Rainwater management for resilient livelihoods in Ethiopia

Proceedings of the Nile Basin Development Challenge science meeting, 9–10 July 2013

Nile BDC Technical Report–5

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Editor: Wolde Mekuria

Contents

Foreword

The Nile Basin Development Challenge (NBDC) is in its final year. Over the last six months, we have been reviewing and pulling together all of the various strands of this research for development program to identify the key messages coming from the work.

This science workshop was convened in July 2013 as a key element in the consolidation process. The workshop set out to examine and review the evidence base that has been built to which support or question the key messages emerging so far.

The results of this review of the evidence base are captured in this technical report. They will be further used to identify research and development gaps and opportunities as well as mechanism to inform the future development of rainwater management strategies in Ethiopia.

Our appreciation goes to all the authors and co-authors of contributions in this report; we particularly acknowledge the excellent efforts of Wolde Mekuria who collated and edited the contributions. Our thanks also to Meron Mulatu and Tesfaye Jemaneh who completed the report for dissemination.

Simon Langan and Alan Duncan

Introduction

The Nile Basin Development Challenge (NBDC) is funded by the CGIAR Challenge Program on Water and Food (CPWF) to improve the resilience of rural livelihoods in the Ethiopian highlands through a landscape (watershed) approach to rainwater management (RWM).

If this development Challenge is successfully met, best practices for rainwater management will be developed and implemented at landscape scales across agro-ecosystems in the Ethiopian Highlands. These will minimize unproductive water losses, soil erosion and nutrient mining across landscapes. Appropriate rainwater harvesting technologies will be deployed, maintained and monitored. Small-scale irrigation techniques would allow farmers to efficiently irrigate their crops and forages. The management system will enable farmers to exploit rainwater for multiple uses, including livestock and fisheries. And overall landscape water productivity will improve. There will be policy adjustments which yield greater focus on rainwater management in the Blue Nile Basin. The system will integrate the needs and decisions of local (formal and communal) institutions, which will in turn work to implement and maintain it. The success of the projects, and the lessons learned will prompt its uptake by government and development agencies leading to the widespread implementation of the system across the Nile River Basin.

Further, the NBDC will provide planning and management tools for efficient use of water resources that would benefit policy makers, farmers, water managers, irrigation planners and development and extension authorities. It will facilitate cross-basin learning and generate new knowledge for Ethiopia, the basin and the global research community at large.

This report comprises the presentations and posters prepared for the NBDC Science Workshop held in Addis Ababa from 9-10 July 2013. Its objectives were:

• To bring together scientists working on NBDC projects, including all research partners,;

• To exchange and share their experiences and research results on all aspects of RWM in the Nile basin;

• To discuss the practical challenges encountered and the solutions adopted.

More information and all the presentations and posters from the workshop are online at: http://nilebdc.org.

Overview of rainwater and sustainable land management

The Nile Basin Development Challenge: Methods, outputs and outcomes

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Introduction

The Nile Basin Development Challenge (NBDC) is one of six global focal basins of the Challenge Program on Water and Food (CPWF). The overall objective of the CPWF program is to increase water productivity and resilience of social and ecological systems, through broad partnerships and research that leads to local impact and wider change. Within this framework, the NBDC has set out to improve and build on rainwater management strategies as a way to improve livelihoods and reduce poverty. The focus of the work has been on the Blue Nile where rainfed agriculture dominates and over 80% of the population relies on subsistence, rainfed agriculture. In contrast, the downstream countries, principally Egypt and Sudan, are dominated by large-scale irrigated agriculture. However they will also potentially benefit from improvements in rainwater management upstream through reductions in land degradation and associated soil erosion which when transported downstream reduces the efficacy of irrigation schemes.

To meet the Nile Basin Development Challenge, it was found necessary to adopt an outcome logic model in which a range of approaches have been used to generate outputs and outcomes to support policy development and enhance best practices in relation to selected land management. These are briefly presented in summary here with subsequent papers in the proceedings developing the issues in greater a depth.

Methods

The approach to the NBDC has been to develop work in three dimensions, social, economic and technical, which when put together will give an overall set of integrated outputs and outcomes. To realize the broad CPWF aims, work was conducted at multiple scales: Households, communities and catchments and the Blue Nile Basin as a whole. Importantly, the project was undertaken in partnership with a range of organizations, universities, regional researchers and NGOs.

Some examples of the methods used in the different disciplines across scales are:

In our sentinel sites (see Figure 1), the project established biophysical monitoring which has involved 'state of the art' technical equipment to measure meteorology, soil–water, groundwater and stream heights. At the same time, the project used farmer and community participation to measure rainfall, river flows and water samples for water quality analysis. Together these data provide primary data to understand water fluxes and stores in detail at a high spatial and temporal resolution. To further understand and engage with communities, we have established, within the same

communities, 'innovation platforms'. These IPs and the processes they involve are designed to ensure full participation and ownership in terms of recognizing issues and potential solutions relating to natural resource management. The process is designed to maximize both indigenous knowledge and the necessary supplementary technical input to bring about change in knowledge, attitude and skills amongst the communities and their advisors. To assess this, the project also collected extensive information on economics, institutional set ups and livelihood strategies. Some of the process methods used in the IPs involved: training members of the community to use audiovisual equipment and then recording of events they see and face in the landscape and also recording of digital stories through use of still photography to test and develop some scenarios for the future; we have used role playing simulation type games called Happy Strategies Wat a Game.
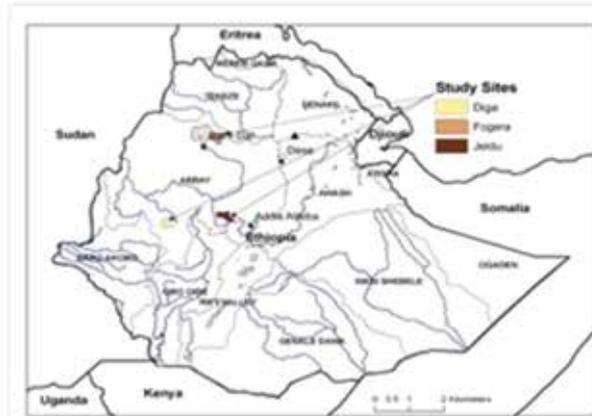
Figure 1.The Blue Nile and the three sentinel site setting.

At a wider regional and basin scale, greater emphasis was given to use of GIS and mathematical models. These tools allow some of the work undertaken at the smaller scale to be scaled out to wider areas to examine the consequences of changes in practice for rainwater management strategies. Finally, at the national scale, the NBDC established a high level think tank or national innovation platform composed of stakeholders from a range of backgrounds and skills. This national IP has been set up to disseminate and consider how best to develop the findings coming out of the work.

Outputs

From this growing body of work, we have developed a range of outputs including formal type publications submitted to the research literature, briefing notes on the various activities undertaken and technical reports and numerous Masters theses. Other outputs are the less formal ones such as field visits, technical meetings and workshops (some of which have minutes and proceedings. Other descriptions can be viewed and contributed through the project web pages and wiki (http://nilebdc.wikispaces.com/).

