstream lands are suffering from varying degrees of erosion. In the past decade, annual cropping has intensified, while fallow times have been reduced from 8 to 2 years since 1970, and cultivation time increased from 1 year to 2 years since 1995. These changes are responding to the Government of Laos' (GoL) 'land-use planning and allocation program', whose goal is to eradicate slash-and-burn and shifting farming by 2010 (Lestrelin et al., 2006). Erosion from upland maize fields has now reached 5.9 t/ha/year of sediments, a six-fold increase since the 1990s (Valentin et al., 2008). All of the farmers surveyed in the Houay Pano confirmed they were aware of erosion problems. Income levels in the farming area, although diverse, are typically very low or subsistent. Most of the population spend an average 95% of income on food.

Surveys in 2007 revealed a clear downstream demand for improved water quality and more constant stream water flow in the Houay Xon catchment (Mousquès et al., 2007). The study therefore focused on how PES could help reach this goal. Survey results also showed that the downstream community is playing a major role in the deterioration of the quality of water in the stream. Downstream villagers, market gardeners, and fish farmers predominantly affect water quality by inputting chemical and organic waste into the stream. The existing garbage collection service is insufficient and used by a small minority of villagers. No grey water collection system exists, while 44% of the interviewed households dispose of more than 1 m3/week of water in the stream. Finally, sewage is also present from leaking toilets as well as direct defecation into the river. When asked for the causes of reduced water quality, 68% of the interviewees mentioned increases in village population and household waste.

Problems of identifying a possible PES scheme included: (1) Water extraction and contamination are diffused along the stream, making the classical WS scheme of upstream suppliers vs downstream buyers poorly suited. (2) Only 3.7% of downstream villagers identified themselves as gardeners or farmers, thus direct water users. The other villagers are employees, factory workers, and shopkeepers. They are unaware of the degradation of the hydrological service, they do not identify themselves as water users, and therefore would be reticent to buy a service that they do not use. (3) The downstream farmers and gardeners derive little profit from their activities. They do not have sufficient income to support a PES market. (4) The major companies in the study area, that is Nam Papa and DLPCP, both bottled water companies, are operating upstream to the pollution sources. They have their own reforestation program to secure large areas around their spring source. They have no interest in investing in the water quality of the river. Nevertheless the survey identified that WTP within the sampled population was approximately US$0.3/month/household which, if used to compensate farmers for implementing new land management practices, would suffice to significantly abate the negative impact of soil erosion on water quality, but not the adoption of waste collection schemes (Mousquès et al., 2007).

In brief, a lack of education, as well as government policy and practice constitutes an important obstacle for implementation of PES. Nevertheless a PES scheme in the area could help promote effective trusting relationships between all stakeholders, and motivate them to become involved in flexible environmental management strategies that could be further developed in the Houay Xon through the work of institutions.

Vietnam

In northern Vietnam, soil erosion under annual crops on sloping lands has led to a drastic decrease in soil fertility and to a loss in the capacity of downstream water reservoirs. In the studied watershed (Tien Xuan Commune, Hoa Binh Province, 60 km west of Hanoi), the annual crop had to be abandoned, and gradually replaced by reforestation, and fodder crops. The impact on the erosion was immediate. A further concern arose with respect to livestock production (i.e. stall fed systems), that being the potential impact of intensive cattle rearing on surface water quality. Another concern for sloping land farmers is a lack of disposable income for the purchase of inorganic fertilizers. This has resulted in farmers in northern Vietnam resorting to the utilization of raw human waste, termed 'night soil' in rural China, in order to fertilize their cropping systems. Consequent to this practice, there is a high incidence of human infections from soil-transmitted Helminthiasis and diarrheal diseases amongst these communities that results in elevated morbidity rates (Phuc et al., 2006).

A potential solution to this issue is the processing of human waste that effectively sterilizes these wastes thereby converting them into safe, high-quality soil fertilizers. This could be achieved through the production of biogas and compost using simple, cost-effective household digester systems. The quantities of household human waste generated on a daily basis, however, are insufficient and of a low quality that precludes this form of safe disposal. This project argued that the development of an enhanced household livestock enterprise, based on the production of high-quality forage production, would generate daily waste volumes that when mixed with household human waste streams, would be sufficient to supply the daily requirements of a household biogas and compost digester units.

A project was proposed to promote the introduction of perennial tropical pasture grass species as an alternative to annual crops on sloping lands as a means of reducing erosion and the establishment of the temperate species Avena in lowland paddy fields to supplement winter feed for livestock raising. The concept behind this proposal was to create a sustainable loop between fodder production on sloping lands, animal husbandry enhancement, animal and human waste use, human health and water quality protection by promoting the establishment of environmentally friendly biogas and compost units. The project requested the contribution of lowland and upland stakeholders, and was requesting significant changes in the practices of both communities, including stalling the cattle, and using biogas fermenters.

The present study addressed the question whether a PES scheme was appropriate to favor the adoption of this new technology by both parties. The project is ongoing. Preliminary conclusions include the followings: (1) WTP is very low; and (2) livestock owners are perceived as wealthier than the average population who are therefore not prepared to buy any WS from them. Public funds have been solicited to cover the cost of biodigesters. Encouraging answers were received to date for a pilot unit. The project had to change from straight PES to include a form of public funding. The concept of WS proved useful in bringing the two communities together to cooperate on a win-win agreement. The agreement mentions that the farmers who receive a biodigester will, in compensation, stop fertilizing their fields with raw organic waste but use compost instead.

Conclusion

Our study aimed to assess the possible emergence of watershed-oriented, pro-poor, PES markets in CSEA. We carried out three case studies, in Laos, Vietnam, and Thailand. The first conclusion is that neither case study demonstrated an immediate opportunity for launching a PES market targeted to the desired goal. The following obstacles were encountered:

- The classic WS scheme with buyers downstream and providers upstream did not necessarily apply to all watershed issues. In Laos, pollution of water originated from upstream and downstream communities, which would require a joint effort toward solution. In Thailand and Vietnam, downstream and upstream communities overlapped.
- WTP was low within the population in all case studied. It is almost zero in Thailand and Vietnam. In Laos, it is insufficient to address the entire problem. It is a constant from all studied cases that smallholders will not pay other smallholders for WS, especially when upstream stakeholders are (or are perceived as) wealthier than downslope stakeholders, as in Thailand and Vietnam.
- Institutional support for integrated action at the watershed level was weak at the local scale. In Laos, villagers distrust their government and do not believe that it can help solve their problems. In Thailand, there is a strong web of relationships at various levels between people and the authorities, but the administrative limits do not match that of the watersheds and two different authorities are in charge of the upstream and downstream sections of the reservoir. In both countries, however, NGOs could provide missing organizational links.

The positive points that would certainly help the adoption of the PES concept are the followings:

- Awareness of environmental issues is clear in all cases. In Thailand and Vietnam, some farmers have changed their practices with no compensation as the result of a conflict-solving process at village level.
- Land tenure issues did not appear as a constraint to set up a PES scheme. Perceived land rights can matter more in the success of PES than legal land rights.
- Farmers are already organized locally, which is the case in Thailand. Such organization may include market-oriented organizations, conflict-solving procedures within the community, and interactions with government agencies at the local level. Conversely, rigid administrative bodies with inadequate funding or will to address watershed issues as a whole may make it impossible to implement a PES market at the local level.
- At different levels for each case study, many pieces of the puzzle that could lead to an effective PES market are present. Despite this, an effective PES scheme is unlikely to emerge in the near future in any of the case study sites without external financial support.
- The concept of PES is rapidly emerging in SEA. Although a direct application was often not possible to date, the concept always proved efficient in the process of building solutions for watershed management issues.

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Impacts of the Chara Chara Weir and Environmental Implications at the Source of the Blue Nile River, Ethiopia

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Abstract

Since the late 1990s, flow in the Abay River (the Blue Nile) in Ethiopia has been modified by the operation of the Chara Chara weir and diversions to the Tis Abay hydropower stations, located downstream of the river's source, Lake Tana. The upstream regulation and diversions have significantly reduced flow over the Tis Issat Falls, a major tourist attraction. This paper presents the results of a hydrological study conducted to estimate environmental flow requirements in the reach containing the Falls, and the findings of a survey conducted to determine the socioeconomic impacts caused by the alteration of flows. The results indicate that to maintain the basic ecological functioning of the reach containing the Falls, an average annual allocation of 862 Mm^3 (i.e. equivalent to 22% of the natural mean annual flow) is required, and an absolute minimum flow of not less than 3.7 m^3/s. Currently these flow requirements are not being attained. The change in flows over the Falls has also had social consequences. Many of the tourists who visit Bahar Dar, as part of a tour of the north of the country, are unaware that flows over the Falls have decreased. According to local people, many visitors are now unhappy with the visual spectacle and, because they are annoyed, refuse to buy locally made handicrafts. In the past, the selling of these products to tourists contributed significantly to the income of many local people. Although a few people have gained employment at the power stations, many have not. Consequently the loss of income from tourists has had a negative impact on the livelihoods of many local people who have not been compensated through alternative opportunities.

Media grab

Given the dam-building program currently being planned and implemented in Ethiopia, the country would be wise to initiate capacity building in environmental flow assessment.

Introduction

Recognizing the indispensable role of rivers in national economic development, and establishing environmentally adequate and socially acceptable limits of their exploitation, is of utmost importance. One of the major challenges for sustainable water resource management is to assess how much water can be taken from a river before its ability to meet social, ecological, and economic needs declines.

One of the dams constructed in Ethiopia, and the only one located on the main stem of the Abay River, is the Chara Chara weir, which regulates flow at the outlet of Lake Tana for hydropower production downstream at Tis Abay. The principal tributary between the lake and Tis Abay is the Andassa River (Figure 1). The weir effectively provides a regulated storage volume of around 9,100 Mm^3, (storage capacity of Lake Tana), which represents approximately 2.4 times the average annual lake outflow (Howard et al., 1997).

This paper describes the results of a survey conducted among downstream households to determine the major social impacts caused by the Chara Chara weir. It also presents the results of an environmental flow study undertaken to determine requirements in the Abay River, including the Tis Issat Falls. These were compared with the actual flows since the weir became operational in 2001. The study is believed to be one of the first attempts to rigorously quantify a full range of environmental flow requirements (both high and low flows), and to assess the impact of flow regulation, anywhere on the Blue Nile River.

Methods

The current study comprised two elements. First, a social survey, conducted to assess local peoples' perceptions of the weir and the impacts of changes in flow regime on their livelihoods and the environment. Second, an evaluation of environmental flow requirements, derived from hydrological indices, through application of the South African Desktop Reserve Model (DRM) (Hughes and Hannart, 2000).

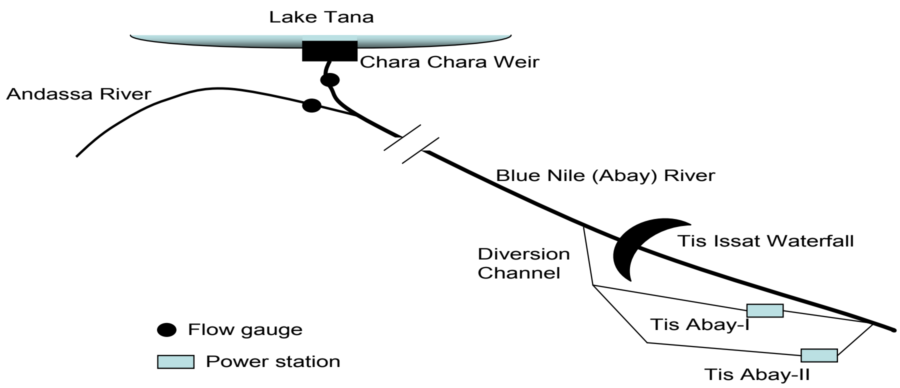

Figure 1. Schematic of the Abay River Flow system *(not to scale)*.

Household survey

A standardized questionnaire was used to elicit information on the social impacts of the Chara Chara weir. This was conducted in households located close to the 35 km stretch of river extending from Lake Tana to Tis Abay village. The survey was conducted in July 2006. About 380 head of households were interviewed to gain insights into how they felt the Chara Chara weir had affected their livelihoods, and their perceptions of whether the weir had brought benefits or adverse impacts. The results were analyzed using the Statistical Package for Social Studies (SPSS) version 11.

Estimating environmental flows

Environmental flows are the water that is left in a river, or released into it (e.g. from a reservoir), in order to maintain valued features of the ecosystem (Tharme and King, 1998). In recent years, there has been a rapid proliferation of methods for estimating environmental flows, ranging from relatively simple, low-confidence, desktop approaches, to resource-intensive, high-confidence approaches. In South Africa, rivers are classified in relation to a desired ecological condition, and flow requirements set accordingly. Six management classes are defined, ranging from A to F. Class A rivers are largely unmodified and natural, and class F rivers are extremely modified and highly degraded (DWAF, 1999). Classes E and F are deemed ecologically unsustainable so class D (i.e. largely modified) is the lowest allowed 'target' for future status. This classification system is used in conjunction with the building block method and flow requirements are computed accordingly; the higher the class, the more water is allocated for ecosystem maintenance and the greater the range of flow variability preserved (DWAF, 1999). In the current study, to reflect the importance of water abstractions for hydropower production, the desired ecological condition of the Blue Nile was set as C/D (i.e. moderately to largely modified).

In the absence of long-term daily flow data and lack of any specialist knowledge on the relationship between hydrology and ecological functioning of the river, the Desktop Reserve Model (DRM) was felt to be the most appropriate method for estimating the environmental flow requirements needed to maintain the aquatic biodiversity. Although the DRM is based solely on hydrological indices, it addresses the ecological information. It incorporates the concepts of the building block method, which is widely recognized as a scientifically legitimate approach to setting environmental flow requirements (King et al., 2000).

Daily flow series and time series of monthly flow data of the Lake Tana, Andassa River, and the Abay River were obtained from the Ethiopian Ministry of Water Resources. Turbine discharge data for both hydropower stations (I and II) were obtained from the Ethiopian Electric Power Corporation (EEPCO). These data were used to estimate the monthly flows diverted to produce electricity as well as the water remaining in the river to flow over the Tis Issat Falls. Analyses of flows were conducted from May 1959 to December 2006.

Results

Household survey

A household survey was carried out to assess the social, economic, and some major environmental impacts that have resulted from the establishment of the weir at the outlet of Lake Tana; and accordingly, the following impacts of the Chara Chara weir were reported by local people. In addition to ecological impacts, the change in flow regime has also had social impacts. For instance the reduced wet season flows have resulted in less flooding. Local communities expressed satisfaction at the reduction in flooding, which in the past used to destroy their crops. Some farmers have also benefited from the higher dry season flows since they enable increased dry season irrigation. This means that they are able to produce a dry season crop, part of which is used for household consumption and part of which is sold (Abeyu, 2007). The increased dry season flows have also benefited women who have to collect household water supplies from the river, thus riparian communities located between the weir and Tis Abay largely perceive the weir to have brought livelihood benefits. The people used to collect wild edible plants (fruits) from the riparian vegetation such as *Syzygium guineanse* and *Mimusops kummel* and sold it and obtained cash every season to improve their living. The productivity of the riparian vegetation, however, has declined significantly since the weir became operational. Consequently, this income source of the villagers has been interrupted (Abeyu, 2007). The amount of water flows over the Falls is significantly reduced and so its spectacular visual effect is lost.

The change in flows over the Falls has also had social consequences. Surprisingly the number of tourists visiting the Falls increased in recent years This is partly the result of greater numbers of tourists generally in Ethiopia, and partly because the Falls are still promoted as a major tourist attraction. Many of the tourists who visit Bahar Dar, as part of a tour of the north of the country, are unaware that flows over the Falls have decreased. According to local people, many visitors are now unhappy with the visual spectacle and, because they are annoyed, refuse to buy locally made handicrafts. In the past the selling of these products to tourists contributed significantly to the income of many local people. Although a few people have gained employment at the power stations, many have not. Consequently the loss of income from tourists has had a negative impact on the livelihoods of many local people which has not been compensated through alternative opportunities. The local community also complains that they have no access to electricity, despite the fact that the power stations are located very close to their village (Abeyu, 2007).

Environmental flow requirements

Unlike low flows that are required predominantly for the maintenance of habitat and aquatic organisms, high-flow events are required to fulfill a range of different functions (maintenance of channel geomorphology, mobilization of sediment, inundation of flood plains, and recharge of isolated pools and aquifers, activation of seasonal side channels, provision of suitable habitat for riparian vegetation, and provision of cues for spawning and migration). Results from the DRM indicate that to maintain the river at class C/D requires an average annual environmental flow allocation of 862 Mm^3 (i.e. equivalent to 22% of the natural mean annual discharge) as shown in Table 1.

Table 1. Summary output from the DRM applied to the reach of the Tis Issat Falls based on 1960-1995 monthly flow series.

Annual flows (Mm^3 or index values)			
MAR	= 4017	Total environmental flow	= 862 (22% MAF)
SD	= 1293	Maintenance low flow	= 626 (16% MAF)
CV	= 0.322	Drought low flow	= 440 (11% MAF)
BFI	= 0.37	Maintenance high flow	= 236 (6% MAF)

	Observed flow (Mm^3)		Environmental flow requirement (Mm^3)			
			Maintenance flows			Drought flows
Month	Mean	CV	Low	High	Total	
Jan	217	0.35	68	0	68	48
Feb	135	0.34	56	0	56	39
Mar	97	0.31	42	0	42	30
Apr	58	0.29	28	0	28	20
May	42	0.35	22	0	22	16
Jun	44	0.46	20	1	21	10
Jul	180	0.43	27	11	39	20
Aug	590	0.38	51	33	83	36
Sep	946	0.39	77	115	192	54
Oct	839	0.36	84	33	117	59
Nov	526	0.33	78	31	109	55
Dec	345	0.33	74	12	86	52

Only from July to October (i.e. wet season months) did the average flow over the period 2001 to 2006 exceed the recommendation of the DRM. This suggests that, in recent years, dry-season flows have been insufficient to maintain even basic ecological functioning of this reach of the Abay River. Furthermore, even though the average over the period exceeds the DRM recommendation, in several years even the wet season flow was a lot less than recommended. For example, in September and October 2005, flows over the Falls were estimated to have been just 44 Mm^3 and 7.6 Mm^3, respectively; less than even the recommended minimum drought flows.

Discussion

The DRM results indicate that the absolute minimum dry-season low flow required to maintain the aquatic ecology (assuming acceptable water quality is maintained), required predominantly for the maintenance of habitat, should not be less than 3.7 m^3/s. Currently, however, this flow requirement is only 2.7 m^3/s. A previous study indicated that the minimum flow likely to satisfy the visual requirements of the waterfalls was 60 m^3/s (Howard et al., 1997). Nevertheless, because of the constant diversion of a large volume of water in the 300 m upstream of the Tis Issat Falls to the hydro power station, this value is achieved in only two months of the year (July and September). In the remaining months, the water reaching the Tis Issat Falls is severely reduced. As a result the ecological and the recreational values of the visual attraction over the Falls are critically affected. Operation of the Chara Chara weir has altered the flow regime of the Abay River. Between the outlet from Lake Tana and Tis Abay, the regulation has significantly increased dry season, and significantly decreased wet season, flows. No ecological surveys have been conducted, but there is little doubt that the reduced inter-seasonal variability will have had an impact on the ecology of the river, benefiting those species that depend on more regular flows whilst adversely impacting those species adapted to seasonal drying. The changes in flow are likely to have affected sediment transport and altered water chemistry and temperature regimes.

Conclusions and recommendations

In recent years the Tis Abay power stations have been vital for electricity production and have contributed significantly to the economic development of Ethiopia. Although detailed studies have not been conducted, there is little doubt that operation of the Chara Chara weir, in conjunction with diversions to the power stations, has resulted in some negative environmental and social impacts. Although preliminary and requiring verification through further research, the results presented here illustrate the viability of using the DRM to provide a scientific base for an initial assessment of water allocation to mitigate some of the negative consequences. Much more detailed hydroecological and social studies are required to validate these findings. The environmental problems associated with the Tis Issat Falls are surely reversible provided that a joint effort is made to overcome the situation. It is recommended that the Ministry of Water Resources take the initiative and work in collaboration with other organizations, such as EEPCO, the Environmental Protection Authority (EPA), the Tourism Commission, and the scientific community to arbitrate the conflict of interests and come up with sustainable solutions

Environmental flows are increasingly recognized as a critical component of sustainable water resources management. In Ethiopia, in common with many developing countries, their estimation and implementation is impeded by lack of data and expertise. The provision of environmental flows is not only a scientific question, but also a social, economic, and political issue. Therefore, establishing an environmental flow regime should involve many different actors, from the highest levels of government officials to local communities.

Acknowledgments

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Benefits and costs of multiple use water systems

Cost and benefits of intermediate water storage structures: case study of diggies in Rajasthan

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Abstract

Increasing scarcity of water and unreliable irrigation supplies are major constraints in canal irrigation commands. 'Diggi,' an intermediate water storage structure, is a farmer's response to this twin problem in Indira Gandhi Nehar Pariyojana Project (IGNP) in Rajasthan, India. The IGNP, a water scarce system, uses warabandi, rotational water deliveries, to distribute water. Equitable water distribution is the main objective of warabandi. But it introduces some uncertainty to meeting crop water requirements. Diggies provide greater control of on-farm water use and facilitate micro-irrigation in canal command areas. This in turn increases crop production. This paper assesses cost and benefits of 'diggies' in IGNP.

Our analysis shows that through better water control, diggies contribute to increased cropping intensity and crop productivity. Net value of crop production per ha of farms with diggies is 68% higher than of those without diggies. A cost-benefit analysis shows that a diggi is a financially viable intervention for farms larger than 4 ha. The findings of impact of diggies are policy relevant. Diggies can be used to organize farmers into better water management groups, spread microirrigation technologies, and improve performance in canal commands. Diggies can be especially useful in systems with rotational supply of water deliveries.

Media Grab

The intermediate Water Storage Structures, such as Diggies in the Indira Gandhi Nehar Pariyojana Project in Rajashthan, can be a pathway to reinvigorate the performance in the canal irrigated areas in India.

Introduction

Unreliable water supply associated with rigid schedules of water delivery is a major constraint for increasing performance at the farm level in canal irrigation commands. Often, schedules of water delivery do not match periods of crop water stress at the field level. They often result in improper input application and low productivity. The canal irrigation through the warabandi system in the IGNP project in Rajasthan in northwestern India is one in which farmers often complain of unreliable water deliveries. Although equitable distribution of available water supply is the main objective of warabandi (Malhotra, 1982) it introduces some unreliability in meeting the crop water requirement. In fact, untimely water delivery for crops is an inherent feature in the warabandi system.

Diggi, an intermediate water storage, is a farmer's intervention to mitigate scarce and unreliable canal water supply in the IGNP. Farmers first store the water deliveries from watercourses in diggies. Next they pump the water out from a diggi to irrigate the crops, through field channels or microirrigation technologies. With increased control of water management, farmers meet crop water requirements the best way they can. A diggi addresses the reliability issue through a self enforcement mechanism and corrects the allocative inefficiency of water use. In the end, the stakeholders achieve equity and efficiency. This report assesses the impacts of the 'diggi' intervention on the irrigation performance at the farm level, and estimates the value of increased net benefits.

Methodology and data for impact assessment

A distributary of the IGNP canal, the Kanwarsain Lift Canal was chosen for this study. The canal branches off from the IGNP main canal, which stretches about 200 km. A stratified random sample of farms is used for assessing the benefits from diggi. First we identify the watercourses with and without diggi across head, middle, and tail sections of the canals. From the watercourses with diggies, 30 watercourses were selected, with 10 each from the head, middle, and tail end of the canal command area. From each selected watercourse, two farmers were selected, with one having a diggi and the other without a diggi. In all, 70 sample farmers were selected for in-depth data collection.

We hypothesized that the adoption of a diggi helps farmers to expand the irrigated area, increase the crop yield, diversify cropping patterns, improve input application, and increase the gross and net value of crop output. These hypotheses were tested using simple statistical techniques–two sample or paired t-tests. We collected the primary data from the selected samples, which include total land holding size, irrigated area and irrigation patterns, seasonal cropping patterns, crop inputs and outputs. The data related to diggi includes the year of construction of a diggi, physical details, fixed and working cost of diggies, tube-well, and sprinklers. We also estimated the cost: benefit ratio (CBR) of adoption of diggies. The benefit is estimated as the net value added with a diggi. The cost includes the capital investments for a 'diggi': sprinklers, electricity connection and electric motors, and the operational and maintenance cost. For estimating the benefit: cost ratio, we assume that the useful life of all structures is 20 years.

Results and discussion

The decreasing number of hours of water delivery to farms and unreliable canal water supply to crops are the main reasons for constructing diggies in IGNP. Data show that over time, water supply has decreased in the IGNP canal system. On average, farmers received 20 hours less canal water supply at the time of construction of a diggi, than when water supply was initially started in their watercourses. Today, the duration of canal water supply is even less than the duration at the time of construction of diggies. In facts, farms with a diggi receive on average only 65-68 hours canal water supply in kharif (July-October) and rabi (October-March) seasons now, as against 148 to 129 hours water supply at the time of construction of a diggi. Farms without a diggi receive only about 32 hours of water supply in each season. The difference in duration of water supply to farms with and without a diggi is due to the differences of farm size, where warabandi system allocates water proportional to the total landholding size.

In general, diggi is constructed in larger farms. The average landholding size of farms with a diggi is about twice the landholding size of farms without a diggi. The landholding size of farms with diggies decreases from head to middle to tail reaches of the canal command. This suggests that diggi is not a viable option in smaller farms, and also perhaps that viability decreases with increasing distance from the main off-take from distributary.

Although equity is a major objective of warabandi, we observed some deviations in water supplies to farms. The average durations of water supply per ha in the head-end farms with and without diggies are 12 and 14 h/ha of land holding size, respectively. The middle and tail end farms with diggies receive about 9.9 h/ha of water supply; and middle and tail end farms without diggies receive 6 and 12 h/ha, respectively. In spite of these inequities, our results show major gains of crop production in farms with diggies and other infrastructure on their farms. An immediate benefit is the land rental value, which has increased by 28%, from US$262 to US$336/ha before and after the diggi construction. This is now on par with the land rental value (US$349/ha) of the farms without diggies.

Irrigated area of farms increased significantly after the introduction of diggies: 47-83%, 53-77%, and 39-59% in the head, middle, and tail reach, respectively (Table 1). Except in the middle reach, these increases are more or less equal to the percentage of irrigated area in farms without diggies (89%, 52%, and 59% in head, middle, and tail reaches). The difference of irrigation intensity in the middle reach is due to duration of water supply, where farms with diggies receive 4 h more water deliveries per hectare than farms without diggies. In spite of improved performance, inequitable water distribution between reaches is a significant constraint for increasing area, especially of farms without diggies in the middle reach and all farms in the tail reach. There is a significant difference of total number of irrigation applications for all crops in farms with and without diggies. Sprinklers helped to irrigate farms with diggies more frequently than those without diggies.

With a reliable irrigation supply, farmers in general can manage their input application better. Fertilizer application per hectare of wheat, mustard, and gram crops in farms with diggies are slightly higher than those in farms without diggies. The differences are not statistically significant. Better water management, however, helped farms with diggies to achieve higher yields. Overall yield differences of gram and mustard are statistically significant (Table 1).

Table 1. Details of performance with and without diggies.

Indicator		Location in the canal							
		Head		Middle		Tail		Total	
		With diggies	Without diggies	With diggies	Without diggies	With diggies	Without diggies	With diggies	Without diggies
Landholding size (ha)		13.7	7.7	12.9	5.6	10.3	4.5	12.3	5.9
Cropped area - % of landholding size		83	89	57	66	79	59	73	70
Hours of canal water supply (hours)		164	108	128	35	102	52	135	64
Number of irrigations (#)	Wheat	5.9	4.8	4.6	4.0	8.3	5.4	6.7	4.3
	Mustard	3.8	2.0	3.5	2.4	4.0	3.4	3.7	2.6
	Gram	3.1	1.8	2.5	1.0	3.0	2.0	2.9	1.7
	Groundnut	1.6	1.7	2.0	1.3	3.1	2.4	2.3	1.8
Fertilizer application (kg/ha)	Wheat	333	288	294	266	277	266	301	279
	Mustard	207	250	255	212	240	196	241	211
	Gram	88	76	130	120	152	40	125	91
	Groundnut	17	17	47	28	10	22	23	55
Yield (t/ha)	Wheat[1]	2.70	2.71	2.85	2.34	2.40	2.35	2.64	2.46
	Mustard[1]	1.30	1.20	1.35	1.02	0.99	0.80	1.20	0.98
	Gram[1]	1.12	0.74	0.90	0.60	0.62	0.80	0.94	0.72
	Groundnut	0.68	0.56	0.97	0.71	0.60	0.55	0.74	0.61

Differences of overall yields are significant at 0.05 level of significance.

Benefit cost ratio of diggi intervention
The annual net value added from diggi construction is the increase in net value of output of agriculture production in farms with diggies from those without diggies. The net value of outputs in agricultural production is the value of production of crop and livestock, minus cost of inputs, interest of the capital expenditure, and variable cost (operation and maintenance cost) of diggi, sprinklers, and electric or diesel motors.

The operationalization of a diggi in canal command area includes: constructing a diggi (US$3486), installing diesel or electric motor for pumping water from a diggi (US$602), and then installing sprinklers for irrigation (US$828). These are the capital investment involved in diggi operations. The variable costs include electricity or diesel for pumping water from diggi (US$454), and the operation and maintenance cost for diggi (US$258), sprinklers (US$141), and electric/diesel pump (US$554). The capital cost and variable cost of a diggi operation in the canal command area is US$4102 and US$815, respectively. The Government of Rajasthan provides a subsidy, of US$718, for construction of a diggi in the canal command area.

Net value of crop production
Net value of crop production is the difference between the gross values of crop production minus the cost of production. The cost of production includes the cost of labor, seeds, fertilizer, insecticide, and plowing, threshing, machinery, and water charges. In the canal command area, the net value of crop production of farms with a diggi is significantly higher than in the area without diggies (Table 2).

Table 2. Net value of crop production and the net value of output per ha of irrigated area per year.

Canal reach	Average net value of crop production per ha in farms with and without diggies (US$/ha)					
	Kharif		Rabi		Annual	
	Without diggi	With diggi	Without diggi	With diggi	Without diggi	With diggi
Head	344	811(136%)	344	468 (71%)	390	810 (108%)
Middle	292	537 (84%)	222	393 (77%)	388	647 (67%)
Tail	282	454 (61%)	289	356 (23%)	492	678 (38%)
All	306	593 (94%)	260	405 (56%)	422	710 (68%)

Values within parenthesis are % increase in average net value of output of the farms with diggies.

The incremental benefits in kharif season are much higher than the incremental benefits in rabi season. This is due to the fact that farmers in IGNP command tend to irrigate more wheat crop in rabi season. Wheat yield is not significantly different between the areas with and without diggies. The increment in net value, however, varies substantially across the canal reaches. The head reach has more than doubled its net crop production value, and has more than three times the incremental benefits of the tail reach. While the head reach has increased the annual benefits by 108% by introducing a diggi, the tail reach has increased only by 38%. This has to do with the available water supply for diggies. As we have shown before, the diggies in tail reach receive on average 60 days less water supply than diggies in head reach. Opportunities for tail end farmers to increase cropping intensity and yield through diggies are therefore much lower.

Benefit: cost ratio in canal irrigated area
The cost of diggi operation in a farm in the canal irrigated area includes cost of constructing a diggi, installing sprinklers and required electric and diesel motors, and investment for electricity connection. For an average size diggi in IGNP this cost is about US$4102. But capital cost is related to irrigable area in the farm lands. Our sample shows that 1% of the irrigated area has incurred 0.31% additional capital cost of diggi and other infrastructure (ln (cost)= 0.31 ln (net irrigated area) + 11.5, R^2=0.46). In estimating the cost and benefits, we assume useful life time of diggi and other infrastructure as 20 years. The cost of diggi and related infrastructure (in 2006 prices) for different irrigable areas is given in Figure 1. Note: UCL and LCL are upper and lower confidence limits.

Figure 1. Cost of diggi and other infrastructure

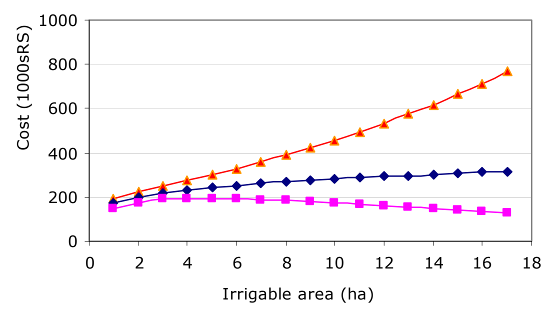
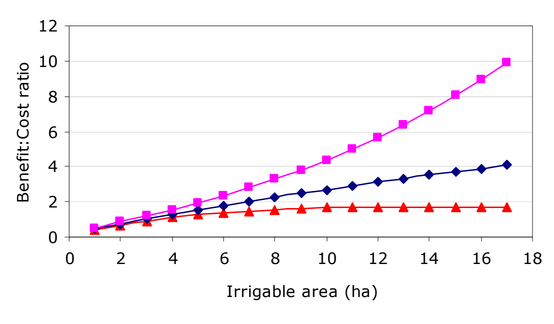


Figure 2. Ratio of benefits and cost



The analysis shows that diggies are an economical viable infrastructure investment for farms with irrigable landholdings more than 4 ha (Figure 2). The benefit: cost ratio is more than one for lands with irrigable area more than or equal to 4 ha. In fact, the average landholding size of the farms with diggies in the command area is 8.7 ha. A farmer with irrigable land more than 7 ha can recover the full investments for new infrastructure in 6 years.

Due to variation in the net crop production benefit across the canal reaches the benefit: cost ratio of new infrastructure is much higher in the head reach area. For example, net value-added crop production benefit of irrigated lands in the head reach due to new infrastructure is about US$420/ha. Total additional benefits for an irrigated landholding size of 4 ha in the tail reach are about US$1674, which is 1.5 times more than the total cost. In fact, a diggi and other infrastructure in the head reach area can even be cost effective for an irrigable landholding size of 2 ha.

Discussion and conclusion

Diggies can be useful for spreading microirrigation technologies in canal irrigation command areas. Microirrigation can be useful in increasing the consumptive water use in a larger area and also increase yield. This in turn can also address waterlogging and salinity concerns due to excess irrigation. Since a small quantity of water is stored in a diggi for a long period, farmers can also think of diversifying agriculture by raising fish in the diggi. The hydrological feasibility and economic cost and benefits of multiple water use in diggies needs to be further researched. With proper water management, however, diggies can eventually become an even better economically viable enterprise for farmers in the IGNP command area.

Diggies combined with microirrigation have substantially increased the irrigated area and yield. They have led to improved input management and increased net economic benefits. With increased benefits, capital costs of diggi and other infrastructure can be recovered within 6 years in a 6 ha farm. At higher landholding sizes, the returns to investments are much higher, and the investment can be recovered quickly from the net increase in crop production itself.

The diggi infrastructure can also become a viable option for small landholdings in canal command areas. Two to three farmers with small landholdings (<4 ha) can get together to construct a diggi. Rotational distribution can be used to deliver water among 2-3 farmers.

It is clear that diggies can help: 1) spread microirrigation technology into the canal command area, 2) increase cropped area, yield, and water productivity, 3) mitigate waterlogging and salinity problems in the canal command area, 4) help to increase crop diversification, and 5) mitigate water scarcities in tail end areas. This justifies further research, especially on the extent of crop diversification and multiple water use and extension in the IGNP canal command areas.

Intermediate storage structures with microirrigation technologies, such as *diggi* and sprinklers in the IGNP, can be a viable solution to resolve water scarcity problems in areas in other parts of the country. Besides the increased benefits, they could mitigate environmental impacts from waterlogging and salinity, as well as reduce groundwater overdrafts. This is especially useful in canal command areas that follow a roster system of water supplies to farms, such as *warabandi* in the northern region of the country.

We need to further explore whether the use of diggies in the head end farms can be a method for allocating more water to the tail end areas. This is important for successful completion of Phase II and III of the IGNP. The extension to Phase II and III of IGNP depends largely on water availability in the main canal for delivery to downstream locations.

Acknowledgments

This paper presents findings from PN48 'Strategic Analysis of India's River Linking Project', a project of the CGIAR Challenge Program on Water and Food.

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Multiple sources and uses of water in northeast Thailand

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Abstract

Many rural households in northeast Thailand grow cassava and other food crops on sandy upland soil and rice on lowland clayey soil. These crops provide only a small income and the simple farming system leads to land degradation. Roof water harvesting and water storage provides homesteads with ample and good domestic water year-round, but it is not enough to extend the growing season and diversify production. In the 1990s, some farmers initiated management changes and developed integrated farming.

Additional sources of water were developed (run-off fed farm ponds in particular) and additional products were grown (mainly vegetables, fish). Such farms have become economically successful. Ten different sources of water are used, >6 per homestead, in eight productive ways. Moreover, this farming system is ecologically sustainable. A regional farmer network that promotes this holistic approach through farm visits and local training centers recognizes that it also increases social interaction and responsibility. The network with already over 100,000 members is spreading rapidly, and with it the application of the 'multiple sources and uses' approach. Sharing domestic and productive water between households in communities is emerging as well.

Now that farmers have a voice through their network, the new way of farming is appreciated by the national government. It gives support through subsidies and a new water law that will give responsibility for rural water management to new local water resources committees.

Key message

Farmer networks emerged in northeast Thailand to counteract recent social and physical degradation. Successful methods include use of water for multiple productive purposes and integrated farming.

The problem

In northeast Thailand, economic development in the 1960s and 1970s was mainly by expansion of direct exploitation and extraction of natural resources, in particular of soil fertility. People relied on ponds for drinking water and on natural water bodies for other domestic and agricultural purposes. In the 1980s this was intensified through modernization and industrial processing. Farming included large-scale harvesting of land and water resources and lacked recycling. Even in the 1990s when value-adding technologies were introduced, farming still caused the extraction of natural resources because agricultural exports were further promoted. Despite evolution in farming practices, mining natural resources remained a basic feature of agriculture. Inevitably, land and water resource degradation became widespread (Noble et al., 2000; Bridges et al., 2001; and Ruaysoongnern, 2001).

The decline in quality of farmland and water resources caused a decline in productivity and farm income and led to an increase in poverty. It forced farmers to be more aware of water resource management and to try out multiple uses of water. It also forced farmers to find off-farm employment, predominantly in the larger cities. This emigration has created further problems associated with increased consumerism, social issues, increased reliance on off-farm incomes, and a dependence on loans. The government supported the local communities with small-scale irrigation systems and some types of farm ponds. These were hardly used, because of high cost and inappropriate technologies. In 2000, the Thai government approved a program to provide revolving funds to villages for any development initiatives, and in 2004 supported a program to create 450,000 farm ponds throughout the country.

The evolution in Thailand in top-down and bottom-up thinking for rural development was reinforced by His Majesty King Bhumibol. He presented his New Theory in 1987 as an holistic approach to stimulate new thinking about water resource rehabilitation, integrated farming, and community development (Ministry of Education, 1999). The influence of the King as mentor of the Thai people is hard to overestimate. Particularly since the economic crises of the 1990s when his concept of the Sufficiency Economy was incorporated in the National Economic and Social Development Plan of 2002. The concept mixes economic ideas of sustainable development, equitable growth, and protectionism with moral sentiments of responsibility, moderation, and selfrestraint. His New Theory aims at self-reliance in terms of food security for households and communities, and has been promoted in many ways and researched in several agroecologies (KaoHinSon, 1999).

Taken all together, the economic crisis has created countrywide and positive awareness about the urgent need for rehabilitation of water resources for agricultural sustainability and autonomy.

The social response: a farmer network

In the 1980s and 1990s in response to the migration to cities and its impact on cohesion of families and on sizeable debt loads, and the general dissatisfaction with city life, some farmers returned to their rural homes to take back control over their lives. With some external support from NGOs these farmers analyzed their problems, assessed lessons learnt, identified potential alternatives, and sought solutions to these problems. Key problems they identified were: (1) degradation of community values and (2) unsustainable systems of agricultural production and use of water. In particular, opportunities for multiple uses of water (domestic and productive) from multiple sources (rain, roof runoff, farm run-on, groundwater) were considered a key to development that would be under their own control (many farmers own land and the water on it). Using household labor and limited financial resources, farmers started to develop integrated farming systems around farm ponds. Income generated from these diverse activities has been used in the development of further water storage structures with support from government or research. Other farmers, feeling the same needs and constraints, joined and the movement 'snowballed,' particularly when some of the nation's leading figures provided moral support.

The farmer groups and networks in northeast Thailand dramatically expanded from less than 100 leading farmers 15 years ago to currently a few thousand leaders and their active groups. The leaders interact at national forums and with leading politicians. The number of members in 2005 was approximately 100,000 households, and the target is 1,000,000 households by 2013. The networks have transformed the water use patterns and national policies to support those activities. Their own activities include local research to identify indigenous water resource rehabilitation and resource management technologies, research proposal screening for end-user participation, participatory technology development, biodiversity promotion, C-sequestration, community forests management, and agroforestry. Through participatory technology development and transfer between farmer networks, integrated farming systems or integrated pest management were developed by farmer groups with indigenous knowledge, as well as connections of producers to markets. To promote adoption of integrated farming, farmer networks and government officials together are now creating Learning Centers for Economic Self Sufficiency.

Even though there are very important communal actions, most of the actual management of natural resources is still at the household level. To create conducive management conditions at the regional level, network leaders and agencies responsible for water recently drafted a new Thai Water Law in which multiple and productive uses of water are identified as proper water management and development techniques.

Physical response

The physical responses consisted of rehabilitation of farms through integrated use of resources and biodiversity, recycling and multiple uses of water to provide food, income, and a stable physical and social environment. In our research, we focused on sources and productive uses of water. Tipraqsa et al. (2007) found that development of the integrated farming system with multiple uses of water has assisted in improving the fertility status of farms on the light textured soils that dominate the region.

The Thai homesteads we surveyed showed an interesting picture of multiple sources and multiple uses. Clearly water from different sources is used for different purposes, driven by the specific requirements of quality and volume. Farms draw from at least 10 different sources and many farms use at least seven of them simultaneously. These are: (1) rainwater harvested from roofs and stored in large jars, and (2) expensive bottled water from shops. Commercial tap ('piped') water (3) from outside the farm is available at 70% of the farms. A traditional source of water, the shallow well (4), from which water is drawn in buckets, was the main source of farm water and is still in use on 30% of the farms, while (5) deep wells (bore holes of 10-30 m) are becoming common where electricity is available for pumps. About 85% of the farms surveyed have (6) ponds that hold water used for productive purposes (fish is grown in adjacent but separate tanks; after harvest the remaining water is used on cropland); this is a much higher fraction than outside the selected groups. Furthermore, about 25% of the farms (7) use water from nearby streams or canals; whether this is feasible on an individual farm depends on the local situation and closeness of such infrastructure. Also 25% of the farms make explicit use of (9) run-on water from nearby fields or roads, water in particular for paddy rice; again feasibility depends on the local topography. And (10) rain, of course, provides the 'green water' for all cropped areas.

As for domestic water, farmers drink overwhelmingly rooftop water stored in jars where it retains a high quality. Its quantity, however, is not sufficient for washing, laundry and cleaning. In several cases, piped water has become available. Even though farms have to pay for this water, it comes in easier and in larger volumes then water from wells. Productive uses of water include watering vegetables and spices, watering livestock (cows, poultry), keeping the fish tank adequately filled, irrigation of fruit trees and the rice crop, and special products (e.g. commercial raising of ducks and frogs). Sources of water are wells, ponds, and piped water for high-value crops. Irrigation of paddy rice occurs if there is plenty of water in the pond or from nearby surface water.

A significant part of these food products is consumed on the farm or given away to friends and neighbors. This brings no income but avoids expenses for condiments and provides highly nutritious food. When food is sold, it usually brings only a small amount of cash but about 10% of the farms are specialized and obtain significant income from fish or from rice. Income generated has given the farmers the opportunity to pay off long-standing debts and to take fewer new loans.

Methods

In this social movement and responses to degradation and new conditions in northeast Thailand, the CPWF-CGIAR project 'MUS' played only a small role in water management by providing farmer leaders with ideas and experiences from other countries, giving scientific feedback on their suggestions for further development, and by providing a scientific liaison to government agencies. MUS documentation of the process (Van Koppen et al., 2008; MUS, 2008; Penning de Vries and Bossio, 2006; and Ruaysoongnern and Penning de Vries, 2008) allows other countries to benefit from Thailand's unique experience and rapid progress.

Our overall method in the MUS Project was 'participatory action research.' That implies: documentation of what happens and why in multiple use water systems, interaction with stakeholders in (actual or potential) multiple use services, analysis of results, formulation of generic conclusions, and suggestions for upscaling. Combining research and action in one project is still unusual. We think, however, that a project that remains at a distance from on-the-ground multiple use systems will not find the generic conclusions needed for major upscaling (Van Koppen et al., 2008).

To learn details about existing multiple water use systems and services, we investigated four groups of 20-40 farm households in four provinces: Buriram, Maharasakam, Nakhon Ratchasima, and Yasothon. Each group is a member of the large farmer's network. Individual farm households adopted integrated farming already, and as such they are not representative of the average Thai farmer. A survey of five farms near each group of those who had not yet adopted integrated farming served as a control. For each farm, we inventoried water consumption for all activities, all sources of water employed, levels of production, and income generated. We asked about off-farm income and management of water, and of activities on farms (men and women take more or less similar roles). Analysis of the results shows (1) that efficient use of water productive purposes in an area that is drought-prone allows households to escape poverty and manage natural resources sustainably, and (2) that showed the current public-private partnership of government agencies and farmer networks is effective in achieving improved water management and rural development.

Conclusion and recommendation

Due to the positive results of productive uses of water on integrated farms in northeast Thailand, multiple uses of water have now become the model for farm development at local, regional, and national level through national development plans.

Financial analysis of homesteads practicing multiple uses of water have not yet been completed. Research about promising schemes to finance new systems could accelerate further uptake. The way in which global changes (climate, prices of food and energy, water shortage) will influence the shape of future integrated farms needs attention. Efficacy of the new water law needs to be determined in view of using principles of that law for water management in other countries, in particular with respect to proposed regional and local water resource committees. Understanding the dynamics of the farmer network during a phase of major expansion will be helpful in bringing multiple use systems and services to farm homesteads in other countries.

Acknowledgments

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Multiple uses of water: a view from reality in rural communities and national politics

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Abstract

The water needs of people living in rural areas are integrated and include personal hygiene, drinking water, food preparation, and small-scale productive activities. Productive activities are important to provide food security, income, and reduce the vulnerability of poor people. The interventions done in water supply projects that follow national policies and regulations are fragmented and neglect innovative approaches. Innovative approaches, which consider basic water-related productive activities, can make a significant difference in the livelihood in poor areas. This paper presents evidence on how families in rural areas of the Valle del Cauca Department (Colombia) manage water, and how this has been ignored by national policies and regulation. Proposals to reduce the gap between rural reality and policies for this sector are also presented. These proposals can help policymakers to take the rural context into account, in order to improve the regulations and contribute to poverty alleviation, equity, and sustainable development.

Media grab

Multiple uses of water: strategies to reduce the gap between poor people and national policies.

Introduction

This paper summarizes some findings from the CPWF Multiple Uses of Water Systems (MUS) Project in Colombia. The aim is to present evidence on how water is used by rural communities in Colombia, how legal and institutional frameworks for providing water in this country do not recognize this reality, and some reflections and proposals formulated to reduce the gap between policies and reality.

Methods

This research was implemented in three phases: awareness about the relevance of productive uses of water for the rural poor family in Colombia, analysis of the legal and institutional framework, and proposals formulation to change these frameworks, which are under the responsibility of the vice Ministry of Drinking Water and Sanitation, a dependent of the Ministry of Environment, Housing and Territorial Development in Colombia. The study cases were developed by Cinara professionals and undergraduate and postgraduate students from Universidad del Valle in five rural communities of Valle del Cauca department and in some farms in the Department of Quindio (Figure 1). Research methods such as household surveys, interviews of focal groups, and water supply technical assessments were developed in the studied localities and systems. In addition, the interventions of the Rural Water Supply Program (PAAR) were studied in 91 rural communities in 29 municipalities of Valle del Cauca, by reviewing the social and technical reports produced from the intervention in each community, and also through interviews and workshops with PAAR staff.

(The main objective of the PAAR Program is to provide water to rural communities of the Valle del Cauca department, by building or improving water supply systems. This initiative brings together several public and private institutions of the department.) This information was analyzed regarding the topics included in the framework developed by the international MUS project, which considers aspects such as water for domestic and productive uses, livelihoods, and sustainability. A comparison between the evidence gathered and the approach of the legal framework for the water sector in Colombia was established. Through the methodology of Learning Alliances, collective proposals were developed to improve the planning, execution, and management of water supply projects to contribute to a more integrated approach of project development. Six workshops with specific topics were held. Around 100 people from the water sector in the region participated actively in these calls. Other sharing information strategies such as Internet groups and conferences were applied. It is expected through this methodology to facilitate the institutionalization of knowledge and its application in several social contexts.

Results and discussion

In rural areas in Valle del Cauca department, people are engaged in small-scale productive activities including keeping animals, having small plots of crops, or small businesses such as cutting hair or food preparation. In the MUS Project in Valle del Cauca, productive activities at the household level were found in 100% of the settlements studied, where the PAAR program worked, and also in all the case studies of the MUS project (Figure 2). This information is supported by the results from the national census (DANE, 2005), which indicates that 73.4% of the rural households in Colombia are engaged in some agricultural activity.

The MUS research found that in 77% of the households served by PAAR systems, coffee is grown along with banana or fruit trees. Vegetables, beans, corn, and yucca were also identified. Animals for household consumption and in some cases for sale were found in 67% of the households. Aromatic plants and vegetables are also an important source of income. The households without animals or crops were engaged in activities linked to agriculture, including harvest transportation, food preparation for people who work in the fields, etc. In rural communities located close to urban centers, small businesses were found.

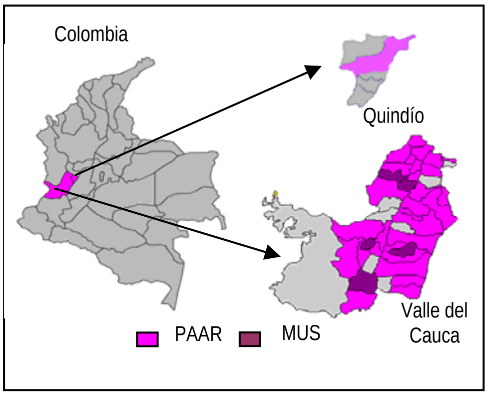


Figure 1 Case study locations (Cinara, 2006)

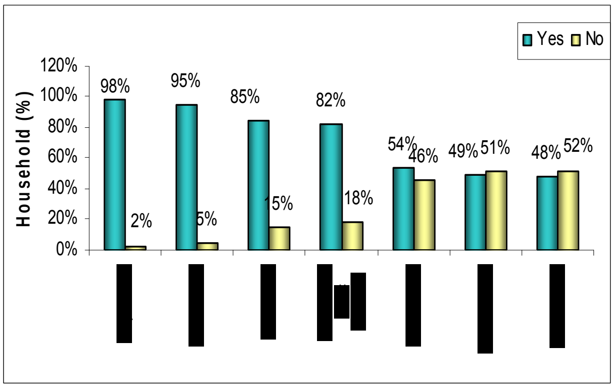


Figure 2 Households with productive activities (Cinara, 2006)

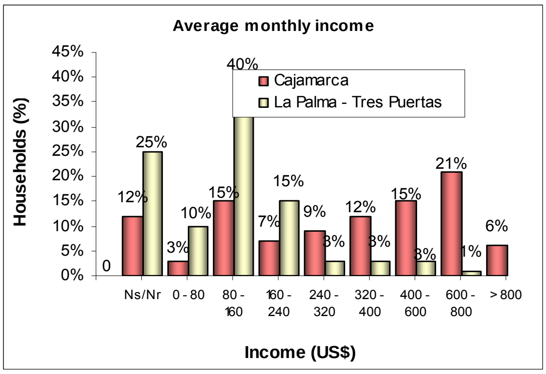
The size of the plots varies, and as a consequence so is the space available for productive uses. Results show, however, that these activities are developed at a small scale. Plot size decreases closer to urban centers. In most of the studied cases the size of plots was under 1 ha. Most of the families have fewer than 5 cows, 5 pigs, 2 horses, and between 6 and 30 chickens. Men are in charge of the most profitable crops (coffee, pineapple, corn, and beans), while women and men share the responsibility for vegetables. Men care for horses and cows, and there is a shared responsibility for pigs. Women are in charge of chickens (78%).

The research showed that family income is linked to water use for livelihoods. In 61% of the households in Cajamarca, 80% of the income depends on the access to water. In La Palma-Tres Puertas income depends less on water (38%). Many people work in field crops that are not their property. In this specific settlement, water availability is lower than in Cajamarca. This situation is reflected in the income level of the families: In La Palma-Tres Puertas income is around US$150 per family per month, while in Cajamarca, which is richer in water, 70% of families have profits over US$150 per month and 27% higher than US$600 per family per month (Figure 3). The income produced makes it possible to pay the tariff for the water service. In La Palma-Tres Puertas there is a flat tariff of US$1.20/month and a default rate considered 'high' for the president of the Water Board. In Cajamarca there are block tariffs from 1.9 to 22.9, depending on the productive activities at the households, and the default rate is 7%. Both systems lack metering devices at households.

Our results show that in the water supply systems (WSS) built for PAAR, surface water is the main alternative for the projects, and 86% of the WSS are supplied from small streams and rivers. In 23% of the projects, the WSS take water from 2 to 4 small streams, and the use of complementary sources was never considered. Some projects were not developed in communities where the availability of water, from surface or groundwater sources, was less than 100 lpcd.

We found that most of the households use the water from the WSS for all their activities, without considering the required quality for the use, contrary to the beliefs of the water institutions. The resource from the WSS is used in most cases (90%) for cooking, drinking (human and animals), and cleaning, which includes water for flushing toilets. The reported use for irrigation is around 70%. Several crops are rainfed, but people could avoid accepting this use, because it is frequently penalized by the Water Committees (Figure 4). During the dry season water supply systems are extremely important to supply irrigation demand. The willingness to use alternative sources of water increases with the scarcity. In Montebello, 46% of the families have used rainwater, and 24% grey water for cleaning (floors, baths), excreta evacuation, and irrigation (López, 2005). In this settlement the water was supplied for 2 hours, every 2 days.

The total amount of water required to satisfy domestic and small-scale productive uses was on an average 213 l/person/day. In the case of Golondrinas, La Castilla, and Los Sainos the human and domestic consumption had the greatest demand, because it includes water for sanitation and washing of clothes. Irrigation demands are around 100 l/person/day, due to the small areas cropped, in several cases under rainfed irrigation. The reported consumption for animals was between 20 and 48 l/person/day.



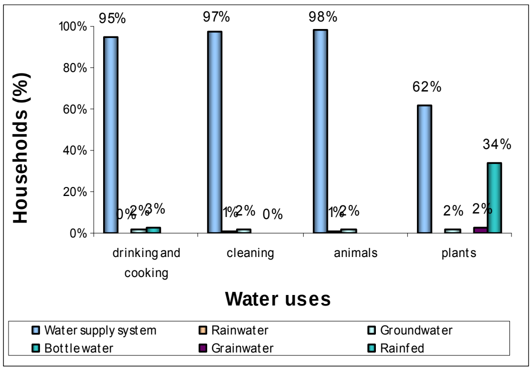


Figure 3. Monthly income per family (Cinara, 2006). Figure 4. Uses and water sources (Cinara, 2006).

Limitations in the legal framework to satisfy water needs of the rural families
In Colombia the government is responsible to guarantee that public services are provided efficiently to people. Its mandate includes infrastructure investment and formulation of regulations to provide public services. At the national level the most important institutions related to water resources are the Ministry of Environment, Housing and Territorial Development, the Ministry of Social Protection, and the Agricultural and Rural Development Ministry. The Environment Ministry has a Vice Ministry on Water and Sanitation which is responsible for the formulation of policy and directives, and to oversee the investments in the sector. This Vice Ministry is in charge of drinking water for 'human consumption,' and as consequence, the policies and investments in this sector have this orientation. In contrast, the Ministry of Agriculture lacks clear policies and regulations oriented to water supply, and its investments are sporadic programs or projects to improve competitiveness in rural areas.

The 1594 (1984) Act establishes as water uses: human and domestic consumption, biodiversity preservation, agriculture, recreation, industrial, and transportation uses. Different institutions have different responsibilities over the water depending on the uses established. The 1096 (2000) Resolution, Basic Regulation for the Drinking Water and Sanitation Sector (RAS), indicates that in drinking water projects for 'human consumption,' besides domestic use, the commercial, industrial, institutional, and public use should also be considered. The 302 (2000) Act, related to water and sanitation services provision, stipulates that one of the reasons to suspend the service to the customer is the use of water for a purpose that is not mentioned in the contract agreement. Generally the permitted use is the 'human and domestic consumption.'

The RAS states for designing a net allocation with a minimum amount of water to satisfy 'the basic water needs for one person.' Hence, supply depends basically on the number of inhabitants in the settlement. It is lower for communities less than 2500 people (100-150 l/person/day) and there is no upper limit for communities with more than 12,500 people. These guidelines, although formulated for urban areas, have been traditionally used for rural communities. In 2007, a rural RAS was formulated, but it adopts the same criteria for the allocation, and retains the purpose of systems for only human and domestic use.

The RAS 2000 defines the water sources for human consumption, as surface and groundwater. It emphasizes that just in exceptional cases rainwater could be considered. RAS 2007 makes a small advance to suggest the possibility of implementing rainwater harvesting for areas with water scarcity. RAS 2000 also presents recommendations on water treatment levels, depending on water quality and the need for achieving the requirements of the 1594 (1984) Act and 2115 (2007) Resolution, which establish quality criteria for drinking water. These directives support the implementation of collective systems.

Conclusions and recommendations

In Colombia, policies and regulations for designing rural water supply systems do consider different categories of uses and users, but do not recognize domestic users with small-scale productive activities. In this regard, as well in the infrastructure planning, water needs have been understood as domestic needs, and do not include the amount of water required for small crops and animals, which are important to guarantee people an acceptable livelihood.

Although rules suggest surveys and the possibility to diversify water allocations, the general practice for designers is to use the guidelines established in the directives. It also promotes inequality, by recommending less water provision to people living in small settlements and more water for those living in more populated settlements.

The approach of the regulation to supply drinking water to have a positive impact on health has led to the promotion of surface water and groundwater as the only source for all water uses. This situation has been exacerbated with the general perception of water abundance in the country. The use of alternative sources has been promoted by policies and laws, but without significant advances made in the regulations to actually put these principles into practice.

Legislation to design, manage, and operate rural water supply systems should recognize the multiple water needs of poor rural people. According to our results, typical needs include: water for domestic uses, water to irrigate a cultivated area of between 1000 and 10,000 m^2 during the dry season, and water to keep 10 chickens, 2 pigs, or 2 cows. The amount required for all these uses would be around 250 lpcd–but it could be less, if water is used more efficiently.

It is important to stipulate incentives at the policy level regarding the use of multiple sources for multiple uses, especially to facilitate rainwater harvesting. The use of alternative sources is a way to promote the efficient use of water and also to maintain the 'better' resource for activities that demand better water quality.

The water quality standards for water supply systems in rural areas need to be more flexible and be based on the different uses of water. In some cases it could be more efficient to promote water treatment at the household level to maximize the use of the community resources (natural, human, economic).

Acknowledgments

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Participants in groundwater markets: who are sellers and who are winners?

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Abstract
Are there winners and losers in the groundwater market in rural China? Data used in this research come from 150 households within two provinces in northern China. Based on our field survey, we found that the farmers who have more wealth, advantages in agricultural activity, and social position are more likely to be the sellers. Transaction costs also have impacts on participants within the groundwater market. The groundwater markets have brought sellers moderate profits, and also provide irrigation service to the buyers at a reasonable price, especially for the poor.

Media grab
Groundwater market in China: A win-win situation.

Introduction
Groundwater markets have spread rapidly in northern China in response to the increased use of private tubewells and water shortage (Zhang et al., 2008). Previous studies on groundwater markets have been mainly conducted in the South Asian countries of India, Bangladesh, and Pakistan. Findings on the sellers of groundwater in available literature are not consistent, however.

China offers interesting case studies on groundwater markets for many reasons. Despite the significant changes in groundwater management, little is known about the nature and determinants of this groundwater market development in a country undergoing the transition from collective ownership to private ownership. Water scarcity is increasing in China, and groundwater markets have experienced rapid development. China's rural economy is also in transition, with nonfarm activity emerging as the main source income for most rural households. Moreover, China has the most equitable land distribution policy in the world under which most farmers are small-scale. This situation may present different implications for the development of the groundwater market. Few data exist regarding the profitability of investment in tubewells, and the potential benefit brought to the buyers, especially the poor farmers, through the groundwater market in rural China. Based on the primary field survey data collected from two provinces in northern China, we identified the determinants of selling water, estimated the profitability of the groundwater market, and evaluated the benefits brought to buyers, especially the poor.

Method
The data used in this paper were collected from Hebei and Henan provinces in northern China. Two counties from each province were selected for this study: Xian and Ci in Hebei and Yanjin and Kaifeng in Henan. We selected these counties for two major reasons: (1) Xian is in the Hai River Basin, which is one of the most drought-stricken areas in northern China; and (2) the other three counties are located within the Yellow River Basin, which is also a typical water-scarce area. Both basins cover a large part of northern China. On the basis of the water scarcity in these counties, we classified them into four categories: (1) the most serious drought-stricken area (Xian), (2) a moderate drought area (Ci), (3) a relatively less drought-stricken area with a groundwater market (Yanjin), and (4) an area without a groundwater market (Kaifeng), which represents the typical characteristics of water resources and the social economy in northern China.

Three types of surveys were conducted: (1) village level, (2) tubewell-owner level, and (3) household level. We collected data from 200 households, from 60 tubewell owners, and from 20 villages. Because there is no groundwater market in Kaifeng, we only use the data collected from the other three counties, which includes 150 households, 45 tubewells, and 15 villages in the empirical analysis. At the village level, the interviewers administered the village questionnaires to the head of village committee and the village accountant. The questions tried to elicit different aspects of the local socioeconomic situation, irrigation conditions, and the status of water resources in their villages. At the household level, the farmers were asked about their socioeconomic situation, personal characteristics, and details of their agricultural production. At the tubewell owner level, we collected information on tubewell investment, the pricing process, and the competition for the groundwater market between tubewell owners.

In addition, special data and information were also collected for our research. For example, the average farmer income at the village level was assessed by the head of the village committee along with the accountant of the village who have a very clear perception on most aspects of the village. The data on the production activity, income detail, land endowments, and market transaction costs were obtained from the head of household. These data assisted in identifying the key determinants of groundwater market participation. The data on tubewell cost, which includes fixed cost and variable cost, power cost, groundwater pricing, service area and groundwater market competition, were collected from tubewell owners. These data were combined with the irrigation costs for each plot, as derived from the household level survey. This information provided us an integrated view on the acceptability of water pricing and identified who are the winners in the groundwater market in rural China.

Three steps were adopted in our research: (1) statistics were given to better understand the determinants of being a water seller, (2) econometric analysis was conducted to identify the determinants of being a water seller, and (3) the benefits from groundwater were evaluated by interpretation of the statistics.

Results

We found no significant difference in land endowments between water buyers and sellers. Our survey also revealed that there is a strong linkage between nonfarm activity and groundwater market participation, which has not been addressed in the literature. Our data show that nonfarm employment is strongly and negatively correlated with the participation in groundwater markets. In 2007, water sellers spent about 1.38 months on nonfarm activities, about half as much as water buyers. The sellers obtain an average of 35% of their income from nonfarm activities, far less than buyers. The latter obtain nearly half of their income from nonfarm activities (Table 1). Our survey also indicated that the wealthier

Table 1. Nonfarm activity and nonfarm income of water buyers and sellers in 2007.

	Water buyer	Water seller
Number of months spent on nonfarm activity	2.42	1.38
Percentage of nonfarm income	48	35

Note: all the data used in the tables come from the author's survey of 150 randomly selected households and 45 water sellers from three counties in northern China, 2007.

households are more likely to be the sellers. On average, 54% of sellers belong to the highest two income quintiles, whereas only 36% of the buyers belong to these richer groups (Table 2). Several other

Table 2. Distribution of samples of water buyers and sellers by income level.

Quintile	Water buyer	Water seller
I (top 20%)	0.10	0.18
II	0.26	0.36
III	0.35	0.27
IV	0.21	0.16
V (bottom 20%)	0.08	0.04

important factors may contribute to the participation in groundwater-markets, for example transaction costs and social network (Table 3). Lower transaction costs may contribute to a decision of farmers to invest in groundwater markets. A wide social network (Table 3) will help a farmer become a water seller (Table 5).

Table 3. Transaction costs and social network of groundwater buyers and sellers.

	Percent of households that have experienced dispute (%)	Number of guests that have attended the most recent ceremony
Buyer	22	114
Seller	33	127

Note: we use the percent of farmers who ever experienced dispute with others on the sequence of irrigation as the index of expectation on transactions costs. We use the number of households who accepted the invitation of the sample households' latest ceremony.

Table 5. Profit of groundwater market in 2007.

Share of income from selling water	Profit rate of investment (%)	Interest rate of local bank (%)
0.16	0.10	0.14

We adopted two econometric methods to test these assumptions. Models 1 and 2 are estimated by Ordinary Least Squares (OLS) with and without village dummies. Models 3 and 4 are estimated by Probit analysis with and without village dummies. The econometric analysis results are shown in Table 4. The

Table 4. Estimated parameters of determinants of being a water seller.

	Water seller			
	OLS (1)	OLS (2)	Probit (3)	Probit (4)
Months of nonfarm activity	-0.012	-0.009	-0.040	-0.029
	(1.04)	(0.91)	(0.93)	(0.77)
Share of nonfarm income	-0.290	-0.327	-1.055	-1.019
	(2.06)**	(2.47)**	(2.24)**	(2.49)**
Income category	-0.126	-0.080	-0.478	-0.247
	(3.28)***	(2.22)**	(3.6)***	(2.17)**
Sown area	0.000	0.001	0.000	0.001
	(0.04)	(0.07)	(0)	(0.04)
Plot number	0.003	-0.015	0.012	-0.038
	(0.11)	(0.57)	(0.14)	(0.5)
Number of guests attending ceremony	0.000	0.000	0.002	0.001
	(0.92)	(0.67)	(1.03)	(0.58)
Previous experience of dispute	0.146	0.155	0.523	0.483
	(1.55)	(1.75)*	(1.78)*	(1.88)*
Other Characteristics of the household (omitted)				
Village dummy	Yes	No	Yes	No

Coefficients are marginal effect, absolute value of z or t statistics in parentheses.
*significant at 10%, **significant at 5%, ***significant at 1%.

variables of advantage in nonfarm activity have the expected signs and large marginal effects consistent with descriptive analysis. Income level also has a large and significant impact on selling water. Wealthier farmers are more likely to be water sellers. Land endowments appear to have no significant effects on the probability of selling water since the coefficients of land area and plot number are small and insignificant in all four models. The effect of social capital is small and insignificant, though it has the expected sign. The transaction costs also contribute to the probability of selling water. Farmers who have experienced water allocation disputes in relation to irrigation have a higher probability of selling water than those who were not involved in disputes. The coefficient is significant at 10% level in models 2 to 4.

Following the method of Shah (1993), we estimate the rate of price to total variable costs as the monopolistic degree. Consistent with the conclusion of Zhang et al. (2008), the average monopolistic level in the survey area is 1.6, even lower than what they found. As shown in Table 5, the groundwater market has offered sellers considerable net income and a moderate profit rate. The irrigation costs of wheat, the most popular crop and main food in northern China, is summarized in Table 6 from different

Table 6. Cost of irrigation per hectare in wheat in 2007.

Irrigation cost of per hectare wheat (Yuan)			
Use own tubewell	Use collective tubewell	Buy water (all households)	Buy water (IV and V households)
189	350	427	252

water sources and for different income level of farmers. Purchasing water is the most expensive, at 20% higher than using collective tubewells, and 125% higher than using privately owned tubewells. If the cost of purchasing water is compared with the benefits from groundwater markets in the drought season, however, the development of groundwater markets appears to have increased the welfare of buyers. Our data also show that poor farmers incur significantly lower expenses for purchasing water, 252 Yuan/ha, which is even lower than using collective tubewells. In our survey, there is no significant difference of wheat yield between the bottom 40% of households and other households.

Conclusions and recommendations
This study sought to understand implications of the political economy of groundwater markets in China. With increasing scarcity of water, a boom of private tubewells and rising irrigation demand has brought a huge opportunity for farmers to participate in groundwater markets. The wealthier households that have significant advantages in agricultural activity tend to be at the supply side of the groundwater market. Transaction costs may affect participation in groundwater markets. Our results indicate that the groundwater market may bring moderate profit to the sellers. Importantly, groundwater markets in China appear to be beneficial to the groundwater buyers, especially to poor rural households.

The policy implications are that groundwater markets offer a win-win outcome when farmers face the problems of water scarcity and insufficient public services. If we want to help farmers deal with drought and increase their agricultural productivity, public investment in collective tubewells, as was done in some areas of China in previous decades, may not be the best choice. According to our analysis, poor farmers are less likely to be the water seller because of high tubewell costs. This makes them unable to share in more of the income brought by water deals in the market. Providing public funds to foster equitable water allocation to the poor in severely water-scarce areas, market may provide better benefit-sharing options, since poor families are more vulnerable to risk. Lowering entry barriers to groundwater markets may also reduce water prices, as groundwater markets would become more competitive, thus benefiting poorer buyers.

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Household preferences for multiple use water services in rural areas of South Africa: An analysis based on choice modeling

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Abstract

The provision of free basic water and a more equal distribution of water for productive uses are seen as important instruments to redress inequities from the past and eradicate poverty in South Africa (SA). Although the government committed itself to providing free basic water for all, this result is still far from being reached, particularly in rural areas. Financing of multiple use water services was identified as an important ingredient to ensure improved access to water for rural poor in SA, and at the same time allow productive uses and broaden livelihood options. Recent evidence indicated the potential contribution that productive use of domestic water might make to food security and poverty reduction in rural areas of SA. This study attempts to fill this gap by assessing the household demand for multiple-use water services in Sekororo-Letsoalo area in Limpopo Province. Choice modeling is the approach used to identify the attributes determining demand for water services, and quantify their respective importance. Results show that households in rural areas are willing to pay for water services improvements, but engagement in multiple water uses is conditional upon meeting the basic water needs. The raising of revenue from the water sector itself is therefore central to cost recovery from consumers and up-scaling of water services.

Media grab

Engagement in multiple uses of water is limited by water scarcity. When households fulfill the basic uses they engage in multiple uses of water for poverty alleviation and livelihood improvement.

Introduction

The domestic water sector in SA is characterized by significant inequities in terms of access to water inherited from the Apartheid era policies of 'separate development.' After the end of Apartheid, however, several institutional and policy reforms were undertaken to address the inequalities. The Water Services Act of 1997 and the National Water Act of 1998 provide the legislative framework for water services and water resource management, respectively (Republic of SA, 1998). Since 1994, the national government was committed to its Reconstruction and Development goals, one of which was to improve basic water services over time. The Water Services Act decentralized the provision of water and sanitation services for domestic purposes to local governments with financial and technical support of provincial and national governments. Also, under this Act, provision of free basic water and sanitation services for all end users is compulsory.

The provision of free basic water and a more equal distribution of water for productive uses (i.e. irrigation, mining, and industry) are seen as important instruments to redress inequities from the past and eradicate poverty in SA (Republic of SA, 1997). At present, the government has committed itself to ensuring that all people will have free access to at least 25 l/capita per day of clean water (DWAF, 2005). The provision of free access to basic water services for all the users is still a major challenge for the water sector, however, (DWAF, 2003). At the same time, the SA public sector is investing in infrastructure and management skills aimed at providing higher levels of water services, particularly in less advantaged areas. This effort proved to be more difficult for rural municipalities located in former homelands, due to inadequacy of human capital to plan, manage, and control the water service infrastructure.

Free provision of water above the basic level is not without risk, as, if not carefully controlled and managed, it would place unsustainable demands on the financial resources of local and central governments. An option to make the increased and improved water services in rural areas financially viable could come from the partial coverage of the investment and operating costs determined by these services.

Financing of multiple use water services has been identified as an important ingredient for ensuring improved access to water for rural poor, and at the same time accommodate for productive uses and broaden livelihood options for the poor in SA (Lefebvre et al., 2005; Hope et al., 2003). Recent evidence has indicated the potential contribution that productive use of domestic water might make to food security and poverty reduction in rural areas of SA (Hope et al., 2003; Hope and Garrod, 2004).

Efficient, equitable, and sustainable investment in improved domestic water services should be demand driven. In other words, it should be based on a thorough understanding of effective consumers' demand for multiple use (domestic and productive) water services (Whittington, 1998). The assessment of demand for improved domestic water services provides the basis for micro-level analysis of consumer benefits from multiple water uses. Such studies are not common in South Africa's rural areas, where most of the studies to date focus on either domestic water uses (Banda et al., 2006) or irrigation water use (Nieuwoudt et al., 2004). This study attempts to fill this gap by assessing the household demand for multiple water services in the Sekororo-Letsoalo area located in the Olifants River Basin.

Methods

Analytical framework

Two main economic approaches are used to assess individual or household's demand for water. Both of them can be regrouped under the category of the stated preferences methods. These are the Contingent Valuation Method (CVM) and Choice modeling (CM). CVM aims at estimating the value of a nonmarketed environmental good by inferring the value that its users are willing to pay for the good. CM is a generalization of the contingent valuation method in that it gives respondents a menu of cases from which they have to choose. CM (or Choice experiments, as the method will alternatively be named later on) is a method for valuing nonmarket goods by making use of attributes used to build policy scenarios. CM was used to elicit passive use values because it has several advantages over other methods (Hope and Garrod, 2004). Valuations of CM are based on attributes. Each of these attributes is valued. CM is also useful for analysis of situational changes and trade-off between attributes (Snowball et al., 2007; Hope and Garrod, 2004).

Data for CM are generated by systematic and planned processes where attributes and levels are predefined to create choice alternatives.

The most common econometric models used to process data in CM are the nested multinomial logit (NML), the conditional logit model (CLM), and the multinomial logit model (MLM). The MLM is applied to data where water service characteriztics and household characteristics are included in the model. The NLM is a generalization of the MLM, which is applied to data grouped into tree-like structured nests. A respondent's decision is sequential. CLM is applied to data where the explanatory variables are attributes. For this study, a CLM was applied as it seemed to be the best fit for the data, given that the explanatory variables are attributes (i.e. choices are not sequential) and there is no status quo in the experiment (Greene, 2007).

Data collection and sampling procedure

This study is based on primary and secondary data. The secondary data came from government publications, research publications, and reports such as students' theses. Primary data came from household surveys and focus groups conducted with local stakeholders. Focus group discussions were conducted in two of the 14 villages in order to validate the attributes for the choice experiment, and to allocate significant levels to these attributes. A structured questionnaire was used to collect quantitative data about the households. Six enumerators (Masters students) speaking the local language were trained to interview the households.

The surveyed population was originally divided into two strata. Stratum 1 includes the households without private taps (in the yard), while stratum 2 is formed by households with private taps. During data analysis, the sample was further stratified on the basis of the household's water consumption and income. A sample of 150 households was initially considered representative (1.9% of the population). The study was then conducted in seven villages in the Sekororo-Letsoalo area where 169 households (62% belonging to stratum 1 and 38% to stratum 2) were interviewed. Selection of the villages was based on: (1) type of water access, and (2) distance from the mountains (proxy for water availability) according to the 2001 census. A CLM was adopted to interpret the data collected through the choice experiment. The dependent variable for this model was the choice of water alternatives, whilst the explanatory variables were represented by the attributes of water service.

Results

Results show that households in the Sekororo-Letsoalo area are willing to pay for improvement of water services. Different groups of households have differences in preferences for water services, and different levels of willingness to pay for different improvements in water services. These differences in Willingness to Pay (WTP) and preferences are due to variations in household income and currently available water sources. Access to water from private tap is a very important improvement to households that do not have private taps, whilst purification of water to improve quality was the most important improvement to households with private taps. Households' price elasticity of water demand was almost the same for all strata, but slightly higher for households without private tap compared to those with private tap. Increases in number of productive uses were only important to households connected to a private tap and with higher water consumption. Frequency results show that the most important attributes that determined household choice of water service in the choice experiment are price and frequency of supply. Results also show that there are significant differences in importance of attributes across households' strata, gender, villages, and household incomes.

Conclusions

The CM approach applied to the rural households in the Sekororo-Letsoalo area showed clearly that local inhabitants are concerned with water availability and quality. This concern results in a clear WTP for improved water supply and services.

The calculated WTP per household are comparable to those observed in similar rural conditions by Banda et al. (2006, 2007). This indicates that there is room for policies aimed at improving rural domestic water infrastructures and services, through a mechanism of partial recovery of the investment and operating costs by introducing water tariffs based on consumption.

Integrated Water Resources Management (IWRM) in developing countries is also concerned with the efficient and equitable allocation of water to rural domestic users. There is considerable inequity in the provision of water services in these areas. A minimum amount of water must therefore be supplied free of charge and in a reliable way (collective taps, private taps) to all rural households. These households demonstrate WTP, according to their low income, for additional amounts of water. These additional amounts would considerably improve the quality of life of rural households and can be used for extra-household uses such as backyard irrigation, beer production, etc., which are likely to foster local economies and improve local livelihoods.

A multiple-step system to charge residents for water could then be adopted, where the first step (basic human needs) is free of charge, and the following ones apply progressive unitary prices to the water consumed on the basis of the demand analyses conducted in the area and the resulting WTP.

A clear interest to engage in multiple uses was observed only in those households that already have enough water to satisfy basic domestic needs. This would confirm that very poor conditions in terms of water availability not only deteriorate drastically the current livelihood of rural households, but their ambitions and willingness to improve their status is affected as well. Only the satisfaction of basic human needs induces a certain incentive to engage in extra-household water uses that could enhance the economic conditions of the household.

CM applied to the Sekororo-Letsoalo area showed the utility of stated preferences methods to elicit local residents' demand characteristics and WTP for various aspects of water services and uses. The combined use of various economic methods in addition to the CM (for instance revealed preferences methods such as the travel cost or a dichotomous choice method such as the CVM) would certainly improve the accuracy and reliability of the results.

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Technology adoption and adaptation for multiple use water services in the hills of Nepal

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Abstract

This paper draws on seven years of multiple use water services (MUS) development effort by International Development Enterprises and partner organizations in Nepal. It describes the genesis of the MUS work and the unique combination of technologies utilized to provide domestic and productive water services. The introduction of microirrigation technologies enabled households to begin production of high-value vegetables, increase their cash income, and increase food security. Scaling up introduction of these technologies. however, required a way for households to increase access to a reliable water supply. The combination and adaptation of water control technologies from both the rural domestic water and microirrigation sectors are explained. We discuss factors that have made the development intervention highly successful as a collective action community undertaking, providing individual household services to meet a range of water needs.

Media grab

Communities building multiple use water services by design in the hills of Nepal place the highest priority on meeting domestic water needs, but also achieve significant crop production benefit by using microirrigation in periods of water scarcity.

Introduction

International Development Enterprises (IDE) and Winrock International are jointly implementing projects in Nepal that focus on linking low-income, smallplot farmers to markets as a means for them to increase their income. IDE has developed and adapted technologies that are appropriate for Nepali hill farmers to access one or many sources of water, transfer the water from the source to where it can be used for irrigation, temporarily store the water, and then distribute and apply the water to crops.

At the household level, a secure drinking water supply is the highest priority for water use. Springs are the preferred source in this area and for the past 50 years the Government of Nepal has assisted many communities in installing piped water systems from springs to meet domestic needs. Since traditional furrow or flood irrigation requires large quantities of water, domestic water programs discourage use of the piped domestic supply for irrigation. Thus, IDE/Winrock introduced microirrigation (sprinkle and drip application) technologies in the hills to enable farmers to use their limited water supply to grow small plots of vegetables for home consumption and for sale in the local market.

This paper describes the IDE/Winrock experience in adapting technologies to enable an increase in the water supply to meet domestic needs, while applying the 'excess' water for productive use. These 'MUS-by-design' systems offer a concrete example of combining and adapting available low-cost technologies for multiple water services.

Methods

In 1995 IDE introduced vegetable production to smallplot farmers in the hills. Both low pressure sprinkle and drip irrigation were developed. The drip systems are sold as kits using soft polyvinyl chloride (PVC) pipe with precision punched holes as emitters, and a bucket or tank elevated 1-1.5 m above the ground for the necessary water distribution pressure. These simple systems are designed to irrigate plots as small as 80 m^2, are produced by manufacturers in Nepal, and sold by retailers near IDE’s project areas. The smallest system retails for about US$20 (IDE, 2008). Over 25,000 hill farmers have purchased and used these systems, increasing their net annual cash income on average by over US$100 (Shrestha, 2007). However, until MUS-by-design was introduced, it remained the farmers’ responsibility to find a water supply for their microirrigation systems.

Although the use of low-pressure, small-scale, drip- and sprinkle-irrigation technologies make it possible to use very small sources of water to irrigate, the water supply in most villages in the middle hills still proved to be a limiting factor in the widespread uptake of microirrigation. Farmers without access to a piped domestic water supply seldom had access to a water source close enough to their field to manage even a small plot of vegetables. Due to design limitations of domestic water systems, farmers with access to a piped system often did not have enough excess water to use for irrigation. Design standards for domestic needs in Nepal are based on an average per capita use of 45 l/day for a projected 15-20 year population growth of the community (UNICEF, 1996). The transmission pipe, sized to achieve daily domestic water needs, restricts other use options. The IDE team decided to explore building piped water supplies to see if domestic water systems could be designed to incorporate additional water for all households in the community interested in irrigation. Therefore, recognition of the role that domestic water systems played in providing irrigation water for drip irrigated vegetable production brought about development of MUS-by-design in Nepal (Yoder et al., 2008).

As participating partners in the CGIAR Challenge Program on Water and Food PN28 Multiple Water Use project, IDE staff carried out process documentation over a four-year period reviewing project implementation reports, interviewing staff of partnering governmental and nongovernmental organizations, and conducting field visits to observe and interview participant households. The experience and lessons of this action research project are compiled in Mikhail et al. (forthcoming, 2008).

Process

In the mountainous terrain of the Nepal hills most communities can locate a spring at an elevation higher than their village, making it possible to install a pipeline for gravity delivery from the source to the community tapstand and eliminate costly pumping. Larger communities sometimes install transmission lines many kilometers long to link a suitable water source to the community. With fewer resources, smaller communities are limited to water sources closer to their village, often with a more limited water supply.

Thousands of piped rural domestic water systems have been constructed with support from the Nepal government. Such systems consist of: a masonry water collection box at a spring, transmission pipeline, a community storage tank near but at a higher elevation than the user community, a distribution pipeline from the community storage tank running through the residential area, and outdoor tapstands conveniently placed for easy user access by small groups of households. In order to reduce transmission pipeline and community storage tank costs, water use is restricted and direct household connections are rare. Design specifications, standards, and norms for these domestic water systems have been established and tested (UNICEF, 1996; RWSSFDB, 2006).

The IDE technical team adopted the domestic water supply design criteria and norms as the starting point for design of all domestic components of the MUS systems, with modifications and additions as necessary to enable productive use options. Springs are the source for rural domestic water supply systems and also for most hill area microirrigation. The bacterial content of most springs in Nepal is acceptable for domestic use without treatment, and has historically been preferred over surface water for drinking. By using springs as the water source, water quality is generally not an issue in combining microirrigation and domestic water delivery in Nepal’s hill region. To achieve this productive use capability, as compared to a domestic water supply only system, no major changes in water access and transport are required except an increase in transmission pipe size.

The design specification for domestic supply of 45 l/capita/day, which is about 270 l/day for the average size Nepali family, was used to calculate domestic demand. To this IDE adds a minimum of 400 l/day/household for productive needs. With a dependable water supply of at least 400 l/day, and using drip or sprinkle application technology, a household can fully irrigate vegetables on a plot of 100-200 m^2 in most areas of Nepal’s hill region. In the driest season of the year with slightly higher evapotranspiration rates using the same amount of water the irrigated area is reduced by about 25%. In the rainy season most farmers choose not to use microirrigation. The maximum productive use supply is generally 600-800 l/day/household to keep pipeline and water storage costs in an affordable.

A domestic-only water supply system in Nepal is typically designed to give all residents equal access to public water points. If the water supply becomes limited, the duration of the delivery period is reduced and residents form a queue to access the supply from the tapstand. For a domestic system, the allocation rules determining who gets water and for what use deal primarily with equity in access. In rare cases when the supply is extremely limited, activities like clothes washing or animal watering at a public tapstand will be excluded if they infringe on equitable access for household consumption.

For MUS-by-design the allocation rules are considerably more important than for single use design. Questions of how much water should be allocated for each purpose and how to achieve equality in distribution for all uses become more complex. While some springs have nearly uniform discharge in the rainy and dry seasons, the discharge of most springs is highest at the end of the rainy season and reduces gradually through the dry season. This further complicates the allocation planning. If a single set of rules is applied, they need to be set for the most limited water supply period and excess water may be lost in the higher flow periods. Communities often establish different allocation rules for each season. The primary community objective is to provide appropriate allocation rules with distribution control that maximizes efficient water use while safeguarding domestic supply.

This highlights the concern voiced by many community members during MUS design discussions: 'How do we keep influential members of the community from compromising equitable access by all for domestic needs if it restricts their access to productive use?' In all cases the primary rule that emerged in MUS community discussions was that all domestic needs must be satisfied before water is delivered for productive use. This presented a challenge with a range of options–a flexible management (software) system for controlling delivery that can easily be adjusted to seasonal water supply differences or a more rigid physical (hardware) control system to make management simpler, with less opportunity for inappropriate manipulation of delivery.

Out of the over 80 MUS-by-design systems built by IDE/Winrock by mid 2008, about half have a water supply that is considered adequate in all seasons to fully meet both domestic and productive use needs provided by the previously explained 'water demand' design criteria. For these systems, a single storage tank and one line distribution system was designed. Distribution is managed by controlling the delivery time for each use period. A rigid, strictly managed schedule is required only during the dry season months when discharge in some springs decreases.

During system design, if community members anticipated periods of water shortage or that distribution would be difficult to control, they selected a double tank storage and two-line distribution option. The transmission line from the spring is connected directly to the first storage tank, the 'domestic' tank. When the tank is full it overflows into a second community tank designated for productive use – the 'productive' tank. This simple hardware solution verifies that the water distribution meets the allocation rule: the domestic water supply is separated at the community storage level and is distributed independently of the productive use supply. While this visual separation provides full control and minimizes potential for unauthorized manipulation, it adds to the cost of the system. Despite the additional cost, however, many communities select the double tank option because it is easy to understand and monitor equity of access.

The point at which community control shifts to the household user is upon delivery at the domestic tapstand or irrigation offtake. Water is carried from the tapstand for kitchen use, animal watering, and latrine flushing. In many cases bathing and clothes washing also take place at the tapstand. For the productive use distribution where the field(s) to be irrigated are slightly more distant from the house, offtakes are designed to allow connection of a flexible hose for filling the tank or bucket reservoir of the drip system or connected directly to a sprinkle system.

Results and discussion

All cases examined by the action research activity illustrated the community desire to improve access to water resources and a well defined hierarchy of access for different uses. In Nepal law, domestic water needs take priority. In some cases domestic priority is realized through system management, while in other cases the priority is hardwired into the system by separating the domestic and productive use water in the distribution system. In one case with an extremely limited dry season water supply, each household has built on-site storage enabling equal distribution with full control over use at the household level. In seasons when a greater quantity of water is available and in communities with access to larger volume sources, prioritization of use is not as necessary. In all cases, it was the user groups that decided how to allocate among uses, but domestic water remains the highest priority.

The IDE/Winrock technical staff in Nepal deserve credit for thinking outside the box as they searched for ways to introduce microirrigation in the hill areas. With little understanding of how the government water sector approach worked, it seemed obvious to them that planning and designing water access and delivery at the community level could and should always take a comprehensive and integrated approach by combining services wherever possible. They depended upon the village communities to show them water sources and provide hydrologic data, and were willing to listen when told that domestic water needs must be addressed before use of water for irrigation was feasible. The importance of 'listening to and learning from the user,' the foundation of human-centered product design, is resoundingly confirmed by the Nepal MUS experience.

Skeptics of MUS-by-design in the domestic water sector cautioned that productive use needs in times of water shortage would dominate and disrupt domestic use, ultimately undermining equal access by all, especially those already marginalized in the community. This prompted a search for ways to safeguard the domestic water supply and provide a visual means of verifying that water delivery matched the water allocation rule that all domestic water needs be met first. Implementation of the double tank temporary storage, together with two-line distribution system to measure and visually separate the domestic and productive water delivery, have successfully avoided conflict in dividing and delivering water for multiple uses.

MUS projects in Nepal have shown that the use of microirrigation in conjunction with MUS is a potent combination. This will become even more important as greater domestic demands from population increase take water away from productive supply. Success of microirrigation is largely dependent on availability of an easily accessible water source. Coupled with higher volume domestic water, the benefits of the system dramatically increase. While microirrigation provides farmers with a useful tool to optimize the use of water, farmers have recognized that drip irrigation as a water application technology has its greatest advantage under extreme water shortage. During periods of more abundant water availability they prefer to use manual watering from a hose or sprinkle can. Shrestha

(2007) investigated the reasons why uptake of drip irrigation was less than expected, and found that 30% of the 50 respondents in Syangja district and 24% of the 50 respondents in Palpa district used manual water application rather than expanding their drip system for expanded vegetable production. They claimed that due to an abundance of water there was no need for drip irrigation. Those interviewed that had MUS systems in their community tended to have less water available, and relied more on drip application to economize water use. Ultimately, there is no single 'best' technology to meet a household's needs in all situations. Instead, a large menu of alternatives must be available for communities and individual households to pick and choose the best options to meet their specific conditions and needs (Mikhail et al., forthcoming, 2008).

Conclusions and recommendations

Treating the community as a customer rather than beneficiary gives the community full ownership of their water system. Ownership means taking responsibility for planning water allocation rules and selecting among water distribution options. Ownership brought community involvement in finding funding and in developing institutions for system operation and management. Community-based MUS are an excellent example of developing local governance skills and allowing communities to creatively find solutions to their water use needs. The activities involved in the creation of MUS strengthened community institutions and changed water use behavior. Inclusion of the productive use component enabled individual action and community action to reinforce one another, improving the situation of both independent households and the community as a whole (Mikhail et al., forthcoming, 2008).

Technologies are 'use neutral.' They simply expand opportunity and enhance management options. For example, a tapstand is a water distribution point that can be used for many purposes—as a shower head for bathing, connecting a hose to transport water directly to the kitchen, or to the drip tank or sprinkler head for irrigation. The ingenuity in the Nepal MUS-by-design systems was not creation of new technologies, but the unique combination and adaptation of existing technologies to deliberately provide communities with water for both domestic and productive needs. It is important to recognize that technologies that evolved for specific use in 'drinking water' or 'irrigation' systems do not determine the purpose of the system. Rather they enable a water control function that can be adopted, with modification and adaptation, in other types of systems. The technologies enable conditions around which management criteria (rules of use) enable effective governance of the service (Yoder et al., 2008).

While MUS is not a new concept for communities and received high acceptance at the community level, it is a shift in approach for water resource development implementers. Despite the sectoral nature of water resource development in Nepal, the multiple use services approach to water development was able to achieve significant buy-in from a variety of implementing partners who have a single purpose mandate. Because MUS inherently requires the involvement of multiple sectors, players within the government that seldom coordinate their activities were brought together to work with communities on a common water-use vision. This created additional opportunities for integrated water resource management in Nepal (Mikhail et al., forthcoming, 2008).

Acknowledgments

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Improved rice-aquaculture integration in coastal rice-shrimp system in Bangladesh

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Abstract

The rice–shrimp system in the coastal zones of Bangladesh suffers from a high risk of disease outbreaks in the dry season shrimp (*Penaeus monodon*), while income from the rainy season rice is often low due to its low yield. This study aimed at improving productivity of the rainy season farming by improving rice yield and integrating it with freshwater prawn (*Macrobrachium rosenbergii*) and genetically improved farmed tilapia (GIFT). Experiments were carried out to compare the effect of three different times of stocking of post-larvae (PL) of prawn and five rice varieties on yield of prawn, GIFT, and rice and on farmers' net economic return. Prawn yield (72.53±4.70 kg/ha) in early PL stocking treatment in June was significantly ($P<0.05$) higher than those of later stocking in July and August. A 60-day difference in prawn grow-out period resulted in an increase of about 237% in average individual body weight. PL stocking time did not affect GIFT and rice yield. Rice varieties of BR 23, BRRIdhan 40, and BRRIdhan 41 significantly outyielded other varieties by 31.83%. Compared with monoculture of local rice varieties, high yielding rice varieties increased farmers' return by Tk. 18,420/ha (US$1=68.5 BDT–October 2008); integration of aquaculture further increased it by Tk. 13,050–38,227/ha. Return from aquaculture increased with advancement of prawn stocking times. While PL stocked in June resulted in a net return of Tk. 28,143/ha, that in July and August resulted in Tk. 8,810 and 3,868/ha, respectively. The rice-GIFT-prawn integrated farming, especially with early stocking of prawn, and using high-yielding rice varieties can significantly benefit farmers of the rice-shrimp system in the coastal zone of Bangladesh.

Media grab

The integrated rice-GIFT-prawn farming, with stocking of freshwater prawn (*M. rosenbergii*) post-larvae 60 days in advance of rice transplanting, and using high-yielding rice varieties, increases net income by about 300% higher than the current wet season mono-rice crop practice in rotational coastal rice-shrimp systems in Bangladesh.

Introduction

In Bangladesh, about 80% of aquaculture production of marine shrimp (*P. monodon*) comes from the southwest inter-tidal coastal flatlands, where shrimp is grown in the dry season (February to mid-August), in rotation with rice, which is grown in the wet season (mid-August to December) when water salinity is lowered by rainfall (Islam et al., 2005). Though alternate rice-shrimp system is one of the more ecologically sustainable approaches to shrimp farming (Brennan et al., 2002), production of shrimp in the rice-shrimp system in Bangladesh is low, from 29 to 277 kg/ha (Islam et al., 2005), with a threat of frequent shrimp crop failures due to disease outbreaks. The rice production in this system is also low, ranging from 1.0 to 3.0 t/ha (Karim, 2006), which is considerably lower than the potential (Mondal et al., 2006). An increased yield of rice and integration of aquaculture production with rice during the rainy season may improve coastal agricultural production and concomitant livelihoods of farmers in coastal zones in Bangladesh.

The contribution of GIFT to net income from rice-aquaculture integration in fresh water (Hazrat et al., 2003) and brackish water (Alam et al., 2007) environments has been reported as significant. Raising freshwater prawn concurrently with rice in the wet season followed by shrimp monoculture in the dry season has been proven an efficient farming system for increased income of coastal farmers in Vietnam (Hung, 2001). Raising freshwater prawn in rainy season rice fields, however, has not been economically successful in Bangladesh (Alam et al., 2007). This is probably because the rice cultivation period is too short for the prawns to grow to marketable size. This can be overcome by stocking prawn post-larvae (PL) before rice is transplanted in the fields, i.e. when water has not yet completely become fresh. We postulated that this is possible, as the natural physiological requirement of prawn larvae is to grow in brackish water and later in their life cycle as adults in fresh water. The present study was conducted to assess the impact of: (1) using high-yielding rice varieties (HYV); (2) integrating GIFT and prawn with rice; and (3) increasing the length of prawn grow-out period, through advancing the stocking of prawn prior to stocking of GIFT and rice transplanting, on agriculture-aquaculture production, and enhancing farmers' economic return.

Methods

The experiment was conducted in 12 farmers' rice-shrimp plots (locally termed as 'ghers'), having approximately an average area of 1150 m^2 each, that were connected to the adjacent river with sluice-operated canals. Each plot was developed with the construction of trenches along the inside dykes, covering about 10% of the total land area with an average depth of 80 cm. Rice was transplanted in the third week of August, after the harvest of the shrimp crop. The experiment had three treatments of stocking times (T) of prawn PL: (i) T1 = in the last week of June; T2 = in the last week of July; and T3 = in the last week of August. Each of the treatments had four replications. The stocking of prawn PL in T1 and T2 was carried out before shrimp harvest, and that in T3 seven days after rice transplantation. After harvesting of dry-season shrimp in early August, the depth of water was lowered and prawns in T1 and T2 were allowed to take shelter in trenches. GIFT fingerlings were introduced in all treatments at the same time as treatment T3. The stocking density of prawn (2500/ha) and GIFT (2500/ha) was the same in all treatments. Each treatment plot above was further divided into five strips, randomly grown with five HYVs of rice, *viz*., BR 23, BRRIdhan 40, BRRIdhan 41, PVS-T2, and PVS-T5, for the purpose of comparing their yields. Preparation of plots prior to rice plantation, post plantation management, stocking and culture management of aquaculture species, monitoring of water quality, rice and fish harvesting, data collection and analysis, were similar to that described by Alam et al. (2007).

Results and discussion

Variations in rice field water depth (15-25 cm), temperature (26-28°C), salinity (0-2 ppt), pH (7.5-8.0), dissolved oxygen (4.0-4.5), PO_4-P (2.5-3.7 μg-at/l), and NO_3-N (2.2-5.8 μg-at/l) were similar in all treatments ($p>0.05$). These were within the suitable range for rice-fish culture (Ghosh et al., 1985; Islam et al., 1998). Soil and water salinity were high during the dry season, but gradually reduced to less than 2 ppt during the rice-fish culture period of August-December (Figure 1). The reduction in salinity was brought about by high rainfall during June–November. The observed low soil and water salinity were not expected to affect the yield of HYVs (Mondal et al., 2006).

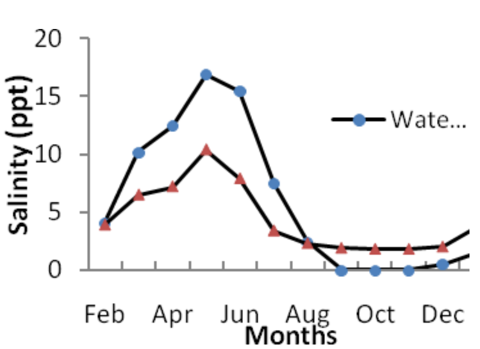

Figure 1. Monthly variations in water and soil salinity in the period of dry season shrimp (March–July) and wet season rice-GIFT-prawn farming (August–December).

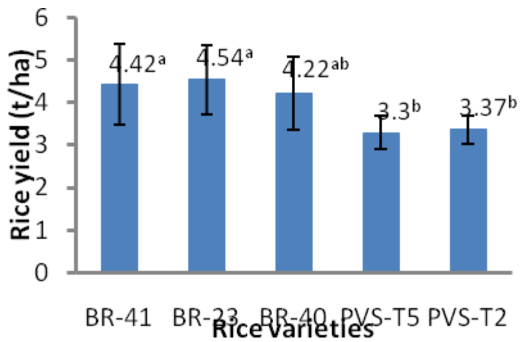

Figure 2. Yield of rice in the integrated rice-GIFT-prawn farming. Vertical and capped bars signify ±standard deviations of the means. Columns with the same letter (a,b) are not significantly different at 5% level by DMRT.

Growth and production of prawn were significantly affected ($p<0.05$) by stocking dates. Yield of prawn stocked in June was 190 and 260% higher compared with those stocked in July and August, respectively (Table 1). Advancing the stocking of prawn, however, did not result in any significant differences in their survival rates (Table 1). This observation suggests that neither the higher salinity nor the preparatory management during the rice plantation affected the survival of prawn post-larvae that were stocked before all the shrimp were harvested. The increase in yield came mainly from the significantly heavier individual body weight at harvest of 57.94 g in prawn that were stocked in June. This was because of differences in length of the grow-out period. Advance stocking of prawn post-larvae had an advantage on shrimp pond productivity. Selective harvesting of shrimp gradually reduced their density thus reducing the competition for space and food, leading to significantly higher growth and production than prawn that were stocked along with GIFT and rice in August. At the stocking rate of 2,500 PL/ha, yield of prawn in T1 (72.53 kg/ha) was equivalent to the yield (73.14 kg/ha) reported by Alam et al. (2007), who stocked at the time of rice transplanting, using a density of 5,000 PL/ha.

Among the treatments, growth and production values of GIFT were similar ($p>0.05$) (Table 1) and quite comparable with that reported for *Oreochromis niloticus* monoculture at a stocking density of 3,000 fingerlings/ha in freshwater rice-fish system (Gupta et al., 1998). The results on growth and production of GIFT in the present experiment are also consistent with those previously reported (Alam et al., 2007), validating the suitability of culturing GIFT with rice at 5,000/ha stocking density, either alone or in 1:1 combination with prawn, in coastal rice-shrimp systems.

Table 1. Production (mean±sd) of GIFT and prawn (*M. rosenbergii*) cultured with rice

Stocking times of prawn PL	Final body weight (g)		Survival rate (%)		Yield (kg/ha)	
	GIFT	Prawn	GIFT	Prawn	GIFT	Prawn
June:*T1*	148.91^{a}±10.03	57.94^{a}±6.43	52.03^{a}±4.48	50.44^{a}±4.81	193.57^{a}±22.85	72.53^{a}±4.70
July:*T2*	149.32^{a}±13.98	31.32^{b}±3.04	51.37^{a}±3.14	48.56^{a}±2.20	192.11^{a}±26.19	38.02^{b}±4.01
August:*T3*	141.42^{a}±10.96	24.42^{c}±1.66	50.87^{a}±5.50	45.74^{a}±1.75	179.69^{a}±23.82	27.88^{c}±1.53

Numbers in each column with the same letters in the superscript are not significantly different at 5% level by DMRT.

There was no significant interaction between times of PL stocking and rice varieties. Yields of BR-23, BRRIdhan-41 (average 4.54 t/ha), were significantly higher than PVS-T5 and PVS-T2 (Figure 2). This confirmed the findings of Alam et al. (2007) who reported superior yields of these HYVs compared with other test HYVs and local varieties. Rice yield rates, however, of tested HYVs are higher than the rates of 1.83-2.59 t/ha (Anon. 2007) that the farmers are currently having from the rice-shrimp system.

The net return from rice in treatments using BR 23, BRRIdhan 40 and BRRIdhan 41 (Tk. 35,500/ha: US$ 1 = Tk. 68.5) was significantly higher than that of those from PVS T2 and T5 (Tk. 21,800/ha). The difference in net return was mainly due to the yield difference (Fig. 2). Average for all varieties, the net return from cultivation of HYV of rice was Tk. 30,110/ha, with a benefit cost ratio of 2.40. The equivalent value for the mono-cultivation of the commonly used rice varieties in the farmers field in the study area has been reported Tk.11,690/ha (Anon. 2007). Integrating GIFT and prawn into rice increased the net return compared with that obtained from mono rice culture. The total net return from the rice-GIFT-prawn system varied significantly ($p<0.05$) with prawn PL stocking times, with highest return of Tk. 68,337/ha in T1 and lowest return of Tk. 43,160/ha in T3 (Figure 3). The aquaculture contribution to net return from rice-aquaculture system increased with the advancement of the prawn PL stocking date: 56% of the total return in T1, 38% in T2, and 30% in T3. While the net benefit of Tk. 9,182 - 10,084/ha from GIFT was similar among the treatments, that of Tk. 28,143/ha (benefit cost ratio 7.26) from the prawn in T1, with an increase of about 728% over T3. This demonstrates that stocking of PL together with the increase of prawn grow-out period can yield considerably higher economic returns. Since the cost of stocking was the main expenditure for prawn culture, early stocking of less costly PL not only reduced the production cost substantially (Alam et al. 2007), but also yielded prawn of higher individual body weight thus demanding higher market price.

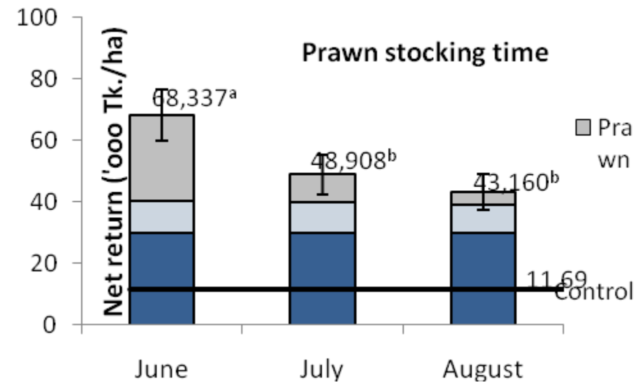

Figure 3. Net economic benefit from rice-GIFT-prawn integrated farming under different stocking times of prawn PL. Stocking treatments were 30-d apart. Rice was transplanted in August, one week before August stocking. Return from rice was the average of the 5 tested varieties. Vertical and capped bars signify ±standard deviations of the means of whole rice-GIFT-prawn system. "Control" presents value for mono-cultivation of commonly practiced rice varieties in the study area (Anon. 2007).

Conclusions and recommendations

Coastal livelihood requirements have been increasing with increased population, and can no longer be satisfied through traditional extensive aquaculture or agriculture production systems. Simply using HYVs of salt tolerant T-*Aman* rice, such as BR 23, BRRIdhan 40, 41, farmers can increase the economic returns by 157%. Integrating aquaculture of freshwater prawn and GIFT with rice during the rainy season, as well as improved marine shrimp production in the dry season (Alam et al., 2007), further offers a promising avenue to increasing production and economic returns of the rice-shrimp system in the coastal zone of Bangladesh. Farmers can stock prawn PL instead of prawn juveniles, thus reducing the production cost. Furthermore, stocking of prawn PL into shrimp ponds 60 days in advance of rice plantation, may further increase production and net return compared with stocking PL at the same time of stocking GIFT at rice transplanting. Such advanced stocking of prawn can provide farm net returns of about 300% higher than is the case with the wet season rice crop that is currently practiced. This wet season farming system would not only provide strategies to overall risk reduction in dry-season shrimp farming, but also provide economic farm sustainability and household food security. The development, however, of existing rice-shrimp lands, particularly for maintaining optimum water depth for shrimp culture in the dry season, may affect rice yields due to waterlogging caused by heavy and prolonged monsoon rain (Alam et al., 2007). Therefore, the introduction of alternate dry and wet season shrimp and rice-aquaculture in a single piece of coastal land requires improvement of water management structures.

Acknowledgments

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Higher level institutions and policies

Water and food in river basins in Africa, Asia, and Latin America: A comparative analysis

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Abstract

The CGIAR Challenge Program on Water and Food was initiated in 2002 to help address three problems associated with the world water and food crisis: low water productivity in agriculture as an obstacle to attaining food security; lack of access to water by the poor; and degradation of terrestrial and aquatic resources. We present a comparative analysis of water use, agricultural water productivity, and livelihoods from the Karkheh, Mekong, São Francisco, and Volta basins, and initial analysis from six others (Andean, Indo-Gangetic, Limpopo, Niger, Nile, and Yellow basin systems). Results help explain links between agricultural water use and rural poverty, in the broader context of poverty reduction processes beyond those related to water. Water resources in basins are under increasing pressure but there remains considerable scope for improved water use by agriculture. Water productivity in relatively dry basins is especially high in certain livestock and crop-livestock systems. Overall, there remains uncertainty about how basin-scale agricultural water use systems respond to the combined pressures of demand, resource constraints, climate change, and institutional capacity to support change. Preliminary results indicate how policy and technological changes could address the challenge of making food and water systems both more productive and resilient in the long term.

Media grab

Water supports people through livelihood systems that vary widely from basin to basin, depending on development status, physical endowments, and institutions.

Introduction

Many parts of the world face a rapidly unfolding and unprecedented crisis of water scarcity. Growing and urbanizing populations will need more water for household consumption, power generation, industrial production, and for the provision of important ecological services. Above all, over the next 20 years, food production must increase by over 30%, much of it in poor, water-scarce developing countries. Within the Challenge Program on Water and Food (CPWF), the objective of Basin Focal Projects (BFPs) is to articulate scientifically the interrelationships between water and poverty, and to identify what can be done at basin scales to improve agricultural water productivity and thereby reduce poverty, improve human health, and preserve the environment.

This paper compares BFP findings from the Karkheh, Mekong, São Francisco, and Volta basins, and initial analysis from six others (Andean, Indo-Gangetic, Limpopo, Niger, Nile, and Yellow basin systems).

Methods

Research of BFPs was divided into several work packages. The first work package–/\'water and poverty/\'–looked for evidence of interrelationships between water scarcity, or availability with poverty (Cook and Gichucki, 2006). The work package on /\'water availability/\' used water accounting methods to estimate the volume of water used, month-by-month, for different land uses (evapotranspiration for rainfed crops, irrigated crops, grassland, or forests, net runoff or discharge) at different times and locations within a basin (Kirby et al., 2006a,b). The work package on /\'water productivity/\' (defined as the benefit of agricultural production per unit of water depleted) used standard methods of estimating water productivity for crops (Cook et al., 2006), and extended the application of the water productivity concept to livestock and fisheries.

The work package on /\'institutional analysis/\' examined the role of policies and institutions that affect decision-making with regard to the distribution of water among uses and users. Finally, the work package on /\'intervention analysis/\' used whole basin and other modeling approaches to explore the cross-scale efficiency and equity consequences of introducing different scenarios or strategies that combine policy, institutional, and technical change.

Results

There are very substantial differences among the BFP benchmark basins. Some are very large. The Nile basin, for example, covers more than 3.25 M km^2. Others are small; the Karkheh only covers 0.05 M km^2. Some are densely populated, like the Ganges with 400 persons/km^2 ,while others are sparsely populated like the São Francisco with only 18 persons/km^2. In the Ganges basin, cropland covers a full 72% of the area, compared with a mere 13% and 11% for the Volta and Nile.