Outcomes

Central to the work of the CPWF and NBDC is to take all of these outputs and transfer them into evidence-based outcomes aimed at transforming the livelihoods of vulnerable communities practising rainfed farming in the Blue Nile Basin. At the same time, such improvements should lead to a more sustainable use of natural resources which in turn should have positive impact on downstream users. At the current stage, the messages we are developing are built around a core concept of an emerging New Integrated Watershed Rainwater Management Paradigm, the elements of which, are:

1.   Local community empowerment and leadership based on demand, equity and inclusiveness;

2.   Partnerships integrating and sharing local and scientific knowledge;

3.   Emphasis on learning process by all parties in a linked manner;

4.   Creating incentives and risk management mechanisms for innovation and success;

5.   Transforming institutional and human capacities of all stakeholders; and

6.   Adapting and using new learning and planning tools.

These elements are highly integrated and success is more likely if all the elements in policies and implementation strategies are included. A landscape or watershed perspective is central to the new RWM paradigm. We believe that the critical innovations justifying our use of the term 'new' emerging from NBDC are:

7.   Integration of the core elements of a new integrated RWM paradigm at watershed level and

8.   Development of tools and methodologies for effective planning, learning and implementation emerging from NBDC.

Therefore, the proposed new paradigm shall not replace existing programs and strategies. Rather, it offers a clear pathway to achieving ambitious conservation as well as livelihood and production outcomes that Ethiopia may otherwise not achieve.

The target audience for these integrated core messages includes senior Ethiopian policymakers and leaders of implementation at federal and regional levels, senior officials at zone, *woreda* and *kebele* levels and Ethiopia's development partners (i.e. donors and international finance institutions). In addition, researchers, NGOs and other stakeholders will also find the messages useful. For effective implementation of the new RWM paradigm, we will develop additional specific technical messages for local level stakeholders, researchers, trainers and technical support staff.

Over the coming six months to the close of the program, we will work on further developing and refining these messages together with developing an indication of the strength of the evidence that underpins them.

Is research for development a good investment? Reflections on lessons from the NBDC

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Abstract: 'Integrated Research for Development' has been promoted as an approach to research and development in natural resources management that is most likely to lead to positive impacts. It has various acronyms, e.g. 'INRM' and 'R4D.' It was the underlying theory of the SSA Challenge Program, managed by FARA and implemented by CGIAR centres and African partners. R4D was a basis for the first phase of CPWF, though in a rudimentary form. It was adopted as the theoretical basis for CPWF phase II. All six basin challenges are based on R4D, including NBDC. All six BDCs promise significant outcomes leading ultimately to poverty reduction and environmental conservation through application of R4D. It is time for a critical review of the lessons learned from the investments in R4D, particularly as it is being adopted as the underlying theory of the new CGIAR Research Programs. This paper is an early contribution to this review. It examines the premises, promises and actual achievements to the extent possible, using the NBDC as a case study. It identifies critical lessons that should inform future R4D programs. The author draws on nearly 35 years of experience in applied water management research, including the CPWF from its early phase and what he has learned from his engagement with the NBDC, including recent work contributing to the NBDC Institutional History (future versions of this paper may include other co-authors, but the present version represents only the author's views). The paper briefly examines the roots of R4D in earlier incarnations of 'action research' and identifies what is 'new': the wide range of diverse partnerships involved in the research. In NBDC and most likely the other BDCs, such diversity brings important challenges that have only partially been solved, as well as new opportunities that have only partially been realized. Future R4D programs will be good investments only under certain conditions. These include effective partnerships; strong commitment from the demand side institutions, including their empowerment *vis-à-vis* the researchers; long-term commitment by funding agencies with periodic reviews to guide the direction of the program; strong links to existing development investment programs; and an excellent science foundation.

Media grab: R4D has a huge potential but this has yet to be realized.

Introduction

Funding for the centres supported by the CGIAR is almost entirely from the development budgets of donors. Donors therefore can reasonably ask for evidence that the research they support is leading to measurable and significant development outcomes. This was relatively easy for the older centres producing improved varieties of commodity crops. However, over time the CGIAR has incorporated more natural resource research centres, focusing on water, forests and aquatic systems. In addition, other centres have also branched out to include significant research on

natural resource systems. These centres have traditionally found it more difficult to demonstrate clear developmental outcomes. All of them point to examples of change that over time are likely to lead to positive impacts, but demonstrating the actual impact of their research on complex human and ecological factors is problematic. Everyone agrees that understanding the basic functioning and processes of, for example, agricultural ecosystems is critically important for identifying potential interventions; but this more basic science is a hard sell to development partners.

One solution pursued for several decades is use of research strategies that include either testing the outcomes of specific interventions (often proposed based on research), or studying interventions being implemented by development agencies or communities themselves to understand the underlying processes and outcomes. These research strategies are known by various terms: 'applied research,' 'action research,' 'integrated natural resources management research,' and most recently, 'Research for Development' (R4D). This paper attempts to review selected experiences specifically related to water management, in order to understand what the outcomes have been and what the lessons are for the future. This is important as R4D is the major underlying paradigm of the next phase of CGIAR research on water, land and environment, the 'WLE Program'.

Methods

The paper draws on the author's experience with 'action research' and more generally applied water management research, mostly during his 20 years at IWMI. In addition, it draws on lessons emerging from the CPWF program over the last decade and especially on the lessons emerging from the Nile Basin Development Challenge (NBDC), with which the author has been associated in various roles from the beginning. He is co-author of a paper still under development that is documenting the experiences, perceptions and lessons learned by researchers and other stakeholders involved in NBDC (Merrey et al. 2013).

Results and discussion

R4D has multiple roots, but one of the strongest is in the 'applied research' carried out by anthropologists beginning in the 1930s. This was research aimed at understanding the social and cultural roots of problems of interest to colonial administrators (or the Bureau of Indian Affairs in the USA). Some anthropologists and sociologists took this a step further in the 1950s to carrying out 'action research:' research intended to observe the processes and outcomes from introducing some kind of change in a community. By the mid- to late-1950s, much of this research came under intensive criticism as being 'colonial,' top–down and disempowering. Sociologists later developed what they called 'participatory action research' (PAR) (Whyte et al. 1989). The basic idea was to work with communities to support their own innovations and to use social science to document, share and learn from the processes and outcomes. CGIAR centres also adopted various versions of PAR from the 1980s. IWMI was a pioneer in using PAR techniques to promote improved management of irrigation schemes in Asia through institutional innovations (see Merrey 1997). Of course there was a wide range of applications and variants of PAR in many different fields by this time. The 'innovation platforms' (IPs) under NBDC are a specific application of PAR.

The concepts of PAR and applied research were carried further in the late 1990s by integrating its principles with those of integrated natural resources management and integrated research for development (Sayer and Campbell 2004) and more recently with the concept of 'innovation systems.' This movement basically places PAR within a firm agro-ecology systems perspective and in the case of innovation systems, a broader institutional framework. R4D is therefore an important development because of this broad ecosystems perspective and because it also escapes the confines of social science to become an integrating interdisciplinary paradigm for doing research. R4D was pioneered by the sub-Saharan Africa (SSA) Challenge Program and has now been carried to a more explicitly developed form in the current phase of CPWF (including NBDC specifically).