The Ganges and Mekong are relatively 'wet,' with well over 1 million m^3 of rainfall/year/km^2, a relatively large proportion of which discharges to the ocean. The drier basins receive half of this or less, of which only a small fraction (sometimes virtually none) leaves the basins as discharge. The way people use water is clearly linked to these hydrological patterns: fisheries are vitally important in the Mekong (and *were* so in the Ganges). Per capita water supply ranges from over 8000 m^3 per person per year in wet basins to less than 1000 m^3 in dry basins (Table 1). The extent to which a basin is /\'wet/\' vs. /\'dry/\' has implications for water availability, degree of basin closure, water policies and management planning, community water 'norms,' and other factors (Harrington et al., 2008*)*.

Table 1. Descriptive statistics for benchmark basins.[a]

Basin/ attribute	Ganges	Indus	Karkheh	Limpopo	Mekong	Nile	São Francisco	Volta	Yellow
Area (M km^2)	1.02	1.08	0.05	0.42	0.81	3.25	0.62	0.41	0.94
Population persons/km^2	401	165	n/a	32	71	46	18	43	156
Rainfall (M km^3/km^2/yr)	1149	762	422	544	1483	639	1008	1001	407
Water supply (m^3/person/yr)	2850	830	n/a	716	8934	2207	8261	2054	361

[a]Area, population, and water supply statistics are from IUCN. Rainfall data are available from the developer URL: http://www.cru.uea.ac.uk/~timm/grid/CRU_TS_2_1.html.

Within basins there is considerable spatial variability. In some basins, rainfall is concentrated upstream (Karkheh, Mekong, Nile, São Francisco), while in others it is concentrated downstream (Ganges, Limpopo, Volta and Yellow). A typical issue in /\'dry upstream/\' basins is how to sustain agriculture in upper catchments. In /\'wet upstream/\' basins, the effect of upstream water management on downstream flows can be critical, leading to potential conflict. In the São Francisco, large urban areas are located in upper catchments. The pollution they cause affects downstream water users. In the Volta, there are few large urban areas in upper catchments.

Rainfall, water availability, population density, and irrigation infrastructure all influence water use. In several basins with low population densities, such as the São Francisco or the Volta, grasslands and woodlands are major users of water. The large proportion of water used for irrigated agriculture in Asia (especially the Ganges, Indus, and Karkheh) contrasts sharply with the very low proportion of water used for this purpose in Africa. Not surprisingly, the proportion of water discharged from the basin into the sea was found to be higher in wet than in dry basins (Table 2).

Table 2. Major uses of water, by basin, M m^3/yr (%).[a]

Basin	Rainfed agriculture	Irrigated agriculture	Grassland	Woodland and other	Discharge from basin	Losses	Total
Ganges	371,840 (30)	285,670 (23)	99,800 (8)	56,700 (8)	345,470 (28)		1,243,320
Indus	147,250 (17)	268,250 (31)	314,465 (36)	53,830 (6)	81,570 (9)		865,360
Karkheh	4,460 (18)	5,950 (24)	10,256 (42)	304 (1)	400 (2)	3,120 (13)	24,490
Limpopo	88,040 (38)	1,880 (1)	118,814 (52)	10,790 (5)	9,680 (4)		229,200
Mekong	184,460 (15)	71,750 (6)	393,248 (33)	45,880 (4)	441,590 (37)	57,030 (5)	1,193,940
Nile	273,380 (13)	26,870 (1)	942,771 (47)	564,830 (28)	56,190 (3)	161,610 (8)	2,025,650
São Francisco	97,160 (16)	2,820 (0)	272,195 (44)	148,310 (24)	81,660 (13)		622,840
Volta	32,110 (8)	0 (0)	329,539 (80)	6,980 (2)	38,940 (9)	6,050 (1)	413,840
Yellow	78,110 (20)	56,700 (1)	147,075 (37)	56,590 (14)	44,660 (11)		399,790

[a]Data courtesy of Mac Kirby, CSIRO. Major water uses are annual averages 1951-2000. Major uses do not necessarily add up to total average rainfall because of storage changes (dams and groundwater). Water uses are based on a land classification derived from AVHRR remote sensing. Resolution is 1 km^2 and may miss small areas of cropping or irrigation. Land use classification is from 1992-93 and may not reflect the current situation in some basins.

There was considerable similarity across the BFP basins on how water availability and water productivity were measured, and how these measurements were used. In all cases, simple water accounting tools were found to be helpful to show the volume and proportion of water that goes to different uses at different locations in the basin (Kirby et al., 2006a).

Water productivity varied across crops and across and within basins, but is generally well below potential. Sometimes it is higher in wetter areas and sometimes in drier. In the Karkheh, for example, agricultural water productivity is relatively low in irrigated areas (gross value product under US$0.01/$m^3$), most likely because part of the area has become affected by salt. It is somewhat higher in /\'marginal/\' rainfed areas, especially when cropping is integrated with grass-fed livestock (gross value product US$0.02-.03/$m^3$). In the Mekong Basin, rice water productivity is relatively high in the productive irrigated areas of the Mekong delta (nearly 0.8 kg/m^3) and lower in the more marginal rainfed paddy areas of Cambodia and northeast Thailand (around 0.3 kg/m^3). In the Volta and much of the São Francisco, water productivity for rainfed crops is far lower than in the Mekong: around 0.15 kg/m^3 for maize, 0.10 kg/m^3 for sorghum, and 0.08 kg/m^3 for millet. Interestingly, since better moisture means higher maize yields, maize water productivity is relatively flat across rainfall levels. In contrast, because sorghum and millet do not respond as well to more favorable moisture, water productivity is lower where rainfall is higher.

There are other things than water productivity, of course. Cross-scale and cross-sector consequences of water allocation were also deemed important. In the Mekong basin, for example, a major issue is the trade-offs between water use for hydropower generation and the possible consequences for downstream fisheries (Kirby et al., 2008).

BFP results suggest that relationships between water and poverty exist, but not as simple causal links. In the Ganges, for example, poverty is concentrated downstream in Bihar, West Bengal, and Bangladesh, where water is relatively abundant. In the Nile, wet Uganda is poorer than dry Egypt. The incidence of poverty in the Mekong is relatively low in dry northeast Thailand. Water availability, access, and quality are just a few of the many factors that affect rural livelihoods, whether measured in terms of flows (income) or stocks (assets). Other factors include farm size or access to land resources; off-farm employment and remittances from family members; crop selection and yields; agroecosystem diversification including livestock; access to markets and credit; market and transport infrastructure and marketing margins; education; inheritance; expenses associated with starting a new family, or with life transitions such as marriages; and, all too often, accidents or disease. The interrelationships among these factors, and between them and water-related factors, are usually complex. While it is clear that water can have a strong influence on crop yields, opportunities for agroecosystem diversification, and the incidence of (water-related) disease, many other distinct roles played by water are not always easy to define, even when these roles are known to be important.

In three of the four basins studied by first-round BFPs, teams found that rural societies are undergoing major transformations and links among water, food security, and poverty are best understood in this context. In the Karkheh basin, rural poverty rates have declined over the past 20 years because of rural to urban migration and national poverty reduction strategies. The Karkheh Basin is less poor than is Iran as a whole and (after adjustments for the cost of living) rural areas of the Karkheh are less poor than urban. Farmers are in the top half of the rural income bracket in the Karkheh. Surprisingly, the poorest rural area of the Karkheh is the lower reach–where irrigated agriculture is concentrated (Ahmad and Giordano, 2007). Water-related interventions can help improve water productivity and improve livelihoods, such as erosion control in upper catchments to reduce siltation of irrigation infrastructure. As a rule, however, nonagricultural interventions show the most promise for further reducing poverty.

In the São Francisco Basin, poverty rates have also declined, but patchily. There has been a strong out-migration of smallholder farm families, some to urban areas but others to seek jobs in large commercial farms that are well connected to markets (Vosti et al., 2008). In the Mekong Basin, the shape of rural transformation varies by country and in some instances within countries. Poverty is concentrated in remote rural highlands (Minot et al., 2006). Analysis highlights the relationship between water and poverty through livelihood assets (Kemp-Benedict et al., 2008). Poverty is relatively low in northeast Thailand, where people take advantage of income-earning opportunities in rapidly growing urban centers such as Bangkok. Agriculture in northeast Thailand is becoming less important in livelihood strategies. In contrast, water and agriculture remain important for poor farmers or fishers in Laos and Cambodia.

In the Volta Basin, home of some of the poorest countries in the world, the transformation of rural society is proceeding more slowly. About 40-45% of the rural population is below national poverty lines, while more than 70% live below an income level of US$2/day. Poverty and water scarcity both increase in a south to north gradient, but so does access to markets. Farming and livestock herding remain fundamental to the livelihoods of the rural poor, and water scarcity and food insecurity are closely linked. Past success in increasing food production has come more from area expansion than yield increase. Poverty is attributed to a mix of institutional and biophysical factors such as low agricultural productivity, poor soils, poor access to markets, price variability, insecure land tenure, lack of access to good quality domestic water, and water-related diseases. Rural to urban migration is important, but does not yet offer a major route out of poverty.

Discussion and recommendations

BFPs seek to understand water availability, water productivity, and people's livelihoods to identify water-related interventions that can help reduce poverty and improve food security. As the proportion of the population employed in agriculture dwindles, as development and rural transformation accelerate, and as nonagricultural sources of income become more important, interventions *other* than those related to 'water in agriculture' are needed to sustain the trajectory of development. As long as agriculture remains central to the livelihoods of the rural poor, however, water-related interventions continue to be important.

Promising water-related interventions that increase water productivity that have emerged from BFPs include the following:

- Increase water available for agriculture, for example through water harvesting and small reservoirs. This can increase water productivity in dryland and marginal environments when substantial amounts of water are lost through unproductive evaporation (Volta).
- Raise crop yields while using less water per unit area, for example by introducing conservation agriculture. Water productivity is increased by improved timeliness of sowing, reduced evaporation of water from a bare soil surface, and sometimes higher yields.
- Increase land productivity even if water use per hectare is not reduced.
- Increase the value of production, through value chain management, diversification and intensification.
- Reduce the risks of water-related disease.
- Reduce negative externalities associated with upstream water use, for example negative consequences of upstream hydropower generation on downstream fisheries.

Diversification and intensification warrant further discussion. These are often raised as possible mechanisms for reducing rural poverty. These processes have taken very different forms in each of the four first-round BFP basins. In the São Francisco Basin, agriculture appears to be shifting away from staple grain production by smallholders toward intensive production of high-value crops by large commercial farmers. In the Mekong Basin, there has been some diversification and intensification of agriculture, especially in areas near urban markets, and in the delta region in Vietnam where both rice production and aquaculture production (much of which is for export) have increased greatly. There are, however, also large areas of low productivity semisubsistence rice and other staple food crops. In some instances, agriculture has suffered from neglect as livelihood strategies have become more dependent on off-farm and nonagricultural income. In the Karkheh Basin, in contrast, diversification out of wheat and other staple grains is actively discouraged by government policies that perceive domestic food production and national food self-sufficiency as an important element of national security. Finally, in the Volta, processes of diversification and intensification proceed slowly, held back by a lack of marketing opportunities, high input prices, and water scarcity.

There are a number of trends that, as they unfold, will affect water and poverty, and opportunities to reduce poverty and improve equity through water-related investments. These trends include demographic change, climate change, and the continued transformation of rural society. Demographic and climate change will have enormous consequences for agriculture, ecosystems, and rural livelihoods in the Limpopo, Nile, and Volta basins. Much of the area in these basins is drought-prone. Risk seems to constrain investment in cropping systems. Many soils have a low moisture-holding capacity, and much of the rain that falls evaporates without having been transpired by plants as part of food production. Improved management practices, including rainwater harvesting, coupled with policies to enhance coping mechanisms for the communities in the basin, could aid in the adaptation to these adverse effects.

Conclusions

BFPs have made good progress in understanding and quantifying water availability, water productivity, poverty and livelihoods–and some of their interrelationships–in four BFP1 benchmark basins. The importance of the development trajectory of rural transformation, and the need for nonwater-related interventions has been highlighted. Under some circumstances, however, it was shown that water-related interventions can promise to reduce poverty and improve food security, and that water productivity is a useful concept in understanding how this unfolds.

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This paper presents findings from Basin Focal Projects from the Karkheh, Mekong, São Francisco, and Volta basins. BFPs are projects of the CGIAR Challenge Program on Water and Food.

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How did we get there? Coping with irrigation water scarcity and its definition

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Abstract

Two dimensions of irrigation water scarcity are examined: the first dimension lies within the very decision-making mechanism of establishing irrigated schemes in basins that are closing. Scarcity, in that sense, is constructed and reflects the disconnection between politically motivated projects and hydrologic reality. It raises critical questions on the governance of irrigation development. The second dimension is the concrete shortages experienced by farmers who increasingly need to grow a second crop on an area that tends to be reduced from one generation to the next. Understanding this other side of the coin is also crucial because coping strategies need to be assisted by governments if the impacts from climate change and growing competition are to be dampened. This paper uses central and northeast Thailand as an example to illustrate these two dimensions and offers attendant policy recommendations.

Media grab

Water scarcity is often artificially generated by overbuilding river basins; but the impact of resulting declines of water endowments per irrigated hectare is relative to wider agrarian change.

Introduction

Water crises and events of water scarcity often coincide with a drought or climate vagaries. Managers and politicians are thus prompt to explain crises, blaming them on 'El Niño,' the rain gods, or bad luck. In the face of people's deprivation, economic slumps, media releases featuring cracked soils, or public outcry decision-makers almost invariably promise a new dam or a new inter-basin transfer to relieve water-short areas and dispel the prospect of a returning crisis. But new infrastructures generally come with new uses, notably expanded irrigation areas that will face water shortages in drought years. Decisions to expand irrigation areas are, consequently, a key factor of perceived water shortages, and these shortages, are therefore a cause and a consequence of human decisions. Understanding the development of irrigation, which sometimes accounts for as much of 95% of total withdrawals, is a key to understanding how crises occur.

This paper first investigates the process by which resources tend to be overdeveloped, thus generating scarcity when supply falls short of the quantity expected and needed to irrigate massive irrigation schemes. But the perception and the impact of scarcity will also depend on the degree of reliance of rural populations on agriculture and on the other opportunities offered to them. In a second part of the paper we explore how farms tend to get divided with time, how water allows intensification on smaller plots, and how the perceived lack of water is linked to diverse livelihood strategies, all of which, in turn, have implications for the suitability of further developing water resources. Altogether, the notion of water scarcity is examined here through its linkages with water resource development on the one hand, and with livelihood strategies on the other, and illustrated by examples drawn from Thailand.

Generating water scarcity, or the sky is the limit

Faced with problems of water scarcity, societies may adopt several types of responses (Molle et al., 2007). They may access and develop new water resources, increase in-use efficiency or reduce diversions, or reallocate available resources among users in order to ease tension or maximize some specific criteria. Augmenting supply is almost invariably the preferred option of decision-makers, at least as long as this is physically and politically feasible. This conclusion is quite robust, spanning all types of climates and political regimes. It has been shown that societal drivers for such a state of affairs include a powerful conjunction of interests whereby main decision-making parties have positive incentives to opt for capital-intensive and infrastructural responses (see more details in Molle, 2008; Berkoff, 2002). Politicians, whether at the local or government level, have long cherished iconic large-scale projects that are seen as the best way to build up constituencies and state legitimacy (O'Mara, 1990); state technical agencies and bureaucracies need projects to ensure sustained budgets and to uphold their professional legitimacy; private consulting and construction firms look for a steady flow of business opportunities; and, last, development banks and cooperation agencies also have vested interests in maximizing disbursement of funds (Chambers, 1997).

Augmenting supply thus maximizes benefits to what could be termed an 'iron rectangle' (the classical iron triangle described in the literature on the American West: (Reisner, 1986), and often minimizes short-term political stress, compared with options where supply to existing users must be reduced or reorganized. Politicians are used to resorting to overriding justifications that close or 'securitize' the debate. New projects are indispensable and cannot be delayed because 'poverty demands that we do something,' development is needed and requires 'sacrifice,' national or food security are at stake, or growing energy needs makes the development of hydropower 'unavoidable.' These concerns are legitimate and often truly pressing. But by closing the debate, decision-makers also make it impossible to discuss alternatives, to examine in detail the social and environmental costs of projects, and to reveal the frequent absurdity of supply augmentation projects when seen through the lens of investment costs (soon to become cost overruns).

But what we are concerned with here is the way the overdevelopment of water use infrastructure, principally irrigation schemes, generates scarcity. When most available resources are committed and little 'slack' remains in the hydrological regime of a particular river basin, any substantial drop in available resources below average values is likely to result in shortages for some users. With a climate change-induced growing hydrologic variability, combined with a tendency to mismanage carry-over stocks in reservoirs (managers being under pressure to generate electricity or to release water at the cost of mid-term reserves and security of supply), the frequency and intensity of such shortages are increasing. Resulting crises call for more water to be tapped, and new water development generally comes with expansion of irrigation: new irrigated areas are often necessary to make the project economically more attractive and also to 'buy' provinces or populations that will be affected by new impoundments or projects and that want to be compensated. The vicious cycle of overdevelopment thus becomes self-sustaining. This process is illustrated here by the Chao Phraya (northern/central Thailand) and the Chi-Mun (Northeast Thailand, or Isaan) River basins, by far the largest basins in Thailand.

In the Chao Phraya River Basin, large-scale development started in the delta (where Bangkok is located) in the 19th century. State-led dam and irrigation development during the second half of the second century gradually spread over the basin: public irrigation developed in intermountain valleys of the northern part of the basin, in the large plains of the middle-basin, and dams closed–one by one–most of the main tributaries. Only flood water–mostly in monsoon times–or heavy rainfall in the lower part of the basin cannot be captured. In the dry season 85% of resources are depleted and outflow to the sea is close to (and sometimes below) the discharge needed to control saline water intrusion in the estuaries. Overbuilding is manifest in the sense that Bangkok will soon receive half of its water from a transfer from the adjacent Mae Kong Basin; that all the medium-scale dams (Pasak, Nakhon Nayok) constructed on the remaining sites and which could have eased the situation of shortage are accompanied by additional irrigation areas that commit the new water made available; and that the percentage of land irrigated in the dry season is only roughly half of the total area. The latter situation is partly explained by the fact that development of 250,000 ha of irrigated land in the middle-basin was predicated on bringing security to wet season rice only. It was recognized at the time that dry-season water was already committed to the delta and that benefits would be meager, but funding for the project was nevertheless secured from the World Bank (which later admitted that the basin was 'overbuilt.'

In the current situation, all the water released from the dam in the dry season is committed and cannot meet the potential demand for dry season irrigation (including from those in the middle basin who–on paper, at the time of project design-were not supposed to receive water but later claimed equality of treatment), a demand that is gradually reduced by the needs of cities. Instead of recalling that background and explaining the physical limits of the water that can be supplied to irrigated schemes, managers and politicians use the shortfall to constantly reinvent their 'hydraulic mission.' This implicit mission, vividly expressed in official public declarations, is to bring water to farmers or to control flood damage. Costly interbasin-transfers to convey water from the Salween River to the Ping River (an upper tributary of the Chao Phraya) through a tunnel, which had been put on the backburner because of extremely high costs, have recently been endorsed by the government (the project is estimated at US$1.33 billion; Eakachai, 2008). The Keng Sua Teng dam on the Yom River, the only main tributary undammed, is also back on the agenda, although studies have long shown that its impact on flood was negligible.

As part of the larger Mekong Basin, the Chi-Mun River Basin (northeast Thailand) was studied by the surveys carried out after the Second World War, based on the assumption that 'multipurpose development of water resources was needed for economic development' (e.g. USBR, 1965). Following mainstream recommendations, irrigation water storage in the Chi-Mun River Basin was raised by 6 billion m^3 between 1965 and 1975, harnessing most main tributaries with suitable dam sites. Facing a lack in possible additional storage, and increasing opposition to large dams, state agencies had to turn to developing small- and medium-sized structures, including hundreds of pumping stations serving areas of 500 ha on average. Initially it was believed that these projects would 'not cause water shortages downstream' (ESCAP, 1991), and that no further construction of storage or flow regulation was needed, although some consultants had reported earlier that 'water requirements of the schemes (were) greatly exceeding the unregulated flow' (NEDECO, 1982). By 1992 the state started to implement the Khong-Chi-Mun irrigation project, aimed at promoting irrigated agriculture by diverting water from the Mekong River to 780,000 ha of additional farmland (Sneddon, 2003), with water stored in several 'weirs' to be constructed on main rivers.

The constant drive to develop new sources of water to augment irrigation supplies has left the Chi-Mun Basin heavily developed, and in parts overdeveloped. In 1995, a study on the Mun Basin (Binnie and Partners, 1995) concluded that 'water shortages regularly occur in a majority of irrigation schemes during the wet season, even though many schemes are only used to 70 percent of their designed command areas.' Furthermore, the report estimated that 'the basin’s water resources will be able to support an average of 11 percent dry season cropping' and that the potential for agricultural development had 'previously been overly optimistic, with an average of less than 5 percent dry season cropping (observed) across the basin.' Although resulting from flawed planning, this situation is used to justify bringing water from the Mekong at extraordinary costs and expanding irrigation areas. The Thai National Mekong Committee (TNMC, 2004) recently claimed that within the Chi-Mun Basin some 427 projects with a potential irrigation area of almost 400,000 ha are possible, and in 2003, the Government of Thailand announced the 'Water Grid' project, a US$5 billion project aiming to divert water to unirrigated farms (Molle and Floch, 2008).

Water scarcity and farming system dynamics

Perceived water scarcity is very much dependent on the degree of reliance of farmers on water. Scarcity induced by the overcommitment of water will manifest itself through a lower cropping intensity, or by crops being grown under rainfed conditions. Farmers will not be able to grow two or three crops as they might desire. But in Thailand as in many other places, no promise has ever been made on how many crops farmers would be able to grow, or on which water rights they would be granted. In that sense water scarcity is relative and depends on farmers' expectations as well as on the alternatives available to them. In a context of closed agricultural frontier and insufficient alternatives, agrarian pressure is first driven by the intergenerational division of land. This division is limited by the 'carrying capacity' of the land, which is tightly related to its access to water.

A comparison of the evolution of three different villages in the Chao Phraya delta with cropping intensities of 2.7, 1.6, and 1.05 has shown that family farm size tended to level off at a level dictated by this cropping intensity; farmers with better access to water were able to intensify and to live better with smaller farms (Molle et al., 2002). But this state of affairs was also modified by the existence of alternative occupations. Where water conditions were poor, farmers diversified their livelihoods, including work by some family members in nearby factories, handicrafts, or animal farming. When livelihoods are diversified, less importance is given to water, fewer people have any expectation of growing a second or third crop, and the sense of scarcity is somehow dampened.

When only rare economic alternatives are available in the local and wider economy, an agrarian crisis occurs. This is what happened in northern Thailand in the 1960s and in central Thailand in the 1970s. In northeast Thailand, water scarcity is much higher than in the Chao Phraya Basin, but the main response to agrarian saturation has consisted of migration to Bangkok (and more recently to the Middle East). The physical limits of the region alongside off-farm labor opportunities in the region and further away mean that the expectation of farmers concerning dry season cropping is generally limited to a small plot of cash crops watered from farm-ponds or with groundwater. While the average farm-family size is shrinking, younger generations are increasingly opting for off-farm and nonagrarian jobs in the wider economy, thereby leaving the rural structure older and more feminized. This is most readily felt in times of peak labor demand during transplanting and harvesting of rice, when laborers from neighboring Lao PDR are filling the void. On a regional scale, it has been shown that four distinctive potential constraints limit the conceived potential for further irrigation development in the Chi-Mun Basin: the lack of water that can be mobilized in a cost-effective way, the limited availability of labor, the pervasive soil salinity problems, and market constraints to intensification and diversification (Molle and Floch, 2008).

Comparison of three pump irrigation schemes on the Lam Se Bai River, north of the provincial capital of Ubon Ratchathani, revealed that access to water is important in the rate of intensification of farming and farms, and that the average farm size tends to be smaller where access to water is more stable. But this, similar to the Chao Phraya, highlights the dilemma of water control in the Chi-Mun Basin. Better access to water is, in most cases, marginally impacted by large-scale hydraulic infrastructure, and dry season irrigation is more a function of location and topography, and favorable access to urban markets (often niches of vegetable products). These areas have, of course, been long developed while later settlements were often located in areas marginally suitable for irrigation development.

Conclusions and recommendations

Resource scarcity has many dimensions, including physical, hydrological, socioeconomic, and political. The imbalance between 'supply' and 'demand' is not just the mechanistic result of population growth. We argue that in many cases the overdevelopment of irrigation facilities is the determining factor of water scarcity. The societal mechanisms that favor and breed water resources development, including a conjunction of positive incentives to most powerful actors, fuel the expansion of irrigation. Hydrologic variability works to create recurrent instances of shortage while the need to intensify cultivation on dwindling farm size calls for increased supply. Both factors militate for more water resource development, which, to be economically attractive or as a compensation to provinces impacted by new water impoundments, generally includes new irrigation areas.

This self-sustaining cycle of human-made scarcity and overcommitment of water resources can only be broken by the realization that its pursuance becomes absurd in economic and environmental terms, and by the provision of alternative economic opportunities to rural populations (diversified livelihoods and migration). As the situation of northeast Thailand shows, even where this is the case, the political and financial interests linked to supply augmentation remain strong and sustain populist discourses that promise to 'green Isaan' and bring water to each farm. Thus, although farmers' perception of water scarcity is linked to the relative importance of irrigated farming within their livelihood systems, scarcity as manufactured and used by decision-makers partly ignores these differences. Both dimensions of scarcity are purely societal, although their economic and political dimensions are generally obscured by efforts to blame natural phenomena for crises. Attention to these two dimensions is needed to improve the analysis of purported crises and the soundness of the responses proposed.

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Dykes, dams, drains, and diversions: the promise of flood protection

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Abstract

The way societies respond to flood disasters is strongly influenced by social and infrastructural legacies. A recent history of reliance on dykes, dams, or diversions strongly shapes current perceptions of risk. Society often turns expectantly toward experts following disasters and 'close-calls.' Experts–especially, holders of technical knowledge about drainage, hydrology, and climate–are widely perceived as key to flood and disaster management. The promise of flood protection is a key part of the rationale of many projects and a political opportunity. This paper focuses on the way decisions are being made around large-scale flood protection interventions in the Mekong Region, drawing on case studies in Thailand, Vietnam, and Cambodia. We draw three main conclusions. First, the inputs of experts are diverse, important to reducing risks of flood-related disasters, but insufficiently elaborated and discussed in the public domain. Second, and as a consequence, these inputs are easily distorted in policy and practices, and projects in the end often fail to consider side-effects of interventions on wetlands, rural livelihoods, and dry season water flows. Third, public deliberation on the merits of interventions, especially new risks they create or old risks they redistribute, is rare and does not adequately consider the complementary value of different sources of knowledge.

Media grab

The promise of flood protection is frequently made with insufficient public scrutiny of risks, uncertainties, and possible adverse side-effects on others.

Introduction

Governments frequently make promises to their citizens about their intentions to protect their subjects from floods. Dams, dykes, drains and diversions are widely seen as key to reducing risks of flood disasters. Flood management is viewed as a technical, apolitical, exercise in which issues of differential vulnerability and redistribution of risks are avoided (Lebel and Sinh, 2007). But many cities now face increasingly difficult flood management challenges as they expand into flood-prone areas and place valuable property and disadvantaged communities at risk. Costs of damage and protection are rising (Takeuchi, 2001). Instances where flood protection seems to make things worse, and promises were not kept, are multiplying. More and more people are becoming aware of the unanticipated side-effects of flood protection measures on wetlands, river ecosystems and livelihoods of people who depend on them. The net consequence is that the public is increasingly asking questions about who really benefits and who is paying for protection(Lebel et al., 2006). This paper explores how decisions are made about flood protection measures for major cities in the Mekong region.

Methods

This paper draws on experiences in five case studies of flood protection for the cities of Chiang Mai and Bangkok in Thailand, Hanoi and Ho Chi Minh in Vietnam, and Phnom Penh, in Cambodia. The five case studies collected information against a common protocol that specified gathering descriptive information about existing flood protection and plans, and asked a series of questions for analysis about the role of experts, organizational interests, and social-ecological legacies. The data gathering activities for each case study varied somewhat depending on amount of prior collated information available, but often included government project and planning documents, technical and academic reports, newspaper articles, and in-depth interviews with officials with experience in flood management in those cities. Our primary analytical methods were stakeholder and discourse analyses. Our stakeholder analysis focused on understanding interests and influence including inaction of different actors in alternative flood protection projects. In discourse analysis our aims to identify the core messages in what different actors say or write and whether this changes with circumstances. This paper reports on progress of this ongoing study.

Results and discussion

Experts

In much of Monsoon Asia river-bank, overflow floods are a normal seasonal event, and intense rainfall events not unusual. But attitudes toward floods have changed as urbanization unfolds around capitals and other major cities. Demand for flood protection increases and so do the costs and technical challenges of trying to meet some of those demands. Society often turns expectantly toward experts following disasters and 'close calls.' Experts are widely perceived as having a major role in identifying options for flood and disaster management. But frequently, the simplest explanation given by the experts is often not what others like to hear: it rained a lot.

The political imperative is to be perceived as acting. Once promises to protect have been made, bureaucracies and consultants take over. The kinds of experts invited to task forces or to submit project proposals are usually from a relatively narrow set of water management backgrounds. Social and environmental scientists are rare, and usually only there to meet peripheral requirements in an impact assessment process. As a result other contributions apart from infrastructure to reducing flood disaster risks have been neglected. Only in recent years have countries started to develop more systematic early warning systems and disaster preparedness programs involving local communities. Much of the 'software' is coming from newly created disaster agencies and not always well integrated with the 'hardware.'

The Vietnamese Government has a challenging task of protecting the rapidly urbanizing region around Hanoi given the huge seasonal differences in the water levels of the Red River. A series of major dykes, some as high as 15 m, have been developed in the region over centuries. Water levels in many places are now regularly much higher than where people live and farm. The current policy to protect the capital Hanoi from large floods by retaining water in the upper regions and diverting excess flood waters into neighboring areas has been in place since after the historic high flood of 1971. When it was originally introduced, central decisions were implicitly followed at local levels. Today, local government and society in flood diversion and retention areas have more negotiating power in the decision-making process to divert excess flood waters, given infrastructure is available. Negotiation of compensation is not well documented but appears to be largely a technical and closed exercise involving scientists in the field and the Provincial People's Committee (PPC) of the potentially affected provinces (DDMFSC, 1999). In 1999, under increasing political pressure to protect Hanoi as a result of concerns with unpredictable flood heights, the Government of Vietnam issued important regulations that include, as a last resort, emergency response actions for when flood level of the Red River in Hanoi reaches 13.4 m. These would involve upstream diversion of flood discharges to primarily the provinces of Ha Tay, Vinh Phuc, Phu Tho, Ha Nam, and Nam Dinh. Diversions into the Day River are decided by the Prime Minister. It is estimated that as many as 675, 000 people would be affected by such diversions (Xuan, 2006). In contrast to Vietnam, Thailand has been without a clear system of compensation when diversions to protect Bangkok result in crop losses, resulting in avoidable suffering and conflict.

Dams, dykes, and diversions can create a vicious cycle in which the promise of protection leads to more risk-taking behavior with the net result that risks and vulnerabilities overall do not fall. Dykes and river walls, like upstream dams, alter risk-taking behavior. People build where they wouldn't otherwise as they misjudge risks of structural failures, and also that heights and capacities might be exceeded. Perceptions about risk are an important factor in their redistribution. Poor perceptions of flood disaster risk appear to be creating a dangerous situation (Hung et al., 2007). Rapid urbanization around Hanoi has led to settlements in river side floodplain areas outside the protective system of dykes, first by poor people and migrants, and more recently, wealthier people (Hung et al. 2007). The riverside settlements have reduced flood plain widths and consequently may also be increasing flood vulnerability for the entire city (Hung et al., 2007). Some agencies believe that the Son La Dam and afforestation works in upstream areas of the Red River will reduce risks.

Storage dams rarely provide as much flood protection as the promises made about them. One reason is that as multipurpose infrastructure there are trade-offs in operations, for example, between minimizing flood risks, especially near the end of the wet season, and keeping storage levels high to maximize dry season irrigation requirements.

Incomplete and poor sewerage and drainage systems are an important cause of floods in Ho Chi Minh City. Some streets and residential areas with no storm drains at all quickly become small rivers after even fairly modest rainfall. In Chiang Mai, problems arise because of weak coordination among line agencies. Roads interfere with drainage, and bridges carry water over irrigation canals into residential areas. Coordination is particularly difficult for non-capital cities without powerful municipal or metropolitan authorities. Experts in Vietnam and Thailand have encouraged more attention being paid to wetlands within built-up areas as storage and more infiltration areas, to compensate for losses in runoff from growth in impervious surfaces with construction.

New risks, new opportunities

One of the difficult challenges for experts is that flood regimes are changing in difficult-to-predict ways. Land-use changes within the basin can have major implications for how much water will runoff, where it will pond and stay, or flow. Climate is also changing further complicating assessments of risks and the robustness of long-term infrastructure-based strategies.

Massive infrastructure projects have been proposed to protect Bangkok from sea-level rises caused by climate change. A recent example, launched by disaster experts and politicians, was a proposal to build an 80 km long wall 300 m offshore and 3 m higher than moderate sea-level to protect Bangkok and two surrounding provinces (Wipatayotin, 2007). Smith Dharmasorjana, Chairman of the National Disaster Warning Committee of Thailand, believes that a system of dykes offshore is needed to protect areas of Bangkok from sea-level rises caused by climate change as well as intrusions of sea water into major rivers (Bangkok Post 2008).

The problem is not that experts make plans or are not able to reduce risks in particular places, but that the promise of flood protection often comes with side-effects for other places and people. Risks not only get reduced but they also get redistributed. In Bangkok dykes and flood walls increase impacts of floods in other locations, effectively shifting risks to those not living in or near the more central parts of the city or in lower-lying areas. Residences in eastern Bangkok, for instance, suffer from deep and lengthy inundation (Dutta and Tingsanchali, 2003). Those without economic capacity to invest in elevated buildings and other local flood protection measures, like pumps, face greater risks. Ultimately experts are a diverse group, varying in how closely their interests are steered by the organizational and power structures they belong to, and how broadly they are allowed to frame problems of flood management–as 'protection' or 'prevention.'

Organizational interests

Although the detailed structure of water agencies varies among countries, there are always some agencies and coalition of associated consultants, firms, and banks whose primary interest is in construction. The views of independent experts are constrained and even subservient to recalcitrant organizational interests. Projects that make something tangible, create work, can be subsequently owned and controlled by an organization. Projects that allow individuals to control resources are pursued because of the political power they bestow. Benefits and risks of a project are only of concern when they stand in the way of getting authority over funds. Floods and disaster are political opportunities to produce projects. Projects do not have to be new; indeed it is not unusual for floods to be turned into political opportunities to dust off old proposals for funding. Many flood-astute actors know quite well that nobody is against safety and protection.

Capital city administrations are powerful and can shape flood management policies of national departments and agencies. The Bangkok Metropolitan Authority (BMA) pursues essentially a zero tolerance flood policy despite the implausibility of such a strategy and the difficulties this creates for upstream and surrounding areas managed by the Royal Irrigation Department (RID). The BMA infrastructure for preventing flooding includes protecting the new Suvarnabhumi airport that was built flouting the advice of environmental experts in the middle of one of the largest wetlands in the region, thus creating another huge set of flood risks and burdens for other parts of the city. Apart from organizational interests, therefore, much more particular elite political interests within the BMA's jurisdiction have had a major impact on who gets flooded and who is placed at risk. Secondary cities like Chiang Mai and small rural towns are in a much more uncertain relationship to national bureaucracy and politics.

Social-ecological legacies

The floodplains upstream and around our five case studies have each been transformed by human activities, both profoundly and for a very long time. Hanoi of course has the most obvious historical legacy in the Red River system of dykes, with the entire surrounding landscape transformed to regulate floods. Culture, social institutions, and norms has probably evolved in parallel with the hydrological landscape. These social-ecological legacies constrain and influence approaches to flood management today.

Bangkok, more than any other city, has acquired its flood protection system largely by fragmented accumulation. After major events, different parts of the city take action, acquiring pumps, building canals, and river walls or dykes. Canals and rivers that were once used for transport are now walled storm drains. Adding new measure in such a complex system invariably creates side effects for others on the wrong side of the wall, end of the tunnel, or receiving end of a drain. Each new intervention triggers a series of compensatory responses, operational and infrastructural. Some are undertaken by state agencies over larger areas, while others are done piecemeal as individual properties lift themselves higher above the floodplain.

The traditional muang-fai irrigation system using canals and weirs is a legacy the Chiang Mai municipality is struggling with. On the one hand there is a nostalgic interest in preserving aspects of local culture; on the other hand, some of the weirs and canals contribute to flooding parts of the city. While formerly diversion of abundant wet season flows in the Ping River for growing rice made a lot of sense, it does not fit new suburban housing and lifestyles anymore.

Conclusions and recommendations

The promise of flood protection is easy to make, but harder to keep. Promises pursued in concrete – as dykes and dams, drains and diversions–regularly exaggerate benefits and ignore side effects on other people and the environment. Promises of protection and how they are pursued, it turns out, are better explained in terms of beliefs, interests, and power than efficacy in reducing risks. This does not imply that infrastructure has no role in flood management, but it does underline how frequently the promise of flood protection rings false.

The high costs, unintended side effects, and fallibility of infrastructure-centered approaches inherent in pursuing promises of flood protection imply that flood management needs to be redirected. Land-use planning, both in terms of uses of floodplains, and in the way different vegetation covers use water in the wider landscape, both need much greater emphasis. Ecosystem-informed approaches that make room for water outside and within urban areas should be explored, especially in highly flood-prone areas where full prevention is not a plausible option. Many people in monsoon Asia already know a lot about living safely with seasonal flood cycles. This expertise and perspective should be part of flood planning in urbanizing regions. In many areas greater investments in early warning systems and community-oriented disaster preparedness may do more for reducing vulnerabilities and risks than a narrow adherence to a logic of control, prevention, and protection. But such alternatives are only likely to emerge as part of wider flood management strategies with changes to current governing practices. Much greater opportunity for public scrutiny of proposals and deliberation of alternative approaches to flood management is needed.

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Evolution of managing water for agriculture in the Indus River Basin

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Abstract

The weir-controlled irrigation system development of the Indus Basin started in the mid 19th century, and has limited capacity for further development. Groundwater has also been developed and even overexploited in many parts, despite having quality (salinity) problems. The management of surface water is weak, however, lacking transparency and accountability, leading to inequitable and unreliable supplies in the lower reaches of the system, while there is no rule or control over groundwater use. The cropped area and production of major crops has increased greatly but both land as well as water productivity is much lower than potential. Improved and innovative management techniques and technologies should be employed at all levels to meet the food requirements of the increasing population, and supporting the 70% of the population dependent on rural livelihoods, and the national economy.

Introduction

Though the Indus River waters have been in use for irrigation for centuries through inundation canals, most of the present irrigation system was developed during the 19th and 20th centuries with the introduction of modern engineering and diversion works across the river beds (Khan and Muhammad, 2000). The construction of two major reservoirs and a network of inter-river-link canals during the 1960s and 1970s not only increased water supply and its reliability, but also increased the cropping intensities and productivity. The average annual water available in the river system is 165 billion m3 (BCM), of which 130 BCM is diverted into irrigation systems and 35 BCM is released to the sea for environmental reasons. The boom in groundwater development going on for the past 40 years has not stopped despite groundwater depletion and quality problems in many areas (Habib, 2004). The number of tubewells has swelled from a few thousand during the creation of Pakistan in 1947 to more than 0.9 million in 2004. Most of these tubewells are concentrated in Punjab (91%) where more than 99% are privately owned and operated by farmers (World Bank, 2005).

This paper looks at various developments that have taken place in the water sector of the Indus Basin, how has it helped increase production and brought more area under irrigation, and what the challenges are to overcome the food crises and livelihood issues of the dominant rural population of this basin.

Water management in the Indus Basin Irrigation System (IBIS)

The design of IBIS is protective in nature, with less flexibility in operations for covering about 80-100% of the total command area in a year or two of crop seasons. The provincial irrigation departments are responsible for managing the available waters of their share, while the Water and Power Development Authority (WAPDA) has been operating the Mangla and Tarbela reservoirs under the Indus River System Authority (IRSA). Severe shortages in irrigation supplies during rabi (winter) season have been eased to a great extent after construction of the Mangla and Tarbela reservoirs (Table 1).

Table 1. Water supply (BCM) improvement after Mangla and Tarbela reservoirs.

	Pre-Mangla (1940-41 to 1966-77)	Post-Mangla (1966-69 to 1976-77)	Post-Tarbela (1976-77 to 1993-94)	% increase post-Mangla	% increase post-Tarbela
Kharif	63.96	81.18	83.64	26.92	30.77
Rabi	29.52	36.90	46.74	25.00	58.33
Annual	93.48	118.08	130.38	26.32	39.47
Average					42.86

Source: Water Resources Management Directorate, WAPDA.

Water supplies increased by about 25% after construction of the Mangla reservoir, while the Indus River contribution increased by more than 58% during the critical rabi season after the construction of the Tarbela reservoir. Post-Mangla increases in the average seasonal discharge have not varied much, and have been 25% in rabi and 26.9% in kharif (summer). The post-Tarbela discharge increased by 58% in rabi and 31% in kharif. Since their completion, the two reservoirs have lost about 4.9 BCM or 23% of their combined original gross storage capacity (WAPDA, 2002).

Canal withdrawals have been increasing during both seasons from 1949 to 1967, mainly due to the construction of new irrigation canals. Canal diversions during 1940-75 for the winter season have been less than half of the summer season, which improved by more than 10% after Tarbela reservoir started operation (Figure 1). Kharif diversions have increased from 58.8 BCM in 1940-47 to about 82.7 BCM in 1975-95, an improvement of about 41%. Rabi supplies have almost doubled from 24.9 BCM in 1949-47 to 46.47 BCM after 1975, an increase of 87%. Annual withdrawals have improved by 55%.

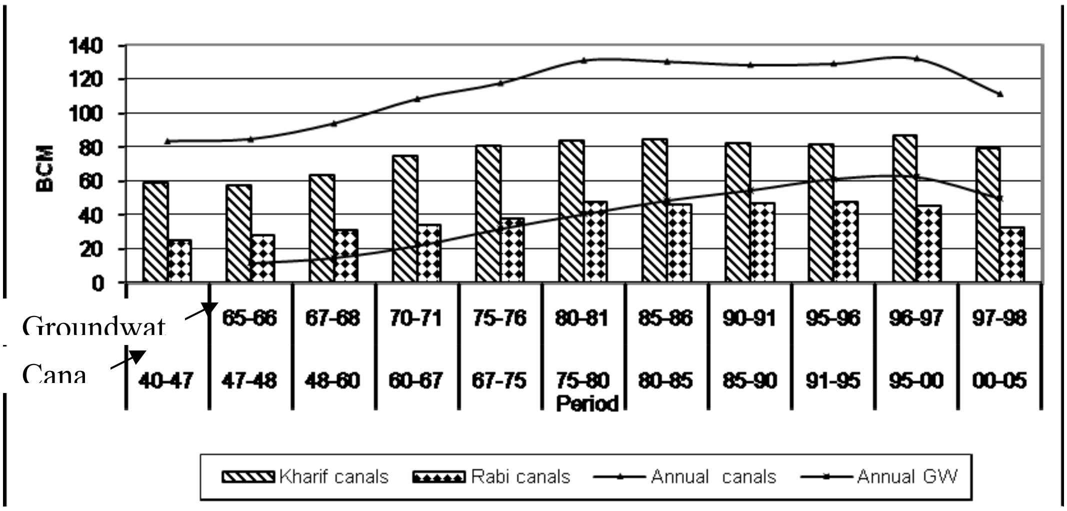

Figure 1. Surface and groundwater development in Indus River Basin.
(Source: Water resources management directorate, WAPDA and Agricultural statistics of Pakistan, Ministry of Food, Agriculture and Livestock, 1998.)

Groundwater irrigation has been progressively increasing from 11.3 BCM in 1965-66 to 52 BCM in 1996-97 (Figure 1), an increase of more than 450% over 31 years. A decline of 13.6 BCM was observed during 1997-98 due to withdrawal of a government subsidy on electricity tariff, and an increase in diesel prices along with abandonment of public tubewells due to high operation and maintenance costs (Randhawa, undated). There was a steady increase in groundwater irrigation from 28% in 1967-68 to more than 400% in the mid 1990s, despite substantial surface water irrigation systems and storage developments. The contribution from tubewell irrigation was about 10% of canal diversions in 1965-66, and gradually increased to about 48% in 1996-97.

Effect on cropped area and production

As a result of surface and groundwater development, cultivation of major selected crops increased from 10.76 million ha during 1971-75 to about 15 million ha during 1991-95. Sugarcane cultivation has substantially increased from 0.61 to 0.93 million ha. Cotton area improved by 44% while wheat and rice area improved by 39% each (Table 2). Similarly, the production and yield of the four major crops (wheat, rice, sugarcane, and cotton) substantially increased over the past 40 years. Wheat production increased by 438%, rice 291%, sugarcane 107%, and cotton 368%. Yields of these crops have also improved considerably, but is proportionately much lower than production. Wheat has the highest increase in yield of 228% during 1965-66 to 1999-2000, while sugarcane has the lowest increase of 23% during the same period (Table 3).

Table 2. Cropped area of selected crops in Indus Basin irrigated agriculture.

Crop	Cropped area (mha)					Increase (%)
	1971-75	1976-80	1980-85	1986-90	1990-95	1971-75 to 1990-95
Wheat	5.93	6.49	7.24	7.60	8.06	36
Cotton	1.92	1.91	2.22	2.53	2.76	44
Rice	1.51	1.88	1.98	2.01	2.10	39
Sugarcane	0.61	0.76	0.90	0.82	0.93	52
Oilseeds	0.59	0.53	0.41	0.41	0.61	4
All fruits	0.20	0.26	0.36	0.44	0.50	150
Total area	10.76	11.83	13.11	13.91	14.96	39

Source: Agricultural statistics of Pakistan, Government of Pakistan.

Production of major crops has kept pace with population growth as shown in Figure 2. In cereal crops, wheat production has almost doubled, from 77 kg per capita in 1965-66 to 153 in 1999-00. Rice has increased from 27 to 36 kg per capita during the same period. In cash crops, sugarcane production has not been matching population growth, while cotton has increased from 8 to 14 kg per capita during 1965-66 and 1999-00.

Table 3. Increase in production and yield of major crops (production million tones, yield tones/ha).

	Wheat		Rice		Sugarcane		Cotton	
	Prod.	Yield	Prod.	Yield	Prod.	Yield	Prod.	Yield
1965-66	3.92	0.76	1.32	0.94	22.31	37.37	0.41	0.25
1999-00	21.08	2.49	5.16	2.05	46.33	45.9	1.92	0.64
% increase	438	228	291	118	107	23	368	146

Source: Agricultural statistics of Pakistan 1999-2000.

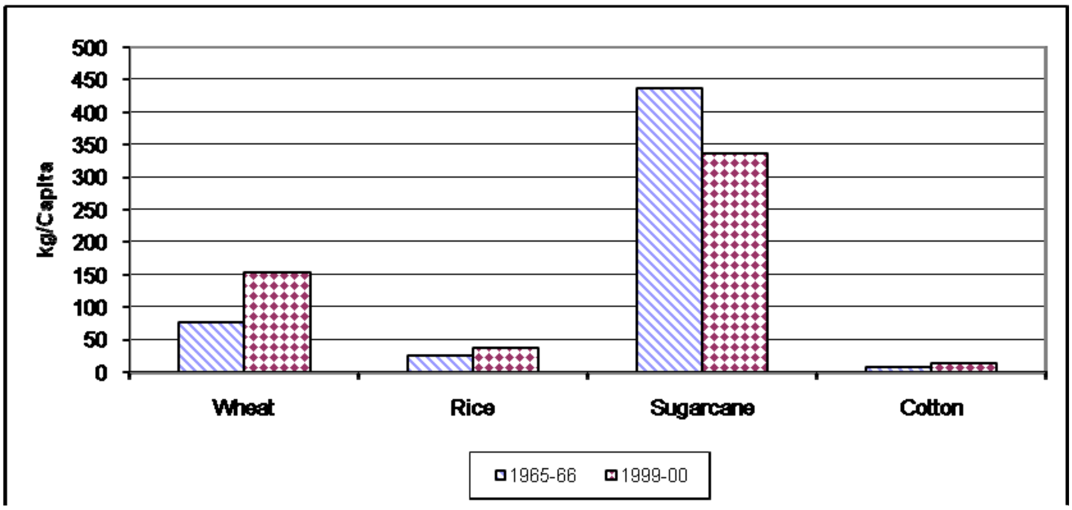

Figure 2. Comparison of major crop production and population growth from 1965-66 to 1999-00.

Contribution of irrigated agriculture to Pakistan economy

Irrigated agriculture of the Indus Basin is considered the backbone of the economy, earning about 60% of foreign exchange every year. Cotton, rice, textile, and leather products are the major exports of Pakistan from the agriculture sector, contributing 24% to the country's economy. It also feeds almost the entire population and provides employment to more than 47% of the work force (www.economyofpakistan.com). The rural population, which makes up about 70% of the total population, predominantly relies on agriculture for its livelihood.

Interventions

Besides the construction of new irrigation canals, reservoirs and inter-river link canals, Pakistan implemented several salinity control and reclamation projects (SCARPS) of vertical and horizontal drainage for lowering the water table, and controlling salinity in the waterlogged areas (Hussain et al., 2001). The massive projects of the National Drainage Program (NDP), Left (LBOD) and Right (RBOD) Bank outfall drains, are recent efforts to provide the essential drainage to the irrigated lands. The 0n-Farm Water Management (OFWM) program for partial lining of the tertiary irrigation canals has been going on since the mid 1970s to control seepage and improve water delivery to the lower reaches. The creation of IRSA in 1992 is aimed at fair regulation and distribution of water among the provinces according to the Water Apportionment Accord of 1991. Provincial Irrigation and Drainage Authorities (PIDA) were established in 1997 to involve water users in water management, and to introduce financial autonomy through creation of water user associations (WUAs), farmer organizations (FOs), and area water boards (AWBs). These are moving slowly due to lack of commitment. Water conservation technologies like bed-furrow, raised beds, zero-tillage, laser land leveling, and dry-seeding of rice have been introduced, but on a limited scale. Many attempts have been made to introduce pressurized irrigation systems but they have not been successful in large-scale adoption.

Issues and Constraints

Pakistan has become a water-stressed country where most of the surface and groundwater resources have already been exploited. Apparently there is no feasible intervention that would mobilize additional water (World Bank, 2005). The immense contribution of groundwater to agriculture in the Punjab is faced with serious challenges of declining water table, quality issues, and increasing cost of operation and maintenance of tube wells. The population of Pakistan has been increasing at an alarming rate of more than 2% over many years, and per capita water availability has declined from about more than 5000 m3 in 1947 to about 1200 m3 in 2006. At the same time, competition from municipal and industrial users is increasing: from 7.2 and 2.7 BCM in 2000, respectively, to 15 and 4.8 BCM in 2025 (Draft National Water Policy, 2002). With climate change effects on water availability, these factors pose a serious challenge to water planners and managers to effectively manage the available resources.

Lower than potential productivity of land and water due to lack of availability and access to modern technology, poor management practices, and unavailability of key inputs are key issues. Conservation technologies such as zero tillage, bed and furrow irrigation, and laser land leveling have been introduced, but their initial cost and lack of skilled personnel is constraining large-scale adoption. The absence of integrated water resources management is impacting productivity. Uncontrolled groundwater development and absence of any legal instrument for its management is facing quantity and quality challenges. Intrusion of saline water into freshwater aquifers, and pollution due to agricultural, industrial, and municipal waste have been taking place without checks or controls. Poor maintenance of the physical infrastructure, financial unsustainability, and negligence have deprived the water users of the lower reaches of their due share of water for many years. Lack of trust and transparency, and lack or absence of coordination among key stakeholders in the government and the private sector, are factors affecting water management.

Major initiatives

The Government of Pakistan has initiated a program of new dams (Basha, Akori, Kurram Tangi) for water and power development. A rehabilitation and modernization program of barrages and irrigation system has been initiated by the Punjab, Sindh, and North West Frontier provinces. Also, the federal government has launched two major projects of tertiary canals lining (US$1.1 billion) and pressurized irrigation systems (US$300 million) to improve productivity of agriculture. The Punjab has also introduced a crash program of providing 2500 laser land levelers at 50% subsidy to the farmers, with the goal of having at least one unit in each union council of the province.

Conclusions and recommendations

Scope for further development of water resources in the Indus Basin is limited, but there is tremendous potential for improving productivity of water and land by employing conservation technologies. A paradigm shift from supply-based to demand-based and integrated water resources management is essential to cope with increasing food demand, environmental issues, and economic pressure. Development of a legal and regulatory framework for managing groundwater is essential, and should be based on detailed pilot studies and ground realities. The half-hearted approach of involving end users in management and the decision-making process needs to be implemented with greater vigor and spirit, using lessons learned locally and internationally.

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A theory and practice of deliberative water politics for the Mekong Region

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Abstract

An infusion of deliberative water politics (DWP) is necessary for a shift in the Mekong Region that improves regional water governance. DWP refers to a type of political, multi-stakeholder engagement, drawing upon the schools of transnational discursive democracy and hydropolitics, which emphasizes deliberation as a way toward fairer and more effective water governance. Deliberative processes foster open, informed, and meaningful conversations among diverse stakeholders. By exploring a broader range of options, more comprehensively, they can extend and complement formal representative processes. DWP in the Mekong Region has been in short supply. A way of putting DWP into practice is to institutionalize deliberative examination of options through the analytical lenses of rewards, risks, rights, responsibilities.

Media grab

An infusion of deliberative water politics is necessary for a shift in the Mekong Region toward fairer and more effective water governance.

Introduction

A new water governance paradigm is needed in the Mekong Region to assist societies make better choices about how to allocate or share water for production of food and energy. On mainstreams and tributaries, disputes exist resulting from interventions to natural flow regimes and overt or default allocation decisions. These interventions are justified on grounds of: flood control, more irrigation for food or fiber production, urban or industrial supply, improving ease of navigation, or boosting energy production via hydropower. There are associated disputes about altered sediment and nutrient loads, groundwater use, water reuse, and diversions (inter-state, intra-state, inter-basin and intra-basin). Regional water governance is vital because many issues have many territorial, ecological, and political dimensions that are best managed via regional protocols, and rules. At present individual national interests prevail over regional interests (Hirsch and Morck-Jensen, 2006). The vaunted Mekong 'spirit of cooperation' often seems optimistically overstated (Dore, 2003).

Methods

Action research acknowledges the researcher has a normative purpose and a commitment to an adaptive, learning-based approach–for more than just the researcher. McNiff (1988) expresses it thus: 'The elegance of action research is that it possesses within itself the ability to incorporate previous approaches, simply because its focus rests on the enquirer rather than his methodology.' Active interviewing has played a key part in the DWP research. Saying this implies an acceptance by the researcher that interviews involve a construction of understanding or knowledge between the interviewer and the interviewee. More colorfully, Holstein and Gubruim (1995) say 'respondents are not so much repositories of knowledge–treasuries of information awaiting excavation–as they are constructors of knowledge in collaboration with interviewers,' and quotes Pool (1957): 'every interview (besides being an information-gathering occasion) is an interpersonal drama with a developing plot.' Conca (2006) might simply call these conversations with many people willing to discuss relevant issues, in an unstructured–which is not to say unfocused–way, devoid of questionnaires and formality. His conversations are active interviews that formed the 'soul' of his learning and analyzis in an excellent recent book on water governance: 'I think of the various documents, statistics, and scholarly works in the pages that follow as the supportive skeleton and tissue of the argument presented here, and of these conversations as its soul.'