It is interesting to note that the 'institutional history' study of NBDC has found a wide divergence of views as to what constitutes R4D. The CPWF management considers R4D to include the full participation of all stakeholders, integrating notions of power, relations among people, institutions and partners and how those dynamics evolve; and making research relevant by transforming its focus to contributing to real development outcomes. This reflects this author's understanding of R4D as well. Based on our interviews, NBDC researchers largely hold narrower concepts: research that somehow will in future be relevant to development; though some mentioned elements such as 'research into action' (Merrey et al. 2013).

Consistent with the other basins, NBDC adopted a specific ambitious goal or 'development challenge,[1] and went through a consultative process to refine this challenge, develop a 'theory of change' that sets out a possible roadmap to use research to address the challenge, identified specific partners and designed the research projects. It has placed strong emphasis on partnerships, communication, consultation and learning from experience; and used a host of media and methodologies to achieve its goals. The 'institutional history' exercise currently underway is an attempt to document the program's implementation processes and how it has changed and adapted over time as lessons have been learned. This paper does not attempt to replicate the many insights emerging from that study. Rather, it draws on this and other personal experiences to offer a few observations and to suggest some lessons learned as a basis for offering conclusions and recommendations for the future.

First, NBDC (and the CPWF in general) have raised expectations to a degree that may have been counter-productive. The goals and objectives were over-ambitious given the limited time and resources; this may have led to some disappointment at not achieving these, as revealed in the interviews for the institutional history. This disappointment has probably obscured the real positive outputs and outcomes achieved and the strong foundation for future work. Three years and about USD 1.3 million/year, especially given international researcher costs, are completely inadequate to develop and test innovations, validate them and achieve impacts in terms of uptake: changes in attitudes, knowledge and behaviour as anticipated in the NBDC theory of change.[2]

Second, it is clear that NBDC has been only partially successful in getting the full buy-in and shared understanding of the many researchers involved in the program, most of whom come from more traditional science backgrounds. The interviews make it clear that while some have fully bought in (usually those with a social science background), others worry that it dilutes the science quality. In principle, quality science is critical to the credibility and therefore success of R4D; there ought not to be any such tradeoff, but perhaps this aspect was not as well managed as it might have been.

Third, NBDC has been insufficiently demand-driven despite efforts to consult and involve stakeholders. This has two dimensions: a) NBDC was not well-integrated with existing SLM/RWM[3] investment programs. This seems to have been a missed opportunity to directly influence large on-going investments. b) Further, NBDC has been driven by international researchers who indeed have reached out to the 'consumers' and national researchers and tried to accommodate their interests—but it is still externally driven. There is a dilemma here. Would the consumers—SLM program managers— have asked for R4D as understood by the CPWF? Or would they have preferred more traditional research, for example, testing physical innovations? Researchers come with their own ideas about innovations and needs, while implementers are understandably driven by practical short-term needs. There needs to be a balance: researchers have an important role in driving innovative projects; they also need to ensure that their ideas are well-integrated with local expectations. There is no easy answer to this; but it is important to note that recently demand has been expressed for establishing a continuing program to promote innovation and capacity building.

A possible way forward, partially reflected in the IPs, is to design the program in a way that empowers the clients to identify and implement possible innovations, with the researchers acting as consultants, coaches and process documenters. The IPs are based on this approach at the local level. The gap appears to be that higher level officials have not been directly engaged in the same process: identifying and testing possible innovations themselves, facilitated

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1. It is to 'improve the resilience of rural livelihoods in the Ethiopian highlands through a landscape approach to rainwater management.'

2. Sayer and Campbell 2004 point out that a long-term commitment to the manager-researcher partnership and full engagement of the researchers are critical to successful R4D.

3. Sustainable land management; rainwater management.

by the researchers. IWMI in the past tried this approach, for example, in Pakistan (water users associations) and in Sri Lanka (institutional arrangements for management of major schemes). The results were mixed but broadly and demonstrably positive, especially in the case of Sri Lanka.[4]

This direct involvement of researchers, playing activist roles as coaches, consultants and facilitators, challenges widely held notions regarding the appropriate role of researchers. Traditionally, researchers believe they should remain objective observers and measurers of phenomena, but should not become embedded in the system under study. This is an epistemological issue beyond the scope of this paper: we recognize the issue, acknowledge its importance and accept that researchers playing activist roles could make future replication of innovations at scale problematic. Nevertheless, the value of the mutual learning process may over-ride this problem at least in the early stages of system innovation processes.

Finally, NBDC has included a much wider and more diverse set of partners than is traditionally found in research projects. The list of international, regional, national and local partners involved in some way in the NBDC program is quite long. Many do indeed play important roles, even if some are more active than others. This has certainly added value, by bringing new perspectives through inclusion of stakeholders previously excluded from SLM applied research. Diversity can promote innovation through creative interactions and generating new perspectives, as well as opening new pathways to implementation. But diversity also has to be managed and space must be created to fully understand and benefit from these new perspectives. NBDC sought to achieve this by using platforms such as IPs, the national SLM platform, periodic stakeholder workshops and the program steering committee. Whether NBDC has found the right formula for maximizing the advantages of including a larger number of partners with diverse interests remains an open question.

Recommendations

Based on this brief review, we offer four recommendations. These are: 1) effective partnerships including empowered demand-side institutions; 2) strong linkages to existing development investment programs; 3) long-term commitment by funding agencies as well as scientists; and 4) a foundation in excellent science.

NBDC has developed partnerships with a variety of institutions and as far as we know, the partners value this relationship. 'Effective' can mean many things, but for R4D we highlight two specific characteristics. First, there needs to be a strong commitment from the demand side institutions; second, this commitment must include their empowerment *vis-à-vis* the researchers. This means the partners must have a strong voice from the earliest stages in designing research programs. In the end they must have an equal voice with the research institutions. Therefore it is critical to invest time and effort in dialogue and establishing and documenting shared understandings, responsibilities and implementation processes.

Related to the first recommendation, where feasible the R4D program should be firmly linked to existing investment programs. Ideally, the implementation and research components ought to be developed together. However, this is not always feasible. Nevertheless, a strong linkage to existing programs, in which the research addresses priority issues affecting that program, has a far greater likelihood of having real outcomes and impacts. It is also a way to 'leverage' investments: co-investment in implementation and an R4D program is likely to achieve synergies and enhance the returns on both investments.

Another critical requirement for successful R4D in complex agro-ecosystems—missing in the case of NBDC—is a strong long-term commitment by the funding agency, combined with adequate resources to enable key scientists to concentrate most of their energies on the program. We define 'long-term' as being a minimum of a decade and preferably two. We recognize this is very difficult for most funding agencies, but it is not impossible. Of course, periodic reviews and course corrections will be essential. The CPWF was originally designed as a 15-year program with three phases, meant to build on each other. Unfortunately, phase 2 only partly built on phase 1 and has been cut

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4. For Sri Lanka see Merrey 1997: 97 and Uphoff 1992.

short as part of the CGIAR reform process. Phase 2 will therefore be closer to three than five years in duration. This is simply not a realistic time frame for such an ambitious program. In addition, the limited budget essentially forces CGIAR centres to allocate too little of their senior scientists' time to this one program. In nearly all cases, they have multiple project commitments and are often pressured to give their attention to other matters. Concentration and full engagement of the researcher is not possible. Multi-tasking is not an efficient use of time for most people.

Finally, as indeed has been emphasized by the CPWF and by the NBDC researchers we interviewed, excellent science is a critical foundation for effective and credible R4D. Excellence is not sufficient by itself but it is necessary. NBDC has carried out excellent research, as will emerge from this Science Workshop. Indeed, we will see that this is far better than many had realized. Which may suggest the problem: NBDC scientists have not been as quick to publish their results in international journals as may be desirable. This largely reflects the inadequate time scientists are able to commit to this program.

In conclusion, NBDC has been an extremely important learning opportunity for all of those involved in the program. In spite of the impediments, it has produced impressive outputs and there is growing evidence for positive outcomes as well. Building on past work in Ethiopia and elsewhere, it has significantly advanced our knowledge of what is required to sustainably 'improve the resilience of rural livelihoods in the Ethiopian highlands through a landscape approach to rainwater management.'

Acknowledgements

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Irrigation and livestock

Impact of small-scale irrigation schemes on household income and the likelihood of poverty in the Lake Tana basin of Ethiopia

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Abstract: This study uses Tobit and Logit models to examine the impacts of selected small-scale irrigation schemes in the Lake Tana basin of Ethiopia on household income and the likelihood of poverty, respectively. Data for these analyses were collected from a sample of 180 households. Households using any of the four irrigation systems had statistically significantly higher mean total gross household income than households not using irrigation. The marginal impact of small-scale irrigation on gross household income indicated that each small scale-irrigation user increased mean annual household income by ETB 3353 per year, a 27% increase over income for non-irrigating households. A Logit regression model indicated that access to irrigation significantly reduced the odds that a household would be in the lowest quartile of household income, the poverty threshold used in this study. Households using concrete canal river diversion had higher mean cropping income per household than those using other irrigation types. Key challenges to further enhancing the benefits of irrigation in the region include water seepage, equity of water distribution, availability of irrigation equipment, marketing of irrigated crops and crop diseases facilitated by irrigation practices.

Key words: Household income, absolute poverty, small-scale irrigation, Lake Tana Basin, Ethiopia

Introduction

Poverty alleviation during the past half century has been largely a result of economic growth (Roemer and Gugerty 1997). Developing countries that promote sustainable economic growth often reduce their poverty levels and can strengthen their democratic and political stability. They may also improve the quality of natural environment and even reduce their incidence of crime and violence (Loayza and Soto 2002). Agriculture is known to be the dominant source of food production and an important sector for sustaining growth and reducing poverty in many developing countries. For Ethiopia, agriculture is the leading sector in terms of income, employment and foreign exchange and national economic growth is determined largely by the performance of agriculture. Irrigation plays a key role in the performance of Ethiopian agriculture. Thus, irrigation may have an important impact on many development indicators for Ethiopia. Irrigation has served as one key driver behind growth in agricultural productivity, increasing household

income and alleviation of rural poverty. According to Haile (2008), there are four interrelated mechanisms by which irrigated agriculture can reduce poverty, including: i) increasing overall food production and income, which can also reduce food prices, each of which helps poor households meet their basic needs, ii) protecting against risks of crop loss due to erratic, unreliable or insufficient rainwater supplies, iii) promoting greater use of yield enhancing farm inputs and iv) creation of additional employment, which together enables people to move out of the poverty cycle. In addition, Zhou et al. (2009) discussed how irrigation contributes to increased value of agricultural production by increasing crop yields enabling farmers to increase cropping intensity and to produce higher-value crops. Therefore, irrigation can be an indispensable technological intervention to increase household income. However, the impact of irrigation on income and the prevalence of poverty in a particular setting is an empirical question. The principal objective of this study is to examine the impacts of selected small-scale irrigation schemes on household income and the likelihood of poverty in the Lake Tana basin of Ethiopia. More specifically, this study examines the impact of access to irrigation on gross household income and the likelihood of the household being in poverty. Because different irrigation methods may have different effects, we also test whether the income levels for households using four different irrigation systems are statistically significantly different.

Methods

To evaluate impact of small-scale irrigation on the annual gross income of the household, all sources of income were considered. The income data were for household agricultural activities (rainfed and irrigated crops, livestock and their products), off-farm and non-farm incomes reported for various time periods during 12 months (from November 2009–October 2010). The income data were collected from November 2010 to February 2011. Data about livestock production and revenues were collected on weekly basis and aggregated to estimate annual income. The values of agricultural incomes are computed by multiplying the amount of each agricultural product (sold and consumed) with their annual average nominal price. Thus, our measure of income includes the total monetary value of production, not just cash income derived from sales. Some households may not derive income from livestock, off-farm and other activities. To control for factors other than irrigation that influence incomes (such as land size, inputs, agricultural production assets etc.), we estimated econometric models based on the agricultural economic household model (Singh et al. 1986). When values of the dependent variable (such as income) can have 0 values, it is appropriate to account for this in the econometric estimation (Barket et al. 2002; Nicholson et al. 2004; Aschalew 2009; Zhou et al. 2009). In this study, the impacts of irrigation on income were estimated using a Tobit model, sometimes referred to as a censored regression model.

The specific form of the Tobit model is:

$$Y_i = \beta X_i + \varepsilon_i$$

We define a new random variable Y_i^* transformed from the original one, Y_i, by

$$Y_i^* = 0, \text{ if } Y_i < 0$$

$$Y_i^* = Y_i, \text{ if } Y_i > 0$$

Where, Y_i is the observed dependent variable measuring combined cropping income, livestock income and off-farm or other income, Y_i^* is a latent variable, X_i is a vector of explanatory variables that influence incomes, β is a vector of parameters to be estimated and ε is a random disturbance term with mean 0 and variance σ^2. Using a Tobit model with zero as the censoring point when censoring occurs at a non-zero value may bias estimated coefficients (such as the impact of irrigation). To avoid this problem, the minimum of the observed values defines the maximum for the censoring value in the econometric model estimation. That means that an upper bound on Y_i is the minimum of the set (Y_i) by the same reasoning, because the observed total income is non-negative. A logical lower bound on total income (Y_i) is zero. In other words, logic constrains the feasible choice for Y_i to the closed interval:

$$Y_i \in [o, \min(Y_i)]$$

This equation provides the censoring points to vary within the range of values that lies below the minimum of the observed, positive quantities (Holloway et al. 2004). The observed total minimum income at household level is ETB 1256, that is, a non-zero value. By considering the above revised approaches Tobit regression model was used with 1256 as lower limit.

Annual mean crop incomes of four different irrigation methods were compared using a single factor analysis of variance (one way ANOVA). Because the variance of the annual household income was statistically significantly different for the four irrigation methods based on the ANOVA *F* (sometimes called the overall *F* or omnibus *F)* post hoc Multiple Comparison tests were applied.