The research and learning that has contributed to my development of a theory and practice for deliberative water politics in the Mekong Region has also involved extensive active interviewing, discussing issues with people keen to actively engage in an exchange of information and views. The research, however, has also involved extensive engagement in political decision-making, which is extremely undeliberative, which has energized experimentation with and exploration of more deliberative, informing possibilities.

The Mekong Region refers to the 'territory, ecosystems, people, economies and politics of Cambodia, Lao PDR, Myanmar, Thailand, Vietnam and China's Yunnan Province' (Mingsarn Kaosa-ard and Dore, 2003). This territory includes major river basins such as: Irrawaddy, Salween, Chao Phraya, Mekong (and sub-basins such as Sesan), and many other smaller basins.

Discussion

Deliberative water politics

Elsewhere I have argued multi-stakeholder processes and platforms have unfulfilled potential in the Mekong Region (Dore, 2007) to improve regional water governance. More specifically, I argue for an infusion of deliberative water politics (DWP): a type of political, multi-stakeholder engagement, drawing upon the 'schools' of transnational discursive democracy and hydropolitics, which emphasizes deliberation as a way toward fair and effective water governance. Deliberative processes foster open, informed, and meaningful conversations among diverse stakeholders. By exploring a broader range of options more comprehensively, they can extend and complement formal representative processes.

Rooted in deliberation

This vision of DWP is rooted in deliberation. Democratic theorist Simone Chambers (2003) has provided a precise definition of deliberation, with which I agree: 'Deliberation is debate and discussion aimed at producing reasonable, well-informed opinions in which participants are willing to revise preferences in light of discussion, new information, and claims made by fellow participants. Although consensus need not be the ultimate aim of deliberation, and participants are expected to pursue their interests, an overarching interest in the legitimacy of outcomes (understood as justification to all affected) ideally characterizes deliberation.' DWP aims to institutionalize deliberation in water-related decision-making.

Part of governance

My vision of DWP is that it is only a part of the larger topic of governance. In the English language governance, as a word, has been around since the 14th century. After a lengthy period of being rather unfashionable, it has experienced a recent renaissance authority and scholars have lessened their over-focus on the role of the state. A reasonable view is that governance: 'has become something of a catch-all to describe the ways in which the activities of a multitude of actors, including governments, non-government organizations (NGOs) and international organizations, increasingly overlap. It describes a complex tapestry of competing authority claims' (Mehta et al., 1999).

Governance refers to the multilayered interplay of negotiations, agenda-setting, preference-shaping, decision-making, management, and administration between many actors and organizations in the state-society complex, at and between different levels and scales, vying for authority or influence, constrained or enabled by institutions.

Transnational, discursive, democratic

My vision of DWP also owes much to the transnational, discursive democratic theory being developed by John Dryzek (1990, 1999, 2000, 2006), which resonates well in contributing to a theory of political engagement that could, if enacted, improve regional water governance. Key elements of Dryzek's conception of transnational discursive democracy are that it be: (1) transnational, transcending state borders, and reaching into areas unregulated–or at least, often less regulated–by state frameworks; (2) communicative, if ever we are to approach widespread understanding of complex issues and perceptions–'about communication as well as voting, about social learning as well as decision making' (2006); (3) pluralistic 'in embracing the necessity to communicate across difference without erasing difference'; reflexive 'in its questioning orientation to established traditions'; dynamic, being responsive to 'ever-changing restraints upon and opportunities for democratisation' (2000); and (4) social-cultural-economic-ecological–recognizing that sustainability has many elements.

Concerned with influence and authority

DWP is more concerned with creating political space for influence, via democratic processes, but is also concerned with the establishment and conferring of authority. Cosmopolitan democrats, according to Dryzek (2006), focus their efforts on the establishment of formal institutions with decision-making authority and establishing models of democracy. Discursive democrats have a different emphasis, theorizing or demonstrating democratic processes that may have influence without necessarily having authority. Conca (2006), via his examination of water-related transnational politics and global institution-building, is another who has provided insights and inspiration to my work: 'The presumption that states, and only states, are the authoritative agents of governance holds constant, at one extreme end of the spectrum, a key group of variables related to the constitution, distribution, and legitimisation of authority. We can conceive of institutions that construct more complex, heterogeneous, or fluid spaces for the exercise of authority, but such institutions would not be regimes as typically designed by diplomats, understood by participants, or interpreted by scholars.' I argue that DWP can be an influential pathway for the construction and use of innovative institutions to overcome some of the present deficiencies in regional water governance.

Hydropolitical–multiscalar and wide ranging

DWP, as the name conveys, explicitly brings in 'the political' and in so doing must acknowledge its debt to the schools of hydropolitics, which for Turton (2002) is all about 'authoritative allocation of values in society with respect to water, at different scales, taking into account a wide range of issues, actors and institutions.' Turton's emphasis on scales (his 'vertical dimension') and range ('his horizontal dimension') is important and I willingly incorporate it into DWP. It is a progression and broadening of the hydropolitics concept beyond the common focus on state actors and the international scale. Turton recognizes that hydropolitical analysis is pertinent at all scales 'from the individual, to the household, village, city, social, provincial, national, and international.' While he does not specifically mention it in the paper from which I have quoted, I am sure he would have no problem in also accommodating the basin, regional, transboundary and transnational, which are the scalar foci of my research work.

4Rs–rewards, risks, rights, responsibilities

A way of institutionalizing the theory of DWP and moving toward fairer and more effective water governance is to institutionalize the practice of deliberative examination of options through the analytical lenses of: (1) the rewards being sought from the use and further development of water resources, and the possible distribution of the full spectrum of the possible rewards/benefits/costs of various options; (2) quantification of involuntary and voluntary water-related risks; (3) clarification and protection of water-related rights; and 4) acknowledgment of various water-related responsibilities of state and non-state actors.

Concentrating on the 4Rs can keep it simple. In putting them forward I am building on the 'rights and risks' approach taken by the World Commission on Dams report (WCD 2000), in which the commissioners stated: 'We believe there can no longer be any justifiable doubt about the following: By bringing to the table all those whose rights are involved and who bear the risks associated with different options for water and energy resources development, the conditions for a positive resolution of competing interests and conflicts are created.'

For Achim Steiner, former leader of the WCD secretariat and now Director-General of the United Nations Environment Programme (2006+), the mainstreaming of the 'rights and risks' approach was a major achievement of the WCD, certainly a paradigmatic shift and an approach worth further developing and promoting. It represented a progressive evolution forward from decision-making relying too much on–at least for political or public justification, where required–often incomplete benefit-cost analyzes, focused on 'proving' there is net social benefit potential. The 'rights and risks' approach has been subsequently elaborated to 'rights, risks and responsibilities' (Bird et al., 2006). I suggest extending the approach further still, bringing in 'rewards', and rearranging the 4Rs in a way that seems to have a more workable logical flow: rewards→risks→rights→responsibilities. But, the important point is to cover all four, rather than overfocusing on the sequencing.

Deliberative deficiency in the Mekong Region

DWP in the Mekong Region has been in short supply. This is partly because proponents meet resistance from actors with vested interests who prefer to reinforce contexts that are unfriendly to DWP. Many actors still believe, or at least rhetorically pretend, that domestic criticism of public policy is unpatriotic. There is often an unhelpful conflation whereby dissent is mistakenly seen as synonymous with disloyalty. Equally problematic is when enquiry or criticism of water resources development plans, which impact across state borders, is seen as unacceptable encroachment on hard-won state sovereignty. The resistances to transnational deliberative politics should not be

Using the 4Rs as an entry point can be useful to highlight some demonstrated regional water governance deficiencies. For example, the Salween dams in Burma's Karen State, and others proposed in Kachin State, and further upstream in China have never been subject to a public analyzis of the rewards, or justifications, for the projects. Impact assessments if done, are not in the public domain. Rights of affected people to be involved in life-changing decisions have been habitually ignored. Risks remain unexplored and unaddressed.

Along the Se San River the risks to downstream Cambodians were externalized by the developers of a Vietnam hydropower project, and subsequently by the operators of the Yali Falls dam. The official Environmental Impact Assessment (EIA), undertaken in the 1990s, adopted a narrow definition of the project impact area, extending only 6 km downstream, and totally ignoring the possibility of transboundary impacts to neighboring Cambodians who were 'never informed, consulted or officially given a copy of the EIA' (Wyatt and Baird, 2007).

In the case of the Upper Mekong mainstream cascade in China, involuntary risk bearers, especially downstream actors, have been denied rights they claim of access to information, participation, and justice about decisions that affect their lives. These rights are enshrined, within a single-state paradigm, in Principle 10 of the Rio Declaration (UNCED, 1992), since embodied at the regional scale in Europe's Aarhus Convention (UNECE, 1998). The Aarhus Convention has been lauded by Kofi Annan, UN Secretary-General (1997-2006), who observed that 'Although regional in scope, the significance of the Aarhus Convention is global. It is by far the most impressive elaboration of principle 10 of the Rio Declaration' and 'As such, it is the most ambitious venture in the area of environmental democracy so far undertaken under the auspices of the United Nations.' As yet there is no Mekong

Region equivalent, although there are many cosmopolitan democrats who consider the formulation and adoption of such an instrument as a worthy project.

The final example I mention is the Thailand Water Grid that could (theoretically) triple the area of irrigation in the country, and require diversion of water from the Mekong River, and other rivers in Laos and Cambodia, into northeast Thailand. The Government of Thailand chose to ignore its responsibilities to share its plans in the early 2000s with the Mekong River Commmision, in the 'spirit' of the Mekong River Agreement (Governments of Cambodia-Lao PDR-Vietnam-Thailand, 1995), to which it is a signatory. In this formal agreement, all substantial water resources development projects in the Mekong River Basin are to be reported to the Mekong River Commission secretariat so that all parties can understand and assess possible impacts of proposals. Other member countries–Cambodia, Laos, Vietnam–have also been lax in notifying neighbors of their various interests and intentions.

Conclusions and recommendations

DWP can improve regional water governance because: (1) political space is created, that transcends boundaries; (2) representation and participation of stakeholders is expanded, potentially increasing the legitimacy of public policymaking; (3) discourses and norms are launched and contested, providing new perspectives; (4) knowledge brokers are used to increase transparency, and deepen exploration of interests, agendas, past decisions, and current options; (5) social learning is fostered across interest groups; and (6) negotiations are shaped and more informed.

Despite these attractive features, DWP is seen by some as disrespectful of, and at times subversive to, existing decision-making structures. Deliberative politics in the Mekong Region, when led by civil society groups, has resulted in them being accused of being 'undemocratic'–an interesting criticism given the undemocratic nature of Mekong Region states–and too empowering of interest groups with policy positions that may differ from dominant policy positions within state governments or parts of their bureaucracy. Advocates claim the opposite, that deliberative politics is complementary to formal state decision-making processes, and actually deepens democracy by enabling 'exploring water futures together.' In the Mekong Region, more work is required to have DWP seen as legitimate by the state, and a useful, accepted part of the new tapestry of governance.

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Metering of agricultural electricity supply on groundwater users in India contrasting evidence on impact in West Bengal and Uttarakhand

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Abstract

As a part of the ongoing power sectors reforms in India, the states of West Bengal and Uttarakhand are in the process of metering agricultural electricity supply. Based on primary data, we assessed this initiative in West Bengal which has embarked on metering in a well-planned way to ensure its success, but this process has been entirely ad hoc in Uttarakhand. In West Bengal, results suggest that most pump owners would benefit from the reforms, whereas water buyers would lose out by having to pay higher water charges and face adverse terms of contract. In Uttarakhand, however, tubewell owners would be better off by virtue of having to pay lower electricity bills, while water buyers will remain unaffected since water prices have not increased in response to metering as in West Bengal. Metering will have limited impact on groundwater markets in Uttarakhand, though it may have some impact in West Bengal. At current low meter tariff rates in Uttarakhand, water use efficiency is unlikely to go up, but it may increase in West Bengal where tariff rates are much higher. At current tariff rates, the electricity utilities are likely to earn less revenue than before in both states.

Media grab

Metering of agricultural power supply may or may not have adverse impacts on groundwater users depending on whether or not the region supports vibrant groundwater markets and the way the actual task of metering is undertaken by the implementing agency.

Introduction

One of the most significant developments in South Asia in the last five decades has been the quiet ascendancy of groundwater as the main source of irrigation. Indeed, the Green Revolution has often been described as a tubewell revolution (Repetto, 1994). But it came at a cost. The groundwater economy of India boomed at the cost of the country's energy economy. This is because, since the late 1970s, all state electricity boards (SEBs) in India decided to shift from a metered electricity tariff to a flat rate tariff system for administrative ease. Although the original idea was to keep raising the flat tariff to reflect costs of generation and distribution, in reality, these tariffs remained downwardly sticky and were used as populist electoral tools. Soon, the gap between cost of supply and revenue earned increased and most SEBs started making huge losses. With the liberalization of the Indian economy in 1991, the losses of the SEBs became a matter of concern and there were calls from donor agencies and national policy makers to undertake power sector reforms. Accordingly, the Government of India (GOI) passed the Electricity Act, 2003 and the power sector reform process picked up pace. While the reform process has several components (Dubash, 2007), of particular interest to us in this paper is the move toward universal metering of all electricity consumers, including agricultural tubewells. In face of strong farmer lobbies, states such as Punjab, Haryana, Gujarat, and Andhra Pradesh eschewed the path of universal metering even at the cost of forgoing loans from the World Bank and the Asian Development Bank (ADB) for power sector restructuring. The states of West Bengal and Uttarakhand, however, decided to adopt universal metering and are currently in the process of metering agricultural tubewells. We offer a first-cut comparative evaluation of the metering process and its impact of tubewell owners and their water buyers in these two states.

Objectives and Methods

These are the three main objectives of our study:

1. To understand the pattern of groundwater and electricity usage in West Bengal and Uttarakhand.
2. To understand the process of metering in both states, and assess them on whether current metering practices would be able to overcome the high transaction cost problems that plagued this system earlier.
3. To understand the impact of metering on tubewell owners, water buyers, groundwater markets, groundwater withdrawals, and electricity utilities.

To achieve these objectives, primary questionnaire survey-based fieldwork was undertaken in West Bengal and Uttarakhand in January 2008. The respondents of this survey were the tubewell owners and the water buyers. Officials of the now unbundled SEBs were also interviewed as were leaders of farmers' groups. In West Bengal, 156 farmers were interviewed from 14 villages, of which 114 were pump owners and 42 were water buyers. In Uttarakhand, 117 farmers from eight villages were interviewed. Of these, 74 were tubewell owners and 43 were water buyers. Further details on sample selection and methodology are given for West Bengal in Mukherji et al. (2008) and Umar et al. (2008) for Uttarakhand.

Results and discussion

Groundwater and electricity in West Bengal and Uttarakhand
West Bengal, an eastern state of India, receives an annual rainfall of about 2000 mm and has a groundwater potential of 31 billion cubic meters (BCM), most of which is available at shallow depths. Only 42% of the total available groundwater resources in the state has been utilized so far (WIDD, 2004). Although West Bengal has plentiful groundwater resources that can be furthered developed, the state has for various political reasons (Mukherji, 2006) adopted one of the most stringent groundwater regulations in India. For instance, procuring electricity connection for tubewells needs permission from multiples sources, such as the State Water Investigation Directorate (SWID) and village level bodies (*panchayats*), and the process is fraught with red tape and corruption. The result is that West Bengal has the lowest proportion of electric tubewells to total tubewells in India (GOI, 2003). The farmers in West Bengal, until 2007, also paid the highest flat tariff (Rs. 2160/HP/year) for electricity among all Indian states. Agricultural consumption of electricity accounted for only 6.1% of total consumption (WBSEB, 2006), and unlike other states where electricity subsidies form a major share of state fiscal deficits, in West Bengal this was negligible (Briscoe, 2005). Existence of a high flat tariff, coupled with small-sized land holdings and abundant groundwater resources, had led to the emergence of competitive informal groundwater markets here, and small and marginal water-buying farmers benefitted substantially through these markets. The main irrigated crop is the summer paddy, called *boro* paddy. Average annual pumping hour varies from 1500 hours to 2100 hours for centrifugal and submersible pumps, respectively.

Uttarakhand in the northern part of India was formed in 2001 and earlier was a part of Uttar Pradesh. Uttarakhand is a predominantly hilly state with the bulk of agricultural lands limited to the southern *Terai* parts of the state. The mean rainfall is about 1500 mm. The state has annual net available groundwater resources of 2.1 BCM, of which 66% is being used presently (CGWB, 2006). Depth to water table depends on subsurface lithology, varying from less than 2 m in the *Terai* region to as deep at 50 m in the *bhabar* zone. Agriculture uses only 12% of the total electricity in the state, though nearly 70% of all tubewells run on electricity. Until 2007, Uttarakhand had a high flat tariff (Rs. 1512/HP/year) compared to other Indian states. Unlike West Bengal where tariff recovery is very high (more than 90%), Uttarakhand is as low as 25% (personal communication with an official of SEB). One of the main reasons for such low tariff recovery is the high tariff rates, coupled with periodic waivers of electricity dues by the politicians that lessens the incentive to pay bills in a timely manner. The main irrigated crop in the state is *kharif* paddy and *rabi* wheat. The average annual pumping is 800 hours because water requirement of wheat is not extensive. Water markets are less developed as compared to West Bengal, mostly because of larger land holdings which makes it economical for farmers to invest in their own tubewells.

Process of metering
As already mentioned, both states are in the process of metering their agricultural tubewells. Although the aim of metering is the same, these two states have adopted entirely different processes.

The government of West Bengal (GoWB) has adopted a hi-tech approach to metering through the installation of remotely sensed tamper-proof meters that operate on the time of the day (TOD) principle. TOD is a demand management tool of differentiating the cost of electricity during different times of the day. Consumers are discouraged from using pumps during peak evening hours and encouraged to do the watering during slack night hours. There are three metered tariff rates: normal rates from 6 am to 5 pm (@ Rs. 1.37/unit), peak rates from 5 pm to 11 pm (@ Rs. 4.75/unit), and off-peak rates from 11 pm to 6 am (Re. 0.75/unit). On average these unit rates translate to around Rs. 6/hour inclusive of Rs. 22/month as meter rent. The new meters use GIS and GSM technologies. These new meters solve many of the traditional problems of metering, including tampering, under-reporting and under-billing by the meter readers in collusion with the villagers, arbitrary power of the meter readers, and the physical abuse that the meter readers were subject to at times at the hands of irate villagers. Meters are now remotely read and reading is transmitted directly to the commercial office. The meter reader neither knows, nor can tamper with the meter reading. Farmers in three districts have started receiving bills based on metered readings and other districts will follow soon.

The government of Uttarakhand (GoU) has installed electronic meters, but it has chosen the conventional form of billing which relies on manual billing by the meter readers. The TOD system has not been adopted and metered tariff has been fixed at a low rate of Re. 0.70/unit, which is even lower than the off-peak tariff in West Bengal. This works out to be even much lower than the current flat tariff rates of Rs. 126/HP/month. So far, meters have been installed on 70% of the agricultural tubewells, but during our survey we did not find a single instance where a farmer reported receiving bills based on actual meter reading. The reason for this is paucity of field staff in the electricity department. New meter readers are not likely to be recruited in the near future. The electricity department has undertaken some half-hearted efforts at involving village self-help groups for meter reading, but we did not gauge much enthusiasm for this among the villagers. On the whole, the farmer leaders, the villagers, and the electricity department officials believe that metering in its current form is unlikely to succeed and that the government go back to the flat tariff system, albeit at even lower rates than at present.

Impact of metering

In West Bengal, groundwater markets emerged in response to high flat rate tariff, whereby tubewell owners were under pressure to sell water just to recover the electricity bill, given that their own land holding was not sufficiently large to justify the high electricity cost. This compulsion on the part of tubewell owners also meant that water buyers, who happen to be mostly small and marginal farmers, had sufficient bargaining power over the water seller. That this reasoning is correct is shown by the fact that, while flat tariff rates increased around 10 fold from 1991 to 2006 (from Rs. 1100/year to Rs. 10,800/year), the water price only rose from Rs. 300/acre in 1991 to Rs. 1800/acre in 2006 for summer *boro* paddy (Mukherji, 2007). Metering of electricity supply, however, has changed the very incentive structure, and the water sellers are no longer under a compulsion to sell water because they will pay for only as much as they pump. So, soon after metering, the pump owners have increased the rates at which they sell water by 30-50%, even though, assuming the same hours of usage as under earlier flat tariff, we found that they would have to pay a lower electricity bill under metered tariff than before. The pump owners have therefore benefitted under the current meter tariff regime in two ways: (1) by having to pay a lower electricity bill for the same hours of use, and (2) by being able to charge a higher water price and therefore increase their profit margins. There are only about 100,000 electric pump owners in the state, and they constitute less than 2% of the total farming households. It is this small group of wealthier farmers who have benefitted directly from metering. On the other hand, the water buyers have lost out in two ways: (1) by having to pay a higher water charge than before, and (2) by having to face adverse terms of conditions of water buying (e.g. advance payments, not being able to get water at desired times). At the current tariff rates and assuming the same usage pattern, the SEB too will lose revenue, but it may gain through decrease in T&D losses. The actual impact of metering on the size of groundwater markets (i.e. whether they will expand, contract or remain the same) and volume of groundwater extracted cannot be predicted a-priori, and has to be answered only empirically.

In Uttarakhand, under the existing metered tariff rates, all tubewell owners will gain by having to pay less than one-third of the electricity bill than they were supposed to pay under the flat tariff rates, but as we found, very few paid anyway. In this state, the main irrigated crops are *kharif* (monsoon) paddy that needs supplementary irrigation, and *rabi* (winter) wheat that needs 4-6 irrigations. Average operation of a tubewell is only 600-800 hours. Informal groundwater markets exist, but they are not as developed here as they are in West Bengal. The main reason for relatively thin groundwater markets in Uttarakhand is the fact that land-holding sizes are relatively larger, and most farmers prefer to install their own tubewells than depend on other farmers for irrigation. Besides, almost every village has a government tubewell, most constructed after 2001 when the state was formed. These function reasonably well and supply water to farmers at rates cheaper than private tubewells. The types of crops grown ensure that there is not a very large demand for water as is the case of summer paddy in West Bengal. This explains why groundwater markets are relatively less developed in this state. Metering of tubewells has had no impact on water prices. Water was sold at a rate of Rs. 50/hour before metering, and the same rates continued even after metering. Similar to West Bengal, in Uttarakhand, the state electricity utility will earn less revenue than before. Given the very low metered tariff rates, it is unlikely that there will be any impact on the volume of water pumped.

Conclusions and recommendations

India is in the midst of power sector reforms, and universal metering is one of the important reform measures. While most Indian states have resisted metering of agricultural tubewells, the states of West Bengal and Uttarakhand have embarked upon metering of all tubewells. We compare and contrast the initiative of the two states in terms of the process of metering and impact on groundwater use and users (including water buyers). We found that both states adopted vastly different attitudes to metering. West Bengal, by choosing hi-tech has successfully overcome some of the traditional problems of metering, such as meter tampering, collusion between the meter readers and the villagers, and lack of electricity utilities staff. The state of Uttarakhand, however, has done none of this and has deployed traditional ways of metering and billing. Given their lack of staff and other logistical difficulties, it is fairly certain that their metering efforts will fail. This is unfortunate because metering (at existing rates) would have benefitted the tubewell owners without creating any negative effects on the water buyers, who are few in number. In West Bengal, however, metering has benefitted a small section of wealthier pump owners at the expense of the majority of small and marginal water-buying farmers, by changing the very incentive structure inherent in the earlier flat tariff system that encouraged pump owners to proactively sell water. Our main finding is somewhat of a paradox: where metering could have generated a win-win situation (as in Uttarakhand), the government has adopted an ad-hoc and ill-planned approach to metering, whereas in West Bengal, where most of the groundwater users (water buyers in this case) would be harmed, the government has taken a well thought out approach. Our recommendations are the following:

1. The GoU should learn from the GoWB example and introduce tamper-proof and remotely sensed meters to overcome the problems associated with meter reading and billing. This will, of course, necessitate additional funds.
2. In West Bengal, to safeguard the interest of the water-buying farmers, the government should ease the process of electrification of tubewells, and provide one time capital subsidy for constructing tubewells, especially for the small and marginal farmers. This will lead to an increase in the number of electric tubewells and enhanced competition in water markets. This could result in low water prices in the future.
3. Village level governments (*panchayats*) can play an important role in West Bengal by regulating the price of water sold to the buyers.

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Assessing policies and institutional arrangements in Karkheh River Basin

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Abstract

Water in the Karkheh River Basin (KRB) is limited and becoming scarcer as population and demand increase. It has been suggested that agricultural water productivity (WP) in the KRB could be substantially increased by improving on-farm irrigation management, introducing precision irrigation, introducing new varieties, adjusting cropping patterns, and integrating appropriate agronomic practices in the crop production system with suitable institutional setups and policies. This study was conducted to review the policies and institutional arrangements on irrigation water use, and to assess the consequences for water allocation and productivity in selected sites of Sorkheh, Azadegan, and Merek in rainfed and irrigated regions in the KRB. Several indicators were defined for assessment of current policies and institutions in relation to environmental, social, economic, and political dynamics. The indicators were food security, economic growth, ecosystem consideration and environmental sustainability, poverty reduction, gender inequity, water pricing, water use technology, water allocation and related criteria, and research activities. A questionnaire was used to analyze these indicators at selected sites. The responses varied depending on social, cultural, and political context, and type of agricultural water infrastructure (canals, wells, small or large irrigation network, rainfed). The results of the analysis suggested that water governance, management, and use cannot be treated independently and must be considered comprehensively. Water governance, management, and use were characterized by plurality complex, and overlapping of rules and responsibilities by organizations and competition between actors. There was a lack of consideration of environmental issues in previous versions of Karkheh irrigation network objectives. Results also indicated that Karkheh irrigation network objectives for water allocation, cropping systems, and environmental issues has been revised recently and needs to be considered in the CPWF Agricultural Water Productivity Project in the Karkheh River Basin (KRB).

Media grab

For sustainable agricultural development in arid and semiarid regions, reform on policy and institutions is needed to address environmental sustainability and gender inequity as well as food security, economic growth, poverty reduction, and water pricing.

Introduction

Iran is situated in one of the most arid regions of the world. The average annual precipitation in Iran is about 250 mm (less than one-third of the world average precipitation), and this is under conditions in which 179 mm of rainfall is directly evaporated. In addition to aridity, distribution of precipitation in Iran is irregular and non-uniform (Dehghanisanij et al., 2006). Agriculture is the main water user in the country. Irrigated agricultural regions in Iran cover about 8.4 million ha and account for 85.2 billion m^3 (BCM) (92%) of all water use (92.5 BCM). Since the possibility of increasing the water resources for the agricultural sector in arid and semiarid regions such as Iran is limited, increasing agricultural water productivity is the only practical strategy.

The KRB, in southwest Iran, is one of the most important agricultural zones in the country. The total area of the KRB is 5.2 million ha (Mha), of which only 1.07 Mha is irrigable and 0.9 Mha is suitable for dry farming agriculture. The agricultural water resources in KRB includes surface and groundwater. Average annual rainfall in the basin is 24.9 BCM, of which 5.1 BCM is flood and surface water, 3.4 BCM infiltrates to groundwater, and 16.4 BCM evaporates. Historically, the use of groundwater for agriculture has been popular in the region. Groundwater exploitation in the KRB was started as early as 1915, when the first well was dug in the Asadabad area. During the past three decades, however, groundwater exploitation in KRB has taken a huge jump. In recent years, increasing water scarcity has prompted more and more farmers to extract groundwater to meet their irrigation requirements. Groundwater now accounts for nearly half of the urban and agricultural water supply in the KRB. Total exploitation of groundwater in the KRB is about 3.8 BCM. This groundwater is exploited with the help of over 17,000 wells and 2677 springs. About 87% of extracted groundwater is used for agriculture, 12% for drinking purposes, and about 1% is consumed by industry.

In KRB, two major agricultural production systems prevail: rainfed in the upstream of newly built Karkheh reservoir, and fully irrigated in the downstream. The river water quality is good, though it varies seasonally and along the river. WP in these areas is also low, not only compared to potential WP, but also to that in other river basins in Iran (Keshavarz and Ashrafi, 2004). The mean maize WP in selected sites of the KRB is about 0.40 kg/m^3, ranging from 0.19 to 0.68 kg/m^3 (Dehghanisanij et al., 2006), while maize WP in a different location of the country with about the same amount of crop water is reported at 1.3 kg/m^3 (Dehghanisanij et al., 2008). Cai and Rosegrant (2003) analyzed WP of cereals at the global and regional levels through an holistic modeling framework, and indicated cereal WP ranges from 0.2 to 2.4 kg/m^3. Since rice usually consumes more water than other crops, the WP of rice is significantly lower than that of other cereals, ranging from 0.15 to 0.60 kg/m^3. The average WP of other cereals in the developing world it is 0.56 kg/m^3 (yield, 3.2 t/ha; WC, 5600 m^3/ha). Based on simulated crop production and water use from 1995 to 2025, WPs vary from year to year due to variability in climate and for other cereals will increase from 0.6 to 1.0 kg/m^3 in developing countries, and from 0.7 to 1.1 kg/m^3 globally. The hypothesis of improvement of agricultural WP is that WP in the KRB could be substantially increased by improving on-farm irrigation management, introducing precision irrigation, introducing new varieties, adjusting cropping patterns, and integrating appropriate agronomic practices in the crop production system with suitable institutional setup and policies.

Poverty, hunger, gender inequality, and environmental degradation continue to afflict developing countries, not because of technical failings but because of political and institutional failings (Merrey et al., 2006). Institution refers to social arrangements that shape and regulate human behavior and have some degree of permanency and purpose transcending individual human lives and intentions. Examples are rotation schedules for water distribution, market mechanisms for obtaining crop credit, membership rules of water user associations, and property rights in water and infrastructure. Institutions are often referred to as the rules of the game in society (North, 1990). Rules are interpreted and acted on differently by different people. Institutions, including rules, are dynamic and emerge, evolve, and disappear over time. A policy is 'a set of interrelated decisions taken by a political actor or group concerning the selection of goals and the means of achieving them within a specified situation where these decisions should, in principle, be within the power of those actors to achieve' (Howlett and Ramesh, 1995).Political and institutional reforms are triggered by internal and external pressures and opportunities, by pressures such as water scarcity, poverty, and food insecurity, as well as by changes in global terms of trade and the requirements of development partners (Merrey et al., 2006).

In South Africa the end of apartheid provided enormous political momentum for radical reforms to correct injustices in many domains, including the water sector. The internal political push for reform led to participatory processes to formulate a new water act and water policies (de Lange, 2004), followed by the more complex and long-term process of implementing the reforms. In Chile tradable water rights were introduced as part of a strong domestic political commitment to a neoliberal, market-driven development paradigm (Carrasco, 1995). Evidence from South America (Peña and Solanes, 2003) and Asia (Samad, 2005) suggests that externally driven reforms are less likely to have a lasting impact unless they are also championed by strong domestic actors. Pakistan in the 1990s and Indonesia during the Suharto regime are cases in which irrigation reform was on the national agenda primarily because of pressure by international development funding agencies (van der Velde and Tirmizi, 2004). There was little domestic momentum supporting reform. In both countries the irrigation bureaucracies neutralized whatever reform efforts were undertaken. In countries of geopolitical importance to the major donor countries, such as Egypt and Pakistan, international development agencies seem to have had little bargaining power to encourage or enforce reform (on reform in Egypt, see Merrey 1998).

The objectives of this study were assessment of policy/institutional response in KRB and suggestions for alternative options.

Methods

This study is based on a review of available policy documentation as well as secondary and stakeholder survey data to assess water and related policies and institutions influencing water use in KRB based on some indicators including: food security, economic growth, ecosystem consideration and environmental sustainability, reducing poverty, gender inequity, water pricing, water use technology, water allocation and related criteria, research and activities.

Farming system of the KRB

The downstream part of the KRB stretches from the Karkheh Dam in the north more than 100 km southward, where the Karkheh River discharges into the marshlands of Hoor-al-Azim. A number of sub-basins in the command area, including Dasht Abbas, Evan, Dusaif, Ardyez, and Bageh, as well as some on the lower plain, are slated a 300,000 ha expansion of irrigation systems, including a new irrigation and drainage network. Agriculture in the downstream is predominantly irrigated (about 111,000 ha), with annual rainfall ranging from 300 mm in the north to 100 mm in the south. The river water quality is suitable for irrigation, though it varies seasonally and along the river, reaching an EC of about 3 dS/m near the outlet. The area is suitable for a wide range of crops. Presently, wheat, maize, alfalfa, and off-season vegetable crops are the most popular (Table 1). Vegetables are grown as off-season crops and include onions, melons, tomatoes, and cucumbers.

Table 1. Cultivated area, cropping pattern, and average yield for the main crops in irrigated agriculture of KRB (Keshavarz and Ashrafi, 2004).

Crops	Cultivated area (ha)	% of total cultivated area	Yield (kg/ha)	Total yield (t)
Cereals (wheat, barley and maize)	236700	63.8	2308	546304
Rice	3900	1.1	2686	10475
Forage crops	37500	10.1	9136	342600
Pulses	16000	4.3	1151	18416
Oilseeds	3700	1.0	1229	4547
Vegetables	39100	10.5	18019	704543
Potato	1100	0.3	15755	17331
Orchards	26100	7.0	6674	174191
Sugar beet	2600	0.7	30065	78169
Industrial crops	300	0.1	1703	511
Others	4100	1.1	1088	4461
Total	371100	100	-	1901548

Institutions of water in Iran

Ministries of Energy and Agriculture (recently renamed as Jihad-e Agriculture) are mainly responsible for the management of water in Iran. The Ministry of Energy is responsible for storage and supply of water to different consuming sectors, agriculture, industry, and domestic. The Ministry of Agriculture is responsible for improvements in water productivity and development of irrigation systems technologies. For the management of water resources, these two ministries also receive help from research institutes, and consultant engineers, and irrigation and water engineering departments of the universities.

In Iran there are 49 research and/or educational institutes concerned with water, 14 research institutes specifically on water research, 25 societies on water or agriculture, 47 consultant engineers in water, and 178 manufacturing and or design companies in irrigation (especially in pressurized irrigation systems).

In KRB, the existence of vast water and soil resources in this region and the exigency of utilizing these resources necessitated vast and thorough studies to be carried out in the region. On May 29, 1960, the national Parliament and Senate passed a bill by which the Khuzestan Water and Power Authority (KWPA) was officially established to carry out the projects in the Khuzestan region. The lower part of KRB is located in Khuzestan Province. The KWPA is the sole custodian of water resources in the province, and therefore responsible for the allocation, operations, and protection of this natural resource with the ultimate goal of optimal development and operation.

Water management in KRB is characterized by complex, overlapping, and sometimes competing networks of actors, rules, functions, and organizations. Multiple actors and organizations involved in water decision-making at different levels means that farmers cannot receive water at the right time and in the right amount. As a result, agricultural fields are facing overirrigation or deficit irrigation throughout the growing season. The situation requires multiple reform strategies, and not just simplified answers for agricultural water problems. Standardized approaches and solutions are usually problematic at the farm level under an irrigation network.

Policies of water in Iran

All the national and local policies were collected and reviewed. The 'Equitable Distribution of Water Law' is one of the important national acts on water policies in Iran after the Islamic Revolution, and was approved by the parliament in 1982, and was slightly modified later. The Law consists of five chapters, 52 articles, and 27 notes. The main chapters are: (1) Public and national ownership of water; (2) Groundwater resources; (3) Surface water resources; (4) Duties and authorities; and (5) Penalties and regulations. Following approval of 'Equitable Distribution of Water Law' in parliament in 1990, the following actions were taken:

- Preparation of 'Fixing agricultural water price' law and its approval by parliament in 1990. Based on this law, water price for a crop season, depending on the water resource (regulated or nonregulated) and type of irrigation network (modern and traditional), varies between 1 and 3% of the value of crop yield.
- Determination of 'Oversight Charging' for water in pumping system (groundwater) and its approval by the 'Economic Council' of the government in 1992. The purpose is to control overexploitation and improve management of groundwater resources. The oversight charge, depending on crop type and crop yield varies between 0.25 and 1.00% of the economic return of the cultivated crop. For higher than average yields, the charge reduces proportionally, and for a yield double the average, there is no charge. In this regard, the Ministry of Energy was ordered to prepare required plans in order to equip all the wells in the country with water volume measuring devices.

Improvements in water supply and improvement in water productivity programs have been one of the most important government policies during the past two decades. Rules are set and different technical infrastructures (including executive, research, and consultative) in public and private sectors are developed.

During the same period, and especially in the first, second, and third five-year national development acts, many attempts and actions have been taken that were not regular and/or not systematic. Huge investments were made to construct dams and new irrigation and drainage networks. Unfortunately, most of the projects were development-oriented and less attention was given to the operation and maintenance of the projects, which in addition to increased costs, gradually reduced the performance of irrigation networks, followed by land drainage and salinization problems. Because the irrigation network under the Karkheh dam was developed mainly for food security and economic growth, less attention was paid to environmental sustainability, gender inequity, poverty reduction, and water pricing.

Conclusions

Although several water policies, strategies, laws, and regulations exist, effective water resource development is yet to be achieved. Example of deficiencies are:

- Fewer water resource development projects, despite high investments, especially for secondary chanals.
- Low water productivity at national (0.9 kg/m^3) and Karkheh River Basin (0.54 kg/m^3).
- Depletion of groundwater, and negative water balance in some basins.
- Simultaneous soil and water resource degradation.
- Less than fully successful achievement of projected provisions of the first, second, and third mid-term development plans on water allocation, productivity, and water resource management.

There was lack of consideration of environmental issues in past versions of the Karkheh irrigation network objectives. The Karkheh irrigation network objectives for water allocation, cropping pattern system, and environmental issues have been revised in two ways, with environmental issues given significant attention. To contribute to poverty reduction, environmental sustainability, gender equity, and water pricing, reforms are needed that should create a framework for development relationships among the key governance actors, nongovernmental organizations, civil society, the private sector, and farmers to identify the most effective resource uses and management modalities. Because incentives are lacking to engage poor people in the governance of water resources, the state needs to use its authority to enhance their input and benefits.

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Constraints and challenges to agricultural development in Limpopo Province, South Africa

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Abstract

Macro- and micro-structural constraints, including those linked to and exacerbated by historical, natural, and financial factors, are some of the many stressors faced by small-scale farmers in Limpopo Province. Low production and productivity, low income, poor working conditions and poor access to inputs, inaccessible credit, and decreasing land conditions characterize small-scale farming. Poor farmers also face problems of insecure land rights, nonviable small farm units, and a history of a lack of supportive infrastructure. These constraints, however, are not uniformally experienced across the province. There are localized cases where the suite of constraints varies. Knowledge of the range and types of stresses and constraints are essential if effective interventions are to be designed and implemented to help farmers manage agricultural risks in the province.

Media grab

Most disadvantaged farmers are not part of mainstream agriculture, and they practice subsistence farming in overcrowded, semi-arid areas. Subsistence farming is characterized by poor opportunities to own land, poor access to inputs and credit, low production and productivity, and lack of market information and training.

Introduction

South Africa continues to strive for empowerment of those who were denied opportunities under apartheid. The process of empowerment is about giving disadvantaged communities and individuals more choice, and, in the case of agriculture, removing the barriers and fully integrating and democratizing the sector (Kirsten et al., 1998). Various efforts to promote small-scale farming have been made in the past decade. It remains clear, however, that much more needs to be done to make a positive difference in terms of the political objective of an integrated agricultural sector. Integration will only happen when small-scale farmers fully participate in the market (Azan and Besley, 1991; Makhura, 2001).

Farmers in the neglected and less-developed rural areas are generally poor (Makhura, 2001). Most small-scale farmers residing in Limpopo Province are poor (Statistics South Africa, 2001; Mpandeli, 2006). According to a discussion on food security by the Department of Agriculture and Land Affairs (DALA, 1997) and the Ministry of Agriculture and Land Affairs (MALA, 1998), many households are vulnerable to food insecurity including those in Limpopo Province (FIVIMS, 2003; Mpandeli, 2006). Poor farmers in South Africa are not really part of commercial agriculture. This is one of the reasons that the contribution of small-scale agriculture to the GNP is still limited (Makhura, 2001). Most disadvantaged farmers practice subsistence agriculture in overcrowded semi-arid rural areas. Subsistence farming is characterized by: low production and productivity, poor opportunities to own land, and poor access to inputs and credit. To generate enough income, these farmers tend to engage in off-farm or nonfarm activities (Makhura, 2001). To a large extent the process of agricultural transformation in South Africa involves moving households from subsistence production to producing for the market. The latter provides a number of benefits and advantages, including rural employment and income generation (Christodoulou and Vink, 1990; Ngqangweni, 2000). Furthermore, several studies (Delgado et al., 1998; Ngqangweni, 2000) have shown positive and strong multiplier effects of investing in agriculture. In other words, agriculture has an important role to play in fostering rural development and poverty alleviation. Constraints, however, affect small-scale farmers in Limpopo Province, and the purpose of this study was to identify the constraints and their importance in three districts of Limpopo Province.

Methods

A survey was targeted at smallholder households resident in the Limpopo River Basin in South Africa in Capricorn, Mopani, and Sekhukhune districts. A three-stage sampling frame was used for selecting districts, villages, and households to be interviewed. Households not classified as smallholder farmers were not surveyed, and examples of such households include teachers, households at mini urban centers in the communal areas, and civil servants. A list of all the villages in each of the selected districts was obtained from the agricultural extension offices responsible for the district. Villages falling outside the basin were identified and deleted from the list. Each of the villages on the list was allocated a unique number, and the numbers were entered into SPSS and a random sample of 16 villages was selected, eight villages for the control area and eight villages for the project area. Villages in the control area had to be at least 100 km away from the project villages. The control villages will be used for the 'with' and 'without' project comparisons. Over 1000 households were interviewed.

Results and discussion

Income sources and expenditure patterns

Most households obtain income from social welfare, and significant numbers also obtain income from remittances, pensions, and formal employment, while very few have income-earning enterprises (Tables 1-3). Formal employment is higher in Mopani than the other districts due to employment in the tourist industry–Kruger National Park is in this district. Mopani district had the highest mean annual household income (R38,679) (Table 4). The mean annual household income for Capricorn district was less than half this amount. This is not surprising because one of the top tomato producers (ZZ2) is located in Mopani district. Some of the street vendors get lower grade tomatoes from this producer. On average, livestock production only contributed about 2% of the total household income in the three districts.

The social development sector in South Africa supports the poor and vulnerable through direct income support and social welfare services. Welfare services such as probation and adoption, child and family counseling, and support services, home and secure centers (including places of safety) for children and older persons are delivered by departmental and nongovernmental organizations subsidized by the social development departments (National Treasury Report, 2003).

Households in Capricorn, Mopani, and Sekhukhune districts are farming in a difficult environment, and some of these households face major problems of high input costs. As a result, most of these households lack capital and cash income. Social welfare support from the South African Government was identified by a significant number of households as a source of income. Social support from the government is in the form of pension, disability, and social grants (Table 1).

Table 1. Sources of income by district, 2005-06.

District	Proportion of households obtaining income from source (%)				
	Remittances	Pension	Social welfare	Formal employment	Labour sales
Capricorn	33.1	10.8	72.8	18.3	12.4
Mopani	11.2	18.5	67.6	30.9	11.2
Sekhukhune	24.0	19.9	76.6	22.8	13.5

Table 2. Other sources of income by district, 2005.

District	Proportion of households obtaining income from source (%)			
	Beer sales	Craft sales	Selling wares	Mopani worms
Capricorn	3.1	1.5	1.9	0.9
Mopani	3.2	0.6	9.1	2.1
Sekhukhune	2.3	0.9	5.0	1.2

Table 3. Contribution of the various income sources to total household income for South African districts, 2005.

District	Proportion of income derived from source (%)					
	Social welfare	Pension	Formal employment	Remittances	Labor sales	Other
Capricorn	51.5	6.3	12.5	12.6	3.0	13.9
Mopani	41.2	11.8	22.7	2.7	3.9	17.4
Sekhukhune	46.4	12.0	13.0	6.5	3.9	18.0

Table 4. Mean annual household income by district, 2005-06.

District	Mean Annual household income (R)
Capricorn	17,847
Mopani	38,679
Sekhukhune	23,973

Many farm laborers in Mopani district work at ZZ2, giving the district a higher income than Capricorn and Sekhukhune (Table 4). The amount of labor available in different households in the three districts may determine the farming practices adopted (ICRA, 2006; Raidimi et al., 2006). Males earn relatively more income than females in Mopani district in comparison with the other districts (Table 5).

Table 5. Mean household income by gender of household head by district.

District	Gender of household head	
	Male	Female
Capricorn	22,183	14,401
Mopani	46,813	30,920
Sekhukhune	24,590	23,177

A small proportion of households did not declare any income (3-5%). In some districts such as Sekhukhune and Mopani, some households did not want to provide detailed information to the enumerators because some members are collecting social grants from the Department of Social Development illegally.

In all three districts, food purchases accounted for about 30% of household expenditure followed by groceries (e.g. bag of maize, bag of rice), with slightly more than 20% of the total household expenditure (Table 6). Other important expenditure items included clothing, close to 10% of total expenses, payment of remittances to other extended family members and funerals, which accounted for about 6% of the total household expenditure. The breakdown in expenditure was similar in all three districts. A significant proportion of households in all three districts had expenditures that were greater than incomes earned, ranging from 29% in Sekhukhune to 35% in Mopani.

In Capricorn, Mopani, and Sekhukhune districts food purchases accounted for about 30% of household expenditure followed by groceries with slightly above 20% of the total household expenditure. Other important expenditure items included clothing (10%), payment of remittances to other extended family members (8%), and funerals (6%).

Tables 6. Main expenditure items for South African households, 2005.

District	Proportion of expenditure items (%)					
	Food	Groceries	Clothing	Remittances	Funerals	Other
Capricorn	32.5	22.1	8.8	7.9	6.3	22.1
Mopani	29.8	24.8	9.1	8.7	5.6	21.8
Sekhukhune	34.7	23.2	8.9	6.1	7.0	19.8

Access to Credit

Most households did not obtain any credit in the 2005-06 season. Relatives and neighbors were the main sources of credit for households. In Mopani district, 3.5% of the households had a bank loan compared to only 0.9% in Capricorn and 1.9% in Sekhukhune (Table 7). Some households especially in Capricorn and Sekhukhune districts indicated that instead of approaching commercial banks for loans, they are using government schemes called Mafisa.

Table 7. Sources of credit by district, 2005.

District	Proportion of households obtaining credit from source (%)			
	Relative	Neighbor	Savings club	Bank
Capricorn (n=323)	17.6	6.2	1.5	0.9
Mopani (n=340)	12.4	8.2	4.7	3.5
Sekhukhune (n=342)	9.6	8.8	0.9	1.5

Financing of small-scale agriculture has been seen as one of the major ways to trigger agricultural transformation. Lack of access to credit among small-scale farmers has had negative effects in agricultural development in most parts of South Africa. Prior to 1994, small-scale farmers, especially in former homelands such as Lebowa, Gazankulu, Ciskei, Venda, and Transkei, had access to credit/loans and government from approved institutions, such as the Development Bank of Southern Africa, Lebowokgomo Development Corporation, and the Venda Development Corporation and Agriculture in Venda (AGRIVEN). These institutions were able to finance groups of farmers with full government/department participation in the project (Van Averbeke et al., 1998). The availability of credit from institutions, however, has been reformed, and farmers are finding it increasingly difficult to get access to credit. This situation is especially difficult for women to overcome since they often lack access to collateral (Torkelsson and Anandayayasekeram, year unknown). The experience of the lending agencies with respect to loan repayment on farming activities, especially for resource-poor farmers, has brought changes in lending policies (Thomas and Stilwell, 1994). Commercial banks are prepared to lend to creditworthy projects and individuals, but are reluctant to lend money if the farmer is not certain to reap returns from the project. Increased tenure security could be used to purchase inputs or to invest in the development of the crop. No bank, however, will accept title as collateral unless the land is saleable (Gootjes et al., 1992; Van Averbeke et al., 1998; World Bank, 2004). Access to credit remains one of the challenges despite the growth of community based micro-finance schemes.

Household food security
In the five seasons from 2000-01 to 2004-05, most of households in all three districts were not able to produce enough grain each year to last them until the next season (Table 8). The food security status of households was calculated by subtracting the household's cereal requirement from the total cereal production. The household cereal requirement for a year was calculated by multiplying the FAO recommended cereal requirement per person per year (162 kg) by the number of members in a household. Around 95% of households were classified as food insecure, while only 3.5-5% of households had a food surplus. As mentioned earlier, whatever surplus Sekhukhune district has, the surplus is used for household food security. Surprisingly Sekhukhune district was declared as one of the 13 nodal areas in the country by the president of the Republic of South Africa in 2002.

The concept of food (in) security has evolved substantially since it was first introduced into the development discourse in the 1970s. FIVIMS (2003) and Devereux and Maxwell (2003) argue that the most significant aspect of this empirically and theoretically driven advancement is the awareness that food security is not simply a failure of agriculture to produce sufficient food at the national level, but instead a failure of livelihoods to guarantee access to sufficient food at the household level. In order to focus on food security programs, a definition of food security was adopted by the World Food Summit in 1996: 'Food security exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life' (FAO, 2000; Maxwell, 2001; FIVIMS, 2003).

Table 8: Households facing large food deficits in the Limpopo Basin over five seasons, 2004-05.

Country	District	Proportion of households facing food deficits in each season (%)				
		2004-05	2003-04	2003-02	2001-02	2000-01
South Africa	Capricorn	63.6	60.9	59.9	57.4	52.2
	Mopani	82.3	73.7	68.7	65.8	72.5
	Sekhukhune	82.9	79.1	70.2	80.5	80.6

Key constraints of farming households
Farming households in the Limpopo Basin have faced several constraints in pursuit of achieving household food security. The most commonly cited constraints were drought (20-25%) and cost of inputs (25% in Capricorn, but only 12% in Mopani, where income is higher) (Table 9). Seed shortage was not a major constraint for most households in Capricorn and Sekhukhune, but was more important in Mopani. Some farmers indicated that, with the launch of the Comprehensive Agricultural Support Programme (CASP) on 30 May 2004 by the Department of Agriculture, they can overcome some of the challenges mentioned. CASP offers a wide range of support services including financial support, purchase inputs, infrastructure development, training and capacity building. The intention of CASP is to increase support to agricultural activities in communal land areas, and other small-scale agriculture. The advantage of this financial support is that they do not require collateral.

Another notable constraint cited by a significant proportion of households, especially in Mopani (14.8%), was the destruction of crops by animals as most of the fields were not fenced. Other constraints mentioned by farmers in the three districts are: poor access to inputs and credit; lack of assets; cost of transport; limited participation in markets; lack of market information and training. Farmers are located some distance away from markets and have poor access to infrastructure. There is a need for structural reform if participation of black farmers in the commercial agricultural sector is to be enhanced (Van Rooyen et al., 1987; Kirsten et al., 1993; Kirsten, 1994; Makhura, 2001; Mpandeli, 2006).

Table 9. Constraints faced by households in South Africa, 2004-05 season.

District	Proportion of households citing factor as major constraint (%)					
	Drought	Lack of inputs	Inputs expensive	Draft power	Lack of skills	Seed shortages
Capricorn	20.5	12.9	25.6	8.2	9.7	0.2
Mopani	23.6	4.4	12.2	13.6	1.3	7.9
Sekhukhune	24.6	12.2	24.4	8.5	4.5	0.7

Conclusions and recommendations

Limpopo Province offers a range of opportunities as well as challenges for farmers. The province is one of the poorest, with high unemployment and a lack of access to resources that frustrate farmers' ability to secure adequate livelihoods. Various macro- and micro-structural constraints, including those linked to and exacerbated by historical, natural, and financial factors remain as persistent challenges for small-scale farmers. These stresses vary across households and districts and thus a 'one-risk reduction approach' to the various stresses will not fit all. Despite the clear agricultural potential in the three districts, there is a range of macroeconomic and other local factors that further constrain future agricultural growth and self reliance in the province.

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Impact of water-for-food research on poverty alleviation

Bayesian methods for livelihood, water, and poverty analysis

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Abstract

A livelihood approach to understanding and alleviating poverty is becoming widely accepted, yet livelihood analysis is characterized by considerable uncertainty. Some of these uncertainties reflect the state of knowledge–data are uncertain, and dynamics are poorly understood–while others reflect irreducible features of social and ecological systems. This makes it difficult to incorporate the understanding of livelihoods, including local knowledge and insights, into policymaking. We present an approach that has the potential to take local understanding and transform it into something of more direct use for policymakers. We present key aspects of Bayesian networks and report on applications drawn from the Mekong Basin,

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New research methodology translates local knowledge for policymakers in the Mekong River Basin.

Introduction

The Challenge Program on Water and Food (CPWF) addresses the physical and socioeconomic aspects of water use (CPWF, 2005). Therefore, from the perspective of CPWF, physical models should be thought of as embedded within socioecological contexts (Berkes and Folke, 1998). It is this larger socioecological system that is the target of policy interventions. This paper demonstrates methods for modeling rural livelihood systems in water-poor communities as part of a larger goal of linking physical models to models of social and ecological systems.

The modeling technique adopted in this paper for livelihood systems is Bayesian networks (Jensen, 1996; Cain, 2001; MERIT, 2005). Other methods can and have been used, including agent-based modeling (Antona et al., 2003; Gurung et al., 2006; Ziervogel et al., 2005), and decision trees (Bharwani, 2006). Bayesian networks have, however, some properties that recommend them to the task of modeling livelihoods (Cain, 2001; MERIT, 2005). First, they are inherently statistical, and therefore capture uncertainty and variability. Second, they allow qualitative and quantitative data to be mixed within a single model. Third, they can provide a natural way to translate the outputs of social-scientific investigations into the model. Such networks are particularly relevant for modeling agricultural livelihoods because they can represent decision-making under uncertainty, and can capture a diversity of livelihood strategies.

Methods

The models described in this paper are implemented as Bayesian networks, which are probabilistic models that systematically combine conditional probabilities (Ben-Gal, 2007; Cain, 2001). Uncertainty is accounted for by using Bayesian probability theory that allows subjective assessments of the chance that a particular outcome will occur to be combined with more objective data quantifying the frequency of occurrence. This ability is particularly important for environmental management, where the complexity of the natural world means that it is rarely possible to predict the exact impact of any management intervention. In an uncertain world, Bayesian networks allow users to estimate the chance that a management intervention will have a particular effect and then investigate the consequences of their uncertainty (Cain, 2001). Bayes' theorem (Bayes, 1763) is used to update or 'train' the model with quantitative and qualitative data and to make inferences from the model. For modeling purposes, such networks can be used to represent hypotheses about causality (Pearl, 1994, 2001). A Bayesian network model consists of a directed, acyclic graph or DAG () that represents variables and the links between variables, as well as a set of conditional probability tables (CPTs) that express the quantitative relationships between the variables.