In the poverty analysis herein, the dependent variable is binary. A household is defined as in poverty and assigned a dependent value of 1 if the household's annual income is in the lowest quartile. If the household is not in the lowest income quartile, the value of the dependent variable is 0. Under this limited dependent variable model, the probability that the ith household is in poverty is given by:

$$\text{Prob } (y = 1 \mid X) = F(X_{i,}\ \beta) \quad = \frac{e^{Z_i}}{1+e^{Z_i}} = \frac{e^{Z_i}}{1+e^{Z_i}}$$

where Z_i is a function of explanatory variables (X_{ki}) and expressed as:

$$Z_i = \beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} + \beta_3 X_{3i} + \beta_4 X_{4i} + \dots \beta_k X_{ni} + \mu_i$$

where μ_i = error term. If P_i is the probability of the ith household is being in the lowest income quartile, then ($1-P_i$) is the probability of not being in the lowest income quartile. Because the dependent variable, poverty, is unobserved and the resulting model is nonlinear, it cannot be estimated by using OLS so maximum likelihood estimation (MLE) is used. Greene (2002) indicates that either Probit or Logit models often are used for the dependent variable that takes dichotomous values (e.g. yes or no) or a choice between two alternatives. Both the Logit and Probit models guarantee that the estimated probabilities lie in the range 0 to 1 and that they are non-linearly related to the explanatory variables. Following Habtamu (2009) and Haile (2008), the dichotomous dependent variable is estimated by Logit model, for its mathematical convenience. The probability of being in poverty can be expressed in binary choice models or a logistic distribution function as:

$$\text{Prob } (Yi = 1) = \frac{\exp(\beta X_i)}{1+\exp(\beta X_i)} \text{Prob } (Yi = 1) = \frac{\exp(\beta X_i)}{1+\exp(\beta X_i)}$$

For the nonlinear dependent variable, the marginal effect of each independent variable is not straightforward to interpret. In the Logit model, the marginal effect of each independent variable on poverty should be transformed to Log-odds ratio coefficient, which is defined as:

$$\frac{Pro(Y=1)}{1-Pro(Y=1)} = \frac{\exp(\beta X_i)}{1-\exp(\beta X_i)}$$

The Log odds ratio shows change of the probability that a household is being in poverty if the independent variable (X_i) changes by one unit.

Basic statistical tests such as the t-tests, chi square, minimum, maximum and percentages used Statistical Package for Social Science (SPSS) for Windows Release (SPSS, Inc., Chicago, Illinois). The econometric models used for the income and poverty analyses were estimated in STATA/SE 10.0 for Windows (Stata Corp LP, College Station, Texas USA). Focus group discussions and key informant interviews were employed to provide irrigation users' perspective on the key challenges to enhancing the benefits from irrigation.

Results and discussions

Impact of small-scale irrigation on total income at household level

Controlling for other factors that influence incomes, access to irrigation (IRR) has a significant positive impact on the mean total income of a household (ETB 3353 per year) a 27% increase over the mean income for non-irrigating households. This supports the initial hypothesis that access to irrigation increases households' income, controlling for other factors. Although the econometric analysis alone cannot indicate directly why the increase in income occurs, irrigation allows the farmers to practise crop intensification and diversification, which increases crop yields and revenues from crop sales. Irrigation also increases the marginal land and labour productivity, increases the crop production and then promotes household income (Table 1).

Table 1. Marginal effects of determinants on household total income

Determinant	Marginal effect	Standard error
Age of household head (AGEHH), years	−16.51	50.65
Education of household head (EDUHH), 1 = read and write; 0 = No	4903.33***	1481.80
Gender of household head (GENDERHH), 1 = Male; 0 = Female	98.48	1752.30
Dependency ratio (DEPRATIO), dmnl	−1029.43	691.43
Family size in adult equivalent (FAMSZADUL),	1552.03***	504.99
Number of livestock (LIVESTO), number in TLU (1 TLU = 250 kg)	2281.29***	373.67
Access to irrigation (IRR), 1 = Yes; 0= No	3353.29**	1219.40
Agricultural asset holding (ASSETHH), Ethiopian birr	2.80***	0.34
Land holding size (LANDSZ), hectare	10274.89***	1604.70

***, ** Indicates significant at the 1% and 5% significance levels, respectively.

Impact of small-scale irrigation access on the likelihood of poverty

For the purposes of this study, the poverty line (often defined as households unable to attain their minimum nutritional requirements) was approximated as the value of current income at the twenty-fifth percentile of sample households. Of the sample households who live below the absolute poverty level, 88% did no irrigation and only 12% irrigated. This suggests that irrigation may have a significant impact on rural poverty alleviation. A Logit regression model is used to assess the impact of various factors including irrigation access on the probability that a household is in poverty. The estimated coefficient for dummy variable for access to irrigation was negative and significant and the calculated odds ratio is 0.14 (Table 2). These results suggest that the probability of being in poverty decreases if one has access to irrigation, other factors being constant.

Table 2. Parameter estimates of a logit model for determinants of a household poverty.

Determinants	Coefficient value		Odds ratio
Age of household head (AGEHH), years	0.02		1.02
Dependency ratio (DEPRATIO), dmnl	0.08		1.08
Gender of household head (GENDERHH), 1 = Male; 0 = Female	−1.58	**	0.21
Education of household head (EDUHH), 1 = read and write; 0 = No	−1.73	***	0.18
Land holding size (LANDSZ), hectare	−1.95	**	0.01
Agricultural asset holding (ASSETHH), Ethiopian birr	−0.001		0.99
Access to irrigation (IRR), 1 = Yes; 0= No	−1.95	***	0.14
Number of oxen in a household, number in TLU	−2.40	*	0.09

***, **,* Indicates significant at the 1, 5 and 10% significance levels, respectively.

Comparison of sample small-scale irrigation systems at household level

It is also relevant to compare the total mean annual household crop income under four different types of irrigating and non-irrigating households, even though this does not control for other factors that may influence mean annual crop income of household. For the four types of irrigation and non-irrigation systems, there are nine pair wise comparisons that were tested for differences with a combined overall significance level using the Games-Howell test (Table 3).

Table 3. Small-scale irrigation types and the mean annual crop income of a household

(I) Small-scale irrigation types	(J) Small-scale irrigation types	Mean difference (I–J)
Concrete canal river diversion	Traditional river diversion	20986**
	Motor pump	1689
	Pedal pump	22111***
	Non-irrigating	30063***
Traditional river diversion	Motor pump	−19296***
	Pedal pump	1124
	Non-irrigating	9077**
Motor pump	Pedal pump	20421***
	Non-irrigating	28374***
Pedal pump	Non-irrigating	7952**

***, ** Indicates significant at the 1% and 5% significance levels, respectively.

The statistical mean comparison revealed that concrete canal river diversion has a significant difference with traditional river diversion and pedal pump. Motor pump irrigation has also a significance difference with traditional river diversion and pedal pump. However, there is no significant difference between concrete river diversion and motor pump, nor a significant difference between traditional river diversion and pedal pump. The four irrigation systems have a significant difference with non-irrigation system.

Major constraints encountered in use of small-scale irrigation systems

A field survey with focus group discussion and key informant interviews indicates that small-scale irrigation's great benefits are accompanied with multi-dimensional challenges, some of them are:

Loss of water through seepage: this is caused by non-durability of the physical structure of river diversion.

Problems with irrigation water distribution: this causes conflicts between upstream and downstream irrigating households. There are no standardized programs to irrigate each cultivated crops. Irrigation water use depends only on spatial location of the farm plot; it does not consider the amount of water required for the type of cultivated crop, time interval of water application and the size of each irrigated land sizes.