The statement that the DAG is 'directed' means that the links in the network have an intrinsic direction. In the case of Bayesian networks, the direction of the links expresses a conditional dependence, which is a one-way relationship. The term 'acyclic' means that, by following a path through the network, it is not possible to return to the starting point. Despite this limitation, feedback loops can be implemented by running in a dynamic mode, in which an output variable in one time step becomes an input variable in the next time step.

Generating networks from field reports

In the types of models reported in this paper, the DAG is created in the course of reviewing field reports. Following Pearl (1994, 2001), the directed links in the DAGs for the models described in this paper represent causal statements. The field reports contain passages such as, 'Villagers say their area is water deficient and they experience drought almost every year. Even in normal years villagers say production of the rainfed rice is very low and that many households do not have enough to meet their requirements. This is especially true of the poor families who have little or no land' (SEI and GMSSRC, 2008). This passage suggests the sequence shown in Figure 1. As shown in the figure, water supply is dependent on rainfall, and the availability of water is an important constraint on rice production.

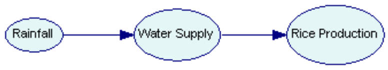

Figure 1. Sequence suggested by field report.

Creating conditional probability tables

Broadly, there are two strategies for constructing CPTs. First, they can be calculated from data. If the states of the parents to a node and the node's own states are known precisely for all possible cases, then it is possible to calculate the CPT directly. More commonly, the data can be assumed to be statistically noisy, in which case a best-fit CPT can be estimated (Jensen, 1996; Cain, 2001; MERIT, 2005). The other strategy for calculating CPTs is by eliciting them from experts. The elicitation task can be made easier by constraining the structure of the CPT (Jensen, 1996; Cain, 2001; Kemp-Benedict, 2008). The constraints reduce the total number of values that the expert must supply, and the elicitation process can be designed so that it is to some degree aligned with the thought processes of the experts. In practice, the techniques are often combined. In the context of CPWF projects, the data may be insufficient to reliably fit (or train) a model. An alternative approach is to create the model, generate elicited probability tables, and then train the model with the available data. In this case, expert inputs provide an initial model parameterization, which is subsequently refined and improved with data through Bayesian updating.

Results

Bayesian network models were created for the CPWF Mekong Basin Focal Project. The network model for the Northeast Thailand case study is shown in Figure 2. Part of the model is shown as five sub-models: Livelihood Assets, Land, Rice Production, Water Supply, and Finances. Note that the work described in this paper is relatively new and is still under development.

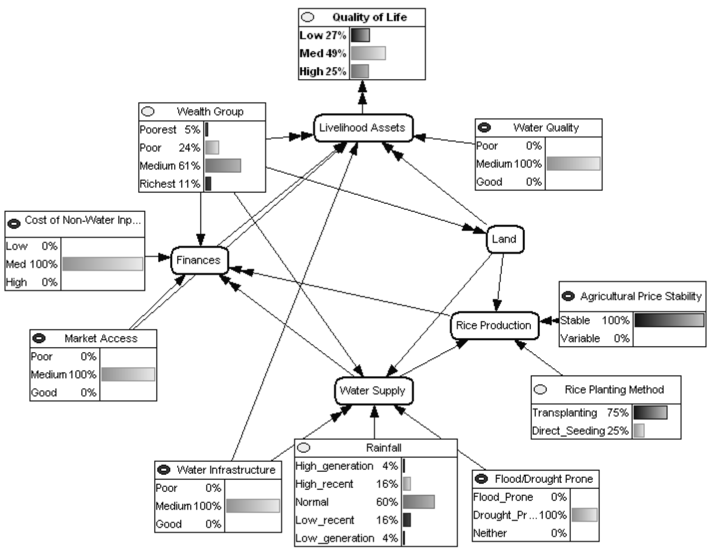

Figure 2. Livelihood model for the Si Sa Ket study area.

The model shown in Figure 2 was used to explore different management options at the local scale, to complement the analysis carried out at the catchment scale. Sample outputs are shown in Figure 3.

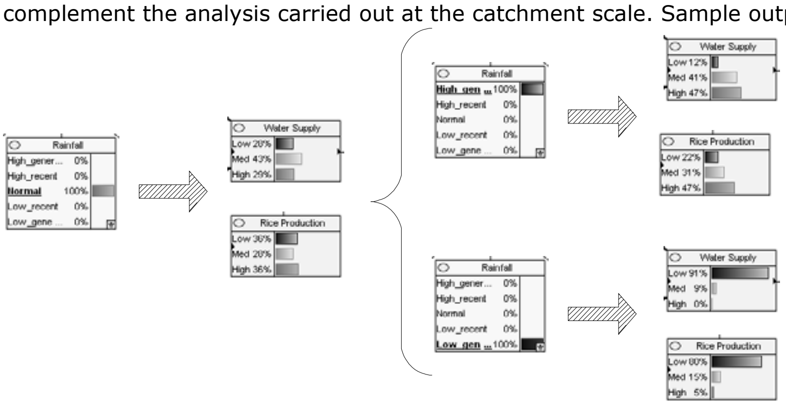

Figure 3: Sample outputs from running the Si Sa Ket model.

As shown in the figure, in this drought-prone region, under normal rainfall, there is a significant chance of low rainfall at some times or for some fields. Accordingly, even in normal years there is a chance of a deficit in rice production. In extremely dry years, defined as a 25-year drought, water supply is extremely low, and there is an 80% chance of having a low level of rice production, over twice the rate for a normal year. Similar observations can be made for unusually wet years. Despite these variations, the Quality of Life indicator (not shown) changes much less from one setting to another than do the rice production and water availability variables, due to a variety of livelihood strategies used by the communities to buffer climatic variability.
While the model described above is preliminary, some initial policy implications can be drawn from the results. Livelihood strategies tend to buffer against shocks, thereby muting the final impact of an intervention, suggesting that monitoring instruments must be carefully designed in order not to miss positive outcomes. A further implication is that dramatic changes in outcome may not be a suitable target. Instead, water-related interventions to reduce water poverty could be designed to make incremental improvements more likely over time: these can have a significant cumulative effect, and project monitoring should reflect this long-term perspective. Finally, water-related interventions should be accompanied with other interventions such as compensation programs for distressed families during drought and flood, improved market access, and opportunities for alternative livelihoods.

Discussion

The model shown in Figure 3 takes a climatic input–precipitation–and links it to livelihood outcomes, including both final outcomes (quality of life) and intermediate outcomes regarding food production. Although not discussed in this paper, there are also output variables in the model, such as the use of pumping to supplement surface water supply in dry years, that could provide a feedback into a hydrological model, thus closing the loop.

Conclusions and recommendations

Bayesian networks were originally developed to allow the impact of uncertainty about management systems to be accounted for in the decision-making process (Cain, 2001). Therefore, their extension to represent livelihood systems in combined physical and social scientific models is both a natural and promising one. It is possible to capture qualitative statements from field reports or directly from respondents in the network structure (the DAG), while using quantitative data from field reports and through 'expert' elicitation to create the quantitative features of the model (the CPTs). While the results are preliminary, they have shown that they can take climatic or hydrological inputs and produce outputs of relevance to physical hydrological models. At the same time, they can capture some of the livelihood strategies used by communities to buffer against climatic and hydrological variability, potentially allowing an exploration of interventions at the social level that can complement and enhance the effectiveness of water-specific interventions.

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Understanding links between collective action, livelihoods, and poverty alleviation in a watershed

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Abstract

Implementation of integrated watershed management policies is often challenged by the presence of poor, marginalized people in upper catchments who typically depend on the natural resource base for their livelihoods. Upstream resource management practices, however, commonly produce water transitions degrading environmental conditions and livelihood support of lowland areas, where the resulting hydrologically vulnerable situation traps people in water-related poverty. This generalized account aptly describes the Nyando River Basin of western Kenya. The Basin is a significant source of sediment loading into Lake Victoria providing strong impetus for conservation in the upper catchment. This is complicated by the widespread poverty conditions of the Basin such that the livelihoods at stake must be considered. An optimal goal is to implement a management strategy that can achieve the desired environmental outcome while simultaneously improving livelihoods and alleviating poverty. Social equity conditions would also be met if this goal is inclusive of all households. This study is part of Theme 2 project, SCALES, which is testing the hypothesis that investments in building social capital and fostering collective action around water management can assist households in escaping poverty traps. This study's main goal is to assess the potential for change in livelihood outcomes that could result from any new cooperative efforts in water management.

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Collective action for water management must overcome market imperfections relating to labor, capital, and technology to achieve its poverty-alleviation goals by making accessible proven remunerative livelihood strategies.

Introduction

Implementation of integrated watershed management policies is often challenged by the presence of poor, marginalized people in upper catchments who typically depend on the natural resource base for their livelihoods. Upstream resource management practices, however, commonly produce water transitions degrading the environmental conditions and livelihood support of lowland areas, where the resulting hydrologically vulnerable situation traps people in water-related poverty (Grey and Sadoff, 2002). This generalized account aptly describes the Nyando River Basin of western Kenya. The Basin is approximately 3600 km^2 in size, smallest of the 11 sub-basins that feed into Lake Victoria, headwaters of the Nile. The Basin, nonetheless, is the source of a significant amount of sediment loading into the Lake with extensive evidence of soil erosion across the lowland areas including the emergence of several large gullies, processes in part attributed to the history of deforestation and agricultural intensification of the upper reaches of the Basin. Accordingly, there is a strong impetus to encourage conservation and management of the upper catchment to reduce these downstream impacts. Complicating realizing this need, the Basin is also an area of widespread poverty with 58-66% of the population living below the national poverty line (CBS, 2003). Thus, any prescribed changes in upper catchment resource management must consider the livelihoods at stake. An optimal goal is to implement a management strategy that can achieve the desired environmental outcome while simultaneously improving livelihood outcomes and alleviating poverty. Social equity conditions would also be met if this goal is inclusive of all households rather than a select few.

SCALES (Sustaining inclusive Collective Action that Links across Economic and Ecological Scales in upper watersheds) is testing the hypothesis that investments in building social capital and fostering collective action around water management can be poverty-alleviating, by assisting households in escaping poverty traps. This study's larger purpose is to assess the potential for change in livelihood outcomes that could result from any new cooperative efforts in water management. Accordingly, the study seeks to understand if improved water management in the Nyando Basin could impact substantially the three pillars of a poverty trap–underinvestment, low productivity, and resource degradation–such that households could escape poverty.

Methods

The SCALES project selected 15 case study villages from across the Basin, representing a wide array of variables including the three prevalent agroecological zones (AEZ). An agroecological zone represents an area where the temperature and rainfall probabilities are such to maximize yields of main leading crops; thus, is instrumental in determining the prevailing and potential remuneration of a livelihood system (Jaetzold et al., 2005). To meet part of its objectives, the study narrows its focus to two villages located in different AEZs, although both are within the Awach River sub-basin. One village is sited upland (~1750 masl) in sub-humid AEZ 1 inhabited by the Kipsigis ethnic group, and the lowland village (~1250 masl) in semi-humid AEZ 3 that is Luo. Both villages have adjudicated land tenure, meaning that households have the possibility to hold the title deed to their land. They are approximately 10 km apart. Selecting neighboring villages permits looking at any differences across spatial scales in adopted livelihood strategies consequential to differences in AEZ and the livelihood outcomes realized. Both are likely to influence the incentives households would have for cooperating in improved water management. The inclusion of a lowland village also permits looking at the impacts of upstream water transitions on poverty trap conditions and related livelihood outcomes firsthand.

The analysis proceeds through several steps in support of its objectives. First is to identify where poverty is located and to what degree across the Basin, to develop a baseline understanding of the socioeconomic context, essentially a spatial understanding of the distribution of poverty. Second a livelihood activities map is drawn over that of poverty distribution to identify which activities would achieve the most successful or remunerative outcomes. These are expected to reflect the prevailing AEZ conditions. Third I will attempt to identify the reasons why households may find themselves trapped in poverty tantamount to how it is distributed across social scales. Quantitative and qualitative data are assembled to further the local definitions of poverty traps, plus some examples of coping strategies and innovations are discussed. Concluding comments will offer some synthesis and discuss what role collective action and social capital would have to play to combat these poverty trap characteristics.

Data were collected on the poverty dynamics in the Basin using the Stages of Progress (SOP) methodology as developed by Krishna (2004). This participatory poverty assessment is a subjective process whereby households identify themselves as poor or not-poor based upon a locally determined poverty line. This methodology thus captures the multidimensionality of poverty plus its dynamism, the transitions in poverty status as households identify over time whether they were entering or escaping poverty as represented by decreases or increases, respectively, in their Stage of Progress. There are four possible resulting poverty outcomes: A = poor in both time periods; B = escape from poverty over time period; C = entered poverty during time period; and, D = never poor over time period. While data were collected for three points in time–25 years ago, 10 years ago, and the present–changes in poverty over the last 10-year period are deemed the most reliable and relevant for this study. Simultaneous to the SOP data collection, information was recorded on the livelihood activities practiced by each village household in all three recorded time periods such that the relationship between a household’s poverty outcome and livelihood strategy could be determined. Logistical regression analysis is used to determine the significance of the available livelihood activities on poverty outcomes. Models are derived for livelihood activities associated with poverty status, measured as a binary poor-not poor outcome, and poverty transition, also indicated with a binary entering/not entering or escaping/not escaping poverty outcome variable. To account for some normal variability in standard of living, in this analysis a household is determined to be transitioning if they increase or decrease in their attained SOP by +/- 3 levels (Baulch and McCulloch, 1998, used a similar approach).

Focus groups and household surveys were administered to identify the reasons a household had attained its past and current poverty outcome, plus gather additional data on household demographics and resource endowments. The Sustainable Livelihoods framework (Chambers and Conway, 1991) is applied to codify the reasons associated with each poverty outcome in terms of asset endowments to highlight which forms of capital are most constraining in attaining a positive livelihood outcome. Farming systems methods enriched this understanding by gathering more detailed information on the specifics of households’ investment abilities and livelihood activity performance, measured in terms of outcomes related to cash income and food security. The time consuming nature of this detailed methodology, combined with limited time in the field, means that these data have been collected from 10 households only. Nevertheless, the results begin to develop a deeper understanding of the nature of poverty traps in each case study village.

Results and discussion

From the Stages of Progress poverty assessment, the distribution of poverty outcomes for the total sample (N=1038) of 15 villages over the last 10-year period is: 12.14% of households remained poor (A); 4.34% of households escaped poverty (B); 15.99% of households entered poverty (C); and, 67.53% of household reported never being poor (D). The number of households that entered poverty during this time period is 3.7 times the number that escaped poverty. The total number of poor households 10 years ago equaled 16.48%, while presently the quantity has risen 70.7% to a total of 28.13% of households. Clustering the sample villages by AEZs, poverty is concentrated in the lowland semihumid AEZ 3, which has become a significantly eroded area vulnerable to flash flooding by runoff from bordering upland areas, and has endured drought conditions since 2002. The lowland area data reflected higher than Basin averages in chronically poor and entering poverty households indicating the general influence of the vulnerability conditions. Regarding the two case study villages, the lowland village (N=101) has higher numbers of households that have remained poor (18.81% vs. 2.74%), entered (37.62% vs. 13.7%) and exited (5.94% vs. 1.37%) poverty than the upland village (N=73), while the upland community has a higher rate of never poor households (82.19% vs. 37.62%). Comparative growth in poverty rates over the past 10 years for the two villages are: upland

= 400%; lowland = 228%. As the data presented below will affirm, the much higher figure for the upland area reflects the increasing population density combined with a lack of available land for farming; farm sizes are now too small after years of sub-dividing amongst sons. The difference between the two figures also is representative of the existence of much higher beginning levels of poverty in the lowland village compared to the upland. Data comparing the dynamic poverty measures determined by the SOP methodology against the national statistics are summarized in Table 1. The noticeable differences between the subjective versus objective poverty assessment reflect the influence of a multidimensional definition of poverty in the former beyond that of cash income.

Table 1. Comparison of standard, national poverty measures against those generated by SOP methodology.

Static poverty measures 1999 (Source: CBS, 2003)		Dynamic poverty measures (Source: SCALES, 2003)			
			10 years ago	At present	% change
National	53%	Watershed	16.48%	28.13%	+70.6%
Nyando District	66%	Nyando District	19.94%	33.97%	+70.4%
Kericho District	58%	Kericho District	11.19%	19.22%	+71.8%
		AEZ 1 (uplands)	12.0%	16.8%	+40%
		AEZ 2 (midlands)	10.02%	17.74%	+77.0%
		AEZ 3 (lowlands)	24.89%	42.34%	+70.1%
		Upland case village	4.11%	16.44%	+400%
		Lowland case village	24.75%	56.43%	+228%

To complement the mapping of poverty dynamics across the Basin and to identify associations with livelihood strategies over time, the livelihood activities practiced by households, disaggregated by poverty outcome, are overlaid. This process is carried out twice: mapping livelihood activities over socioeconomic scales as represented by the households' attained Stage of Progress for the current period, and over spatial scales corresponding to difference in AEZ. The panel-type dataset collected permits that changes in activity participation may also be recorded. The findings, presenting results across the two scales for comparison are summarized in Table 2. The results show a critical dependency of the upland community households on farm-based activities to escape poverty or remain never-poor. Most diversification within these groups is represented by mixed farming activities. Conversely, in the lowland community, while on-farm activities are more common across socioeconomic scales, they do not have the level of performance to achieve poverty escape (B) or never-poor (D) status. Instead, diversified strategies involving formal employment are instrumental in achieving these ideal poverty outcomes. Across spatial scales, high participation rates in casual labor, combined with the reduction in or complete loss of on-farm activities, are found in households that are entering poverty or are chronically poor.

Table 2. Summary of findings on livelihood strategies of two case study villages across socioeconomic and spatial scales.

SCALES, 2003 adapted by Jensen, 2008.

Spatial Scale	A: chronically poor	B: escaping poverty	C: entering poverty	D: never
Upland	Casual labor only. No maize or livestock activities.	Casual labor in combination with maize and livestock activities.	Exit from maize and livestock activities, which are replaced with casual labor. Reduced diversification in off-farm activities.	Most diversified group with mix of on- and off-farm activities. Almost full participation in maize and livestock. More than 2/3 participation in cash crops (tea).
Lowland	Diversified into on- and off-farm activities, but casual labor is dominant activity. No livestock or formal employment activities.	Most diversified group, but with lowest participation in casual labor. Combination of livestock, formal employment and on-farm activities.	Least amount of diversification. Highest rates of casual labor. Most exit by any group from on-farm activities.	Diversified, but no dominant activity. Some exit from on-farm activities.

Socioeconomic Scale

Logistical regression models are calculated to determine which particular livelihood activities significantly change the odds of being poor or not poor with results varying depending on village location. (All values are significant to at least the 0.05 level.) For the upland village, maize production is the only significant activity, decreasing the odds of being poor by 95.2%. This contrasts with the finding that livestock ownership is the only significant activity that reduces the odds of entering into poverty by 83.0%. Conversely in the lowland village, the odds of being poor are significantly reduced by having formal employment (96.6% reduction in odds), working as a skilled laborer (86.8%), and cash crop production (84.7%). When modeling what activities reduced the odds of entering poverty, the significant activities change to include formal employment (85.7% reduction in odds) and maize production (77.6%). These results suggest that these livelihood activities, assuming no new ones are possibly to be introduced, should be the ones to be supported if poverty alleviation is a serious goal.

Understanding the reasons behind the four possible poverty outcomes (A through D) is sought by analyzing the comments provided during household surveys. In total, 41 separate reasons were identified by respondents as driving their poverty dynamics. These reasons are clustered according to the five capital assets or a generic 'strategies pursued' category, argued by the proponents of the Sustainable Livelihoods framework as combining to achieve livelihood outcomes (see, for example, Chambers and Conway, 1991). For the upland village, 71% of respondents identified the particular livelihood strategy pursued as the most critical factor in achieving a positive livelihood outcome. Specifically, 80% of this group identified earning a farm income as the key strategy reinforcing the above statistical and empirical findings, while the remaining 20% identified diversification among on-farm activities as integral. Having sufficient human capital resources, mostly in the form of supplemental labor to that provided by the household, was identified by 29% of respondents as critical in achieving a positive livelihood outcome. For households in this village who are not achieving a positive livelihood outcome, indeed declining in their stage of progress, 40% identified the loss of human capital especially due to alcoholism and drug use as the main explanations. The second most common response, registering with 26% of households in this impoverishing sub-group, is a lack of financial capital primarily due to high health care expenses[1]. The third most common reason cited by 21% of households relates to limitations of physical and natural capital, in particular too small a land size relative to family size and low productivity.

There are some general similarities in terms of the most important assets with the lowland village despite the differences in particular reasons behind them. Households improving in their stage of progress determine this to be almost equally due to adopting the right livelihood strategy (50% of responding households), with 80% of those agreeing that this must include an off-farm job, again echoing statistical results. Forty-five percent of households believe human capital to be the key factor with 89% of this sub-group citing education as the most important component, unsurprising given the acknowledged importance within the village of formal employment to evading poverty. Households descending into poverty, like their upland counterparts, identified missing human capital resources as the primary reason (71% of respondents); however, in this context this is due to death of the major income earner (40% of responses), illness leading to low productivity (27%), and the taking in of orphans (13%). The second most significant factor, with 19% of responses, is constraints on financial capital due to health care expenses. Both of these factors highlight the substantial impact HIV/AIDS is having in this lowland region.

It is interesting to note that only in one instance (out of a total of 105 responses) was social capital mentioned by the sample from both villages as having a positive impact on reducing poverty. This one result was obtained in the lowland village, which differs significantly from the upland village in terms of the total number of local groups historically and presently active in the village (t-test 2-tailed sig. 0.001). Many of these groups were active in various resource management issues including reforestation; but, their lack of identification with poverty reduction is suggestive of the potential difficulty faced as the SCALES project moves forward in testing its hypothesis.

A synthesis of data collected through farming systems methods is presented (Table 3) in an attempt to draw a characterization of the poverty traps found in each of the case study villages. It assembles data to highlight the differences in resource investment levels (broadly reflective of household capabilities), crop production output levels (focusing on maize only as the main staple crop) and livelihood outcomes, including cash income and food security. From this, it is possible to begin to identify some more specific success factors and quantified tipping points that account for why some households can make sufficient investments and achieve better performance thus avoiding poverty traps.

By interpreting the above with the addition of other empirical and anecdotal information, the following characterizations about the differences in livelihood systems between the two villages can be made. The upland village with its bimodal rainfall pattern is generally populated with households engaged in semicommercial farming, commonly participating in local labor markets through the hiring of informal (casual) laborers. Population density and years of land subdivision have erased any land market leaving households struggling to acquire new lands and unable to make a sufficient livelihood from the small parcel they control. Credit markets, too, are deemed largely inaccessible, the result of a combination of factors including insufficient collateral and/or too short loan terms that do not extend the full length of a planting-harvesting-selling cycle. Remittance income is not reported by any of the households studied in depth; but, active participation in local merry-go-round or revolving credit

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[1] Malaria is the most commonly reported health care issue with 23 out of 31 households interviewed reporting at least one incidence of the illness in a year. The range in expenditure for medical treatment was KSH 200 to 6350 (US$2.75 to 86.00–September 2008). (*Source*: SCALES, 2003) The impact of these expenses is compounded by the time of year they happen; incidences of malaria are reported as occurring in June-July when cash is most constrained in the households after months of no ready produce to sell, household food stores are often empty, and cash requirements for food purchases are at their peak.

schemes is a common alternative responding to this credit market failure. Markets for the selling of goods are available; however, difficulty in access by some households finds them constrained to choosing to sell through brokers at a discounted price. Buyers coming from as far away as the capital, Nairobi, indicate the degree of market integration of the village.

Table 3. Comparison of levels of investment and crop productivity as indicated by maize for sampled households in upland and lowland villages. Results have been presented clustering sampled households according to whether they are currently stable in the never poor SOP category D or descending toward poverty in their SOP ranking. These groups for simplicity have been designated non-poor and poor, respectively.

	Variables		Upland village		Lowland village	
			Poor	Non-poor	Poor	Non-poor
Household characteristics and resources implicating levels of investments made in livelihood activities	Human capital	Household dependency ratio	> 1	< 1	> 1	< 1
		Hiring of supplemental labor	No	Yes	Yes	Yes
	Physical capital	Total farm/land size (in ha)	< 1	> 1	< 1	> 1.2
		Total area in crop production (ha)	< 1	> 1	< 1	> 1
		Access to additional (rental) land, land markets	No	No	No	Yes
	Financial capital	Access to credit market	No	No	No	No
	Technology employed	Fertilizer expenditure (in KSH)	2333-3000	1878-4600	0	0-400
		Pesticides or herbicides	No	No	No	No
		Hybrid seed purchases (in KSH)	1153-1560	956-1780	500-3610	2010-6480
		Pump irrigation	No	No	No	No
		Access to labor-saving means of production (e.g. ox-plow)	No	Yes	Yes	Yes
Livelihood strategies and outputs (productivity and performance of livelihood activities)	Maize productivity (yield in kg/ha)		1290-2160	1500-2160	215-7775	660-1730
	Volume of maize retained of household consumption (in kg)		27-450	450-900	All	All
	Annual revenue from maize sales (in KSH)		0-6750	24750-40000	0	0
	Cash income from livestock-related activities as a percentage of total cash income from farming		9-15%	21-43%	0-13%	31-83%
	Percentage of total farm income reinvested in on-farm activities		14-27%	23-44%	12.7%-24.3%	~23.5%
Livelihood outcomes	Average cash income from all sources (in USD per day)		< $1 (range $0.62-0.92)	> $2 (range $2.17-3.50)	< $2 (range $0.33-1.37)	> $2 (range $1.98-4.86)
	Percentage of income from women's sources only		24-33%	0-100%	80-100%	0-9%
	Food expenses as percentage of reported total annual expenses		69-84%	32-45%	n/a	n/a
	Total number of months maize is purchased for consumption		0-5	0-3	2-8	7

The situation in the lowland village is very different despite being distance-wise closer to markets. The village, however, is partially isolated by the destruction by flash flooding of a bridge in December 2006, which had not yet been repaired (June 2007). Regarding productivity levels, the eroded soil conditions and hydrologic vulnerability are compounding the natural variation due to differences in AEZ such that output levels are less than half those observed in the upland village. For example, maize production per hectare averages between 270-450 kg compared with 900 kg. This is reinforced by the low levels of investment made in farm inputs including almost no reported use of fertilizers. This vulnerability often necessitates replanting of crops two and three times per season due to repeated flood events. Where there is still a land market, lowland villagers who have the available funds are renting fields away from their homesteads to evade the vulnerable conditions, especially flooding, from overflows of the Awach River. Ultimately, subsistence farming predominates; no surpluses of staple crops such as maize are produced for sale nor is enough produced to provision the household for the entire year. Households report large reductions in food purchases in the spring when food stores are used up and no cash is coming into the household. Compounding the low on-farm cash incomes; the absence of credit markets makes it difficult for alternative livelihood strategies to be tried.

Several additional coping strategies and innovations, most of them on-farm, are found within the villages to compensate for missing capital resources. For example, novel intercropping practices are a common adaptation by households in both villages to have produce to eat or sell at times other than the main harvest season, to satisfy ongoing cash needs despite the often negative impact on yields. Having only one true planting season per year in the lowland village makes this a particularly important strategy, needing to combine subsistence crops with some that potentially could be taken to market. The negative impact on yields is, though, even more pronounced in this context, aggravated by the poverty trap conditions of low investment, consequential to the above constraints on human and financial capital, and low natural fertility and lost soil cover. Related to intercropping is often a high intensity of farming reflected in close plant spacing and planting calendars that fill plots year-round. These planting calendars, however, highlight differences in farming intensity between the upland and lowland villages revealing that the diversification into a wider variety of livelihood activities by the latter's households across poverty outcomes A through D does not translate into higher intensity production, attributable to the same poverty trap conditions just highlighted. Farming intensity is also reflected in the amount of technology used in production, which is found to vary, according to current cash availability in poor versus not poor households, within each and between the case study villages (Table 3). In cases where households have some capacity to acquire fertilizers, they are often applied at rates sometimes half those recommended by the Kenyan Ministry of Agriculture, translating into less than 50% of what they have determined as attainable crop yields. In response to market imperfections relating to credit, there is a preponderance of revolving credit groups in particular in the upland village. These are serving a critical function, often enabling households to invest in livestock, which as the livelihoods analysis affirmed is a key activity in remaining out of poverty. Emerging threats to livelihood outcomes to which no responses other than reduced use have appeared include the rising cost of, in particular, fertilizer inputs and casual labor, which in addition to being reported as becoming more expensive is also becoming less available for hire. Given that both of these are identified as key success factors in achieving a positive livelihood outcome in the upland village, these changing market conditions pose significant threats.

Some ongoing innovation and livelihood activity adoptions observed in each village in response to the poverty trap conditions warrant highlighting. The dominant new activity in the upland village is tea production, which is viewed by residents as promising future livelihood security. The attractions of switching to tea production are mainly: (1) once the plants are established and mature the revenue per hectare is potentially much higher than other local crops; and (2) while there is some variability in the quantities harvested in the different seasons, weekly harvesting implies there is an important smoothing effect to cash income over the year, eliminating the risk of food insecurity and hunger in the months when household stores are empty and there is no crop to sell. The services to local tea farmers provided by the controlling parastatal, the Kenyan Tea Authority, include information, technology and credit access, assisting households in overcoming these otherwise market imperfections. Reported experiences with other government agencies including the Kenyan Ministry of Agriculture, also advocating for alternative livelihood activities, were less favorable with few reported visits, or offering only prescriptions that require inputs the households could not afford. In the lowland village a variety of alternative livelihood activities are being tried. These include aquaculture ponds and rice. There is a cooperative garden group who tend the communal production of tomatoes for selling with proceeds shared, commonly spent to purchase livestock as a longer-term investment. This project is supported by a local schoolteacher who owns a generator, renting it to the group to power irrigation pumping from the river. Households interviewed for this study expressed interest in having generators of their own so that they too could irrigate their crops, overcome frequent drought and dry season conditions and produce more than one crop a year. While there is no evidence to date that households have successfully taken this approach and escaped from poverty, hampered by their lack of cash or credit and more detailed information on the best practices of this technology, there appears to be a growing impetus to try.

Conclusion and recommendations

To meet this study's larger goal an effort must be made to extrapolate from these findings what the potential changes in livelihood outcomes from collective action toward water management could be; what are the types of needs water management might address to break these traps? My argument suggests that efforts to supply or supplement missing household capital assets are a critical place to begin. Observations regarding farming practices adopted in response to missing resources (e.g. intercropping and farming intensity) to secure a positive livelihood outcome highlight the risk of not doing so, potentially leading to further production externalities and resource degradation, the third pillar of a poverty trap–in sum, fomenting the opposite to the conservation behavior sought for upper catchment management.

To arrest this self-reinforcing of a poverty trap through attempts to escape the other two aspects–investment and productivity–requires supporting households in their acquisition of capital resources necessary to engage in livelihood activities capable of generating nonpoor livelihood outcomes. As the results show, efforts to increase human and financial capital resources are most needed to enable more successful livelihood outcomes. Some of these missing resources could be compensated for through local, cooperative efforts such as revolving credit schemes; however, the extent to which these local efforts can fully overcome wider market imperfections is questionable. Higher education for human capital development is a direct function of the cash available in the household to pay for secondary school and beyond, reinforcing the need for more remunerative livelihood outcomes.

How might collective action around water management fill these capital asset gaps? The cooperative garden in the lowland village offsets limited household labor resources and, through the use of pump irrigation, also offsets some of the hydrologically vulnerable conditions. There is also a history of cooperative efforts around sisal planting along riparian areas to secure the soil surface against erosion; but, these efforts are said to have broken down (perhaps attributable to lack of incentive given the widespread understanding that formal employment is key to poverty escape) and are seen to have only a limited impact on stopping erosion from taking more land out of production. Collective efforts for spring protection and sanitation infrastructure to maintain water quality are frequently promoted strategies with a history in both villages. The livelihood impacts from these efforts relate more to health although such improvements have an indirect influence on livelihood outcome by enhancing human capital. The expected gains from these types of efforts in the two case study villages are obscure, given that water quality was not reported to have declined in the past 10 years. So, while health issues are a major source of loss to both human and financial household resources, solving the issues related to HIV/AIDS and malaria, the two primary diseases found in the Basin, are beyond the exclusive scope of the community level. Efforts to reduce the time burden on women attributable to water collection by installing and maintaining community stand pipes also have obscure livelihood impacts. While freeing up women's time is a positive, the assumption cannot be made that this time will be diverted to productive work generating more cash income than presently, thus any potential for change in livelihood outcome is also obscure.

In total, while the pathway of influence to improving livelihood outcomes and escaping from poverty via collective action around water management may be either direct (e.g. through irrigation) or indirect (e.g. through improved health increasing the availability and productivity of human capital), its sufficiency in compensating for all the reasons behind underinvestment and low productivity must be questioned. Wider market imperfections are likely beyond reach for change. This said, understanding which livelihood activities are most remunerative and the necessary success factors can be used to direct whatever local efforts are possible toward their most efficient use.

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Poverty, water, and livelihoods: A case of two upper-catchment villages in the northern Lao PDR

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Abstract

This paper reports the findings of a study on poverty, water, and livelihoods in two research sites representing the northern mountainous region of Laos. The geographic nature of poverty is apparent. The sites have higher poverty incidence than the national average. The 'higher-uplands domain' village (Silalek) is worse off than the 'lower-uplands domain' village (Fai) in terms of poverty and rice security. The differential is primarily because of better lowland and livestock asset endowment and market-orientation of Fai farm households. Ethnicity, family size, lowland (weighted by wet and dry season irrigation accessibility) and upland endowment, and livestock asset worth, were significant determinants of household poverty and rice security. Income decomposition analysis identified lowland rice and livestock as inequality-increasing; and upland rice, non-rice crops and forest products as inequality-decreasing sources of income. Investments in inequality-decreasing sources will have positive impacts on food security and poverty alleviation. The impact of water on livelihoods and poverty is mediated through lowland rice production. The ethnic groups Lao Theung and Lao Soung, and recent immigrants (<10 years) have poor lowland resource endowment. Given the skewed lowland distribution (Gini 0.80) and its potential impacts on food security, cash generation, and poverty, a deeper inquiry into the sociopolitical, economic, and cultural processes and dynamics of household lowland acquisition is important.

Introduction

Although not a sufficient condition, water availability is a crucial and a necessary condition to improve agricultural productivity and to fight poverty. It is well established that the poor have water security problems and investments in water resources management and delivery of water services are central to poverty alleviation (ADB, 2003). The linkage between water, agriculture, and poverty is, however, complex and non-linear (Cook and Gichuki, 2006). This suggests that relationships are contextual, as determined by geophysical, political, social, and economical conditions. Contextual study of these relationships is important to derive relevant technological, management, economic, and policy interventions for improved water access to increase agricultural production and alleviate poverty.

Lao PDR in the past decade has attained self-sufficiency in rice, the primary staple of the country (Shrestha et al., 2006), and the national estimates of poverty incidence has declined from 46% in 1993 to 33.5% in 2003 (World Food Programme, 2007). The self-sufficiency in rice has been achieved primarily through rice technological interventions in lowland farming systems (Shrestha et al., 2006). Higher poverty reductions have been achieved in urban areas rather than in rural areas (Lao PDR., 2003), and in locations with low poverty rather than in locations with high poverty incidences (Pandey et al., 2005). Poverty thus has strong geographic features. Urban and accessible areas have not only higher impacts of poverty reduction programs, but effects and impacts of poverty reduction programs are felt or begin first in these areas. The corollary is that the mountainous region, which is rural and inaccessible, is spatially and temporally disadvantaged in terms of poverty alleviation.

This study is an endeavor to study the nature of poverty and rice sufficiency in the two field research sites of the CPWF PN11, representing the northern mountainous region of Lao PDR, and its relationship with water and other determinants to contribute to the overall goal of the project:'…to design land-use options that improve water productivity at different scales…improve access to water by the poor, and assure sustainable food security to farmers in the upper catchments' (Schiller et al., 2006). The specific objectives of the paper are to:

- Study the nature of farm household poverty and rice sufficiency and identify their correlates in general, and water in particular.
- Study the livelihoods and income structure of the farm households.
- Identify the implications of research findings and come up with appropriate recommendations.

Methods

The study is on two CPWF PN11 field research sites: Fai village (ca. 300 m) representing 'lower-uplands' and Silalek village (ca. 600 m) representing 'higher-uplands' domains of the topological sequence in the northern mountainous region of Lao PDR. A sample household survey and participatory rural appraisal (PRA) were conducted in 2006 to collect data. A sample of 101 households was randomly selected in Silalek. Because of size, a complete enumeration of 57 households was done in Fai–four households were excluded because they had no land ownership.

The poverty line of 82,000 kip (US$1 = 8,871 kip) per person per month at 2001 prices (for rural area) is used to study incidence of poverty. It is based on the criterion used by the National Poverty Eradication Programme (Pandey et al., 2005). The household income (2005 annual) was deflated to 2001 prices based on Laos consumer price index. To get a better insight into poverty, besides the dichotomous (below and above poverty line), a trichotomous categorization of households was done. Households with annual earning two times of poverty line were classified 'well-off,' and subjacent households between '<poverty line' and 'well-off' were categorized 'vulnerable.' Besides the poverty study, rice security, in terms of number of rice-deficient years in the past 10 years collected during the survey based on recall, was studied. In Laos, rice security is tantamount to food security–rice is life. Rice accounts for some 80% of the area under crop cultivation in the country, and 80% of calorie intake in rural areas (Adams and He, 1995).

Chi-square, probit, tobit, multiple regression, and cross-tabular analysis were run to study the correlates of poverty and rice sufficiency, and relationship between poverty, water, and livelihoods. The water dimension of poverty and food security was studied by introducing it into the analysis as an interaction between lowland holding and wet and dry season irrigation availability, i.e. lowland holding weighted by irrigation accessibility: 1 for only wet season, and 2 for wet and dry season irrigation. Also, PRA was used to acquire information on water use, availability and conflict, if any. Livelihoods of the farming households were studied by directly asking how the farming households dealt with food and rice shortages, and by studying income decomposition. Decomposition analysis of income was based on 'Gini coefficient' following Adams and He (1995). Income decomposition analysis enables one to identify inequality-increasing or inequality–decreasing income sources and their contribution to overall income inequality. An income source is defined 'inequality-increasing' if the 'relative concentration coefficient' is greater than unity, and 'inequality-decreasing' if the coefficient is smaller than unity.

Findings and discussion

Village level incidence of poverty and rice sufficiency
Poverty rates are very high in the study villages as compared to the national estimate (33.5% in 2003). Some 57.5% of the population and 51.3% of the households live below the poverty line. Poverty rate is higher in Silalek than in Fai, in terms of household and population below the poverty line (Silalek: household 69.3%, head count 72% c.f. Fai: household 17%, head count 19.4%). The poverty depth and poverty severity indices are 0.196 and 0.098, respectively, for the study villages. A Chi-square test gave a significant association between the villages and poverty levels (χ^2=38.094, p= <0.001).

Table 4. Annual household income by source (US$ 2001 constant).

Village	Lowland rice	Upland Rice	Non-rice crops	Forest products	Livestock	Others	Total
Fai	142.6	135.6	197.6	14.3	353.2	116.1	959.4
Silalek	42.7	218.4	37.1	41.8	120.5	58.3	518.9
Combined	77.1	189.9	92.4	32.3	200.6	78.2	670.5

A study of income by source reveals that Fai village households on average have higher household income and earn higher levels of income from all sources, but upland rice and forest products (see Table 1). The higher level of income for Fai village is primarily due to better lowland endowment and livestock raising. A large number of Fai farmers primarily raise pigs for selling. It is noteworthy households with better lowland endowment are able to produce their rice requirement from lowland, while they produce non-rice crops like job’s tear, sesame, and maize in the uplands for cash purposes. Since Fai has better lowland endowment, it enables Fai farmers to grow non-rice crops for cash. The two villages are not very different in terms of market access. Both have access to roads. While Fai has access to black-topped road, Silalek has access to graveled road. Land constraint may restrict Silalek farmers growing non-rice crops for cash; however, a higher level of livestock raising for cash purposes by Fai farmers is indicative of their market orientation.

Similarly, the rice sufficiency situation in Silalek is worse-off than in Fai village. While 23% of households in Fai reported at least one rice-deficient year in the past 10 years, 73% of the households in Silalek reported at least one rice-deficient year. Average number of rice-deficient years for Fai and Silalek are 1.25 and 3.0, respectively. A Chi-square test for association between village and rice-secured households (deficient and sufficient) was significant (χ^2=34.629, p= <0.001). The better rice security situation in Fai village may be attributed to better lowland endowment, the inherent higher rice productivity of lowland (2.6 t/ha cf. 1.8 t/ha), and smaller family size. While 51% of the households in Fai own lowland, only 17% of the households in Silalek own lowland. Similarly, the average lowland holding size in Fai (0.51 ha) is larger than in Silalek (0.08 ha). The average family size in Fai and Silalek villages are 4.8 and 6.6 persons, respectively. Given the lowland endowment, the inherent higher rice productivity of lowlands, and smaller family size, Fai village is better rice-secured (food secured) than Silalek village.

Household determinants of poverty and rice sufficiency

A binary probit regression model was estimated to identify determinants of poverty between households 'below' and 'above' poverty lines. And, to get a better insight, a multinomial (trichotomous) probit regression analysis was also run to compare households in the '<poverty line' and 'well-off' categories with the households in the 'subjacent poverty' or 'vulnerable' category. The results of probit analyses are presented in Table 2.

Table 5. Probit regression analysis of poverty.

	Binomial probit		Multinomial probit			
	<Pov line Vs. >Pov line		<Pov line Vs. Vulnerable		Well-off Vs. Vulnerable	
Variables	Co-eff	p	Co-eff	P	Co-eff	p
HH head education	-0.023	NS	-0.029	NS	0.074	NS
Lao Theung (ethnicity)#	0.902	0.004				
Lao Soung (ethnicity)#	1.060	0.022				
Theung+Soung#*			0.728	0.099	-2.089	<0.001
Family size	0.293	<0.001	0.371	<0.001	-0.487	0.007
Lowland holding x wet/dry season irrigation accessibility	-1.366	<0.001	-1.955	<0.001	0.460	NS
Upland holding (ha)	-0.248	0.004	-0.302	0.011	0.257	NS
Livestock asset worth (US$)	-0.001	<0.001	-0.001	0.002	0.001	<0.001
Constant	-0.454	NS	-0.085	NS	0.672	NS

#Lao Lum is the reference category; *Because of small number of Lao Theung and Lao Soung in the well-off category, the two were combined for multinomial probit.

All determinant variables, except household head education, were found significant in discriminating 'below poverty line' from 'above poverty line' and 'vulnerable' category households. Only three variables, however, ethnicity, household size, and livestock asset worth are significant in discriminating households across all categories (see Table 2). Household distribution and estimated statistics for the variables of interest are presented in Table 3. Besides the probit regression analysis of poverty, tobit regression analysis was run on the number of 'rice-deficient years' in a period of 10 years (1994-2004). The tobit regression results are presented in Table 4. Ethnicity and lowland holding x wet/dry season irrigation accessibility variables were found significant.

Table 6. Household distribution and estimated statistics by poverty status.

Variables	<Pov line	Vulnerable	Well-off	Total
Household count	79	43	32	154
Avg. HH head education (yrs)	3.9	4.2	4.5	4.1
Lao Theung (household)	63.1%	33.8%	3.1%	65 (count)
Lao Soung (household)	79.4%	17.6%	2.9%	34 (count)
Lao Lum (household)	20.0%	27.3%	52.7%	55 (count)
Avg. Family size (head count)	6.7	5.7	4.6	6.0
Avg. lowland holding (ha)	0.05	0.29	0.58	0.23
HH count (only wet season irrigation)	2	5	8	15
HH count (wet+dry season irrigation)	4	14	11	29
Avg. upland holding (ha)	3.61	3.75	3.34	3.59
Avg. livestock asset worth (US$)	357.7	713.3	896.1	568.9

Table 4 Tobit regression on number of rice-deficient years in a period of 10 years.

Variables	Co-eff	P
Lao Theung (ethnicity)	3.533	<0.001
Lao Soung (ethnicity)	1.870	0.008
Members ≥ 15 yrs	0.104	NS
Lowland holding x wet/dry season irrigation accessibility	-1.490	0.004
Upland holding	-0.168	NS
Constant	-0.766	NS

A perusal of Table 3 and Table 4 reveals that the economic variables lowland endowment and livestock asset worth are important, whose estimates vary considerably between the economic groups.

Therefore, further examination was done to identify sociocultural variables significant in explaining household lowland endowment and livestock asset worth.

During the participatory rural appraisal and questionnaire pretesting it was identified that a number of farm households had in-migrated to the villages during and after the war in the 1970s, and because of government policy (through a decree) to move farm households from higher uplands to lower uplands and to road heads with a dual objective of environmental and socioeconomic enhancement of uplands and farming communities, respectively. Of the total, some 75% of sample households have in-migrated, of which 45% and 17% of the households have been living in the area for '<10 years' and '10-20 years,' respectively. The sample households were categorized into four: (1) immigrant <10 years stay; (2) immigrant 10-20 years stay; (3) immigrant >20 years stay; and (4) indigene for analytical purposes. Lowland endowment and livestock asset worth were regressed upon ethnicity, and categories derived based upon immigration status and length of stay. The results of the multiple linear regression analyses are presented in Table 5. The regression results indicate that Lao Theung, Lao Soung (lowland endowment only) and new immigrants are disadvantaged in terms of lowland (surrogate of access to water) and livestock asset endowments.

Table 5. Multiple regression analysis of household lowland endowment and livestock asset worth.

Variables	Lowland endowment*		L/stock asset worth#	
	Co-eff	p	Co-eff	p
Theung (ethnicity)	-0.326	<0.001	-201.16	NS
Soung (ethnicity)	-0.247	0.033	520.83	0.008
Immg <10 yrs stay	-0.230	0.034	-378.86	0.038
Immg 10-20 yrs stay	-0.184	NS	-120.80	NS
Immg >20 yrs stay	-0.097	NS	29.57	NS
Constant	0.545	<0.001	673.17	<0.001

Livelihood and household income decomposition

The two villages are overwhelmingly agricultural. Some 97% of the households depend on agriculture. The farmers grow rice in the lowlands and uplands for food. They grow non-rice crops like job's tear, maize, sesame, paper mulberry, peanut, soybean, and vegetables, primarily for cash. They also raise animals such as pig, buffalo, cattle, chicken, and duck for meat, draft, and cash. A few households also work for wage, weave, and collect forest products for cash. The farmers are heavily rice-oriented. The farm households exclusively eat rice to meet the food grain shortfall. They either borrow rice, work for rice, or purchase rice to meet the food grain shortfall. Only two households reported eating cassava and maize although a few households (14) reported foraging in the forest to supplement rice.

Table 6. Income decomposition analysis: Annual household income, Gini coefficient, relative concentration coefficient and factor inequality weights

Village/ Poverty status	Lowland rice	Upland Rice	Non-rice crops	Forest products	Live-stock	Others	Total/ Overall
6.1 Annual household income by poverty status (US$ 2001 const.)							
< Poverty line	16.2	203.1	42.4	29.4	61.7	25.4	378.3
Subjacent	114.4	193.8	90.1	43.0	218.6	106.2	766.0
Well-off	177.3	152.2	218.8	25.1	519.2	170.6	1263.3
Mean	77.1	189.9	92.4	32.3	200.6	78.2	670.5
Std. Dev.	143.1	111.6	112.8	50.1	308.1	171.5	457.2
% HH involved	28.6	86.4	77.9	53.9	94.8	61.0	
6.2 Gini coefficient							
Silalek	0.89	0.24	0.61	0.54	0.69	0.86	0.33
Fai	0.61	0.50	0.34	0.95	0.58	0.71	0.29
Combined	0.79	0.33	0.59	0.69	0.68	0.81	0.36
6.3 Relative concentration coefficients of source incomes							
Silalek	2.14	0.35	0.16	0.70	1.78	1.81	
Fai	0.96	-0.07	0.28	1.44	1.76	1.16	
Combined	1.64	0.04	0.85	0.30	1.68	1.45	
6.4 Factor inequality weights of source incomes							
Silalek	0.18	0.15	0.01	0.06	0.41	0.19	1.00
Fai	0.14	-0.01	0.06	0.02	0.65	0.14	1.00
Combined	0.19	0.01	0.12	0.01	0.50	0.16	1.00

The primary sources of income for the farming households are livestock, upland rice, and non-rice crops, followed by forest products, other sources and lowland rice in terms of average household income and percentage of households earning income from these sources (Table 6). Besides rice, the other income sources are primarily cash source for the farm households. It is interesting that although livestock is the highest ranking source of income, it is 'inequality-increasing' source of income–the relative concentration coefficient is greater than unity (Table 6). This suggests that investment in livestock development will largely benefit the well-off category of farmers more than the other two, unless special efforts are made. Although staple, lowland rice is 'inequality-increasing' income source, given the Gini coefficient and relative concentration coefficient, upland rice followed by non-rice crops and forest income sources are inequality-decreasing. Public investment, in research and development, in inequality-decreasing income sources will have higher impact on alleviating poverty in rural mountainous villages.

Conclusions and recommendations

Geographic manifestation of poverty is evident. Incidence of poverty in these uplands villages is high. And, the incidence of poverty and rice insecurity is higher in the higher-uplands domain village (Silalek) than in the lower-uplands domain village (Fai). The differential can be attributed to better lowland (51% in Fai and 17% households in Silalek own lowland), which enables them to grow non-rice crops in the uplands for cash, and livestock asset endowments, and market orientation of Fai farm households.

At the household level, ethnicity, family size/family members ≥15 years, lowland holding (weighted by wet and dry season irrigation accessibility), upland holding, and livestock asset worth were identified as important determinants of poverty and rice security. Lowland endowment is one of the important determinants of rice security and poverty by enabling the growing of non-rice crops for cash. But, lowland distribution is skewed–Gini coefficient is 0.80, and only 27% of households own lowland. PRA revealed that the primary agricultural use of water is growing paddy. And, availability and access to water is largely geophysical dependent. There is little direct conflict in water use, and water shortage is primarily confined to the dry season. Noteworthy, given the characteristics of water use, and availability, access to water is tantamount to access to lowland and dry season irrigation to grow rice. Since lowland is surrogate of water, the impact of water on food security and poverty is mediated through lowland. Income decomposition analysis identifies that while lowland rice and livestock is an inequality-increasing source of income, upland rice, non-rice crops, and forest products are identified inequality-decreasing income source.

Based upon the research findings the following recommendations may be formulated:

- Investments into inequality-decreasing sources of upland rice, non-rice crops and forest resources are instructive for food security and cash income. Given low productivity of upland rice (1.8 t/ha) well below potential (4.0 t/ha) research investment in upland rice is doubly important.
- Given (1) the Lao Government decree to move smaller and remote highland villages to more road-accessible areas, thus relocating hundreds of thousands of families, and (2) lowland is important for food security, poverty alleviation and environmental enhancement, is proxy of water access, distribution is skewed; and is inequality-increasing income source, a deeper inquiry to understand the sociopolitical, economic, and cultural dynamics and processes of household lowland acquisition is deemed important. Additionally, identification of areas appropriate for terrace building is important, as is research into identification of household constraints to construction of terraces, in order to formulate sound policies and procedures that contribute to improved rice production and food security.
- Farmer yield of lowland (2.6 t/ha) and upland (1.8 t/ha) rice is well below potential. Varietal and management research into improving their productivity is warranted. But, given their inequality-changing nature, upland rice research should be given priority to benefit impoverished farmers in both villages.

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Impact of access to water on livelihood strategies in northern Thailand

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Abstract

We describe water management systems in the highlands of Mae Suk watershed (Mae Chaem district, Chiang Mai) and use a sustainable livelihood framework to evaluate the impacts of access to water on farmers' livelihoods. The primary data were collected in four villages of two different ethnic groups, namely lowland northern Thai and upland Karen. Farm households were classified according to upland and lowland communities and water availability, as well as both farm and non-farm income. Cluster analysis was used to investigate relationships. During the dry season in the Mae Suk watershed, water competition is growing as commercial irrigated vegetable production is used more intensively in both lowlands and uplands. Irrigation systems have been developed to cope with the increasing demand. Irrigation has been used increasingly for commercial crops in the uplands. Several indicators were used to characterize vulnerability, capital assets, livelihood strategies and outcomes of each group. A livelihood approach used in this analysis helps in understanding how access to water and water availability can contribute to poverty reduction and enhance income of farmers.

Media grab

Improving access to water using private water management systems and new technologies can enhance a farmer's household income.

Introduction

Farm households with restricted access to reliable water for both household and productive purposes are a central feature of poverty in developing countries (Merrey et al., 2005). Improving the access to water is an important way of diversifying livelihoods and reducing the vulnerability of poor farm households. The important questions asked are how to help farmers improve their access to agricultural water, what role access to water plays in local livelihood strategies, and how that relates to the use or availability of other assets.

Methods

The conceptual framework guiding this paper is the sustainable livelihoods framework (SLF) (Ashley and Carney, 1999; DFID, 2000). In this study, the SLF is used to examine the relationships amongst the farmers' human, natural, physical, financial, and social livelihood assets. Each component of livelihood assets is measured using indicators as follows: (1) Human assets: age and education of household head, labor availability in person-equivalent unit and health threats of households; (2) Natural assets: agricultural area, irrigated area, fallow areas, number of livestock; (3) Physical assets: value of shelter and building, sufficiency of household water supply and sanitary, type and number of vehicles, type and value of farm equipment; (4) Financial assets: access to credit, pension and remittance, value of household assets; and (5) Social assets: membership of water user group, leadership of existing groups, kinship network, and community network.

A qualitative scoring system was used to value a household's asset base and to facilitate comparison between the asset bases of different household groups according to access to water and income. A maximum of five points was allocated for each indicator and each asset has four indicators. Therefore, a maximum possible score of each asset is 20 points. These scores were given to each household separately. Scores of each indicator under each asset were summed to produce an average for that asset. The individual asset scores were aggregated to give an overall score for each group of households. The scores of each component of livelihood assets were evaluated and compared by testing for significant differences between groups.

Farm households use various assets in their productive activities in order to create income and satisfy their consumption needs, maintain their asset levels, and invest in their future activities. The ways in which they do those activities show the livelihood strategies of farm households. The vulnerability of farm households was examined using indicators, including shocks (e.g., natural hazards, floods and drought, and conflict over water use), trends (i.e. variation in several sources of income), and seasonality (i.e. fluctuation of output price and lack of seasonal hired labor for agricultural activities). Percentages of households facing those problems are used to present the indicators. Finally, livelihood outcomes of each farm household group are presented.

Process

The Mae Suk sub-watershed was selected as the study area (Figure 1). It covers an area of 96 km^2. The upper part of the sub-watershed is surrounded by hills of 1068 m, whereas the lower part is plane areas with paddy fields. The primary data based on interviews with farm families using a structured questionnaire were collected in 2006 in four villages of two different ethnic groups, lowland northern Thai and upland Karen, in Mae Suk sub-watershed, Mae Chaem district, Chiang Mai. A total of 158 farm households in four villages was selected using multi-stage sampling. All sample farm households were classified according to upland and lowland communities, irrigated area, and sources of earned income using two-step cluster analysis in SPSS.