Lack of spare parts for water pumps: this means lack of imported spare parts for motor pumps and pedal pumps are main causes for reduced efficiency in small-scale irrigation in the study area.

Lack of markets and marketing facility: this means that cultivated vegetables using small-scale are highly perishable and bulky crops, so an efficient marketing channel is necessary. However, the study area marketing system does not always facilitate outcomes desired by farmers. One reason is the similarity of products and marketing patterns. Onion and tomato are the dominant crops, often harvested by farmers at the same time, which leads to a high availability and low prices during the main marketing period. Compounding this, because there is no efficient storage system in the study area, products quality deteriorates rapidly, which means that farmers must sell within a very short time, often at what they consider low prices.

Crop diseases: this means the study area is intensively cultivated with the same crops for long periods of time. In addition to the loss of productivity and fertility, irrigated cultivation facilitates crop disease like root rot and cut warm.

Conclusion

Econometric analyses that control for other factors influencing household income indicate that accesses to small-scale irrigation increases mean household income significantly, by about ETB 3353 per year, or a 27% increase over non-irrigating households. The study indicates that a much higher proportion of households in poverty are non-irrigating rather than irrigating households. This suggests that irrigation has an important influence on rural poverty alleviation. The Logit model analysis indicates that use of irrigation reduces the probability of a household being poor, controlling for other factors. Additional analyses using ANOVA suggest that different irrigation systems may result

in different income and poverty outcomes by type of irrigation system. However, this does not control for other factors influencing income, so the results are suggestive and should be explored further with a larger number of observations that would allow econometric analysis of the different systems. Qualitative results from focus groups and key informants suggest that the full potential of irrigation may not be achieved in the region based on problems and challenges identified with existing irrigation systems. The main problems identified by the study are lack of access to surface water, loss of water through seepage, irrigation water distribution, lack of spare parts for water pumps, high cost of fuel for water pumps, lack of market transparency and marketing facilities, crop disease and the perceived high cost of inputs.

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Realistic assessment of irrigation potential in the lake Tana basin, Ethiopia

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Abstract: Although Ethiopia has a large potential to develop irrigation, only 5% of the 3.5 million hectares of land potentially available has been developed. To examine the underlying causes, this study evaluates the suitability of surface water irrigation for the Lake Tana Basin development corridor. Surface water availability and land potentially suitable for medium and large-scale irrigation development (200 ha and larger) was considered. Surface water potential was examined by considering river discharges. Land suitable for irrigation was determined with a GIS-based multi-criteria evaluation (MCE), which considers the interaction of various factors, such as climate, river proximity, soil type, land cover, topography/slope and market outlets. The result indicates that nearly 11% of the Lake Tana Basin is suitable for surface irrigation. However, by analysing 27 years of river discharge, less than 3% of the potential irrigable area (or less than 0.25% of the basin area) could be irrigated consistently by run-of-the river-systems. Thus, the irrigation potential in the Lake Tana Basin can only be met by increasing dry season flows (if proven feasible) and by supplying water from existing or future reservoirs or by using water directly from Lake Tana.

Media grab: Ethiopia is blessed with extensive land areas suitable for irrigation, but actually irrigated area is limited by very low river flows at the end of the dry monsoon phase. Thus, expanding the irrigated area can only be achieved by overcoming the low flow constraints by either increasing base flow or by using water stored during the rainy monsoon phase in reservoirs or from existing lakes.

Introduction

Ethiopia has a large potential of water and land resources that could be easily developed for irrigation. Instead, the country continues to receive food aid for about 10% of the population who are at risk annually (Makombe et al. 2007). Ethiopia's irrigable land is underutilized; only 4 to 5% of the potential 3.35 million hectares has been developed (Seleshi et al. 2007). The Government of Ethiopia is committed to solving this paradox through an agriculture-led development program that includes irrigation development as one of the strategies. While the Ethiopian highlands are contributing more than 80% the Nile flow in Egypt, only a tiny portion of the Nile waters are being used in Ethiopia.

In the 2010–2015 Plan for Accelerated and Sustained Development to End Poverty (PASDEP), Lake Tana in the upper Blue Nile Basin is considered a development corridor for economic growth. To optimize the use of the renewable

water resources, comprehensive, reliable and timely information on the agricultural resources is required. Therefore, the aim of this study is both to identify potential areas suitable for irrigation using a multi-criteria evaluation (MCE) and to quantify the available surface water potential for surface irrigation by analysing past river discharges.

General objectives

The general objective of this research is to assess the irrigation potential based on river discharge and land suitability in the Lake Tana Basin. The specific objectives of this study are:

- Quantifying river discharge available for irrigation in the major rivers of Lake Tana Basin and their potential for surface irrigation.

- Mapping of areas suitable for irrigation based on a GIS based multi-criteria evaluation by ranking and pairwise comparisons.

- Identifying medium- and large-scale areas over 200 ha, those that are suitable for irrigation and areas that can be irrigated with existing river discharges.

Description of study area

The study is carried out in the Lake Tana Basin, with a total catchment area of around 15,000 km^2, of which the lake covers around 3000 km^2. The lake is located at 12°00'N, 37°15'E in the northwest highlands of Ethiopia (Abeyou 2009). The elevation of the watershed ranges from 1786 to 4107 masl and the slope ranges from 0 to 167%, with an average slope of 47%. The mean annual rainfall (1992–2006) is 1430 mm at Bahir Dar Station, south of the lake and 1090 mm at Gondar Station north of Lake Tana.

Methodology

Suitable irrigable area determined by land suitability

Land evaluation involves the execution and interpretation of basic surveys of climate, soils, vegetation and other aspects of land in terms of the requirements of alternative forms of land use (FAO 1976 and 1981). Based on GIS techniques pioneered in the Abaya–Chamo Basin by Wagesho (2004) and in the Beles subbasin by Hailegebriel (2007), this study evaluates land suitability for irrigation by mapping major factors such as climate characteristics like river proximity, soil type, land use, topography/slope and market outlets.

Factor vector maps consisting of the basin's road network, river network and towns are projected in Universal Transverse Mercator (UTM) Zone 37 N. These maps are interpolated by Euclidian distance to determine road, water and town proximity. In addition, the daily aggregated long-term average monthly rainfall and potential evaporation data are interpolated by Thiessen Polygon method to determine the spatial distribution of the rainfall deficit, by subtracting rainfall from the evapotranspiration. The monthly deficits are accumulated to estimate the annual deficit and to represent the annual irrigation water requirement. Finally, land use and soil maps of the study area are reclassified to four different ranges of suitability groups based on their suitability and FAO soil definition (FAO 2006) and the slope map is computed from a 90 m SRTM DEM pixel by pixel.

Weighting of decision factors are determined based on the importance of each variable in determining the irrigation potential and are mainly based on expert knowledge. In this study, two types of weighting approaches are applied: the ranking technique and pairwise comparison technique. The ranking involves ordering of decision factors in their relative order of importance. (Rossiter et al. 1999). To calculate the weights, the pairwise matrix is prepared comparing factors head-to-head using pairwise comparison scale (Saaty 1977). The overall weights of the factor maps are then distributed to the suitability classes by equal interval ranges technique. The reclassified and weighted factor

maps are overlain and a preliminary surface irrigation area suitability map is computed for two different weighting scenarios by the Weighted Overlay tool of ArcGIS Spatial Analyst Toolbox. Using Equation 1 the preliminary suitable area is mapped.

$$S = \sum_{i=1}^{n} f_i w_i$$

$$(1)$$

where S: is the pixel value in the preliminary suitability map, f_i: factor map and W_i: weight of the factor map, n : number of factors.