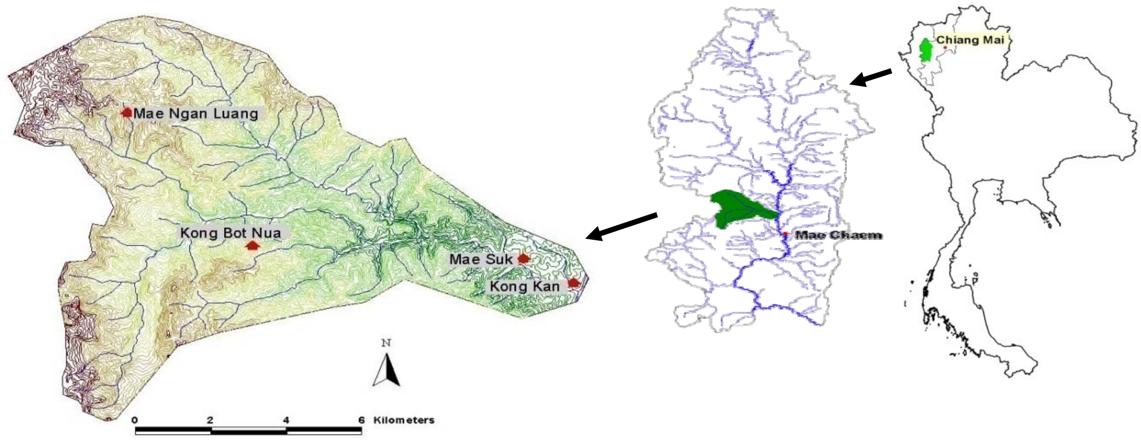


Figure 1. Mae Suk sub-watershed, Mae Chaem watershed, Chiang Mai province, northern Thailand.

Several livelihood indicators were developed and tested for significant differences between household groups according to different access to water and to characterize vulnerability, livelihood assets, livelihood strategies and outcomes of each group. All surveyed households were classified into four groups. The first group (66 samples) is the lowland households with poor access to water (LL-PoorAW). The second group (13 sample) is also lowland households but with good access to water (LL-GoodAW). The third group (50 samples) is the upland households with poor access to water (UL-PoorAW), and the fourth group (29 samples) is also upland households but has better access to water (UL-GoodAW).

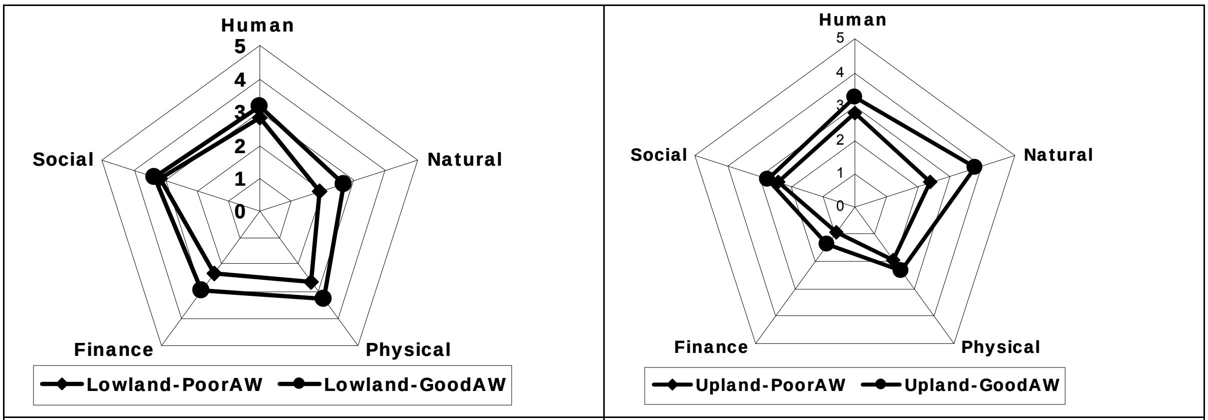
Water use and irrigation management systems

Different water use and irrigation management systems are used in the lowland and upland parts of the Mae Suk sub-watershed. In the lowlands, a traditional irrigation system known as *Muang Fai* (canal and weir) system was used prior to 1954. The irrigation system had been improved along with the change of farming system from subsistence to more. In this irrigation system, weirs along the stream are used for diverting water to the fields. In each main weir, a committee is selected by farmers who use the water (weir members). Regulations and management system are set by the group and the weir members need to follow the regulations and help to maintain the weir. If a water shortage exists, the committee manages how the water will be distributed equally to all members regardless of their distance from the weir. Irrigation is required for the whole year. During the rainy season water from irrigation canals is diverted mainly to terraced paddy fields for rice cultivation, whereas during the dry season, only a part of a paddy field was used for shallot and soybean production and irrigation was required. Fruit trees, mainly longan and tamarind, also consume significant irrigation water during the dry season.

In the Karen upland communities, crop production systems have been significantly changed from rice with other rainfed upland crops such as maize and soybean to be mainly rice and irrigated vegetable crops, such as shallot and cabbage. This change led to greater demand for irrigation water, especially during the dry season and consequently increasing tension over water use between upland and lowland communities. Irrigation water used for cash crops is transferred from streams through PVC pipes. Sprinklers are used to distribute water into the fields. In the upper parts of streams pipes can be placed directly in the stream. In the lower areas weirs need to be constructed to lift the level of water. The regulation of using this system is that once a farmer has established a weir, others can use the same stream but only below the existing weirs. The regulation cannot be maintained, however, when the demand for water is high (Badenoch, 2006). As the number of pipes increased some users moved their intake upstream to ensure more regular water flows. Conflict over water use has been rising. Tension has also increased as lowland communities claim that land use practices in the highlands have created floods, droughts, sedimentation of water resource infrastructure, and perceived decline of water quality (Thomas et al., 2002).

Results

Results of livelihood asset analysis show that in the uplands, the human assets of the households with good access to water are higher. There is, however, no significant difference between the lowland households with respect to good and poor water access. The natural assets in place of access to land, water, fallow, and livestock were weakest at the lowland households with poor access to water, and strongest at the upland households with good access to water. The physical assets, representing basic infrastructure and producer goods, of the lowland households were stronger than the upland households. Although upland households with poor access to water were weaker in the physical assets. Similarly, the financial assets were also generally weaker for the upland households but they were significantly stronger in the upland households with good access to water. While upland households enjoy significantly better social assets than lowland households, there is no significant difference in the social assets between the households with poor and good access to water. This result shows the lowland communities have stronger social networks and relations as well as better relationship with the state than the upland communities. The relative strengths and weaknesses of individual assets are illustrated in an assets pentagon (Figure 2). The overall strength of an asset is indicated by the area of the pentagon.



A. Livelihood asset pentagon of Lowland communities	B. Livelihood asset pentagon of Upland communities

Figure 2. The pentagram illustrating the five components of livelihood assets.

The access to water in the lowlands mainly refers to the access to irrigation canals and weirs that are communal property, whereas in the uplands it mainly refers to private or individual access to water from creeks or streams. The relationships of livelihood assets to access to water are different for different irrigation systems. Almost all components of the livelihood assets show a significant relationship to private or individual access to water, whereas only natural assets have a significant relationship to access to communal water.

For comparing vulnerability context across groups, the differences of vulnerability in terms of natural disasters as well as income trends between the upland and lowland communities were observed in this study. Percentages of households facing floods and drought as well as high variation in farm income in the lowlands are larger than in the uplands. But there was no significant difference between the households with poor and good access to water.

In this study, the livelihood strategies are reflected in the land use and farm activities, labor use, and expenditures. The surveyed results show that the cultivated areas of paddy rice, shallot, maize, and soybean were greater for households with good access to water, although the test of mean difference using ANOVA show that there were no significant differences between groups (Table 1). The focus group discussions revealed that the capital cost of buying 'mother' bulbs for shallots, an important dry season crop, is a significant issue for some farmers. Furthermore, price fluctuation of shallot year by year is another significant factor affecting shallot production. High capital requirement and price fluctuation make shallot production risky. Limited size of shallot production is a strategy practiced by lowland farmers for reducing the risk.

Table 1. Land use strategies of the different farm households in Mae Suk sub-watershed.

Items	LL-PoorAW (n=66)	LL-GoodAW (n=13)	UL-PoorAW (n=50)	UL-GoodAW (n=29)
Average land/household (ha) %	1.53^{a} (1.06)	1.98^{ab} (1.11)	2.29^{b} (1.47)	3.48^{c} (1.68)
of land that is irrigated	31	59	14	53
Land use(ha):				
- Paddy rice (RS)	0.43^{a} (0.25)	0.72^{a} (0.40)	0.07^{c}(0.28)	0.01^{c}(0.06)
- Upland rice (RS)	-	-	1.09^{a} (0.57)	1.50^{b} (0.71)
- Shallot (DS)	0.25^{a} (0.27)	0.54^{ac} (0.61)	0.07^{b}(0.17)	0.61^{c} (0.48)
- Maize (RS)	0.93^{a} (0.91)	0.95^{a} (1.06)	0.20^{b}(0.53)	0.14^{b} (0.42)
- Cabbage (RS and DS)	-	-	0.38^{a} (0.39)	0.56^{a} (0.54)
- Soybean (DS)	0.11^{a} (0.20)	0.36^{a} (0.51)	-	-
- Fallow	0.25^{a} (0.85)	0.37^{a} (0.76)	0.71^{b} (1.01)	1.64^{ac} (1.58)

Note: Figures in parentheses are standard deviation. DS = Dry season crop and RS = Rainy season crop.

In the upland areas rice and shallot cultivated areas of the households with good access to water were significantly larger than that of the households with poor access to water. Shallots cannot be grown if farmers have no access to irrigation water during the dry season. The upland farmers adopted sprinkler irrigation systems for growing shallots in the dry season, but a limited cultivated area of shallot was also observed. Cabbage was grown two times a year by farmers who have access to irrigation. The use of household labor for own-farm activities and as hired labor for neighbor farms or non-farm sector were not significantly different with respect to access to water. Similar to the expenditure item, the lowland households spent more cash to buy food than the upland households, but there is no significant difference according to access to water.

Livelihood outcomes are the achievements of livelihood strategies. The results of farm income as well as family income show that the households with good access to water had earned more income (US$2893 per household for lowland and US$3637 per household for upland) compared to the households with poor access to irrigation water (US$844 per household for lowland and US$1805 per household for upland). More than half of the upland farmers still did not feel secure in their livelihood, however, which may be explained by land use policy in this area. Researchers on land use stated that nearly all land in Mae Chaem watershed is classified as protected watersheds, and the 60,000 people living there (72% ethnic minorities) depend on these lands for their livelihoods. Only small areas of paddy field in lowland areas have official land tenure recognition, and although informal local land use institutions have provided a basis for managing community land for generations, they are vulnerable to pressure and encroachment from more powerful outside forces (Thomas et al., 2002).

Discussion

Due to different irrigation management systems, private irrigation systems have a strong relationship to livelihood assets. The upland farmers who have good access to water can extend their crop production into the dry season and have greater success with commercial crops, whereas farmers who have poor access to water or rely only on rainfall, have limited production. The upland farmers with limited access to irrigation improved their income with other strategies such as using labor for livestock production during the dry season, which contributes to more than one-third of their family income. In the lowland areas where access to non-farm jobs is better, the farmers with poor access to water earned on average one-fourth of family income from non-farm employment. In uplands and lowlands, the farmers having better access to water are better off and feel more secure in their livelihood.

Conclusions and recommendations

This empirical study showed how sustainable livelihood framework can be applied to explain the relationship between livelihood outcomes and access to water and other livelihood assets and strategies. Access to water, in particular private irrigation systems, has a strong relationship to other livelihood assets. Improving access to irrigation for the upland farmers can be achieved by providing access to other assets such as credit. These relationships, however, are also related to the existing irrigation system, as well as possible irrigation systems that farmer have access. In Mae Suk watershed, where market access is good, improved access to water can enable farmers to adopt new technologies such as sprinkler irrigation systems, and thus to have greater success with cash crops and intensified cultivation, leading to increased income from farming. Similar improvement may not have comparable results in very remote areas where access to market is quite difficult.

Nevertheless, improving access to water for upland farmers is likely to reduce the amount of water available to the lowland farmers. Participatory management of water at the stream/watershed level may be necessary to achieve a compromise position that will be acceptable to all farmers.

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Agriculture and fishery concerns in Stung Chinit Irrigation, Cambodia

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Abstract

Irrigation has been an important public policy issue in Cambodia for many years. The current leaders are using this form of development as one of the major public works to mobilize political support and for rural transformation. It is widely believed by some of the key policymakers in Cambodia that without large-scale irrigation schemes, farmers will remain trapped in a life of poverty and hunger in subsistence agriculture. This belief has justified the push for irrigation expansion, which has received wide support from society, including donor agencies.

This paper draws early lessons learnt from the first large-scale Strung Chinit Irrigation Scheme and Rural Infrastructure Project (SCIRIP). Our results show that the scheme has not achieved its expected outputs, resulting in cost overruns, a negative impact on fish migration through fishways construction, and problems with project governance. We hope to provide some insight into irrigation planning and management processes in Cambodia.

Media grab

The rush to large-scale irrigation investment resulted in cost overruns with few benefits

Introduction

In the early 1990s, the Asian Development Bank (ADB) approved the Special Rehabilitation Assistance Loan (SRAL) for emergency rehabilitation of infrastructure, including some irrigation systems. During preparation of the SRAL, it became clear that there was scope for further investments in irrigation, as agriculture dominates the economy, and the rural infrastructure was decimated by war (ADB, 2000).

The Tonle Sap Lake and its 12 tributaries, with total catchment areas of 86,140 km^2, is the most important region, not only for poverty alleviation but also for economic development in the country (JICA, 2007). Many irrigation schemes are found on these tributaries. Stung Chinit is one of the tributaries with total catchments of 6770 km^2 (ADB and CNMC, 2004). The total length of the tributaries is 300 km, and the highest elevation is 414 m (Puy, 2004). The reservoir created by spillways is approximately 12 km long with a total area of 25 km^2, and could store 60 million m^3 of water.

The spillway is built across the tributary to divert water for irrigation. It is located in Kampong Thom about 129 km from Phnom Penh, covering two districts: Santuk and Baray with 8 communes, 62 villages, 11,250 families, and 59,878 people in the surrounding the project area. The scheme was built during the Pol Pot period in 1977. The total command area during this period was 12,000 ha, and has been increased during 2001 and 2007.

The study assessed agricultural productivity, cost benefits, impact on fishery resources, and the governance system of the scheme.

Methods

We formed an interdisciplinary team with people from IWMI and the former Mekong Wetland Biodiversity Conservation and Sustainable Use Program (MWBP) based in Cambodia and Vientiane, to assess the impact on fishery migration and agricultural productivity. Farmers participated in the scheme operation, and we interviewed project staff during November 2006. I made frequent visits throughout the entire period, up to 2008. Some key project reports and documents, including the relevant studies on the issues, have been reviewed and cited.

Agricultural extension: planned vs. actual outcomes

One of the primary aims of the scheme was to increase agriculture productivity and stimulate the rural economy in the district of Santuk, Kampong Thom Province. Rice is the main crop, and the project expected to achieve 2.5 t/ha with irrigation in place. During the project implementation from 2001-2006, however, the rice yield using conventional methods is still low at 1.6 t/ha in 2002, 1.3 t/ha in 2003, 2.17 t/ha in 2004, and 2.17 t/ha in 2005.

Use of new technologies in rice cultivation

The system of rice intensification (SRI) is a new technical option for rice cultivation and improving yield. It comprises a set of principles and the method was introduced in 2002. It is now gaining acceptance among farmers (Table 1).

Table 1: Progress of SRI adoption/adaptation in the command areas.

Year	2002	2003	2004	2005	2006	2007
No. farmers	32	189	586	608	1276	2030
Cultivated land (ha)	16	54	340	263	731	1307
Yield (t)	2	2.3	3	2.8	3.6	3.6

Source: Agriculture Research and Development (2008).

Although the introduction of SRI has been progressing, the technological transfer is still below expectations. One of the good things, however, is that farmers know how to collect and save compost (organic farm), know how to identify insect effects on the rice crops, and SRI method. The saving groups were established to arrange exchange visits with other villages, thereby building up social capital. These groups were also able to write simple reports and keep financial records.

There was a tendency to decrease SRI adoption and practice within the scheme when external support from GRET/CEDAC ceased in July 2008. This was also partly due to the poor transfer of knowledge about opportunities for rice cultivation to the local people living within the scheme.

Cost overrun with shorter benefits

One of the big concerns of the scheme is the higher cost of renovation with fewer benefits. The potential irrigated areas were 12,000 ha in the wet season and 2,000 ha in the dry season. The total project cost (Table 2) was estimated at US$23.8 million equivalent, comprising US$9.6 million (40%) in foreign exchange and approximately US$14.2 million equivalent (60%) in local currency costs. The proposed irrigated areas have been reduced to only 7000 ha, 5000 ha in the wet season and 2000 ha in the dry season. The overall project implementation period was six years (2001-2007). The land ownership survey and titling activities were to be completed during the first 2 years, as well as the technical investigations. The construction and renovation of the scheme was expected to start in 2003-2004, and the complete operation of the scheme was to be in place by 2007.

In fact, the construction started in 2006 and then extended to July 2008. The delay of construction came partly from the political turmoil of government formation in 2003, and the restructuring of the proposed scheme construction. The delay of scheme construction also affected the farmer water mobilization (in particular the social development component), which forms the software component. Although this sector has taken place from 2001 to 2008, they are still having difficulty managing the scheme. The current FWUC needs an extension for another 5 years starting from 2009 with financial support from AFD (Agence Française de Développement).

Table 2. Financial plan and estimation.

Source	2000	2007	2008
	US$ Million	US$ Million	US$ Million
ADB	16	18.5	20.1
AFD	2.6	2	2
Government	4.6	5.5	5.5
Beneficiaries	0.4	-	-
Total	23.8	26	27.6

The benefit area of the scheme has been reduced from two districts, seven communes, 62 villages to only one district, three communes, and 24 villages.

Problems related to fish migration

The Stung Chinit System has one of the richest natural fish populations migrating upstream and downstream. To facilitate this, the system designers took into consideration fish migration between downstream and upstream, and included fish migration structures (fishways) next to the spillway. A fishery survey in 2003-2004 showed 79 species belonging to 9 orders, 19 families, 57 genera, and 79 species (Puy, 2004).

The fish catch survey before fishway construction showed 7000 t/year came from the current five commercial fishing lots downstream in Tonle Sap Lake, and 1406 t/year come from families and artisanal catches. In addition, fish catch from the riverine system is shown in Table 3 below.

Table 3. Fish catch (kg) in Stung Chinit River System in dry season (DS) and rainy season (RS).

Dry season		Rainy season	Yield	Yield RS	Yield DS
River (38km)	57	114	60	6,840.00	3,420.00
Tributary	1.2	2	60	120.00	72.00
Lake, floodplain lake	150	800	120	96,000.00	18,000.00
Main canal	21	36	80	2,880.00	1,680.00
Pond/burrow pits	15	20	100	2,000.00	1,500.00
Floodplains	400	2,500	200	500,000.00	80,000.00
Rice field	660	660	10,000	50	500,000.00
Total (kg)	1,304.2	13,472		1,107,840.00	137,672.00

Source: KOSAN Engineering (2003).

After the construction and the operation of the fishway, only 53 species were found. Migration through the fish ladder is difficult for fish. Some species cannot migrate upstream, resulting in the loss of these species to upstream residents. Most of the fish that migrate through the fish ladder are small, and can only be used to make fish sauce, food for pigs, or used as fertilizer with low economic value.

During the dry season, the water level from the reservoir and downstream is quite significant, and the water level will not permit fish to migrate through the fish pass. Most of the fish collect at 'brush parks' downstream. A brush park is any kind of area where bushes or tree braches are cut from the nearest available sources, usually flooded forest. They are set out next to each other inside the stream close to the riverbank. They are operated from December to June in the stream, where the current is not too strong. After demarcating the chosen location by wooden poles, the brush and tree branches are placed evenly inside. Fish seeking shelter are attracted to the brushwood. To collect the fish, a long seine net is put around the park. Then the brushwood is taken out starting with the brushwood next to the net. When a brush-free space has been created, the net is moved close to the remaining brush, and the fish inside are harvested.

There are about 50 brush parks set up from the spillway to the bridge at the national roads. It is estimated that each brush park could catch 50 to 1000 kg per month. Fishers increased the fish catch downstream by using gillnets during the wet season, and by using brush parks during dry season (from December to June). These fish concentrated at these refuges, and could not migrate upstream in the dry season.

Actual project organization and coordination

In practice, the overall scheme is operated by the MOWRAM. To facilitate the work, MOWRAM has established the Project Implementation Unit (PIU), which includes technical experts and engineers from the ministry in a social development component and infrastructure component. The social component is contracted to Research and Technological Exchange Group (GRET) and the Center for Study and Development in Agriculture (CEDAC) to undertake activities such as mobilization and formation of Farmer Water User Communities (FWUC), Agriculture Development and Research (ARD), land registration and titling, environmental research, and institutional support. Government staff from agriculture and water resource and meteorology departments were trained to work in this sector. The infrastructure components contracted international and national companies to work with PIU.

Related components were not well coordinated and integrated. In terms of agricultural sectors, the provincial director of the agricultural department explained:

> *The role of the Provincial Department of Water and Meteorology (PDOWRAM) is to build and renovate irrigation schemes including establishing FWUC and a reservoir committee. However, in some cases, even though we have irrigation in place, it does not mean the whole area turns green and farmers start to grow crops. The case from Stung Chinit shows that the scheme has been completely built and able to irrigate about 2000 ha in the wet season with 9800 plots of paddy. The delay in scheme construction makes farmers feel less interested. In 2008, during the dry season, we spent about 20 million riel (US$5000) to mobilize and assist farmers to prepare their land for cultivation. We managed to plant 300 ha, of which 65% of the rice crops had been destroyed by insects. This also pushes farmers to keep moving upstream for forest cutting and to sell labor for commercial plantation companies (July 10, 2008).*

The role of PDOWRAM is also limited to scheme construction and formation of FWUC for scheme operations and maintenance. The effectiveness of the FWUC to execute the scheme was short-lived. In most cases, when the project was being implemented with external support, the FWUC was functioning well. But when external support ended, the FWUC responsibility for O&M became weak. The provincial director of PDOWRAM has strongly supported this argument, but failed to explain the details why FWUC could not function properly after the external assistant left.

Conclusions and recommendations

This project was promoted by the state, donors, and the project designers as a model to be replicated in achieving rural development and economic transformation in other parts of Cambodia. This created high hopes among the local people residing within the project command, and others near the area, even outside of the project command. Meanwhile, the concept of Participatory Irrigation Management and Development (PIMD) and Integrated Water Resource Management (IWRM) has been applied within the scheme implementation (Roux, 2005; Molle, 2007).

The findings show that the project has not yet been able to achieve many of its objectives, despite modifications at different phases of its implementation. The command area originally to be served by the project has been reduced. There has been poor rice yield production, poor design that flooded villages and wet rice fields, poor farmer participation, and weak local institution-building, and fish migration concerns. Up to 2008, the cost of project construction and operation has increased from US$23.8 to US$28.7 million (US$1.6 million borrowed from ADB to renovate the main canal), with an attendant in reduction of command area, from 12,000 ha to 7000 ha, and finally to only 2000 in the wet season with one district, three communes, and 24 villages benefitting.

Because there are many schemes to be renovated surrounding Tonle Sap Lake using the model from Stung Chinit, it is recommended that any project physical infrastructure design should be done after a farmer water user community has been established. And physical infrastructure design should be considered on social factors (relationship and collective action). The formation of an FWUC should be done before the rehabilitation and construction takes place, so that their capacity will be well developed. The financial planning should be more realistic and transparent.

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Coping strategies of rural women in the context of male out-migration

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Abstract

Male out-migration has been prevalent in Nepal for centuries. The deteriorating conditions of agriculture and water scarcity increasingly result in low productivity and food insecurity that compels men to migrate. They leave their families behind, remitting some of their earnings to mitigate the shortfalls of farm production. The migrants' wives single-handedly shoulder the management of their households, farm livelihoods, and social activities in the absence of their husbands. They determine their coping strategies by exercising their social capital, over which they have control and access. Their strategies are mediated by the type of family they live in, the surrounding natural resources that are available to them, and the relationship they share with their social and kinship networks. This study concludes, however, that the efficacy of their strategies is not based on absence or presence of their husbands but the social bonding they share within their community. This social bonding helps the women who are more vulnerable and strengthens women who are better off in the absence of their husbands.

Media grab

The literature poses a question: 'Are migrants' wives better or worse off in the absence of their husbands?' Our findings show there is no clear answer. It is a question about how effective social capital could strengthen and enable women's access to productive resources and reduce their overall vulnerability.

Introduction

In Nepal, migration is a key option for rural people to cope with population pressure living with limited cultivable land in mountains and hills. Past research shows that the high rate of rural-to-urban migration is largely due to food scarcity and security (Gurung, 1989). In this study, the primary

Table 1. Reasons for male out-migration.

Ranking	Employment opportunities	Low agricultural productivity	Political situation	Change in environmental condition
	Frequency in %	Frequency in %	Frequency in %	Frequency in %
Lowest			58.5	41.5
Probable		9.8	36.6	53.7
Medium		90.2	4.9	4.9
Highest	100			
Total	100	100	100	100

Source: Household survey in November 07, Majthana Village Development Committee (VDC), Nepal (Lamichhane, 2008).

reason for out-migration has been the deterioration of agricultural outputs that have resulted in low productivity and food insecurity (Table 1). This has compelled men to migrate from the three studied villages (*Gaon*) (Bhurtel, Lamichhane, and Thapa) of Majthana VDC in Kaski District, Western Nepal, to urban centers. With the absence of men in these villages, women have become solely responsible for managing farmland and households. This study focuses on 'migrants' wives' to find out how they cope with such change, and whether their situation improves or worsens in the absence of their husbands. The study also provides insights into community development issues where women's involvement is quite prominent in relation to governance and participation. The study is intended to inform the future policy process to take into account the complexity of women's capacity to adapt and improve changing social and environment patterns.

To address this, the effects of male out-migration on two groups of women are examined: those from nuclear (comprising of husband, wife, and children) and extended (three generations living under the same roof) households. The study also examines their coping strategies in light of their existing social networks, livelihoods, and productive assets.

Methods

This research employs a mixed method approach where primary and secondary data were collected mostly from the field in Majthana VDC, and supplementary information was gathered in Kathmandu and Pokhara City. The research took place in three phases: (1) participant observation and collecting secondary data on the study site; (2) focus group discussions (FGD) and in-depth interviews with key informants; and (3) a survey to examine livelihood patterns in male-migrated households to test the pervasiveness of the findings collected from the qualitative study. The questionnaire was comprised of personal and socioeconomic information, participation status in community activities, status of natural resources, and perception on mutual help/support. The data collected from the survey were inserted into SPSS to check the frequencies and perform cross tab checks within the data.

The main respondents for this study were migrants' wives and other key informants (village elders, project staff, well known people) of the villages. One FGD was conducted at each village among the migrants' wives, and one FGD was conducted at each village among other key informants. In-depth interviews were conducted with 14 respondents chosen from the FGDs based on the type of family they live in. The survey was conducted among 41 respondents from migrated households.

Results and discussion

We found that migrants' households depend on remittances as their main source of income, which had been agriculture in the past (Table 2). The changing trend of agriculture produce in the past 15 years among these households is shown in Table 3. Agriculture, however, is still considered an important source for their subsistence. Left-behind family members experience a major loss of male labor to carry out farm activities in the peak season. Persistent water scarcity also increases food and water

Table 2. Main sources of family income in migrants' household according to women respondents.

Sources	Percentage
Agriculture	14.6
Labor	4.9
Remittances	80.5

Source: Household survey in November 2007, Majthana VDC, Nepal (Lamichhane, 2008:23).

Table 3. Change in agricultural produce (1992-2007).

Change	Frequency	Percentage
Increased	12	30
Decreased	12	30
No change	17	40
Total	40	100

Source: Household survey in November 2007, Majthana VDC, Nepal.

security. These villages still practice a traditional form of rainfed agriculture. With the initiation of community forestry programs, however, old water sources have been restored and new sources are appearing. Available water sources are claimed by one (Lamichhane) village for irrigation purposes. This village still exercises traditional water rights because it commands the water source. Thapa *Goan* is most hit by the water conflict as it doesn't have any source of water. Bhurtel *Goan*, however, does have another water source from a different stream other than Dudh Khola subwatershed. Women now have to deal with water conflicts in these villages and have to develop new strategies to cultivate their farms.

Our findings shed further light on two current debates on male out-migration. These are: (a) the idea that women are better off without men, and (b) the idea that women are more vulnerable without men. The outcomes for women's situation are mediated by existing conditions, such as the natural resource base and social network they live in. They find coping strategies that are purely based on their situation of survival (in managing agricultural farmland, food crisis, financial arrangements, and household responsibilities) to deal with hardship.

In the first debate, some cases have shown that migrants' wives are better off without their husbands. Among the two categories, the positive outlook for women living in nuclear families is that they have the power to decide as argued by Kabeer and Anh (2000) and Rao (2006), who said that 'women gain autonomy in the absence of men.' They can choose which crops to grow (Nelson, 1992) and participate actively in all social events and meetings. This process has a direct effect on women's decision-making role as they have to decide and manage the household in men's absence purely in the context to a nuclear family setting. Decision-making was taken by some of the respondents as an opportunity (12%) or beneficial activity (37%) for them. About 14% women found decision-making a constraint because they felt isolated and felt the gap of not having a partner to discuss pros and cons on major household or farm-related issues (Table 4). There is a gap in the literature to assess how women feel about decision-making roles without consulting a male (husband).

Table 4. Respondent's feeling about managing the household and decision-making process.

Respondents perception	Frequency	Percent
Beneficial	15	36.6
Opportunity	5	12.2
Constraint	6	14.6
Total	26	63.4
No comment	15	36.6
Total	41	100.0

Source: Household survey in November 2007, Majthana VDC, Kaski District, Nepal.

(Note: Most of the respondents are from nuclear families and some from extended family settings; however, the women who did not have any say on the matter, have not answered this question which shows as No comment.)

For women living in an extended household, not having their husbands intensifies their workload in the household and the farm, but socially they do not have much responsibility as elder members of the household manage social activities or events. Women work according to the rules and customs of their households, and do not work outside the house as it is culturally restricted. Instead of their husband, all the decision-making activities are done by another male substitute, and women have to work accordingly, which is consistent with the arguments placed by Nelson (1992) and Weisner (1977, cited in Nelson, 1992). With respect to labor, financial, or food crises, the whole family tries to arrange for alternatives. There are, however, situations where women have to manage their reproductive workload alone. In such cases, it was seen that women mobilize their social networks of friends and relatives to get the work done. In case of financial difficulties, women arrange money through friends and neighbors and not with their in-laws.

Referring to the second debate, migrants' wives living with a nuclear family are seen as more vulnerable than the migrants' wives living with an extended family. The reason given by women was that they had to manage their household at the same level of productivity as left by their husbands. In cases where remittances are not enough to meet the needs, which was seen in 10% of the 19 nuclear households, women have to find a balance between low agricultural production, no water availability for farming, no control over the assets or resources, lack of livelihood options (for women) in the villages, and managing food and basic necessities for their family following stringent traditional and cultural norms. It is important to understand the burden they have to face on a daily basis while their husbands continue to work in labor-intensive jobs in Gulf countries. Similar to the arguments made by Ellis (2003), the only focus for study becomes the remittances that are being sent by the husbands, while other factors are ignored on how the left-behind family is surviving. Their autonomy, however, leads to vulnerability as uncertain yield from the farm and absence of labor forces them to rent out land on a sharecropping basis. Some households also opt to leave land fallow in areas of less water availability due to water conflicts. They took loans from kin and engage in wage labor (Kabeer and Anh, 2000), formerly a cultural taboo for women since husbands' remittances were also not sufficient. Unlike findings from Moser (1998), however, here the diversification of livelihoods adopted by women does not necessarily increase the well-being of their family, but it helped them to meet minimum basic requirements by generating income for the household. By contrast, women from extended households were controlled by their in-laws and had less autonomy in household and farm decision-making. They had the security, however, and shared their work and assets with other family members with much more regularity.

In the social context, both the categories of women were also actively involved in activities community development organizations. Their involvement initiated Multiple User System (MUS) Scheme to address their demand for water. IWMI Nepal through this project has been successful in initiating small-scale irrigation and drinking water projects with the help of IDE Nepal. Now women do not have to walk for hours to fetch water. The time saved while fetching water, however, has been replaced with vegetable farming. Many projects in these villages target women because of the absence of men and most importantly due to the requirement of women's participation in development initiatives. Although some projects do target women in the name of participation and involvement, many do not look at actually enhancing women's capabilities and rights (Osman, 2002). It was also found that inclusion of women in the water user steering committee groups and other community activity-based groups was taken as a project requirement. Numbers of women in these groups were high, but their active participation was low (Table 5). On a positive note, such projects have enabled women to take

Table 5. Cross-tabulation of respondents' involvement in community meeting and their role in these meetings.

Respondent's involvement in community meeting/groups	Your role in community groups or meetings			Total
	Actively participate	Speak only sometimes	never speak	
Always	3	6	5	14
Sometimes	2	6	14	22
Never	0	0	0	0
Total	5	12	19	36

Source: Household survey in November 2007, Majthana VDC, Kaski District, Nepal.

on a new role socially, which earlier was only exercised by men. Now women are seen as active in community roles. The community on the other hand has started accepting women into more social roles than before (Upadhyay, 2003), and women have been able to capitalize on this role by forming stronger social capital for themselves. Women have, however, raised the issue of time constraints to give continuity to such roles.

Linking it with the livelihood framework of Ellis (2003), among all the assets, social capital seems to be the most regular asset women fall back on at times of labor, food, and financial crises. Unlike other capitals, where they have very little ownership, social capital is their entitlement that they maintain by exercising their autonomy. Social capital differentiates the effects of male out-migration in both the categories of women. Women living in a nuclear household are strongly indebted to social capital because of their isolation in managing their household. For them, social networks provide them the best solution for any kind of crisis, not just to herself but for her family. This is unlikely for women living in an extended household, where social capital's effects are mostly concentrated around her individual self. For them, friends and neighbors help them with their work burden, and give them support emotionally and financially when husbands are away.

Apart from the existing factors that determine women's coping strategies, external factors such as development organizations, welfare organizations, community organizations that are present in the rural villages, also influence women's behavior or decisions. The objectives of these organizations are mostly to strengthen people's livelihoods, motivate them, provide awareness on the new technologies, and involve people from all areas in the development process. Since young men have mostly migrated, the projects target the wives as the representative of the households. These women are given training, skills, and awareness on the technologies or community development activities. They become equally important actors in the public sphere, and have accepted their new roles as well as performing the old roles. For them this platform has been a medium to put forward their priority issues that can be addressed. On the other hand, social capital has proven to be vital for both categories of women, and especially for the women living in a nuclear setting; social network is the entitlement she has to cope with vulnerable situations.

Within the three villages, women's participation in community projects have revolved around programs such as skill development, tailoring, vegetable farming, and targeted programs for women's empowerment that provide data on women's centered development initiatives. This suggests that development projects have understood the absence of men in these villages, but have not tried to address the issue of male out-migration before implementing any kind of a program. With the existing approach of program implementation, the time and work burden intensifies for the women, at times leaving men outside the development spectrum.

Conclusions and recommendations

Given the instances and situations found in this research, wives of migrated husbands have various ways of coping to address the loss of male labor. In an agricultural resource-poor situation, the coping strategies of women are mostly mediated or influenced by their social capital. Women are able to cope better if they have relatives they can rely on despite the absence of their husbands. So it is not a question of whether women are better or worse off when their husbands migrate, instead it is about how effective social capital could strengthen and enable women's access to productive resources. Social capital therefore differentiates the effects of male out-migration in the both the categories, where some are more autonomous but vulnerable, yet others are more socially controlled but more asset- and labor-secure. This research thus provides a strong argument that coping strategies of women within the same context may differ as a result of their household types, productive assets, the quality of their relations with social networks, and the flexibility with which they can alter gender norms. These conditions therefore define the situation of left-behind women in this study–a situation that is far more complex that just being either autonomous or vulnerable in the absence of men.

Development organizations with their international expertise are urged to initiate activities to create economic opportunities within these villages. The expansion of MUS scheme (with involvement of men) can benefit local people if they are able to earn consistent income from vegetable farming. An establishment of good linkages between the market networks to connect these backward villages would be effective.

Strengthening of networks seems to be important and projects should create a local mechanism that binds the group even after project completion. IWMI's initiation of CBINRM at the sub-basin level is seen as important. A good local mechanism needs to be installed to translate such networks into a regular activity among the women. Gender-related concerns can be translated through these kinds of networks, where women can initiate and alter social and cultural constraints.

Development project planners with a concept to introduce new innovation into rural areas such as these villages, should always remember that women are not free of work. The program might be beneficial to a certain extent with the labor gained from the women folk. But to give continuity to the programs, it is always important to look at the gender division of labor that is being practiced in the villages. Mostly, the presumptions on the culture might mislead the project planner. The changing cultural norm in these villages sets an example on how women are involved in every sphere due to male out-migration. Involving elder, retired men would also be exemplary in such new technological projects.

Research on food insecurity and its consequences at the local level is necessary in these villages. Our research should also encompass changes in land use pattern and weather conditions, as these are clearly changing. This research would help policymakers understand this in detail, and to recommend needed policy at the village, district, and national level.

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Understanding water property rights creation, re-creation and de-creation: a case study of Lorraine and Fumukwe Villages, Limpopo Basin

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Abstract

This paper examines and clarifies water property rights creation in two villages: Lorraine in Sekororo (Olifants), South Africa; and Fumukwe in Gwanda (Mzingwane), Zimbabwe. Unpacking and understanding water property rights creation in the two villages entailed a rigorous analysis of how such property rights creation and the changes involved affect men and women; the nature and type(s) of water sources involved (access and use); and the choice of technologies available for use. This paper focuses on how villagers create, re-create, and de-create[2] informal and formal water property rights in water access and use for multiple uses in their everyday lives. The researchers gathered data through in-depth interviews, group discussions, group interviews, and literature search to understand the evolution of water property rights creation in the two villages of the Limpopo Basin. Results from the study indicate that water property rights creation in the two villages is characterized and defined by the nature of investment that an individual or group of people put together in order to claim access and/or use stakes in water and (in some instances) land. Investment in infrastructure and technologies such as water pumps and boreholes at individual (or household) level tended to consolidate the creation and re-creation of 'formal' water property rights in both villages. On the other hand, investment in social capital through labor contributions by members on allotted times for digging and cleaning the water diversion (or informal) canal, and shallow wells also guaranteed participation and a claim by resource-poor individuals and households. Water property rights re-creation also entailed the 'conversion' and 'adoption' of derelict government- and donor-funded infrastructure by the villagers, where only individuals who contributed either in cash or kind in its maintenance can claim a stake. From the foregoing discussion, it is important to note that the nature and type of investment required in creating and re-creating water property rights (primarily water access and use) is largely influenced by the type of water sources available, available technologies, and support from external agencies that include government, private and nongovernmental organizations (NGOs) stakeholders. The creation and re-creation of water property rights serves to empower actors, but does not affect men and women in the same way as illustrated in this paper.

Media grab

Water rights depend on (water) sources, and individual investment in infrastructure and technology guarantees a stake in water property rights.

Introduction

This paper is part of an ongoing doctoral research study by P. Sithole under the supervision of B. van Koppen. Research carried out for this paper contributes to the understanding of local and intermediate level institutional arrangements as a subgoal of CPWF project PN17 (Integrated water resources management for improving rural livelihoods in the Limpopo Basin). The paper seeks to examine and understand water property rights creation and recreation in Lorraine village, South Africa, and Fumukwe village in Zimbabwe. This goal was to trace and analyze the manifestation and embeddedness of power relations and stakeholder participation in local institutions. It also highlights the importance and centrality of water sources for locals when claiming a stake in the resource: water rights depend on water sources, and investment in infrastructure and technology secures and guarantees a stake in water property rights.

Methods

The researchers gathered data through in-depth interviews, group discussions, group interviews, and a literature search to understand the evolution of water property rights creation in the two villages of the Limpopo Basin. We mapped water resources, infrastructure, and technologies by walking through the entire ward, identifying the quality and quantity of water (re)sources. Social maps were used to locate key features and diagrammatic representation of key institutional interactions identifying and mapping access to social networks, services, and infrastructure, and to relations between different

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2 The term 'create' is used here to refer to the formation and/or bringing into existence of water property rights, especially for the first time within a given local, individual or group; and is closely associated with investment in infrastructure, technology, and social capital at source point. The term 'de-create' is used here to refer to the dysfunctional state, withdrawal, and/or collapse of existing water property rights. The term 're-create' is used here to refer to the re-invention, reformation, and reclamation of water property rights.

social groups within the villages.

Results

Results indicate that water property rights creation in the two villages is characterized and defined by the nature of investment that an individual or group of people made–those who made higher investments claimed more access and/or use stakes in water and (in some instances) land. Investment in infrastructure and technologies such as water pumps and boreholes at individual (or household) level tended to consolidate the creation and recreation of 'formal' water property rights in both villages. On the other hand, investment in social capital through labor contributions by members at allotted times for digging and cleaning the water diversion of a formal or informal canal, as well as shallow wells, guaranteed participation and a claim by resource-poor individuals and households.

Investment (social and capital) in infrastructure by households without external assistance safeguards and guarantees the use rights of the participating households, and a stake in decision-making. Cleaning the earthen-canal on a rotational basis is a mutual and beneficial activity which members undertake with the incentive to make a claim to use water from the diversion. The farmers and/or participating households in Lorraine self-organize and contribute labor for cleaning and maintaining the canal. Each member is an active informant and potential enforcer of the penal code for those who break the norm of equitable-rotational water allocation, and duty roster. Where individuals and households took the initiative to invest in infrastructure, the household and/or individual had full rights to use the technology, and to abstract water from a common source.

In Lorraine and Fumukwe, external intervention through NGOs and local government established new infrastructure, with new systems, for a select number of beneficiaries. This selective-intervention, or project-intervention, brought with it new realities where beneficiaries earn a leveraged advantage over nonbeneficiaries for competing claims on common-pool resources. Such beneficiaries have access to both common pool resource stakes and (specific) project resource stakes. This tended to leverage their bargaining power when negotiating with nonproject beneficiaries. Although such interventions enable poorer households and individuals to have a claim to some resource, this does not guarantee the claim as envisaged. Such well-intended gestures by NGOs have met with failure, often due to lack of resources and know-how to utilize the technology provided by the recipients. A case in point is the drip-kits that were distributed in Fumukwe village to very poor households, which were never used, and in some cases sold to well-off households.

Water property rights re-creation also entailed the 'conversion' and 'adoption' of derelict government- and donor-funded infrastructure by the villagers, where only individuals who contributed either in cash or kind in its maintenance can claim a stake. Villagers in Fumukwe 'converted' a communal access and government-funded borehole into a 'group' access, where only households and individuals who in fact contributed labor and financial resources to repair a dysfunctional borehole are allowed to access water. The initiative came after relentless efforts failed to have the government and the local headman organize people and resources to get it repaired. The headman, after the initiative, was left with little choice and had to sanction the norms laid down by the members who invested in the repairs and maintenance of the borehole. Each member is an active 'policeman/woman' to ensure that those who did not contribute also do not have access to the borehole.

Discussion

This paper tries to present an understanding of water property rights creation and re-creation at the local level, what Mollinga (2008) calls local level politics. It tries to underscore the point that the rationale and ideological underpinnings of various narratives and concepts that populate the water sector need to be investigated. This is done through exploring the historical and political depth of water in society, and untangling the web of social relations (and power play) between and among users and user groups, individuals and households, local and international intervening agencies, and local and national government structures. The dichotomy is not as simple, but presents a scope for analysis and understanding the new patterns of winners and losers along political, class, gender, and ethnic lines. Investment in water infrastructure and the creation of water property rights depends on the nature and type of water sources, as well as the range of interaction patterns in water management, including negotiation and competition over resource stakes, plus the less explicit and longer-term disputes and controversies. Investment on its own does not necessarily guarantee assured access to water. Rather, the control of water is the main issue. Water control is used here in its broadest sense to refer to the manipulation of the physical flow and quality of water, and the socioeconomic, legal, administrative, and other structures in which water management is embedded, and that constitute conditions and constraints for management and regulation (Bolding et al., 1995; and Mollinga, 2003).

Institutional arrangements at the local level are largely a reflection of the power relations within society, where membership is often open to all, and decision-making is a preserve for the few, often powerful individuals such as headman and other wealthy individuals. For the poor, especially women, to have a stake and a voice in deliberations on water governance at the local level, investment in infrastructure and technology is one way to secure their rights. This is where external agencies such as NGOs, the private sector, and government can intervene to try and lift the ordinary stakeholder from a mere member to an active and empowered participant.

Conclusion and recommendations

The nature and type of investment required in creating and re-creating water property rights (primarily water access and use) is largely influenced by the type of water sources available, available technologies, and support from external agencies that include government, private, and non-governmental stakeholders. Investing in infrastructure and technologies to lift, divert, convey, and pump water ensures secure access rights. Water rights, therefore, depend largely on water sources, while investment in infrastructure and technology guarantees access to the resource.

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Poverty and potential household trajectories in the Limpopo Basin

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Abstract

This paper analyzes the socioeconomic conditions in rural areas of the Limpopo Basin, after more than ten years of democracy and efforts toward agricultural development in South Africa. Based on extensive fieldwork in Makgato and Sekgopo, two rural communities, the paper includes empirical and methodological results. On the one hand, income analyses highlight some alarming aspects (40% of all rural households survive with less than US1$ a day per individual in this middle-income country), and underline that agriculture represents a minor income source in rural South Africa. On the other hand, through livelihood strategy analyses, a better understanding of household behavior and strategies is obtained and 'not-intentional' specialization is observed. Through the identification of possible household trajectories, policy recommendations are presented, including some reflections on water access and infrastructural development. Without neglecting the benefits to poor people, the paper questions, however, the potential impact of water-linked measures on poverty alleviation in South Africa.

Media grab

Extreme poverty prevails in South Africa's rural Limpopo, with surprisingly only small agricultural contributions. Presently, water access would increase well-being, but have little impact on poverty alleviation.

Introduction

Since 1994, South Africa has seen active policy development, partnered with massive financial efforts by the public sector toward rural development and poverty alleviation. A sizeable share of public spending is now devoted to social grants, improved public services, including health care, education, electricity, water, sanitation, and housing. Yet, despite visible achievements and successes, few changes have actually occurred in rural people's lives, owing to both the legacy of apartheid and the ineffectiveness of certain programs and/or policies (e.g. land reform, agricultural restructuring, rural development planning, water management) (Greenberg, 2001; Anseeuw, 2004; Perret, 2004; Pauw and Mncube, 2007).

It is against this background that the present research was initiated. This paper examines the socioeconomic circumstances in South Africa's rural areas and efforts toward rural development since the advent of democracy. The overall objective is to examine the socioeconomic conditions of the rural population in South Africa and identify current trends in rural livelihoods.

Methods

A literature review emphasizes the fact that rural households are diverse and that poverty alleviation at the household level, entails more than increasing household income. In order to assess the evolution of poverty and the ways households cope with it, the project combined two approaches: 1) an income group analysis, including investigations of the sources of income at the household level, and an assessment of the average incomes per source in order to profile income groups; and 2) a livelihoods analysis at the household and community levels, implying the identification of livelihood groupings, through the construction of household typologies according to diverse criteria including income levels, and income sources, household configurations and trajectories, and livelihood strategies. The combination of the two approaches not only allows comparison of the two, it enables analysis of the extent and determinants of livelihood diversification, as well as the interplay between diversification, poverty at the household level and selected household characteristics. Such analyses are necessary to understand people's strategies in a broader context of rural development and poverty alleviation planning.

Household data were collected from two communities (Makgato and Sekgopo) in the Limpopo Basin; as former homelands, they represent one of the poorest areas in South Africa, with more than 85% of the population being rural (Forgey et al., 2000) (Table 1).

Table 1. Characteristics of Makgato and Sekgopo communities.

Characteristic	Community	
	Makgato	Sekgopo
Historical background regarding land	Forced removals	Traditional land
Institutional framework	Strong traditional hierarchy	Democratic institutions
Population size (Households)	1000	4600
Livelihood activity	Farming	Farm labor

A total of 70 detailed livelihood questionnaires were administered to 35 households in each of the two communities (random sampling in Makgato, mixed systematic stratified-random sampling based on existing sub-villages in Sekgopo). To achieve representativity based on the population size of the two communities, an additional 50 (8.5%) and 165 (4.25%) short questionnaires were administered in Makgato and Sekgopo, respectively. Since the results of both communities are markedly similar, it was decided to merge data and to carry out the rest of the analysis with a unique sample, amalgamating both communities.

Results

Extreme rural poverty and diverse–but specialized–rural livelihoods

The average monthly income per household is R1759 (1 Rand = US$0.15). With a poverty line established at 70% of the poorest households, however, and the ultra poor households defined as the 40% poorest households, it appears that 70% of households live with less than R1300 per month, while 40% live with less than R495 per month (Table 2). On a daily basis, per household membership unit, the total income corresponds to R22.71, R9.25, and R4.02 for the three income groups, respectively. Most alarming is the average daily income per household member in ultra-poor and poor households, which amounts respectively to less than US$1 and US$1.5. The situation is all the more disturbing in a country such as South Africa, where social safety nets and welfare already exist.

Table 2. Average monthly income as per source or activity, for households benefiting from such source, in the three poverty groups, in Rand (standard deviation is between parentheses).

Source of income:	Better off (n=21)	Poor (n=21)	Ultra-poor (n=28)
Total income	3904.8**a** (2766.8)	1300.0**b** (246.6)	494.6**c** (281.5)
Crop and stock farming	2575.0 (1728.9)	925.0 (217.9)	-
Employment	2085.6**a** (1240.0)	805.0**b** (491.3)	600.0 (0.0)
Self-employment	3300.0 (3396.1)	400.0 (270.8)	333.3 (152.8)
Old-age pension	743.1 (617.5)	513.3 (474.4)	438.2 (306.4)
Remittances	510.0 (475.7)	264.4 (110.7)	264.3 (143.6)
Childhood allowance	320.0 (233.5)	363.3 (272.9)	298.5 (281.1)

Two figures attached with different letters are significantly different, as tested with a bilateral Student *t* test at 0.01.

Almost 70% of the income originates from social and family transfers (pension, allowances, and remittances). Only 30% is derived from employment activities: 16% through salaried positions, 14% represent independent activities. Farming counts for only 2.85% (livestock 1.44%, crops 1.44%) of the total sources of income, and represents a minor income source. All three groups display a relatively similar–although diverse–portfolio of sources of income, and appear to resort to the same wide range of sources of income. The latter confirms previous research (Scoones, 1998; Ellis, 2000). It can be emphasized that, according to the income group analysis:

- All income groups resort to the same wide range of sources of income.
- All household groups resort to employment and self employment, still, they are more prevalent in better-off households than in the two poorer categories.
- All groups receive remittances, although they decrease strongly in the better-off groups. In contrast to what Roberts (2005) shows, the ultra-poor are not the ones receiving the highest remittances or social grants.
- Farming is not well developed in general as a source of cash income.

In an attempt to move away from average figures and amalgamation at community level, in-depth analysis of the different livelihoods highlighted different household strategies within the communities. Engaging a more complex ensemble of critical features (e.g. capital, source and level of income, social linkages, family structures, community integration, professional status), a typology of households was developed (Davidova et al., 2000; Barret et al., 2001; Perret, 2004).

The following nine types were ultimately identified:

- Type 1: Fixed salaried (11%); households whose (mostly male) head is permanently employed (with no other activities).
- Type 2: Multiactive fixed salaried (6%); permanently employed (mostly male) head, with spouse self-employed/business (little social transfers). Farming is present.
- Type 3: Full-time entrepreneurs (10%); self-employed male head with one or several activities/businesses (little social grants). Some are engaged in crop farming.
- Type 4: Part-time entrepreneurs (10%); temporary employed male/female-headed households, with activity/business; some have livestock and/or depend on remittances.
- Type 5: Irregular salaried (8%); casually employed (mostly female) head, benefiting from childhood grants and remittances. Some do have livestock.
- Type 6: Pension transfer dependants (24%); pensioner-headed households, with a limited livelihood portfolio, some benefiting from other social transfers or remittances. Some do have livestock.
- Type 7: Social grants dependants (18%); mostly female-headed households depending exclusively on welfare, most from child grants.
- Type 8: Integrated dependants (9%); female-headed households depending mainly on remittances.
- Type 9: Isolated poor (4%); female-headed household (often with poor health related to HIV-AIDS), without income-generating sources and isolated from any form of self-help/community systems.

Contrary to the income analysis detailing that all income groups display a diverse portfolio of sources of income, the typology emphasizes the existence of types presenting relatively homogenous income structures (Table 3). As such, type 6, representing 24% of the households, depends nearly entirely on pensions and remittances (on average 75% of their income). Type 7 and 8, representing a combined 27% of the total number of households, depend only on remittances and childhood allowances. Finally, the alarming type 9 (ultra-poor, isolated, sick, single women with children), representing about 4% of all households, depends only on childhood allowances.

Table 3. Sources of income in the types, shown as percentage of households relying on given sources.

Sources of income:	Livelihood types								
	1	2	3	4	5	6	7	8	9
Childhood allowance	64	0	*100*	0	*100*	50	92	75	*100*
Old-age pension	50	33	25	0	0	*100*	0	0	0
Employment	*100*	*100*	0	0	50	8	0	0	0
Self-employment	7	*100*	*100*	*100*	0	8	8	0	0
Remittances	21	0.0	25	33	25	25	8	*100*	0
Health allowance	0	0	0	0	0	4	8	0	0
Crop farming	0	*14*	*25*	0	0	0	0	0	0
Stock keeping	0	7	0	*33*	0	8	8	0	0
No source of income	0	0	0	0	0	0	0.0	0	0
Other sources	0	0	0	0	25	0	8	0	0

The livelihood analysis highlights some form of livelihood specialization, which is often forced at the household level. Livelihood stratification also highlights several other facts:

- Farming income is only generated by households in type 2 and 3, i.e. households with a fixed salary and households engaged in full-time self-employment and business. If farming seems to represent a commercial activity for types 2 and 3, it is an activity to secure means of living (mainly auto-consumption) and a way to build patrimony (mainly types 6 and 7). The lower income types do not practice any agricultural activity.
- Salaried employment and self employment are the only activities that can alleviate poverty; only 4 types out of 9 (1, 2, 3, 4) rely principally on these sources of income.
- Types 6, 7, 8, and 9 depend mainly on one source of income. Overall, it appears that any form of specialization, except when employment or successful self-employment is involved, means deeper poverty.

Livelihood trajectories and policy implications

The livelihood analysis presented gives a picture at a particular moment. A household belonging to one livelihood group can evolve into another type. The identification of these trajectories allows the assessment of opportunities for change and subsequent improvement at household level, which leads to recommendations for policy and development support. Several mechanisms are identified in these case studies–and special attention is given to water aspects.