An additional constraint map is prepared for those areas that are defined as permanently not suitable by FAO (1976 and 1981) framework, are mainly consisting of water bodies, wetlands, urban areas, forest and protected areas. These maps are than filtered for identifying large and small-scale continuous areas that are suitable for irrigation.

Surface water availability

Information on low-flow is required for the amount water available for surface water irrigation application during the dry monsoon phase. The low flows were calculated for the major tributaries (i.e. Gilgel Abay, Gumara, Ribb and Megech rivers) with daily averaged discharges for the years 1980–2007. These four rivers contribute more than 93% of the total lake inflow (Kebede et al. 2006). The daily discharge data were obtained from the Ethiopian Ministry of Water and Energy. Low-flow characteristics were estimated using a flow duration curve and by determining the 90 percentile available flow and is described as the flow exceeded for 90% (Q90) of the time. The flows were determined by ranking all daily discharge (Reilly and Kroll 2003; Saeid et al. 2010).

Irrigation potential area determined by water availability

The irrigated area was estimated as the quotient of the Q90 (discharges exceed 9 out of 10 years) and the maximum crop water requirement during the growing season of the crop. The dominant crops in the Lake Tana basin include barley, corn, millet, wheat, sorghum, teff, beans and rice. According to FAO '56' (Richard 1998), the maximum value of the crop coefficient for the dominant crop is 1.15 which is for rice. In the calculation of the consumptive use, we consider the evaporation of the crop (rice in this case), inefficiencies in irrigation water application and water requirements for special application such as land preparation and leaching were taken into account. Irrigation efficiency considering all losses was assumed 60% of the total crop water requirement. The crop evaporation is computed using Penman-Monteith by multiplying the potential evaporation by 1.15 (crop coefficient of rice at the mid-season) which is the maximum value. The total crop water requirement can then be computed as:

$$CWR = ET + \text{application losses} + \text{conveyance loss} + \text{special needs}$$
$$CWR = ET + 0.60 * ET \qquad (2)$$
$$CWR = Kc * Eto + 60\% * Kc * Eto$$
$$CWR = 1.84 Eto$$

where CWR: Crop Water Requirement; ET: Crop Evapotranspiration; ETo: potential evaporation and Kc crop coefficient.

Results

Weighting of factors and suitable areas for irrigation

The pairwise matrix was constructed first. It consists of the first eight columns in Table 1. Eight factors are listed ranging from soil to slope. The pairwise matrix compares the importance for surface irrigation of each of the factors on the left to another factor on the top. Thus, for example in Table 1 'river proximity' is much more important factor than land use for determining the suitability of a particular piece of land for irrigation. Hence, we assign the value of 7 (the highest number but the actual value is arbitrary) at the intersection of the row of 'river proximity' and the column

of land use. Conversely, 'land use' on the left of the Table 1 is much less important than 'river proximity' on the top and we assign the reciprocal of 7 (i.e. 1/7) to the intersection of these two factors. In Table 1 we can see that river proximity is the most important factor since it has all integer values followed by road proximity that only has one value less than 1 in its row and that is in the column with river proximity. The least important factor in considering surface water irrigation is land use with all values in the land use row being less than 1.

Next, the weights were computed by pairwise weighting according to Saaty (1977) and ranking method by Rossiter et al. (1999) and as described above. These calculated weights are listed in the last two columns of Table 1 where the greater the value, the more important the factor. The sum of each of the last two columns is 100. Both weighting approaches ranked the factors in the same order: river proximity was the most important factor followed by proximity of the road and slope of the land. Land use as expected was the least important factor. The factors' weights in pairwise comparison have a higher standard deviation than ranking technique (11 and 5 respectively).

Table 1. Pairwise comparison matrix and weighting by ranking technique

Factors	Soil	Land use	River proximity	Urban proximity	Road proximity	Rain deficit	Slope	Pairwise weighting	Ranking weighting
Soil	1	4	1/3	4	½	2	1/3	12	15
Land use	1/4	1	1/7	1/2	1/6	1/3	1/5	3	7
River Proximity	3	7	1	6	2	4	2	32	20
Urban Proximity	1/4	2	1/6	1	1/5	1/2	1/4	4	9
Road Proximity	2	6	1/2	5	1	2	2	22	18
Rain deficit	1/2	3	1/4	2	½	1	1/3	8	14
Slope	3	5	1/2	4	½	3	1	19	17

The weights of each factor in the last two columns of Table 1 are further subdivided into four intervals for each map pixel to indicate how favourable the pixel is in determining the irrigation suitability. For example, the 'river proximity' factor in the pairwise weighting method the pixels closest to the river are given a value of 32. The pixels at greatest distance from the river are assigned a value of 32 divided by four or eight. By summing all the modified weights of each pixel, a preliminary surface irrigation area suitability map is computed using the Weighted Overlay Tool available in ArcGIS Spatial Analyst Toolbox. Subsequently, the non-suitable areas according to FAO are taken into account, followed by filtering and thresholding to determine continuous suitable areas for irrigation that are greater than 200 ha. More detail is given in Worqlul et al. (2013).

In Table 2 the irrigated areas suitable for irrigation and larger than 200 ha for the pairwise weighting methods are shown for each of the major tributary rivers of Lake Tana Basin. These areas are in the same range as Seleshi et al. (2007) and capture reasonably the existing irrigation area on the Fogera and Dembia flood plains. For that reason, the pairwise weighting is preferred above the ranking weighting technique. The distribution of the suitable areas for each basin are shown in Figure 1, where the green colour indicates the areas suitable for irrigation in the Gilgel Abay basin, yellow are the areas suitable in the Ribb, light blue for the Gumara and the intermediate blue of the Megech. The dark blue colour is the Lake Tana. Table 2 and Figure 1 show that the Gilgel Abay has the largest suitable area of 54,900 ha but at the same time, the smallest portion of the total basin (12%) compared to the other basins. Table 2 also indicates that the highest portion of suitable area of 19% is in the Megech watershed but at the same time has the lowest total area. Most of the large and medium scale command areas suitable for irrigation areas are in the Gilgel Abay basin (see Figure 1 and Table 2).