The saving dynamic

This covers the importance of regular sources of income (mainly linked to salaried positions but also through independent activities). Although it emphasizes the promotion of formal jobs and the development of independent activities that could sustain saving dynamics, the latter is also facilitated through making local production activities possible. Several recommendations arise: (1) infrastructure development for local activity development (accommodation, irrigation systems, and abattoirs); (2) access to financial services to promote financing capacities; and (3) institutional arrangements to lower risks (could lead to higher local savings).

The decapitalization dynamic
This dynamic is strongly affected by HIV/AIDS and by the fact that saving/investing mainly takes the form of livestock (due to the lack of financial services). The lack of access to land, combined with a lack of infrastructure development, makes saving highly dependent on climatic and natural conditions and thus weakens the accumulation process. Policy measures could focus on access to land (private, rental, or communal) and agricultural/water infrastructure (irrigation schemes, feeding plots).

The unemployment dynamic
Job scarcity strongly affects the rural areas, both directly and through the decrease of remittances**.** Although social and welfare services have improved in post-apartheid South Africa, they do not allow one to overcome poverty. With the exception of old-age pensions, welfare services do not enable, on one hand, the alleviation of poverty, on the other hand, the acquisition of a recognized status limiting access to services (in particular financial ones).

The aging dynamic
This dynamic addresses access to universal pensions (which can represent relatively important amounts of capital). Due to HIV/AIDS, combined with migrant labor, rural populations are relatively aged. Support systems for elderly people should include the institutionalization of their status (which will facilitate access to credit).

Two major issues–linked to water–do arise.

Firstly, regarding poverty alleviation, the dynamics detailed above do emphasize the complementary character of the recommendations and the need of multisectoral interventions. If implemented in isolation, measures linked to the improvement of water and water access solely will have little impact on poverty alleviation as a whole.

Secondly, although, in the framework of this paper, special attention is given to water aspects, it has to be emphasized–as seen here above–that only few agricultural activities are developed on the South African side of the Limpopo Basin. The latter is not a consequence of a lack of major input factors, but of diversification strategies of rural poor populations in a middle-income, more urban-oriented country. As such, water access would increase people's well-being, but it can be doubted if it will impact the (agricultural) production base and, subsequently, poverty alleviation. In addition, results show that only the better-off engage in agricultural production–leading to the observation that measures linked to water would mainly benefit the better off and thus increase inequalities.

Conclusions

Income group analysis provides a clear and alarming presentation of poverty in South Africa's rural areas: 40% of the households survive with less than US$1 a day per individual in Sekgopo and Makgato. Although it is widely recognized that diversification of income sources facilitates the struggle against poverty (Bryceson, 2000; Barret et al., 2001), 'not-intentional' specialization is observed. This study therefore challenges the current global views on livelihoods in developing rural areas. The shift away from natural resource-based activities and the diversification of livelihoods are confirmed. The combination of an income group analysis with livelihood strategy analyses was necessary to understand better the nuances of poverty, its structural determinants, and how it affects the livelihood strategies of rural households. Results show that poverty is correlated with certain vulnerable groupings and activities. Women, children, those with health problems, and individuals who are excluded from the local social system are over-represented among the ultra poor. Farming, formal jobs and independent activities are rare within these groups. In addition, the identification of livelihood typologies enabled the identification of mainly negative livelihood trajectories and dynamics. Feeding as such the assessment of opportunities for change and subsequent improvement at household level, it leads to recommendations for policy and development-support (land reform policies, irrigation and (water) infrastructure development). If the paper shows that rural South Africa has not benefited much from government's development policies, it also questions by emphasizing the little engagement in agricultural–and thus water-linked–activities, the potential impact of water-linked measures on poverty alleviation.

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Scaling up and out of food and water innovations

Scaling up and out mechanisms that work: Evidence from a CPWF impact evaluation

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Abstract

In 2007 the CPWF requested projects to describe their most significant changes. We received 50+ stories. Five CPWF research leaders then selected the ones they thought most significant. This paper presents some of the findings of an evaluation of these changes which are: 1) changes that have resulted from the proof of concept of aerobic rice; 2) policy change in Thailand, Colombia, South Africa and Zimbabwe that a project on multiple use systems helped bring about; 3) policy change resulting from the use of a database of African Water Treaties, 4) research into upstream and downstream issues serving as a trigger for NGOs and individuals to attempt to change policy, 5) INRM research leading to livelihood improvements in saline – freshwater environments in Vietnam. The paper draws lessons about what mechanisms prove effective for achieving positive change through research in different contexts with different types of intervention.

Characterization of scaling out and scaling up networks of CPWF projects

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Abstract

Impacts of new knowledge and technologies depend on their spread and use. In this paper we differentiate between two adoption processes – scaling out which is a horizontal spread from farmer to farmer and community to community within the same stakeholder groups. The second is scaling up which is a vertical institutional expansion, based largely on a desire or need to change the rules of the game. These processes can be modeled using network maps. Impact Pathway Workshops were held for all CPWF projects (40+) in all the CPWF basins. Participants drew their projects' scaling out and up networks which were then combined, basin by basin. In this paper we present the results of dyadic regression analysis to establish similarities and differences between basin scaling networks and link this to the characteristics of the basins and projects within them. We attempt to relate individual project performance, as measured by ranking, with network characteristics. We discuss implications for the design and implementation of the CPWF's Second Phase.

Gradual evolution of a participatory process of technology development

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Abstract

In mid 2006, a sub-project on participatory technology development (PTD) was initiated within the Livelihood Resilience Project in the Upper Karkheh River Basin, with the aim of facilitating a more participatory approach to developing agricultural technologies and improving resource management. The aim was to adapt the process of change to the diverse livelihood of the local people, and the complex, heterogeneous agroecological systems prevailing in dry mountainous areas and watersheds. Adopting such an approach would entail a shift from the linear trend of technology development by researcher and transfer of technologies to farmers, through extension staff currently being practiced in Iran, to a more interactive collaboration between researchers, farmers, and facilitators. This paper presents the group's endeavor to facilitate this process of learning and change, and focuses more on: process aspects such as the increasingly inclusive participation of local communities, and the growing influence of their realities on the various stages of the process; the more and more demand-driven and context-specific nature of technology selection and adaptation; the continuous multi-stakeholder negotiations and reflections and their impact on professional behavior and interaction; and the team building that has led to a relatively decentralized management of the project activities.

Media grab

The converging outlooks and perceptions of the various stakeholders testify to the process of dialogue and constant reflection facilitated by the provincial Participatory Technology Development teams.

Introduction

Two trends have probably paved the way for the emergence and development of the PTD approach more than any other: (1) the inability of conventional, discipline-specific technology research to adequately respond to the complex, diverse, and interrelated agroecological dimensions of local life and livelihood; and (2) the lack of participation of local end-users of technologies in the search for, selection of, and experimenting with options that could provide solutions to local needs and problems. Hence the need for a more integrated and participatory approach that can accommodate the involvement of local people and the multidisciplined interaction of research and technology experts. Adopting a participatory approach to technology research would necessarily entail a shift from the normal linear trend of researchers developing technology, and then extension staff transferring the findings and products to farmers, to the building of an interactive farmer-researcher-facilitator partnership. Rather than adhering strictly to the chronological steps of the methodology from the outset, however, this PTD group has had to adapt itself to seeking, and iteratively building upon, opportunities for instigating methodological, attitudinal, and perhaps even institutional change with respect to participatory research.

Increasingly inclusive participation of local communities and the growing influence of their realities on the process

Throughout the 2-year period of the project, the PTD group has been guided by the fundamental belief that seeking and involving the weaker and more marginalized farmers and groups is paramount to any process of development that claims to be participatory and empowering, with their reality determining how the process develops and how it is assessed. There is evidence that we have perhaps been able to reach some of the community members who had been neglected previously. Over the first year, we were able to approach and involve some of the farmers who had not been part of previous experiments. The noninvolvement of women was also a major concern up to a certain point, after which the team formation, field activities, and technology search were modified to facilitate their more active participation. The second year, wider sections of the communities took part in the needs assessments, including the women and the youth, leading to a more diverse range of technological needs being addressed and technologies being introduced, and also leading to a greater number of experiments.

The combination of visual and group analysis, realistic discussion on possible outcomes and obstacles, and genuine seeking of farmers' own experiences and priorities can provide a conducive environment for joint learning and commitment, and this was demonstrated in:

- The involvement of the farmers in all stages of the final season of the project–appraisal and needs assessment, technology selection, experiments, cross-visits and evaluations.

- The informal and open setting of the technology fairs and cross-visits and the freedom with which the visiting farmers could 'roam around' and discuss each technology with the researchers and farmer experts and amongst themselves (this was more taxing on the experts but also more leveling for the relationship).
- Revisiting the farmers who had volunteered for the technologies after the fairs in order to achieve transparency on what could and could not be expected from participating in the experiments.
- The use of participatory tools and techniques.

It can also be claimed that the participation of the farmers has been less motivated by outside incentives and inputs. The group took deliberate steps to ensure that those volunteering would be aware of the experiment costs, and that these would not be fully subsidized, as was previously the normal practice with innovations and new technologies. This did lead to some volunteers withdrawing from the experiments, but it did also give rise to optimism that any would-be beneficial outputs and outcomes would follow a more realistic path of scaling out.

Demand-driven and context-specific nature of technology selection and adaptation

Guided by the argument that diverse needs require diverse technologies (technology is intended to include new ideas and inputs, as well as modified management and application of existing ones), we adopted a strategy of seeking options that show potential in terms of adapting to local conditions and needs and contributing to an improved and more resilient livelihood, and to better management of resources. The search for potential options was based on separate participatory problem identification and needs assessments in each of the villages. At the same time, these had to be options to which the farmers could relate, and therefore apply and adjust as they saw fit. The technologies were meant to 'be simple to understand,' 'not require changes in major parts of the existing farming system,' and 'rely on few external inputs and labor resources.'

Over the two years, there have been fifteen technologies for which experiments have been conducted, with the range, diversity, and flexibility of the technologies and experiments gradually increasing. More important than the actual technology has been the characteristics of the experiment from a PTD perspective, each of which could be a point for reflection and entry when it comes to working on technological change with local communities. The technologies at this stage could actually be viewed as starting points in a long-term process of analyzing farmer issues and seeking appropriate and relevant options and solutions, with the initiative being handed over more and more to the local people. To illustrate the perspective with which the technologies and experiments have been approached in the PTD project, and perhaps how this might have differed with conventional approaches, six of the fifteen ideas tried out in the PTD process are summarized in Table 1.

Table 7. Technology features and characteristics from a PTD perspective.

Technology	Main innovation or expected impact	Main features from a PTD perspective	Number of participants
Potato cultivation	Better marketing compared to current sugar beet situation	The PTD team in Kermanshah pursued this idea with its corresponding expert after it was suggested by young farmers looking for a substitute for sugar beet, which had been facing marketing and transport problems lately. Even farmers with modest resources have invested in the seeds on their own initiative. They have also used different planting and irrigation methods based on their own resources and preference. During latter cross-visits, farmers have been assessing comparative strengths and weaknesses amongst themselves.	22
Azetobacter fertilizer for wheat and barley	Low-cost, easy-to-apply, non-chemical input which does not require major changes in farmers' practice	This technology had been introduced before the PTD process started, but afterwards, the teams tried involving some of the weaker and smaller farmers. The technology has been examined over three consecutive years, making it possible to track changes over a longer period, for example in terms of: the wider socioeconomic range of farmers approached and how they have got involved increasingly on their own initiative[a]; the direct and indirect yield and soil impacts of the technology; or the more interactive and coordinated relationship and converging attitude of the national and local experts, and the PTD team.	25
Autumn chickpea	Improve yield and soil quality compared to spring chickpea varieties	Again this was a technology employed for three consecutive years. Field days were conducted in a relatively open manner, and the PTD team and the expert have been on the alert for cases elsewhere that could provide a cross-visit opportunity. Although farmers from the first two seasons were not obliged to take part in subsequent experiments, there has been growing interest from farmers in neighboring communities.	25

Urea and phosphor fertilizers	Based on tests on soil composure	The experts 'sieved' the varieties based on local needs and based on tests conducted on the composure and quality of soil, and were prepared to change the normal application procedures based on changing conditions. They have also spent a lot of time discussing experiment stages and requirements, both with the PTD team members and the farmers.	11
Mushroom growing	Additional income for households, with accessible and affordable material	This idea had the potential to provide additional income without imposing too much extra workload. Family members have been able to help out with the activity. It also utilized unused space inside the household yard. The basics were easy to grasp and monitor and the experts have visited the breeders frequently, basing their suggestions on the resources available to the farmer.	4
Shallot growing	Legalizing a highly popular and profitable illegal activity by cultivating on farms	This idea has required very little outside expertise as it has been a traditional, albeit illegal source of income from the rangelands. The local natural resource department has collaborated with the PTD team in providing the seeds and recognizing the activity.	22

[a]Apart from the twenty-five farmers who volunteered for the experiments in the third season, the local extension department in Honam, Lorestan, purchased and distributed azetobacter–albiet with the conventional subsidized mechanism–for close to 300 farmers from surrounding villages who had been convinced by the results of the first two seasons.

Continuous multi-stakeholder negotiations and reflections and their impact on professional behavior

One of the basic aims of this PTD process has been to change the current linear research-extension-farmer transfer-of-technology approach and mode to a dynamic triangle of constant interaction between farmer communities, technology experts and researchers, and facilitator teams. This path has not always been smooth, but the converging outlooks and perceptions of the various stakeholders can testify to the process of dialogue and constant reflection facilitated by the PTD teams, which has included approaching researchers about the type of needs explored and assessed with the communities, and the possible technological options that could respond to these needs, discussing, repeatedly, the PTD concepts, farmer-managed experiments, context-specific technology development, and changing roles, and looking back critically at previous activities.

Box 1: The 'milestone' experts' meeting in Lorestan

One specific meeting with the experts in Lorestan was particularly significant, and perhaps symbolic of the developing relationship between the experts and the PTD teams. The meeting started with the PTD team presenting the results of the participatory needs assessments, which was received by the researchers with mixed reactions ranging from supportive to the dismissal of its credibility. People from different disciplines then started presenting different sides to various scenarios, being openly critical but at the same time maintaining an atmosphere of respect. (In fairness to the experts, it has to be said that they were as critical of themselves and their past work as they were of ours.) The meeting continued for three and a half hours, being facilitated more and more by the experts themselves, who ultimately proposed the formation of expert working groups based on the topics that had emerged from the needs assessments to draw up lists of possible options for the technology fairs.

The farmers have eventually been recognized by the experts as legitimate counterparts in the negotiations, decision-making, experiments and evaluations, and this changing attitude toward the farmers' roles has had a visible impact on the level of interaction, rapport, and mutual trust. The experts admitted that they had spent too little time inside the community, and were seeking ways to get feedback from the farmers.

Perhaps one strategy that facilitated this change in behavior was the PTD group's constant reminder that it was not the technical credibility or effectiveness of the technologies, but rather, as mentioned before, their adaptability that we were aiming to explore in the PTD process. The adaptability of a technology is how a technology and its surrounding issues can be flexibly modified to fit in with diverse livelihoods and resources in different socioeconomic conditions. This is somehow different to the technical quality of a technology and is influenced by other factors as well, such as the variation of the climatic conditions under which the technology can still be effective, the resources and equipment required and how much they can be replaced or substituted for, and the level of expertise required and how easily this is accessible for and transferable to the farmers. This probably contributed greatly to the experts' more open and flexible attitude with respect to their particular technology, allowing for a critical approach to the experiments. Experimenting with the adaptability of the technologies rather than their technical value is the main reason why the process can provide new learning for the expert as well as the farmer. For example, the different management practices for potato cultivation can provide new insights for the expert in accordance with the local conditions and constraints, and recognizing this opportunity to learn could be one reason why the potato expert has moved from a classic detailed power-point extension-mode 'teaching' of his technology to frequent on-field, farmer-responsive discussions on the various aspects of the experiment as they have emerged.

Team building and decentralized management of project activities

The formation of the Tehran team and the two provincial teams in Lorestan and Kermanshah got under way almost as soon as the project had started, and the stages through which this group has gone have had varied impacts on its development and maturing. These are some factors we believe have had the most influence:

> **Box 2: The turning point for the provincial PTD teams**
> The autumn technology fairs were important turning points in the maturing of the provincial PTD teams. They took the initiative in organizing the fairs. After that, the Tehran members of the team have tried to coordinate themselves more and more with the provincial teams, and witness, as a result, a growing autonomy at local level.

- From the start, the international PTD expert's visible eagerness to strengthen the participatory research capacity of the local group members, and to delegate, supportively, as much of the process facilitation to the group members as their capacity would allow, was matched by the group's acknowledgment and acceptance of him as the team coach and consultant. This mutual recognition fostered mutual trust and respect, as well as: growing confidence in each member's own ability and that of their teammates; a healthy and secure atmosphere for critical reflection and collective learning; and a sense of solidarity and empathy.
- The team formation in the two provinces changed several times, due to: disagreements leading to mutual consent on staying and leaving; the necessity of adding female members to the teams to be able to communicate with women in the communities; increasing amount of field workload; the need to temporarily substitute for team members; and to fill voids such as documentation. At the same time, a few core members in each of the teams stayed with the process till the end, which ensured a decent level of continuity for the group.
- Decision-making on activities has been relatively decentralized and participatory, with the process increasingly being governed by the provincial teams' conditions and constraints, and their interaction with the local communities and the experts.
- As the project has developed, most of the team members have shown a growing desire for being in the field, and not only when the group have had something to say, but also to follow-up on previous activities and to remain accessible to local people, and this has been significant in their facilitation of field activities. Team members have also been highly motivated despite organizational constraints and personal issues and problems.
- The technology experts' approachability and willingness to collaborate has not come lightly. The patient approach of the PTD teams has led to an enhanced capacity to facilitate negotiation processes.
- The fact that local young men and women were approaching the PTD teams to suggest and request their involvement in possible experiments can be a sign of growing trust and interaction between the local communities and the PTD teams.
- Capacity building has taken many shapes and forms for the group, and apart from formal training workshops on PTD and other topics such as report writing, this has included: fieldwork and practice, coupled with reflections afterwards; trips to ICARDA headquarters and PTD projects in Aleppo; and increasingly systematic and supervised documentation of activities.
- The team has received this feedback from the experts that 'this team has a capacity to listen.'

Conclusions

The conclusions list: (1) the main lessons learned; (2) what the project would do differently; and (3) opportunities for institutionalization.
Main lessons learned

- In most cases, the shift toward participatory research approaches should imply an iterative and gradual modification of the various aspects of the research process, with facilitators on the lookout for entry points and opportunities for instigating change and transferring the initiative to local people. At the same time, adopting a process-oriented outlook toward technology development means that even with small, simple technologies, it is possible to seek ways of making the process of problem identification, and technology selection, adaptation and evaluation more participatory and empowering.
- Despite good intentions, the process of negotiations, reaching mutual understanding and common grounds, and agreeing on methods and criteria for action can be taxing on human resources. The facilitating team would have to consider this in their division of work and support for each other.
- Even local people with modest resources are prepared to invest in a process they believe to be relevant to their needs and conditions, and in one in which they have been a part of from the early stages.
- Experiments can explore the adaptability of technologies and innovations rather than focusing on their technical value. This could provide a more secure working environment for the researchers and more flexibility regarding possible modifications in adapting the technologies to the local context.

- Team selection and team building is definitely an ongoing process, and can take many shapes and forms, from the planned training workshops to the informal discussions and reflections. The important thing is to foster a learning attitude toward the anticipated and unanticipated, toward the pleasant and seemingly unpleasant, and toward everybody's role and behavior.
- If the team can be equipped with adequate documenting skills and tools, the field-to-documentation-to-publication path can become more spontaneous and consequently more time-relevant.

What the project would do differently

- We could try to start some of the activities earlier, such as the needs assessment, or the initial negotiations with the technology experts. We lost a couple of useful ideas because their season had past.
- The presence in the field in the early stages could be more frequent and lengthier, as this would lead to more coordination amongst the team members, a better understanding and assessment of local capabilities and constraints, and a more realistic grasp of what to rely on and what *not* to rely on.
- It might be possible to invest more time in trying to adapt the technical requirements to the resources available to the weaker farmers who were willing to participate but were unable to fulfill the original requirements.
- Deliberate steps to form interest groups amongst farmers involved in similar experiments could make the exchanges and consequent co-learning even more synergic.
- We could improve the relevance and effectiveness of training inputs by phasing them out over the process in accordance with what the team members and other collaborators need and are involved in.

Opportunities for institutionalization
Individuals from different departments at different levels have been in touch with and involved in the 3-year lifespan of the project–from field extension staff to provincial technical experts and research heads to research directors and deputies in the central research organization of the ministry (ARREO)–many of whom have shown a marked change of attitude from skepticism to treating the approach and methodology with much more recognition and optimism. Discussions have been underway on how the PTD approach and methodology can contribute to a wider scale integrated watershed management system. More significantly, the level of authority and decision-making autonomy gradually delegated to the local teams regarding the process components has been sufficient enough to suggest that any follow-up to the project activities and findings would necessarily depend on a provincial willingness, proposal, and organizational and administrative support.

Acknowledgments

This paper presents findings from PN 24 'Livelihood Resilience in dry areas,' a project of the CGIAR Challenge Program on Water and Food.

Promoting farmer innovations in Karkheh River Basin: A promising process to improve rural livelihoods

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Abstract

Farmer experimentation/innovation, a demand-driven process, has been identified as an important and effective factor in rural development. The 'Livelihood Resilience Project' as part of the Challenge Program on Water and Food, has conducted multidisciplinary research to improve rural livelihoods within an integrated watershed management context in two pilot sites of Karkheh River in Iran: Kermanshah and Lorestan. In the first phase of this project, researchers were made aware of farmer innovators and their contribution to agricultural research and development. Although skeptical at first to apply participatory methods, the researchers quickly continued to identify 53 local farmer innovators and their 70 outstanding innovations in the two pilot watersheds, Honam and Merek, in the Karkheh River Basin. In the next step, the identified innovations were evaluated by a group of multi-disciplinary specialists against a set of agreed criteria. A process of ranking and final selection of best bets was used, and during a PTD joint experimentation subproject, farmer technology fairs and farmer cross visits were organized to disseminate and test selected innovations through farmer participatory field experiments.

Media grab

A survey of farmer innovations in two pilot watersheds in Karkheh River Basin of Iran revealed the existence of high-potential new ideas as valuable options for rural livelihood improvement in such dry areas.

Introduction

Historically, farmer innovation has been the means through which technological advances have been made and traditions developed. This process, however, has been masked by the emergence of a more structured, scientific paradigm involving researchers and extension agents termed the 'transfer of technology' (TOT) approach. While the TOT approach was quite successful in the high potential farming locations in the tropics, especially during the 1960s and 1970s, it has largely failed to address the needs and limitations small-scale farmers are facing (Mutunga and Critchley, 2001). Currently there is growing attention being paid to the importance of indigenous knowledge. 'Promoting Farmer Innovation' is based on the hypothesis that farmer innovators: possess a storehouse of knowledge and ideas; provide a fast track toward successful and adaptable land husbandry systems; provide a direct and quick entry into the society; constitute a preselected team with which to work; respond well to recognition through positive feedback; network well together; make good onfarm researchers; and enjoy spreading knowledge.

A recent pilot research study on indigenous knowledge in Iran, carried out in the central province area, Khorhe village, has revealed that a wide range of methods and intellectual tools exists for the production and processing of high quality food, for treatment or control of human, livestock, and plant diseases, to increase productivity, and for the sustainable use of natural resources. Further methods and approaches were found in the area of meteorology, communal actions, and conflict resolution (Emadi and Abbasi, 2004).

The objective of this study was to provide a basis for further technology development that combines indigenous and appropriate external knowledge. It also aims to enable institutions of formal education to prepare future researchers and extensionists to engage in this process. This process is facilitated through a partnership of researchers, extension workers, and of course, farmers themselves. The study has been carried out in Merek and Honam watersheds, in the Karkheh River Basin (KRB).

Methods

The research method in identification of farmer innovations has its roots in participatory concepts, such as participatory technology development, participatory monitoring and evaluation, and participatory extension as the main subgroups. For the current research component, within the Livelihood Resilience Project, a framework based on program development processes and field surveys has been used (Critchley, 2000). The program-development-processes can be considered as the structure for field activities. The following steps were taken in carrying out this study:

- Hold a one-week training workshop on 'Promoting Farmer Innovations' for the staff of the project partners from the study regions Lorestan and Kermanshah provinces, different disciplines (research, extension and executive sectors), review the subject along with a one-day field trip.
- Organize meetings with farmers to identify farmer innovations and innovators in both study pilot watersheds (Honam and Merek), using preplanned forms.
- Summarize the collected data of innovations and characteristics of innovators.
- Organize meetings with staff of different research disciplines to receive relevant updated findings to be used at community scale, and plan for joint experimentation.
- Collect the views and suggestions of extension and executive sectors suitable for objectives of the study.
- Conduct a one-week participatory technology development (PTD) workshop in Lorestan for the related project staff
- Set the criteria to select 'best-bet' innovations for implementation (practicality, economic viability, and farmers' and social acceptability).
- Analyze and rank the recorded innovations, research findings, and extension suggestions in the order of their importance in different aspects of community livelihood resilience.
- Extract 'best-bets' as the guidelines for extension or improvement through joint experimentation in a process with the contribution of the main stakeholders.
- Verify selected 'best-bets' in the field, through more detailed interviews with the respective innovators by direct involvement of the relevant experts.

Some of the expected outputs from this study are identification and verification of outstanding innovations in the pilot watersheds to be used as the first input to select potential 'best-bets.'

Site specifications

An overview of the pilot watersheds is presented in Table 1. Crop production and animal husbandry are the main sources of income in the pilot watersheds. Some other sources of income are jobs in industry and service sectors in the nearby cities. In addition, there are some nomadic people in the sites who are mainly using the natural resources of the rangelands to feed their animals.

Table 1. Location and some specifications of the pilot watersheds within Karkheh River Basin, Iran.

Specification	Merek	Honam
Area (ha)	25000	15000
No. of villages	25	15
Population*	2000	1500
Location in Karkheh River Basin	Northwest	northeast
Min. Latitude	N 34, 0, 22.05	N 33, 44, 51.32
Max. Latitude	N 34, 9, 28.85	N 33, 51, 50.24
Min. Longitude	E 47, 4, 37.69	E 48, 12, 31.52
Max. Longitude	E 47, 22, 20.16	E 48, 28, 42.83

*Census of 1996.

Results

A total of 70 innovations were found in the survey. The main subjects of the different innovations are summarized in Table 2. The gender of the innovators is listed in Table 3.

Table 2. Distribution of identified innovations in the two watersheds based on their categories.

Subject of innovations	Number of innovations		% of innovations	
	Merek	Honam	Merek	Honam
Animal husbandry	2	15	7	35
Agronomy	16	9	59	20
Medicine	3	2	11	5
Soil fertility	1	6	4	14
Horticulture	0	6	0	14
Fisheries	0	2	0	5
Communal	1	2	4	5
Art	0	1	0	2
Irrigation	4	0	15	0
Total	27	43	100	100

Table 3. Distribution of identified innovators in the two sites based on gender.

Gender of innovators	Number of innovators		% of innovators	
	Merek	Honam	Merek	Honam
Male	14	25	82	69
Female	3	11	18	31
Total	17	36	100	100

NB. Some of the identified innovators had more than one innovation. Therefore the total number of innovations (70) exceeded the sum of innovators (53).

Selection criteria

According to the research methodology, the criteria for selection of innovations, as listed below, were determined during various expert meetings:

- Among the high priorities of the people's needs and acceptable to them.
- Based on full participation of people and the relevant executive sectors in all processes.,
- In the line of poverty alleviation and water productivity.
- Easy to implement with simple technology and high capability for dissemination.
- Its profit to be accessible in short term and covers middle to low resource farmers.
- Socially-economically justifiable.

These criteria were used to select some outstanding ones from the list of identified farmer innovations. Similar activity was done for the list of relevant research results and extension experts' recommendations, some of which have been used in a joint participatory experimentation subproject carried out in the same area (Moosavi et. al., 2008). In this paper only the findings of the selection procedure for farmer innovations are presented (Table 4).

Table 4. List of the selections from the identified innovations of the two sites.

No.	Site	Village name	Innovator's name	Title of innovation
1	Honam	Haji Abad	Mr. Morad Ali Hosseini	Bee keeping
2	Honam	Chahar Takhteh	Mrs. Nahid Hosseini	Change in the feeding system of turkeys
3	Honam	Lower Presk	Mr. Azizollah Saremian	New method of forage production
4	Honam	Bardbal	Mr. Nour Mohammad Nazari	Rainwater harvesting
5	Honam	Upper Presk	Mr. Mohammad Karam Haji	Water aeration in fish farming
6	Honam	Lower Presk	Mr. Seyed Jalal Jafari	Soil and water conservation in steep slopes – Planting suitable fruit trees
7	Honam	Siahpoush	Mr. Ali Morovvat Seifi	Planting in 13 rows
8	Merek	Bagh Tiqoun	Mr. Ali Taheri	Greenhouse for vegetables
9	Merek	Bagh Tiqoun	Mr. Nour Mohammad Taheri	Planting safflower
10	Merek	Bagh Tiqoun	Mr. Hamid Azizi	Compatibility of native cow
11	Merek	Sarab	Mr. Ali Rahm Khoda-yari	Cultivation of alfalfa
12	Merek	Seyed Shekar	Mr. Shokr Ali Naseri	Water harvesting for irrigation by making a small water reservoir

Discussion

The main differences between the types of innovations in the two sites are show in Table 2, which are probably caused by the differences in topography, climate, and other land potential parameters in the two regions. For example, the percentages of innovations match the fact that the main livelihood option in Merek is crop production, and animal husbandry in Honam. On the other hand, 15% of the innovations in the field of irrigation indicate the importance of water in agriculture in both watersheds.

Although the percentage of female innovators was lower than that of male innovators in both sites, (Table 3), based on discussions during various sessions with the farmers one can easily conclude that women were the main actors in the developing some of the innovations made by men. Therefore, in most cases the term ‘family innovation’ might be more suitable. The reason is that most of the family members usually undertake agricultural activities in close collaboration with each other (Reij and Waters-Bayer, 2001). Determination of the real role of women in farmer innovation development and having their active participation would require comprehensive studies in each site. The results of such studies may be used as a basis for planning and implementation of appropriate activities: training and employment of female extension workers, effective and continuous public awareness plans, increasing the level of women's self confidence, and carrying out long-term cultural programs (Critchley, 1999).

Conclusions and recommendations

Based on the objectives of the 'Strengthening Livelihood Resilience in Karkheh River Basin' project, and the importance of farmer innovations on rural livelihood, an intensive study was carried out in Honam and Merek. The participatory methods were used in all aspects of the study with the involvement of the main stakeholders, including farmers, researchers, and extensionists. In the first phase of the study, 53 farmer innovators were identified with their 70 innovations in different disciplines in both sites. The trend of distribution of innovations in the two sites showed that the identified innovations in Merek were mainly on agriculture and those of Honam were on animal husbandry, which are proportionate to the current livelihood bases in the relevant site.

In addition, the number of female innovators (14) was low in comparison to the male innovators (39), which may not reflect the actual role of women in the farmer innovation development processes. In the second phase of the study, 12 outstanding innovations out of 70 identified ones were selected in a participatory procedure against agreed criteria, to suggest for further improvement through joint experimentation with farmers and researchers. Active participation of the main stakeholders (researchers, extensionists, and farmers) in this process is the key factor in the success of these activities, which can only be achieved by the implementation of proper plans of training, capacity-building, and team formation. Facilitators usually play one of the major roles in providing a suitable environment for this purpose.

Acknowledgments

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Overview of streamflow variability and water accounts for the Karkheh Basin, Iran

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Abstract

This paper provides an overview of the streamflow variability in the semiarid to arid Karkheh River Basin of Iran, using daily data for the period 1961-2001 at seven key locations. It also provides a snapshot of the basin level water accounting for 1993-94, which is considered the reference year for the future water resource planning for the Karkheh Basin. The study showed that the streamflows of the Karkheh River and its tributaries exhibit large inter- and intra-annual variability. The study concluded that the Karkheh Basin appears to be an open basin during the period of investigation. Considering the water availability and the current and ongoing water resources development planning, however, the basin will very likely approach a critical stage during the first quarter of this century, and meeting the demands of all users will be an extremely challenging task.

Media grab

The Karkheh River and its tributaries exhibits large inter- and intra-annual variability, and inclusion of this information into water resources allocation planning will help to develop a sustainable management regime.

Introduction

Assessment of the spatio-temporal variability of water resources provides essential scientific information that in turn could be used for making water resources policies, for instance, regarding sustaining the food production, ecosystem health, and socioeconomic benefits from the use of water. This is extremely important for water-limited environments, such as the semiarid to arid Karkheh Basin of Iran, where scarcity and variable distribution of water and nutrients makes these environments highly vulnerable and sensitive to change. The Karkheh Basin (Figure 1) is subjected to a fragile balance between environment and human uses of natural resources. The demands for water are increasing and sustainable management of water resources has become an important issue. In this river basin, massive irrigation development is under way, but the knowledge and understanding of basin hydrology (including the water balance variations in space and time) and impacts of these developments on other users and water uses across the basin are patchy (Qureshi et al., 2005).

This paper provides an overview of the surface water hydrology of the Karkheh Basin and details on the nature of its spatial and temporal variability. The basin level water accounts are also provided for 1993-94. This study is part of the Basin Focal Project for the Karkheh (CPWF, 2006), and is expected to guide further water resources research and development planning by the Challenge Program on Water and Food and Iranian stakeholders such as the Ministry of Energy and Ministry of Jihad-e-Agriculture.

The Karkheh River Basin has a drainage area of 50,764 km^2, of which 80% is part of the Zagros mountain ranges of Iran. The climate is semiarid in the mountainous parts and arid in the lower plains. The mean annual precipitation in the basin is about 450 mm, ranging from 150 mm in the lower arid plains to 750 mm in upper mountainous parts. The annual renewable water resources of the basin are about 8.5×10^9 m^3 (JAMAB, 1999).The details on the study area can be found in Sutcliffe and Carpenter (1967), JAMAB (1999), CPWF (2006), and Ahmad et al. (2008).

Methods

For this study, seven river gauging stations (Figure 1) were selected on the basis of their geographical importance, availability of consistent length of records, and longer time series. The data on the surface water withdrawals was not available, therefore the analysis accounts for the abstractions for various uses such as irrigation and domestic. The naturalization of streamflows can be made if the withdrawals are known or estimated through indirect means, if the information on daily crop water demand, cropping pattern, and cropped area and irrigation efficiencies are available (Masih et al., 2008). A streamflow naturalization approach for agricultural withdrawals in the Karkheh Basin has been devised by Masih et al. (2008) for the period 1987-1997. It was not possible, however, to carry out naturalization of streamflows over the 40 years of the study period 1961-2001, because the required information was not available.

The analysis included: (1) basic statistics and trend detection; (2) flow duration curve; and (3) water accounting. Daily stream flow data for the period 1961-2001 were acquired, quality controlled, and used. The trend analysis was carried out on the monthly and annual time series of streamflows using Spearman rank test (e.g Yue et al., 2002). We attempted to attribute the trends and patterns by analyzing available (limited) information on climate, irrigation developments, reservoir construction, and land use changes. We analyzed the precipitation data of three climatic stations, Kermanshah and Khorramabad (data from 1951-2003) and Ahwaz (data from 1957-2003), each representing the upper, middle, and lower parts of the basin, respectively. We used 90% confidence interval (one tailed) for evaluating presence or absence of trends, as in the semiarid to arid environment of the Karkheh Basin changes that are significant at this level could have quite serious implications. The annual data series was used to derive Flow Duration Curve (FDC) for the Q_1, Q_5, Q_{10}, Q_{25}, Q_{50}, Q_{75}, Q_{90}, Q_{95} percentiles. FDC is a cumulative distribution of flows at a site showing the flow assurance that how often any flow is equalled or exceeded (see Linsley et al., 1982).

The IWMI water accounting framework (Molden and Sakthivadivel, 1999), which provides a unique way of distinguishing different water use categories (e.g. net inflow, depletion, committed and uncommitted outflows), was applied for the basin level water accounting for the water year 1993-94, as most of the required information was available for this period from the study of JAMAB (1999), and also because this year is considered as the reference year for the future water resource planning for the Karkheh Basin. Although the similar exercise for an extended period, i.e., for one decade or more, and for dry, medium, and wet years could be much more helpful, but was not possible due to unavailability of the required data . A brief description on the estimation of water accounting components is provided here, and details can be found in JAMAB (1999). The estimates were based on the observations on climate (e.g., precipitation, evaporation), streamflows, water uses, and other water balance components. For the purpose of detailed water balance analysis, they divided the basin into 47 subcatchments, and their water balance results were aggregated at the basin level. The inflow components of the water accounting were composed of precipitation, inflow from outside of the basin, and changes in surface and subsurface storage (Figure 3). The precipitation data were based on the 61 climatic stations spanning the basin. Changes in subsurface storage were estimated based on the groundwater measurements related to water level changes, specific yield, and domain area. Since there was no major storage dam in the basin during 1993-94, the surface storage was considered as zero. The actual evapotranspiration was estimated through empirical equations calibrated for selected locations in the basin where detailed data on climate and water balance were available. The actual evapotranspiration from diversions for agricultural purposes was estimated as the difference of total abstraction and return flows. The subsurface outflow was regarded as zero, whereas outflow from rivers and drains were based on the observed records. The data on committed and uncommitted water were not available through the study of JAMAB and, therefore, we estimated these values in order to complete the water accounting exercise. The committed water was estimated in the range of 10-50% of the available streamflows, based on Tennant (1976), who suggested that allocating 50% of the available streamflows to riverine ecosystems can maintain healthy ecosystems, whereas the minimum flows should be at least 10%, although the ecosystem degradation will be inevitable at this level. It should be noted that this method is simple to apply but has the potential for inadvertent misuse, because it does not account for specific species/life phase habitat requirements, short-long-term changes in flow rates, seasonal variability, or channel geometry.

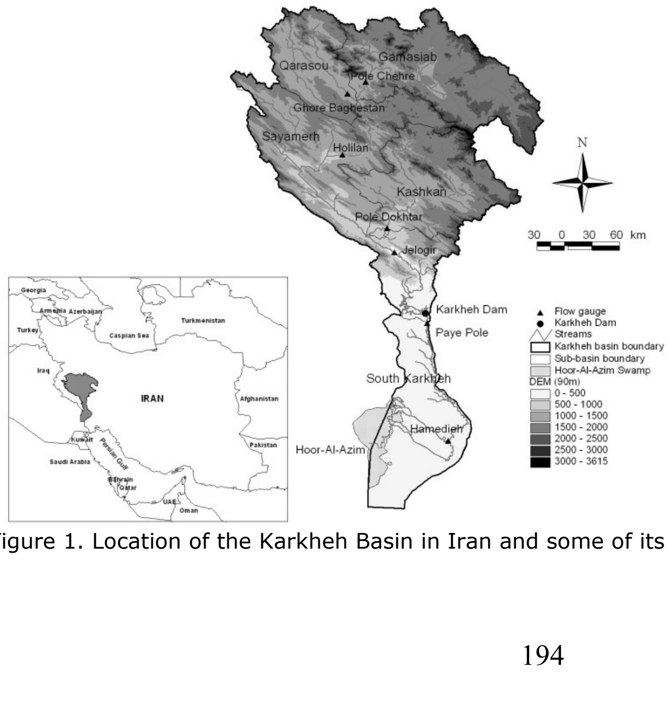

Figure 1. Location of the Karkheh Basin in Iran and some of its salient features.

Results and discussion

Spatial and temporal variability of the streamflow regimes

The streamflows show large variability within a year and between years. The general temporal pattern of streamflows, however, is quite synchronized when different streams or flow behavior at different locations on a single river are compared (Figure 2). This is indicated by the similar timings of the high- and low-flow months. The high-flow events are mainly concentrated during November to May, with peak flows mainly in March-April. The duration of these events varies depending on the precipitation timing and snow melt dynamics. Generally high-flow events of small duration (i.e. 1-5 days) occur due to high rainfall events; but the high flows prevailing for 1 or 2 months, mainly observed during February-May, are caused by the snow melt and combined effect of snow melt and rainfall. The low flows are observed during June-September. The maximum values of CV are observed for November ranging from 0.96 to 1.77, and the minimum values of CV are observed in February ranging from 0.44 to 0.53. In spatial terms, highest variability is observed for Pole Chehre and Ghore Baghest, located in the upper parts of the basin. The annual values of CV fluctuate around 0.47, with the range of 0.41-0.54 (Table 1). These high inter- and intra-annual variations are mainly governed by the variability of precipitation, topography, soils, land use, and geology. The high variability in autumn streamflows and precipitation has implications for the management of rainfed and irrigated lands. This adds to the uncertainty of the water availability through surface flows as well as through precipitation. As a result, the decisions related to cropped area and agronomic operations (e.g. sowing operations for wheat and barley) remain at risk. Improved forecasts and their use by farmers could greatly help in getting ensured and better agricultural outputs from the land.

The results of the trend analysis show that declining patterns were observed during May at all stations. Generally decline during May-September were observed in upper parts of the basin, though trends were significant only for May at Ghore Baghestan and Holilan. December and March show increasing patterns all across the basin, with December streamflows significant at Holilan, Pole Dokhtar and Jelogir. Increasing trends were observed during October at Pole Dokhtar and Hamedieh. Decreasing trends were observed for August at Ghore Baghestan and Holilan, whereas Hamedieh station showed increasing trends in August and September. The decline in flow during May was mainly attributed to the decline in precipitation during April and May, whereas increase in December flow was not clearly attributed to climate alone but was likely to be triggered by the combined effect of climate and land-use changes. These would include increasing patterns of precipitation in December, though not significant, and the watershed degradation due to a decline in the forest cover and a deterioration of rangelands (Mirqasemi and Pauw, 2007). Increasing trends at Hamedieh, particularly during July-September, were mainly attributed to the operations of the Hamedieh reservoir. This analysis has highlighted the need of further (modelling) studies on the linkages of streamflows with climate, land use, and reservoir operations.

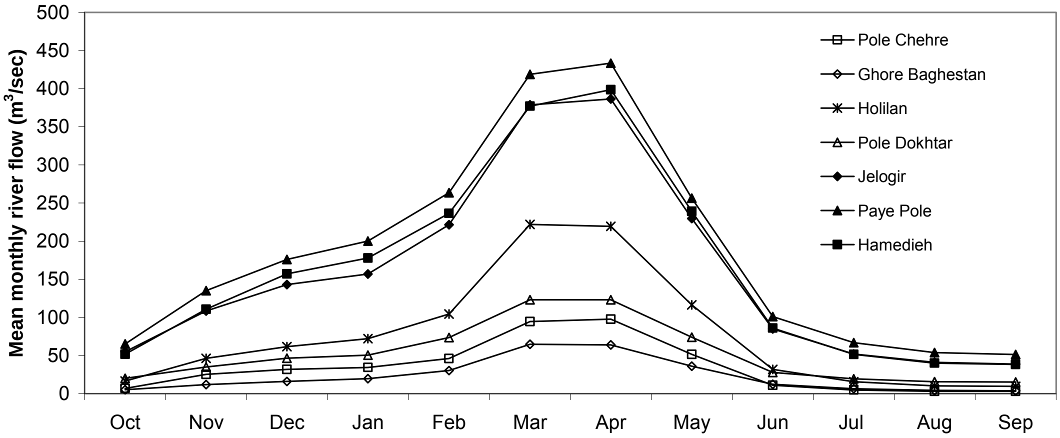

Figure 2. Mean monthly discharge at the selected locations in the Karkheh Basin, Iran.

The comparison of mean and median annual surface water availability indicates that the mean values are 0-7% higher than the median estimates. This exhibits the classic arid and semiarid hydrology characteristic that the mean is greater than the median, but, in this case, not by a big margin at an annual scale (only 4% on average). Further examination of annual surface water availability (Table 1) shows that maximum flow of 12.59×10^9 m^3 occurred in the wet year 1968-69, whereas the minimum flows of 1.92×10^9 m^3 correspond to the drought year 2000-01, at Paye Pole station. In the time period of this analysis, 1961 to 2001, a drought persisted from 1999 to 2001, though the longer term time series do depict high- and low-flow years throughout the study period. These large temporal variations indicate high levels of supply insecurity for current and further withdrawals for human uses.

The analysis of flow duration curves (Table 1) provide further insights into the annual availability of surface water along with the corresponding level of assurance. For instance the value of Q_{75} at Paye Pole station at the Karkheh River is 4.082×10^9 m^3, which shows that this much volume of surface water could be available for 75% of the time, i.e. 30 out of 40 years. Further examination was done to see the assurance levels associated with mean annual water availability. For this, FDC plots were generated, using annual data (not shown in the paper), and the exceeding level of means were noted for each station. This analysis indicated that mean annual surface water availability has an assurance level of about 45% at the basin scale, ranging from 40% for Pole Chehre to 52% for Pole Dokhtar. This shows that the annual mean is biased toward water years with high values for Pole Chehre (and also for Ghore Baghestan) and, therefore, the median is a better measure of central tendency for these stations. Furthermore, due to the construction of the Karkheh dam in 2001 and ongoing irrigation schemes in downstream parts, one can anticipate that during the below average/low-flow years, the most serious conflict would concern retention of water in Karkheh dam for hydropower generation and reduced supplies to the downstream agricultural users, whose situation will be exacerbated by soil salinity problems. This would also be accompanied by the diminished flows to riverine ecosystem and floodplains as well as to the Hoor-Al-Azim swamp further downstream.

Table 1. Some basic statistics and flow duration characteristics showing annual variability in streamflows.

	Units M^3/year	Pole Chehre	Ghore Bagestan	Holilan	Pole Dokhtar	Jelogir	Paye Pole	***Hamedia***
Mean	10^6 m^3/	1080	722	2431	1639	4974	5827	5153
CV	-	0.50	0.54	0.53	0.41	0.43	0.43	0.48
Minimum	10^6 m^3/	198	104	607	645	1790	1916	1068
Maximum	10^6 m^3/	2851	1914	6193	3206	10773	12594	11324
Median	10^6 m^3/	1003	712	2292	1637	4692	5590	4852
Q_5	10^6 m^3/	2416	1844	6042	3081	8958	10755	9280
Q_{10}	10^6 m^3/	1684	1183	4250	2455	8227	9280	8641
Q_{25}	10^6 m^3/	1303	957	2977	2064	6193	7756	7555
Q_{50}	10^6 m^3/	1022	716	2343	1645	4836	5651	4873
Q_{75}	10^6 m^3/	766	419	1499	1113	3562	4082	3447
Q_{90}	10^6 m^3/	549	353	1168	854	2601	3020	2254
Q_{95}	10^6 m^3/	294	268	871	778	2230	2404	1648

Overview of the basin level water accounting

Basin level water accounts are given in Figure 3. The annual gross inflow, net inflow, and total depletion were 24.96×10^9 m^3, 25.08×10^9 m^3, and 19.94×10^9 m^3, respectively. Direct depletion from precipitation constituted 82% (or 16.39×10^9 m^3) of the total depleted water (19.94×10^9 m^3). This water was mainly depleted through cropped areas, pasture, forests, and bare lands. The quantified data on these uses were not available for the study period; however, the estimates could be seen in a recent remote sensing-based study of Muthuwatta et al. (2008) who has estimated actual evapotranspiration for the different land uses in the basin for 2002-03. The portion of irrigation diversions, during 1993-94, depleted as evapotranspiration from irrigated areas was estimated as 3.21×10^9 m^3. The annual depletion of water in municipal and industrial sectors was very small (only about 0.05×10^9 m^3), as most of the water diverted to these sectors generates return flows (about 76%). The total annual outflow from the basin during 1993-94 was 5.09 ×10^9 m^3, which is composed of outflow from the Karkheh River (3.99×10^9 m^3) and from the drainage network (1.10×10^9 m^3). The annual outflow from the Karkheh River is 54% or 3.99×10^9 m^3 of the total annual streamflows volume of 7.37×10^9 m^3 available in 1993-94.

We estimated committed water required to support riverine ecosystem functions in the range of 0.74×10^9 to 3.69×10^9 m^3. It should be understood that most of the environmental flow assessment studies recommend that in order to keep healthy, resilient, and productive riverine ecosystems, water management policies should aim to restore the natural flow regime of the rivers, including flow variability, as much as possible (Poff et al., 1997). Based on these simple assumptions, however, uncommitted outflow from rivers (i.e. Total outflow minus committed outflow), in a year like 1993-94 available for further allocation to various uses, would be in the range 1.070×10^9 to 4.02×10^9 m^3.

Considering the water accounting analysis for 1993-94 and long-term streamflows measured at the last gauging station of the basin (Hamediah during 1961-2001), the Karkheh Basin appears to be an open basin. A river basin is termed closed when additional water commitments for domestic, industrial, agricultural, or environmental uses cannot be met during all or part of a year, while in an open basin more water can be allocated and diverted (Falkenmark and Molden, 2008). But when we view the Karkheh Basin in terms of surface water variability and long-term water availability with the ongoing and future water allocation planning, then it is likely to attain the basin closure stage in the near future. For instance the annual water allocation to different sectors for 2001 was 4.95 ×10^9 m^3 (JAMAB, 2006), which is about 60% of the total renewable water resources available during the reference year 1993-94. The allocation to different sectors will be 8.90×10^9 m^3 by the year 2025, among them the irrigation share will be the biggest (7.42×10^9 m^3), almost equal to the renewable water supplies in an average year.

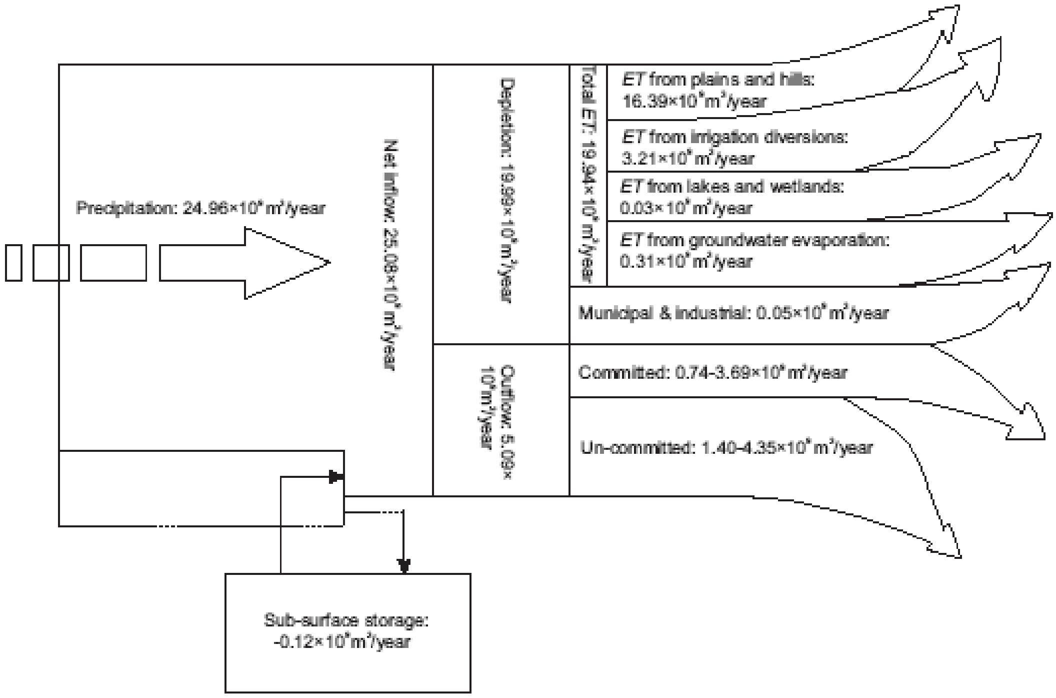

Figure 3. Schematic representation of the basin level water accounting of the Karkheh Basin (1993-94).

Conclusions

The study shows that the streamflows of the Karkheh River and its tributaries exhibit large inter- and intra-annual variability, inclusion of which into water resources planning is pivotal for sustainable management of the available water resources. The Karkheh Basin appears to be an open basin and the competition among various uses of water was not alarming during the study period. This was exemplified, for instance, by the fact that about half of the total renewable streamflows were flowing out of the basin during 1993-94, the amount which is generally considered sufficient to maintain healthy ecosystems. This was further supported by the records at Hamedieh station indicating no decline in the streamflows over the study period 1961-2001. Considering the water availability and current and ongoing water resources development plans, however, the basin will very likely approach closure stage during the first quarter of this century. Meeting the demands of all users will then be an extremely challenging task, particularly during dry years. The analysis conducted in this study is helpful in gaining further insights into the hydrological variability of surface water resources, and in turn could be instructive for the (re)formulation of a sustainable water resources development and management regime for the Karkheh Basin. For instance, this study has shown that streamflows in the upper two sub-basins are more variable compared to the middle parts, indicating a declining trend during low-flow periods, most notably in upper parts and during May. This means that contributions from the upper two sub-basins toward the Karkheh River would likely be reduced during low-flow periods, and additional irrigation developments may exacerbate this. Furthermore, the water accounting exercise has generated useful information about the availability of water, and different pathways by which water resources were depleted or moved out of the basin. The estimation of committed and uncommitted outflows provided practical insights about the degree to which water resources can be further developed. The analysis also highlighted trade-offs between different uses of water. For example, increasing allocations to irrigation will increase the depleted portion of the water accounting and consequently reduce outflow from the basin that will likely have a negative impact on the environment. Further studies are recommended on the linkages of streamflows with climate and land uses, management of the flow regime close to the natural variability, estimation of environmental flow requirements in terms of temporal and spatial dimensions, and setting up river/reservoir management targets that can minimize the negative impacts for the environment while ensuring the food security and economic gains from the use of water.

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Mainstreaming capacity-building in food and water research in the Limpopo Basin: linking across scales and across disciplines

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Abstract

In improving global food production, the problem is not always due to the physical scarcity of water, but rather the lack of integrated land-water management approaches and weak institutional arrangements. An integrated approach to green and blue water management from the farmer's field to the river basin scale is required to promote and upscale smallholder rural livelihood improvements. This cannot be achieved through the introduction of innovations alone, but requires the building of appropriate capacity in land and water management at all the scales at which interventions are implemented, or management decisions are taken. Too often capacity-building is seen as a follow-up activity. As an alternative, WaterNet's approach is to integrate capacity-building into the research activities from the planning stage onwards. Key research in the Challenge Program on Water and Food Project PN17 is being undertaken by seven doctoral fellows and masters students, registered at WaterNet member institutions and supervised by scientists from universities and CGIAR centers within PN17. Many of these students come from the WaterNet regional masters program in Integrated Water Resources Management. They are supervised by doctoral fellows and scientists from universities and CGIAR centers within project PN17. The project also involves capacity-building at community, extension officer, and water manager level. A particular benefit is the development of transdisciplinary scientific teams for the supervision of students and the guiding of community training. As project PN17 progresses, there is constructive feedback between the research project and WaterNet's capacity-building programs, especially the regional masters program. The program benefits as researchers from PN17 are brought into teaching, and as new research ideas from PN17 are integrated into the masters curriculum. The masters program thus provides students who are well-equipped to begin their research projects, some of which are on water and food. Beyond this, WaterNet aims at training a new generation of water managers. By the integration of PN17 and the masters program, new ideas and philosophies of more crop per drop are passed on to the students, who, returning to their home countries and workplaces in southern Africa, can implement the new knowledge.

Media grab

Too often capacity-building is seen as an add-on to research: a follow-up activity in which the main researchers are uninvolved or uninterested. WaterNet's approach is to integrate capacity-building into the research activities from the planning stage onwards.

Introduction

In improving global food production, the problem is not always due to the physical scarcity of water, but rather the lack of integrated land-water management approaches, and weak institutional arrangements (Falkenmark and Rockström, 2003; Jaspers, 2003; Love et al., 2006; van der Zaag, 2005). An integrated approach to green and blue water management from the farmer's field to the river basin scale is required to promote and upscale smallholder rural livelihood improvements (Love et al., 2004). This cannot be achieved though the introduction of innovations alone, but requires the building of appropriate capacity in land and water management at all the scales at which interventions are implemented, or management decisions are taken.

Capacity-building is often seen as an add-on to research: a follow-up activity in which the main researchers are uninvolved or uninterested. WaterNet's approach is to integrate capacity-building into the research activities from the planning stage onwards. This is show-cased through the Challenge Program on Water and Food project (PN17), which from proposal stage has been integrated into WaterNet's capacity-building programs in Southern Africa.

Methods

PN17 was conceptualized with seven doctoral fellows and 21 masters students. In implementation, key research in PN17 has been undertaken by the seven doctoral fellows, registered at WaterNet member institutions and supervised by scientists from universities and CGIAR centers within PN17. Each fellow is linked to masters students (40 to date) who undertake their dissertation projects within PN17. Many of these students come from the WaterNet regional masters program in Integrated Water Resources Management at the Universities of Dar-es-Salaam and Zimbabwe, supported by four other regional universities. Others come from programs at other WaterNet member institutions. They are supervised by doctoral fellows and scientists from universities and CG centers in PN17. The project also involves capacity-building at community, extension officer, and water manager levels. This includes participatory on-farm pilot experiments (involving farmers and extension officers) and participatory development of institutional and water resources models (involving water managers). Direct training and extension are also provided in key areas.

Results and discussion

Part of the impact of capacity-building within PN17 can be seen in the number (twice the target) and distribution (half of SADC countries) of the masters students (Figures 1 and 2).

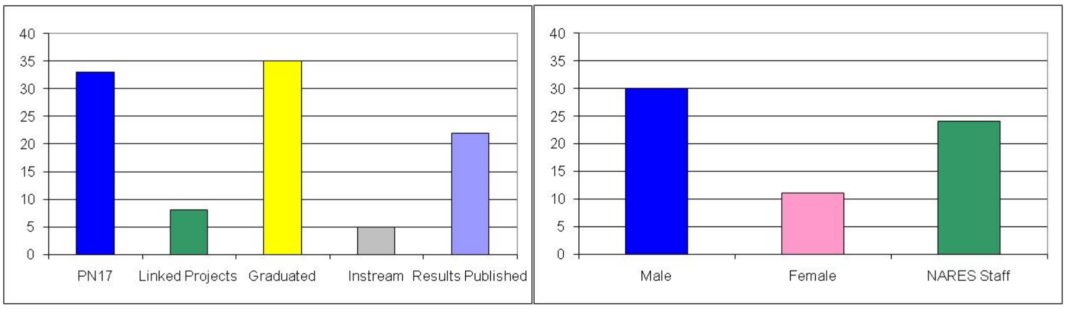

Figure 1. Masters students sponsored by PN17: almost all have now graduated and most have had their work published internationally (left). Whilst staff from national agricultural (or water) research and extension services (NARES) are well represented, gender balance has not been achieved (right).

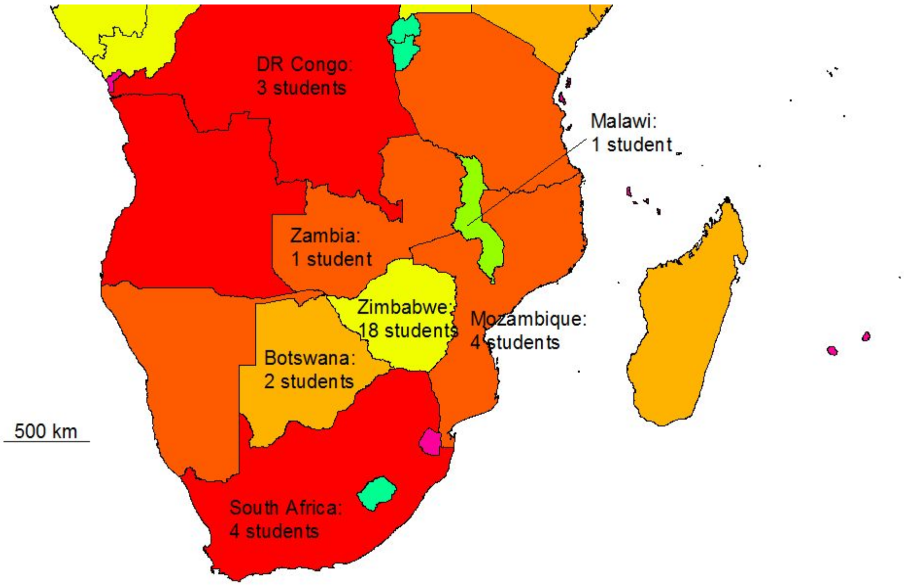

Figure 2. Map showing the distribution by nationality of the masters students sponsored by PN17 (excludes European exchange students). The bulk are from the four Limpopo Basin countries: Botswana, Mozambique, South Africa, and Zimbabwe.

The capacity-building component of the project has influenced the project's research output, with 22 students publishing papers, articles, or both (Figure 1). Contributions have been made in all major areas of PN17 research: Farmer field-based action research (Maisiri et al., 2005; Dhliwayo et al., 2006; Moyo et al., 2006; Mwenge Kahinda et al., 2007), water resources research (Moyo, et al., 2005; Kileshye-Onema et al., 2006; Moyce et al., 2006; Ngwenya et al., 2006; Vilanculos et al., 2006; Tunhuma et al., 2007; Arranza and McCartney, 2008; Chilundo et al., 2008; De Hamer et al., 2008; Khosa et al., 2008; Masvopo et al., 2008; Ncube and Taigbenu, 2008), and institutional research and development (Munamati et al., 2005; Nare et al., 2006; Svubure, 2007), as well as synthesis work such as where Basima Busane et al., (2005), integrated the research of four students who had been working on the same small reservoir.

Published research results have an impact in the broader scientific community: van der Zaag (2007) showed that articles published in the journal Physics and Chemistry of the Earth following the annual WaterNet/WARFSA-GWP-SA symposia (where most PN17 results have been presented) achieved an impact factor of between 0.3 and 0.8, with the water and land theme having an impact factor of 1.03. The paper by Moyce et al. (2006) received the Phaup Award from the Geological Society of Zimbabwe, for the paper contributing most to the understanding of Zimbabwean geological science during the year 2006. The approach of Vilanculos et al. (2006) is being used for flood forecasting. The work of Maisiri et al. (2005) and Moyo et al. (2006) on drip kits has been developed into a protocol on drip kit distribution that is now widely used in the NGO community in Zimbabwe. Initial steps have been taken for the work by Masvopo et al. (2008) to be developed in partnership with a private company, to supply water for smallholder citrus production. The results and model of Khosa et al. (2008) has been shared with the Zimbabwe National Water Management Authority for use in planning and at a stakeholder workshop. Recommendations by Svubure (2007) for rolling out water users associations and intermediate tier management structures were adopted by the Mwenezi Subcatchment Council in Zimbabwe.

By a participatory approach, PN17 has trained communities, extension officers, and water managers in a variety of interventions (Table 1).

Table 1. Intervention matrix for PN17: examples of interventions developed by a participatory approach.

Intervention package	Community beneficiaries	Organizational beneficiaries
Conservation agriculture	Communities in Insiza, Gwanda, and Mwenezi (Zimbabwe) and Capricorn (South Africa)	Department of Agricultural Research and Extension (Zimbabwe) Limpopo Department of Agriculture (South Africa)
Rainwater harvesting	Communities in Sekororo (South Africa) and Chókwè (Mozambique)	Limpopo Department of Agriculture (South Africa) Chókwè District Agriculture Department (DDA) (Mozambique)
Low head drip kits	Communities in Insiza (Zimbabwe). But mostly this work was learning from the communities	Department of Agricultural Research and Extension (Zimbabwe) Many NGOs that distribute drip kits
Alluvial aquifers for smallholder irrigation	Communities in Matobo (Zimbabwe) (planned).	Zimbabwe National Water Authority
Improving flood forecasting	-	AraSul (Mozambique)
Modelling upstream-downstream interactions	-	Zimbabwe National Water Authority
Building institutional sustainability	Communities in Sekororo (South Africa), Insiza, and Mwenezi (Zimbabwe)	Zimbabwe National Water Authority

A particular benefit of the project is the development of transdisciplinary scientific teams for the supervision of students and the guiding of community training. This is made possible by the broad nature of the PN17 partnership, backed up by the wider WaterNet membership (Figure 3). The involvement of scientists in the supervision of research and capacity-building projects at different scales, from farmer's field to river basin, results in the development of a core capacity with an appreciation of the challenges and linkages at the different scales within the basin. Methodologies, research tools, and results are shared through integrative scientific and stakeholder workshops. Students are also required to present papers at symposia and encouraged to publish in journals. Quality control is conducted from conceptualization of research ideas to implementation, publication of papers, and synthesis of research findings.

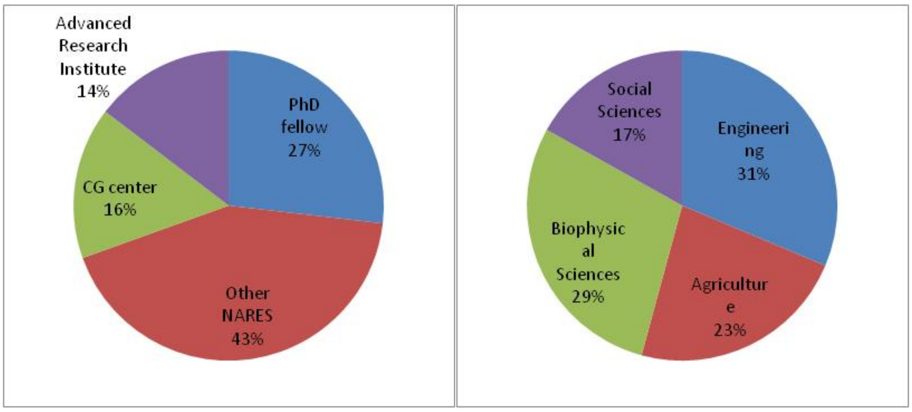

Figure 3. Affiliations and disciplines of supervisors of Masters students. Most students had two or three supervisors. NARES = national agricultural (or water) research and extension services. Doctoral fellows who are also NARES staff are only recorded as doctoral fellows. Institutional affiliation (left) shows the extent to which local scientists had ownership of masters supervision. There is a good balance between disciplines of supervisors (right), making for good transdisciplinary teamwork.

Conclusions and recommendations

Integrating research and capacity-building is a win-win scenario. At WaterNet, the masters program benefits as researchers from PN17 are brought into teaching, and as new research ideas from PN17 are integrated into the masters curriculum. The masters program thus provides students who are well-equipped to begin their research projects, some of which are on water and food. Beyond this, WaterNet aims at training a new generation of water managers. By the integration of PN17 and the masters program, the new ideas and philosophies of more crop per drop are passed on to the students, who, returning to their home countries and workplaces in southern Africa, can implement the new knowledge see Figure 4).

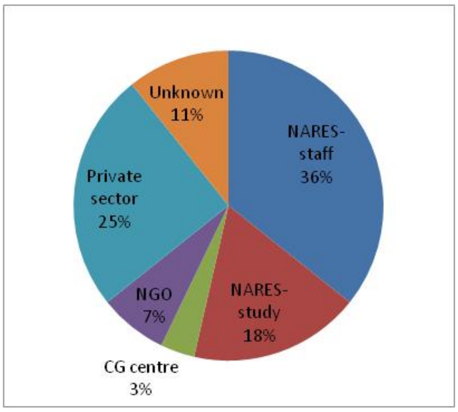

Figure 4. Deployment of masters graduates from PN17, as at July 2008.

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Interactive knowledge sharing and adoption of technologies in Makanya, Tanzania

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Abstract

This study was conducted to encourage the wider adoption of agricultural water and moisture system innovations. Such adoption is currently low among smallholder farmers. The innovations increase productivity of agricultural water and enhance livelihoods in semiarid areas. One of the project strategies was to involve farmers in experiential learning through study tours that would actively facilitate and enhance farmer to farmer knowledge sharing and learning. This would hopefully create a good atmosphere for scaling-out. After interaction with fellow farmers during exchange visits, and seeing the benefits of practicing improved water management techniques followed by practical training, we observed a rapid adoption of water management technologies in all villages. Within one year of project implementation, farmers adopted a number of technologies in their farms and shared knowledge with fellow farmers in their villages. By August 2007, in one of the study villages 189 households had constructed 1876 terraces. Farmers were motivated to construct terraces after seeing that they would earn more income by planting high-value crops such as bananas and vegetables that would fetch a good price in the nearby market, thus increasing productivity of scarce water resources.

Media grab

Use of interactive and participatory approaches to knowledge-sharing and learning has increased farmers' enthusiasm to adopt innovations that were available for more than 50 years.

Introduction

The agricultural water and moisture systems' innovations (WMSIs) in the semiarid and arid areas offer the potential to reduce poverty and play a pivotal role in realizing an African 'green revolution.' Rockstrom et al. (2004) defined water and moisture system innovations as any management technology or practice that has the objective of reducing risks of rainfed-induced water stress and/or increase agricultural productivity. They include water harvesting, drip irrigation, precision agriculture, and conservation farming technologies aimed at improving water productivity while conserving resources. The importance of WMSIs is increasingly high given the negative impacts of climate changes and increasing population, both of which put severe strain on water resources (Postel, 2000; Wallace, 2000). At the same time, the adoption of WMSIs is associated with several factors such as household capital endowment, land tenure system, access to markets and other services, government policies, and the stock of technologies available (Nkonya et al., 2006). This paper provides analysis of stories of some farmers who were involved in the initial stages of the knowledge-sharing and communication strategy implementation, and how the strategy has enhanced adoption of high-potential interventions for increasing agricultural water productivity in the Makanya River Catchment in Tanzania.

Methods

The most significant change (MSC) technique was used in the Makanya watershed to conduct monitoring and evaluation of the CPWF SG 503 project. MSC is a participatory action research methodology with diversity in both implementation and outcomes. This study was conducted in five villages: Chajo, Mhero, Malindi, Mgwasi, and Makanya. The MSC technique is a dialogical, story-based technique. Its primary purpose is to facilitate program improvement by focusing the direction of work toward explicitly valued directions and away from less valued directions. MSC can also make a contribution to summative evaluation through both its process and its outputs. The technique involves a form of continuous values inquiry whereby designated groups of stakeholders search for significant program outcomes, and then deliberate on the value of these outcomes in a systematic and transparent manner (Dart and Davies, 2003). The MSC technique in this study was done as indicated in the MSC guidebook (Davies and Dart, 2005). Essentially, the process involved the collection of significant change (SC) stories emanating from the field level, and the systematic selection of the most significant of these stories. Most significant stories were collected from a total of 28 farmers who participated in the knowledge sharing and learning carried out through focus group discussions, dialogue, and participation of farmers in agricultural shows, training, and exchange visits in areas with successes in practicing WMSIs. The farmers were asked to write their own stories indicating significant changes they experienced since they started to be part of the project. The stories cover the period of more than 2 years, from 2006 when the project started. The stories were written in May 2008 and were then collected from the farmers and sorted according to story domains. About five story domains were identified, which were used to analyze the areas where the farmers have experienced the most significant change in their lives or farms. The stories were ranked based on the how the farmer has explained the changes he/she has experienced, and the number of domains which the story covers.

Results and discussion

Farmer stories domains

The analysis of most significant change stories showed that all farmers experienced change in their attitude and behaviors toward use of innovations. About 79% reported envisioning the future at farm level, 79% have enhanced social networks, 61% reported enhanced farmer to farmer sharing of knowledge, and 46% reported enhanced productivity and livelihoods. Out of 29 stories, 10 were ranked higher because the farmers showed how the interactive knowledge-sharing process had influenced most of their current farming practices. The outstanding story was from the Chairperson of Malindi village, who explained the sequence of changes and narrated the steps she took to share the knowledge with other farmers and a primary school in the village, as an effort to persuade the next generation to practice better and improved farming.

Attitude and behavior change toward use of improved technologies

The interactive methods used to share knowledge has given farmers the freedom to learn and decide what they would like to implement on their farms. Despite having long experience with farming, they have not been exposed to better and alternative ways to learn and improve their farming practices, other than conventional top-down extension approaches. This has made them more rigid in their traditional ways of farming, which was neither profitable nor sustainable. Therefore, through this project they were able to visit other farmers who practice better farming techniques, attend agricultural exhibitions, and have other farmers from different locations coming to train them in various farming practices. One farmer said that …

> *…I have been cultivating my farm for so long without any conservation structures; even the rainwater harvesting I was practicing was not technical, and I was mixing so many crops in my farm. After this project I have learnt better farming practices like making terraces and conservation agriculture. I have managed to practice conservation farming in my farm which has improved moisture retention in the soil. I have also shared this knowledge with my fellow farmers during our village meetings…*

Another farmer testified that …

> *…After study tour and agricultural exhibition visits I have made an effort to change by trying to make compost manure which I use to cultivate vegetables. I have made terraces which help to conserve soil and water…*

The results showed that all farmers' stories were citing change of attitude and behavior as one of their significant changes (Table 1).

Table 1. Analysis of innovation adoption as a result of attitude and behaviour change based on MSC stories.

Innovation	N	Cases (%)
Soil and water management	28	100
Improved germplasm	28	100
Soil fertility management	25	89
Tree nursery establishment	5	18
Planting fodder grass along contours	3	11
Total responses*	89	

*–Multiple responses.

Soil and water conservation innovations practiced include making terraces (mostly bench and fanya juu), rainwater harvesting (through construction of sunken bed, basins, infiltration ditches, runoff harvesting), and conservation agriculture. Most of the improved germplasm includes bananas (Chinese, Cavendish, Williams, Grandnine), vegetables, and maize. In soil fertility, most farmers reported adopting use of farmyard manure for growing bananas and vegetables, and others reported to have adopted use of compost manure. One farmer said that …

> *...I was one of the few farmers who attended national agricultural exhibitions in Arusha in order to learn new technologies and share with our communities. I was very keen to learn what I saw, and I managed to practice in my farm by making terraces for the purpose of conserving water and manure. I used proper spacing (90 cm by 30 cm) to grow maize and used one seed per hole instead of 3 to 4 seeds. I have seen great change and achievement compared to my previous practice ……another thing that attracted me was environmental conservation. I established a small tree nursery of about 100 seedlings of grevillea, quinine, and fruit trees (pawpaw and passion), which I expect to plant in my fields...*

For example, in Malindi village alone the chairperson reported that 189 households had constructed 1876 bench terraces by August 2007. Farmers themselves indicated that they were motivated to change their farming behavior by constructing bench terraces after taking into account that they are likely to earn more income by planting high-value crops (bananas, tomatoes, onions, carrots, and spinach) that fetch a good price in the nearby markets, and that would increase productivity of scarce water and land resources.

Empowerment to reach other farmers

After interaction with fellow farmers during exchange visits and seeing the benefits of practicing improved WMSI techniques in Lushoto and Karatu, followed by practical training, we observed that there is rapid adoption of WMSIs on all villages. Within the period of project implementation farmers have implemented a number of WMSIs on their farms and shared knowledge with fellow farmers in their villages. Sixty-one percent of the farmers reported that they were able to enhance their ability to share what they learned from the project with other farmers. Most of them said that the change that is observed in their farms has attracted other farmers who were not part of the project to ask for advice. For example a farmer said in his story that….

> *…I have given training on improved banana technology to three farmers in my village...*

Another farmer said:

> *…I advise my neighbors to attend farmer field school sessions and in the next season I am planning to invite them onto my farm to see what I am doing…*

The observation from Malindi village showed that within 6 months there has been an addition of 45 new farmers among 189 farmers in 2007 who adopted bench terraces and contours, and an additional of 758 new terraces. This rapid adoption can be attributed to the project farmers sharing knowledge with other fellow farmers in the village. Many farmers have adopted different technologies they learned from fellow farmers. Other farmers have been seriously involved with horticultural crops, including growing bananas, and a few farmers have tried fanya juu terraces.

Increased productivity and enhanced livelihoods

About 46% of the farmers' stories mentioned that there has been an increased productivity and enhanced livelihoods at the household level. These were achieved through farmers' engagement in cultivation of high-value crops, mostly vegetables. One farmer said....

> *….I have planted banana for so long but I did not practice proper procedure; following the technical advice given to me I de-suckered and de-trashed my bananas and within 3 months I managed to harvest and sell bananas and got Tshs. 60,000/= (US$50), something I have never experienced before this project...*

Another farmer told her story by saying that:

> *...after this project I managed to cultivate some vegetables for home consumption and selling. I no longer buy vegetables and the money I get from selling helps me to pay for minor household needs…*

Another farmer said:

> *…in 2008, I expect to harvest water melons, green peppers, and lablab beans planted in a half-acre plot each. I am doing supplementary irrigation using the water stored in my charco-dam as a result of runoff harvesting...*

The small percentage of the farmers reporting increased productivity and enhanced livelihoods is attributed to the fact that most of the farmers have adopted banana technologies, which need about 12 months to realize the benefits. From their stories, however, the pace at which the improved banana plants are growing gives a glimmer of hope and amazes most of them as they compare to the local varieties. For example one farmer said:

> *…I received six banana suckers in November 2007; they are doing well and have reached a height of 1.5 m and have started to produce suckers at an average of four suckers per plant, and they are doing very well. I am so impressed with the growth of the banana plants…*

Farmers' plans

About 80% of the stories also give some indication of farmers' visions for the future, mostly to do with achieving increased productivity for enhanced livelihoods. Most of the farmers said they planned to continue expanding their current farming areas while practicing improved technologies. For example one farmer said in her story that:

> *…my expectation is to plant 200 banana plants by 2011. I will start with 50 plants in 2008-09, 50 plants in 2009-10, and 100 plants in 2010-11. Achieving this goal will enable my family to get enough food and surplus for improving its income…*

Enhanced social network

About 79% of the farmers have reported enhanced social networks in their village. Self-led institutionalization was experienced whereby farmers in the study villages have organized themselves and started farmer learning groups (FLGs) and farmer field schools (FFSs) to ensure continuity in sharing the knowledge they gained from the project. For example, in Malindi the farmers organized themselves and formed a group known as 'Kikundi cha Migomba Malindi' (KIMIMA) which means 'Malindi Banana Group.' One farmer said:

> *…I have made an effort to change my farming practices, which has influenced my neighbors and now we have started a sustainable farmer group (KIMIMA) which is doing well…*

In Mhero village, as a result of field visits to Lushoto, more farmers have joined the existing Saving and Credit Cooperative Society (SACCOS). About 10 farmer learning groups were established as a result of conservation agriculture training. These groups involved more than 130 farmers who meet once every week for experiential learning in the FFSs. Some groups have prepared draft constitutions to acquire legitimacy with the district authorities, and for easy access to credit facilities.

Conclusions and recommendations

Interactive and participatory processes in knowledge sharing and learning used by the project to promote activities have enhanced attitude and behavior change toward conservation farming and increased farmers' enthusiasm to adopt WMSIs that have been there over 50 years. We recommend the experience with interactive and participatory approach in knowledge sharing from this project. It could be used to enhance adoption of improved technologies elsewhere with similar socioeconomic conditions. We also recommend use of significant stories to influence policy and decision-making processes that would influence positive action toward improving the livelihoods of poor farmers.

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Increasing field water productivity of irrigated crops in the Lower Karkheh River Basin

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Abstract

The potential for increased agricultural water resources in Iran is limited, and thus agricultural water productivity must be increased to meet the increasing demand and shrinking supplies. The effects of field management and agronomic practices on water productivity (WP) were studied for irrigated wheat and maize in the Lower Karkheh River Basin (LKRB). The study was conducted during 2006-07 at Safi-Abad Research Station in Dezful, Iran, and in two nearby farmers' fields to determine the potential levels of WP and evaluate methods for its improvement. For wheat, there are two cropping systems of fallow-wheat and maize-wheat in Sorkheh. The treatments in the wheat fields after fallow included: (1) TW1–disking, broadcasting, corrugation irrigation; (2) TW2–raise bed with three crop rows on 60 cm-wide raised bed, i.e. flat top ridges; (3) TW3–furrow flat bed sowing, 12.5 cm row spacing, flood irrigation; and (4) TW4–farmer practice, i.e. disking, seed broadcast, border irrigation. For wheat after maize, treatments were: (1) TW5–use of corn chopper then combined planter; (2) TW6–use of corn chopper then seed broadcasting, disking, corrugation irrigation; (3) TW7–flat bed sowing, 12.5 cm row spacing, flood irrigation + corn residue. For maize, furrow spacing was 75 cm in all cases and the treatments consisted of: (1) TM1–Plant row spacing 75 cm, alternate furrow irrigation; (2) TM2–two plant rows spaced 25 cm on furrow ridge, full furrow irrigation, (3) TM3–single plant row inside furrow, full furrow irrigation; (4) TM4–two plant rows inside each furrow, full furrow irrigation; and (5) TM5–farmers practice: single plant line, full furrow irrigation. Results were promising, indicating that the mean wheat and maize water productivity of, respectively, 1.02 and 0.40 kg/m^3, can be improved to 2.32 and 0.52 kg/m^3 when improved practices were applied. The main causes of reduced productivity at the farmers' fields were excess irrigation and runoff, followed by inadequate management practices.

Media grab

When farmers adopt a set of improved soil and water management practices, higher crop water productivity can be achieved.

Introduction

Iran is situated in the arid and semiarid belt of the world, with an average annual precipitation of about 250 mm, which is less than one-third of the world average. Moreover, 179 mm of the precipitation evaporates, representing 71% of the total precipitation (Dehghanisanij et al., 2006). The agricultural sector is the main water user in the country. The irrigated agricultural area in Iran comprises about 8.4 Mha and presently uses 85.2 BM^3 (92%) of the total water use (92.5 BM^3). Since development of more water resources for the agricultural sector in Iran is limited, agricultural water productivity needs to be increased. The Karkheh River Basin (KRB) is an important agricultural zone, located in southwest Iran. Here, two major agricultural production systems prevail: a rainfed system upstream of the newly built Karkheh Reservoir, and the fully irrigated system downstream of the dam. The river water quality is generally good for agricultural use (EC = 0.9-1.7 dS/m), though it varies both seasonally and along the river. The area is suitable for a wide range of crops, i.e. wheat, maize, alfalfa, and off-season vegetable crops. The total area of KRB is 5.2 million ha (Mha), out of which only 1.07 Mha is irrigable and 0.9 Mha is suitable for dry farming agriculture. Out of the total cultivated area, more than 70% is under cereals (wheat and barley). Water resources in KRB consist of both surface and groundwater, though the basin suffers from water shortage and droughts are becoming a permanent feature of this region. Water productivity (WP) in KRB is also low, not only compared to potential WP, but also to that in other river basins in Iran (Keshavarz and Ashrafi, 2004).

Yields of irrigated wheat range from 4030 to 5510 kg/ha at Sorkheh, a typical (non salt-affected) area in the cropping land of the lower KRB. Wheat water productivity varies between 0.4 to 1.3 kg/m^3. In the same area, irrigated maize yields range from 3383 to 6900 kg/ha, with WP values from 0.19 to 0.68 kg/m^3. Wheat and maize WP seem to vary in different farms depending on the source of irrigation water (well, network, and river). Mean wheat yield was highest for irrigation when water was from a combination of groundwater (wells) and the irrigation network, and it was least when fully irrigated from wells. The mean maize WP irrigated from the network, well, river, and a combination of well and network, was 0.38, 0.46, 0.39, and 0.34 kg/m^3, respectively. Average maize WP in different locations of the country with about the same crop water requirement is 1.3 kg/m^3, and ranges from 0.8 to 2.3 kg/m^3. This suggests that there must be a high potential for increasing WP of irrigated maize in the KRB. The highest mean WP in Sorkheh is reported for the fields irrigated from wells, where farmers could apply the water into the fields as needed. However, the highest WP variation was observed in the fields irrigated from the irrigation network, which could be attributed to the unreliability of supply in relation to demand. The main cause of low water productivity at Sorkeh was runoff.

The farmers' practice for wheat production consists of plowing, disking, seed broadcasting, and border irrigation. Their seeding rate is high for broadcast seeding, which may cause low crop yield. Under border irrigation, water distribution uniformity is low due to non-uniform slope and high deep percolation amount at the field entrance. For maize, the farmers use furrow irrigation and single planting line, many of them inside the furrow. Water losses are high due to runoff and deep percolation.

Higher crop WP can be achieved by: using less water while maintaining production, by increasing production with the same amount of water, increasing yield more than water use (not a solution if there is no additional water), or by reducing water use more than yield (not a solution if food security is important). Indeed, some of the greatest increases in water productivity have been achieved through improved irrigation practices and increased crop yields through the use of better varieties and mineral fertilizers. Dehghanisanij and Moayeri (2008) introduced different challenges and opportunities though evaluation of WP in lower KRB including: modifications in cropping pattern to optimize water use, optimized water consumption through modified planting dates in some irrigation areas to avoid drought effects during ripening, development of land leveling and land consolidation plans, and estimation of appropriate farm sizes and dissemination of raise-bed furrow and alternate furrow irrigation methods to farmers.

The objectives of this paper were to study the effects of field management and agronomic practices on water productivity for the two major irrigated crops, wheat and maize, in the Lower Karkheh River Basin.

Site description

The study was conducted in Sorkheh Plain, a representative irrigated area of LKRB. Sorkheh is located in eastern LKRB, west of Khozestan Province and below the Karkheh Dam. The region has a semiarid climate (De Martonne classification). The temperature and humidity in this region range between 6.7-45.6°C and 27.4-74.5%, respectively. The rainy season usually starts in October and continues until the middle of May, with an average annual rainfall of about 330 mm. The annual potential evaporation in this region is about 2400 mm, ranging between 50 mm/month during December and January and 400 mm/month during June and July. The Sorkheh agricultural area is about 10,000 ha of which about 4100 ha is under a surface canal irrigation network, 5800 ha has well water resources and 460 ha is irrigated by pumping from surface water (rivers). In total, there are 196 wells in this area and 29 pumps for pumping water from rivers. Winter wheat-maize is the main cropping system in this region. Wheat is grown from mid November to mid May. The rainfall does not fully meet the needs of wheat for its normal growth, especially during the dry, windy spring season. Therefore, 3-4 irrigations are needed to maintain high yields. Maize is grown from late July to late October, when the rainfall is almost zero, and is totally dependent on irrigation.

Methods

There are two cropping systems for wheat in Sorkheh: maize-wheat and fallow-wheat. The sowing date in the fields of maize-wheat cropping system has a delay of about 5 weeks compared to that in the fields of fallow-wheat cropping system. The study was conducted for the fallow-wheat cropping system as follows: (TW1) disking, broadcasting, corrugation irrigation (similar to furrow irrigation, but with narrow and shallow furrows formed by shaping the soil surface using corrugators); (TW2) three rows on 60 cm-wide raised bed (i.e. flat top ridges, furrow); (TW3) flat land sowing, 12.5 cm row spacing, flood irrigation; and (TW4) farmers' practice (i.e. disking, seed broadcast, border irrigation). For wheat after maize, treatments were: (TW5) use of corn chopper then combine planter; (TW6) use of corn chopper then seed broadcasting, disking, corrugation irrigation; and (TW7) flat land sowing, 12.5 cm row spacing, flood irrigation + corn residue. The farmer system (control) for both cropping systems was border irrigation with broadcast seeding and disking. Wheat was sown at 165 kg/ha (the range used by farmers at Sorkheh is 150-350 kg/ha).

For maize, four field management systems were compared with traditional practice (control) at Sorkheh, in farmers' fields. The treatments were all irrigated by furrows spaced at 75 cm and consisted of: (TM1) plant row spacing 75 cm, alternate furrow irrigation; (TM2) two plant rows spaced 25 cm on the furrow ridge, full furrow irrigation; (TM3) single plant row inside the furrow, full furrow irrigation; (TM4) two plant rows inside each furrow, full furrow irrigation; and (TM5) farmers' practice (control): single plant line, full furrow irrigation. All the furrows were 130 m long. Maize plant density ranges from 45,000 to 100,000/ha in Sorkheh. We applied a seeding rate of 75,000 seeds/ha for maize, as recommended by local extension.

Each treatment was conducted in three replications in full-sized fields (130 m long) where they received the same amount of applied irrigation water. The in-flow and out-flow was measured using a calibrated cut-throat flume. Analysis of variance (ANOVA) was used to compare treatment effects on yield and water productivity.

Data collection included: soil characteristics, soil fertility analysis, water quality (salinity), land slope, size of fields, irrigation amount and runoff, number of irrigation events, crop varieties, cropping calendar (time of planting, harvest, etc.), crop yields (by sampling from 1×1 m^2 area), tillage and cultivation practices, crop growth stages, timing and amount of inputs including fertilizers and pesticides, seeding rate, and climate parameters to estimate crop water requirement.

In agricultural production systems, crop water productivity (WP) accounts for crop production per unit amount of water used (Molden, 1997). The numerator can be expressed in terms of crop yield (kg/ha), or in monetary units (i.e. $/ha). A number of options are available for the type of water use in the denominator (e.g. transpiration, evapotranspiration (ETc), irrigation water (irrigation), input water (irrigation and effective rainfall), and water diverted, water beneficially consumed, and water beneficially and nonbeneficially consumed). We used the following definitions of crop WP (Dehghanisanij et al., 2008);

$$\text{WP (kg/m}^3\text{)} = \frac{Ya}{I + Re} \qquad (1)$$

where WP is based on the irrigation water (I) plus effective rainfall (Re) (Doorenbos and Pruitt, 1977) and Ya is the marketable part of the total aboveground biomass production (i.e. grain yield for wheat and maize).

Results and discussion

For wheat after fallow and after maize, the farmer practice yielded WP values of 1.11 and 1.12 (TW4 & TW7 in Table 1). This was improved to a mean WP value of 1.46 kg/m^3 in fields with improved practices with a range of 1.17 to 1.84 kg/m^3 (Table 1). In the improved practices, there were significant differences between the wheat yields after fallow and after maize. On average the mean wheat yield was higher in fields after fallow than in fields after maize. The amount of water input (irrigation plus rain), however, was always less in fields after maize compared to those after fallow, mainly because of the shorter wheat growth period after maize. Accordingly, wheat WP was higher after maize than after fallow. The wheat WP was significantly higher in TW5 (1.84 kg/m^3) than all other treatments. After fallow, TW1 and TW3 had a similar and small impact on wheat WP in comparison with the control. Both were lower compared to the full furrow irrigation, however, with the raised-bed system and sowing using the local furrower (Hamadani Barzegar type).

Table 1. Irrigation (I+Re), yield, and water productivity in wheat fields under different treatments.

Treatments*	Irrigation water applied (m^3/ha)	Yield (kg/ha)	Water productivity (kg/ha)
After fallow			
TW1	4820	6466[b]	1.34[ce]
TW2	4880	7134[a]	1.46[b]
TW3	5000	5836[d]	1.17[e]
TW4 (control)	4921	5124[e]	1.12[e]
After maize			
TW5	3470	6369[c]	1.84[a]
TW6	4390	6480[b]	1.48[b]
TW7 (control)	4377	4694[f]	1.11[e]

*(TW1) disking, broadcasting, corrugation irrigation; (TW2) three rows on 60cm-wide raised bed i.e. flat top ridges, furrow; (TW3) flat land sowing, 12.5 cm row spacing, flood irrigation; (TW5) use of corn chopper then combine planter; (TW6) use of corn chopper then seed broadcasting, disking, corrugation irrigation.

Irrigation water applied in all maize improvement treatments was less than in the control (Table 2). The significantly lower irrigation amount for the furrow bed system with a single planting row (TM3) compare to that for double planting row could be attributed to the furrow bed system and higher water advance rate in furrow with a single planting row. Maize grain yield in the furrow bed system (TM3) was significantly lower than in all other treatments. The highest maize grain yield was measured in TM4, but irrigation application was also highest in TM4. As a result, maize WP was similar in TM4 and the control, and significantly lower than in all other treatments. Maize water productivity in TM2 was 0.58 kg/m^3, significantly higher than in all other improvement treatments. Even then, maize WP was still very low compared to the average country level of about 1.3 kg/m^3.

Table 2. Irrigation, yield, and water productivity in maize fields under different treatments.

Treatments*	Irrigation (m^3/ha)	Grain yield (kg/ha)	Water productivity (kg/ha)
TM1	11620	6361[b]	0.55[b]
TM2	10920	6367[b]	0.58[a]
TM3	9760	5283[d]	0.54[b]
TM4	13360	6514[a]	0.49[c]
TM5 (control)	14360	6118[c]	0.49[c]

*(TM1) Plant row spacing 75cm, alternate furrow irrigation; (TM2) two plant rows spaced 25 cm on the furrow ridge, full furrow irrigation; (TM3) single plant row inside the furrow, full furrow irrigation; (TM4) two plant rows inside each furrow, full furrow irrigation.

Conclusions

In the Karkheh River Basin, low irrigation water productivity is one of the main issues in agricultural production, mainly due to poor field water management and agronomic practices. The recommended wheat seeding rate is less than that applied by farmers, but was associated with higher yields in combination with improved sowing and irrigation management. Wheat WP was almost the same in both control fields for the fallow-wheat and maize-wheat cropping system. The improvement treatments for maize-wheat cropping system (TW5) use of corn chopper then combine planter and (TW6) use of corn chopper then seed broadcasting, disking, corrugation irrigation, improved wheat WP compared to the improvement treatments for the fallow-wheat cropping system. The sowing date in the fields of maize-wheat cropping system was the main factor in reducing irrigation amount and increasing WP compared to that in the fields of fallow-wheat cropping system, without a significant decrease in yield. The mean wheat WP was improved by 43% due to management practices. The mean maize water productivity was improved by up to 20% by improved field management systems, especially by raised beds with 75 cm bed width and full furrow irrigation. Results indicated that the mean wheat and maize water productivities of traditional practice were 1.02 and 0.40 kg/m^3, which were subsequently increased to 2.32 and 0.52 kg/m^3 when improved practices were applied at the farms.

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Impact of metering agricultural power supply on groundwater users and market in West Bengal, India

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Abstract

West Bengal, in the eastern Indo-Gangetic Basin, has abundant groundwater resources, but their use is limited due to the poor economic status of the farmers and the small and fragmented landholding pattern. In this region, informal groundwater markets are very common, whereby nonowners of pumps buy water from the pump owners. One of the main reasons for the proliferation of groundwater markets has been the high flat rate electricity tariff that gave an incentive to pump owners to sell groundwater. As part of the larger power sector reforms underway in India, however, the State of West Bengal is metering all agricultural tubewells. This study aims to capture the impact of metering on different stakeholders. Based on primary data, the results show that pump owners are likely to be winners by being able to earn higher profit from selling water, while the water buyers will lose out. Under Time of Day (TOD) metering at the current tariff rates, the government will earn less revenue than with the flat rate system, though it may ultimately gain by reducing the transmission and distribution (T&D) loss and commercial losses. The exact impact of transition from a high flat tariff regime to the TOD system on the volume of water pumped and the size of the water markets is difficult to predict, and further research is needed. Set in a broader context, this paper sheds new light on marginal cost pricing of groundwater (through metering of electricity consumption) and the way it affects water users.

Media grab

The introduction of meters for agricultural water use will only benefit the wealthier water sellers, at the cost of poorer water buyers, in regions of abundant groundwater in West Bengal, India.

Introduction

Around 60% of the irrigated land in India is under groundwater irrigation due to the unreliability of other sources (Deb Roy and Shah, 2003). A major boom in groundwater irrigation started in the mid 1970s to early 1980s when the flat tariff system (based on pump capacity (horsepower)) replaced the prevailing metered electricity supply for agriculture. The flat tariff was introduced to avoid the high transaction costs of metering, but over time, the State Electricity Boards (SEBs) found it very difficult to increase the flat tariffs in spite of financial loss, for various political reasons (Shah, et al., 2007). Under pressure from international donor agencies to reform the power sector, and also realizing the gravity of the situation, the Government of India (GOI) promulgated the Electricity Act of 2003 to improve the economic viability of SEBs through partial financial assistance from the Asian Development Bank (ADB) and the Power Finance Corporation of GOI. SEBs were unbundled, and converted into profit-making companies under the surveillance of different State Electricity Regulatory Committees (SERC), through the initiative of 100% metering for all categories of consumers, rationalization of tariffs, total rural electrification, etc. (ADB, 2002). West Bengal was one of the first states to adopt the principle of universal metering.

West Bengal, an eastern Indian state, has very high groundwater potential of which only 42% has been utilized so far. In 2000, there were 60,367 shallow tubewells (STWs), 5139 deep tubewells (DTWs) and 7392 river lift irrigation pumps (RLIs) operational in the irrigation sector (WIDD, 2004). As far as electricity is concerned, West Bengal is one of the few states in India with the capability of producing surplus energy, around 4500 MW per year (IBEF, 2005). In spite of these favorable conditions, West Bengal farmers pay the highest flat electricity tariff in India (Mukherji, 2007a). Though 98% rural electrification has been achieved (Finance Department, 2007, only 18.5% of the tubewells were connected to the electricity supply system (WIDD, 2004; WBSEB, 2007) due to the lengthy and expensive process of permits imposed by the State Water Investigation Directorate (SWID).

The new TOD metering technology adopted by the state of West Bengal is different in many ways from the previous meter system in India. Tamper proof TOD meters (with optical load sensors) have been installed to minimize theft. The TOD system is basically a tool for demand–side management where certain sections of consumers are discouraged (by higher pricing) to use energy in evening peak hours when there is huge demand from other sectors. The meters have been devised with three sectors activated rotationally in three distinctly different time slabs for agricultural pump sets:

- 0600–1700 (Normal daytime, 'N'), @ Rs 1.37/kWh (1 USD ~ Rs. 42).
- 1700–2300 (Evening peak hours, 'P'), @ Rs. 4.75/kWh.
- 2300–0600 (Off-peak hours, 'O'), @ Rs 0.75/kWh.

Through a sophisticated meter reading instrument (MRI), data are captured and transferred to a zonal/circle computer for bill generation. For the collection of meter readings, local self help groups (SHGs) have been recruited (Vidyut Baarta, 2007). The whole system is under the surveillance of GSM and GIS technology and scope for meter tampering, and foul play is almost negligible.

The objective of our study is to present a first cut analysis of: (1) the impact of the introduction of the TOD metering system on the pump owners who are also water sellers, water buyers, and groundwater markets; (2) identifying the winners and losers with the new metering system; and (3) how metering will affect the functioning of groundwater markets.

Methods

Surveys were undertaken in 14 villages from five districts in 2006-07 (Figure 1). The number of respondents was 156 out of which 114 were pump owners and 42 were water buyers. Of the 114 pump owners, 104 electric water-extraction mechanism (WEM) owners (82 with submersible and 22 with centrifugal pumps) were surveyed.

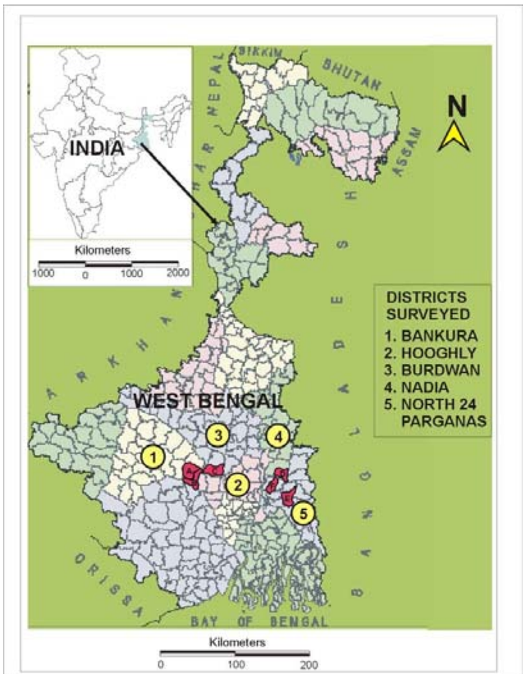

Figure 1. Location map of the study blocks in West Bengal.

Results

Winners and losers in meter system

Pump owners

The flat tariff rate in West Bengal for a 5 HP pump was Rs 8,800/year for centrifugal pumps and Rs 10,800/year for submersible pumps; 60% of total hours of pump operation was done during 'normal' day time, 10% in the evening 'peak' hours, and 30% in 'off-peak' hours for irrigating the land of the pump owners and for selling water to others. A 5 HP pump consumes 3.73 KwH in 1 hour (@0.746 kWh/HP). Based on these figures, the average cost of power consumption per hour of pumping of a 5 HP pump can was calculated to be Rs.5.68/h ((0.60 hr x 3.73 units x Rs.1.37) + (0.10 hr x 3.73 units x Rs 4.75) + (0.30 x 3.73 units x Rs 0.75)).

'Breakeven point analysis' was done to find out the gain/loss of different stakeholders. The term can be described as the optimum annual pumping hours at which the energy charge in the existing flat tariff will be equal to the metered tariff rate under the TOD system. Break-even points for submersible and centrifugal pumps are 1800 hours and 1500 hours, respectively. We found that among the 82 submersible pump owners only 24 were pumping for more than 1800 hours annually, which implies that 70% (54 out of 82) submersible pump owners will gain by having to pay a lower electricity bill than before under the existing meter tariff (average benefit of Rs 2800/tubewell/year) (Figure 2a). In the case of centrifugal pump owners, all will gain under the existing meter system by an average of Rs

4600/tubewell/year (by virtue of having to pay a lower electricity bill than under the previous flat rate tariff) (Figure 2b).

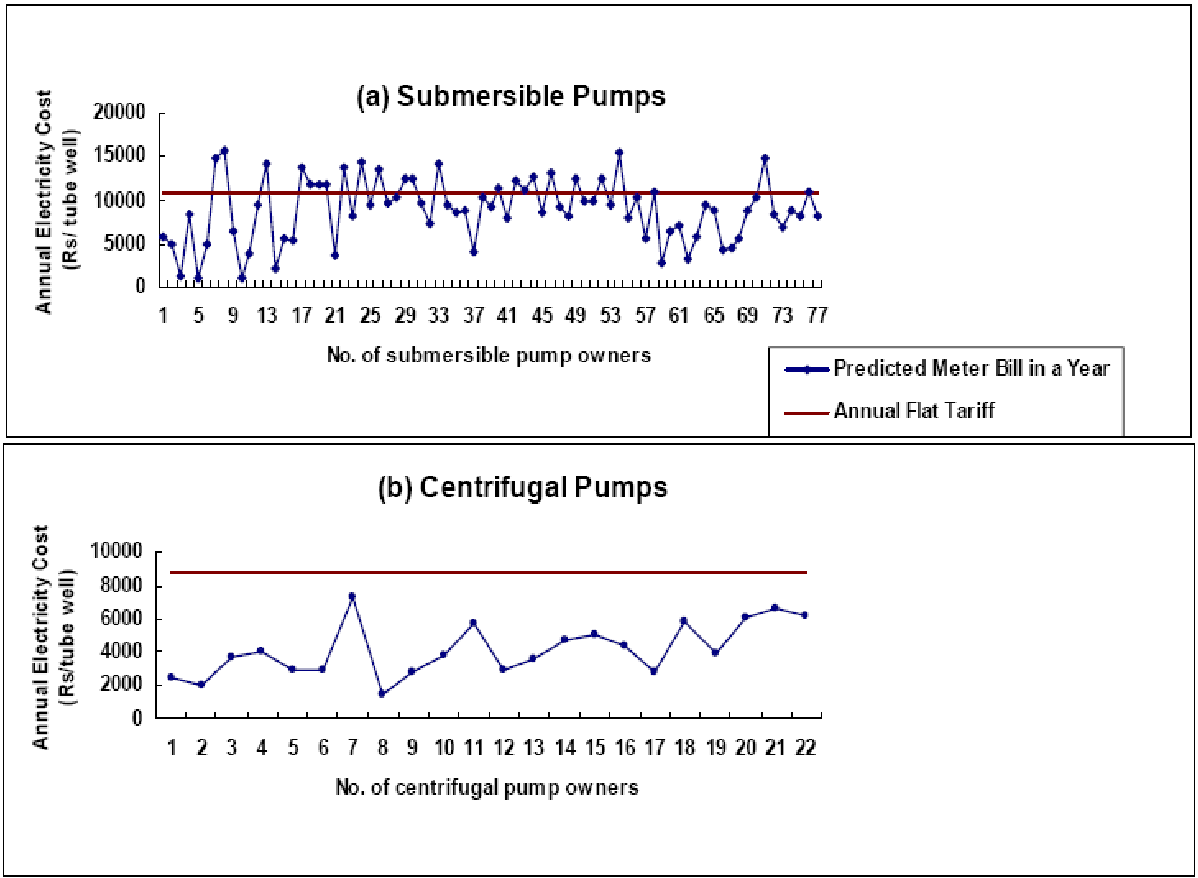

Figure 2. Comparative study on the possible electricity cost in flat tariff and metered tariff systems.

Water buyers
As in the newly introduced TOD system of metering, the pump owners no longer need to sell water, and the buyers are at the mercy of the pump owners. Water buyers lose out under the new metered tariff regimes if: (1) the price at which they buy water goes up in response to metering; (2) water sellers show unwillingness to sell water due to changed incentive structure under metered tariff, and instead force the buyers to lease out their lands to the water sellers; and (3) other terms and conditions of water sale become unattractive for the buyers (e.g. if the sellers ask for advance payments, or refuse to give water at desired times). All of these have happened in response to metering and hence the buyers, who are mostly small and marginal farmers, have lost out under the metering system (Mukherji et al., 2008)

Impact on groundwater market
What will be the condition of groundwater market transactions as result of metering of electricity supply? This can only be answered definitively once the metered tariff system is introduced everywhere, and pumping and water selling behaviors are studied and compared with their behavior under the flat tariff system. In the absence of such data, we can only hypothesize on the impacts of metering on the size of the water markets. Based on our survey, the average price at which water was sold (averaged over all seasons within one year) was Rs 18/hour. Motivation of the pump owners plays an important role in influencing the market size, with various considerations such as:

- The pump owners may be motivated by increased profit margins under the metered tariff, and keep selling water as long as they get additional water buyers. Under this scenario, water markets would expand.
- Pump owners who just recover their annual energy expenses through selling water, in the flat rate system, may have the same tendency in the metered tariff system. In that case water markets might contract, expand, or remain unchanged (Table 1).
- Similarly, if pump owners would like to maintain the same amount of profit as they were making under flat tariff system then again water markets might contract or expand (Table 2).

It should be noted that the expansion or contraction of water markets will not influence hours used for self irrigation and the average price of selling irrigation.

Table 1. The transition of the water market based on the motivation of recovering the energy charge in flat and meter tariff systems.

Cases	Hours of operation of a submersible pump under flat rate tariff		Hours at which flat rate is recovered	Hours at which meter rate is recovered	Expansion, contraction or no change in hours of water sold after metering
	For self use (A)	For selling (B)			
Case 1	900	600	1500	1350	Contraction by 150 hours
Case 2	1200	600	1800	1800	No change in water market
Case 3	1500	600	2100	2150	Expansion by 50 hours
Case 4	0	600	600	Any positive value	Indefinite*

*This will not happen in real field because the pump owners with no landholding indicate that they have installed the pump for profit making.

Table 2. The transition of the water market based on the motivation of keeping the same profit margin in flat and meter tariff systems.

Cases	Hours of operation of a submersible pump under flat rate tariff			Profit making hour in flat rate [(B-600)]	Hours of pumping in metered tariff for making same profit as under flat tariff	Expansion, contraction or no change in hours of water sold after metering
	For self use (A)	For selling (B)	Total (C)			
Case 1	900	600	1500	0	1350	Contraction by 150 hours
Case 2	0	1500	1500	900	1350	Contraction by 150 hours
Case 3	700	1400	2100	800	1550	Expansion by 750 hours
Case 4	0	2100	2100	1500	2250	Expansion by 150 hours

Discussion

The above study was carried out at a critical time when, like other states in India, West Bengal has been in the process of shifting from a long-serving flat tariff-based power supply to a metered electricity supply. In accordance with the National Electricity Policy, the agriculture sector has top priority in this regard. The highest flat tariff for agricultural power consumption in West Bengal induces the agri-tubewell (electrified) owners for 'pro-active' water selling. Water buyers, on the other hand, are in the advantageous position of being able to purchase water from tubewell owners who have no alternatives but to sell water. This is again attributable to small farm size of the tubewell owners, with no scope to compensate for the amount of the annual flat tariff payable to the government. In the newly introduced TOD metering system, it appears that most of the tubewell owners are going to benefit as their average annual hours of pump operation is less than the break-even time (1900 hours for submersible pumps and 1500 hours for centrifugal pumps). Marginal (< 1 ha) and small (1-2 ha) farmers who own tubewells will be the main beneficiaries of the metered agricultural electricity supply system, if they continue to operate pumps for the same duration as under unmetered supply. Moreover, if the water price for selling water in the unmetered supply system is maintained in the metered tariff system, most of the tubewell owners can still be predicted as gainers. The situation of water buyers is indeterminate if the electricity price remains unchanged. They will be losers if the water charge by tubewell owners is increased.

Conclusions and recommendations

It can therefore be concluded that the majority of pump owners will gain under the metering system through: (a) same hours of pumping but lower electricity bill; (b) same hours of selling water but higher profit; and (c) electricity bill paid only on actual energy consumption. For the water buyers the situation will be different. Since the high bargaining power they enjoyed under a high flat rate tariff will be eroded under a metered system, they will face adverse terms of exchange and higher water prices. Overall they will be at the mercy of the pump owners. There are also some complexities in the TOD system which in turn favor the pump owners to increase their water price. Lack of awareness is playing an important role in this respect. Impact on the size of the groundwater market and the total volume of groundwater extracted is indeterminate at this time, and will depend on the motivation of the pump owner, that is, whether or not he wants to increase his income from selling water, just wants to recover the electricity costs without bothering to make extra income, or wants to maintain the same profit as under the flat tariff system. As the majority of pump owners have to pay a lower electricity bill under the meter system, the electricity board will lose out in terms of revenues but may gain by reducing T&D losses. The worst affected group seems to be the water buyers, who also happen to be poorer farmers than pump owners. If there is a contraction of the water market, the availability of irrigation water will be reduced and their fate will be in the hands of the pump owners. To help them cope with the situation, the following steps can be taken:

- Make it easier for nonpump owners to invest in tubewells through withdrawal of stringent SWID certification requirements.
- Give a capital cost subsidy for installation of tubewells especially to the small farmers. Both these measures will increase competitiveness in groundwater markets by adding more sellers and might help in bringing down water prices.

- Seek involvement of local village level government structure (panchayats) in putting a ceiling on maximum water price such that water sellers cannot charge inappropriately high charges (Mukherji, 2007b; Rawal, 2002).
- Awareness should be created among the farmers regarding the different aspects of the TOD metering system.

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