Table 2. Spatial distribution of irrigation area suitability of the major tributaries of Lake Tana Basin

	Suitable Area (ha)	Number of large scale command areas (>3000 ha)	Number of medium scale suitable command areas (>200 ha and < 3000 ha)	Percentage of suitable area
Gilgel Abay	54,894	4	78	12
Ribb	31,780	3	4	16
Gumara	24,805	2	16	14
Megech	19,029	2	8	19
Total	130,508	11	106	
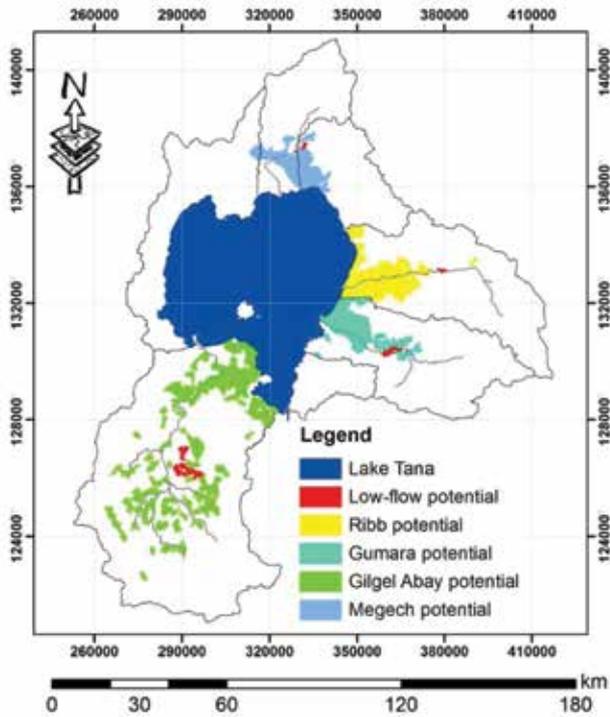
Figure 1. Surface irrigation potential of Lake Tana indicated by green for the Gilgil Abay yellow for the Ribb, light blue for the Gumara and the intermediate blue of the Megech. The red area is that can be irrigated during the dry monsoon phase for 9 out of 10 years and are located in those areas that have the greatest irrigation potential.

Surface water availability

The 90 percentile available flow is determined by making flow-duration curve (FDC). FDC provides the percentage of time (duration) of a daily or monthly stream flow is exceeded for the 27 year period from 1980 to 2007 (Vogel and Fennessey 1994). The FDC graph of logarithmic daily river flow vs. exceedance frequency is plotted for the major tributaries as shown below in Figure 2. The FDC of Megech has steep gradient, which indicates high variability of daily flow, with only one per cent of all days for the study period have zero flow. The FDC of Ribb River indicates a distinct dry season with steep gradient showing about 5% of all days have zero flow. FDC of Gilgel Abay indicated no distinct dry season and it has relatively little variability in stream flow. The Q90 obtained from flow duration curves in Figure 2 and that is exceeded 9 out of every 10 years are given in Table 3. The Gilgel Abay has the greatest Q90 flows has also the largest drainage basin. The Megech has the lowest Q90 and has the smallest suitable area.
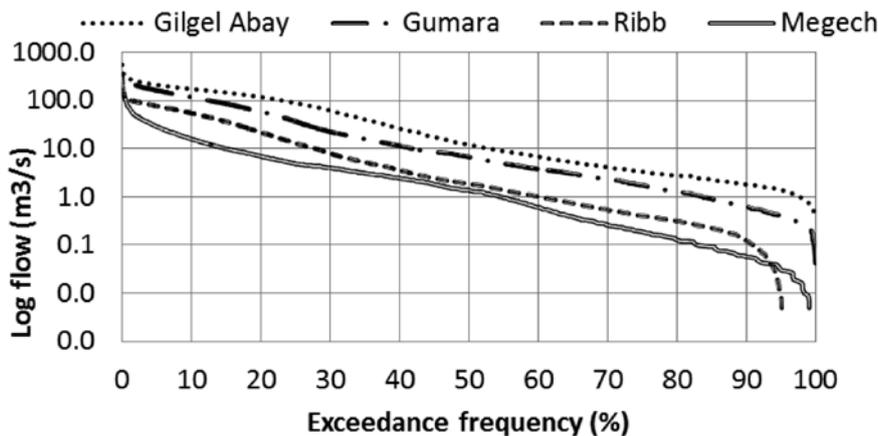
Figure 2. Flow duration curves for the Gilgel Abay, Ribb, Gumara and Megech for 1980 to 2007

Table 3. Flow duration curves for the major tributary rivers of Lake Tana

Flow exceedance probability	Gilgel Abay (m³/s)	Gumara (m³/s)	Ribb (m³/s)	Megech (m³/s)
90%	1.90	0.70	0.12	0.06

Areas suitable for irrigation vs. surface water availability

To calculate the crop water requirement a potential evaporation rate was calculated by Penman Moenteith approach and it ranges from 2.8 mm in June (cold and rainy) to 4.4 mm in April (the warmest and driest month). The total crop water requirement computed on monthly basis with Equation 2 ranges from 5.2 mm/day in the rainy season to a maximum of 8.1 mm/day.

The irrigation potential of the 90 percentile available water is computed by dividing the available water by the total crop water requirement. The result indicated, November has the maximum irrigation potential of approximately 4100 ha and April has the minimum potential of 3000 ha. In Figure 2, the irrigation potential of the 90 percentile available flow are shown in red and are located in the most desirable places mainly based on distance to the river and access to the markets. Figure 1 also indicated the irrigation potential of the available water is very small especially, the irrigation potential of the available water in the Ribb and Megech basin is almost insignificant.

Conclusions and recommendations

In this study, surface water irrigation potential of Lake Tana Basin is mapped based on landscape related factors such as proximity to river, slope and soil of the areas that were suitable irrigation projects larger than 200 ha in the Lake Tana basin. We found that less than 3% of this potentially irrigable land could actually be irrigated with the available flow in the river at the end of the dry monsoon phase. We conclude that the main limitation for surface irrigation in the Ethiopian highlands is the available water and not land suitable for irrigation. Future estimates of irrigation potential should take into account that run off of the river systems can only be expanded to a limited degree and that future expansion should involve building of reservoirs, or sustainable use of groundwater if available.

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Unlocking the potential of livestock technologies in Ethiopia: Shifting from individual pieces to optimizing the sum of the parts

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Abstract: The reasons why farmers are unable to harness the benefits embedded in technologies and take advantage of business opportunities in livestock sector in developing countries remain unresolved. Drawing on insights from innovation systems approaches, this paper assesses innovation constraints, identifies the bottlenecks and missing links in dairy sector and suggests some instruments needed to address the constraints. We find that missing actors, limited capacity of existing actors, inadequate interactions between actors and poor coordination of activities along dairy value chain have been the major reasons for low technology adoption and underdevelopment of dairy subsector in developing countries. Future research should pay attention to designing, prototyping and experimenting with alternative institutional arrangements that can effectively coordinate inputs, services, processes and outputs in livestock value chains.

Media grab: There is increasing demand for milk and milk products in Ethiopia due to increasing urbanization and rising income. However, milk production in the country has not been able to keep pace with growing demand. Although there is sufficient *scientific* knowledge about the dairy production technologies in Ethiopia, the number of smallholder farmers using these technologies is very low. New organizational arrangements that coordinate activities along the dairy value chain are needed in order to reap the benefits from technologies.

Introduction

The demand for dairy products is growing rapidly in Ethiopia. For example, the demand for milk and milk products in Ethiopia is projected to increase from 19 kg per capita in 2008 to approximately 27 kg per capita in 2020 (Francesconi et al. 2010; Duguma et al. 2011). However, milk production in the country has not kept pace with growing demand. Per capita milk production in Ethiopia is estimated at 20.83 kg in 2009 (Tefera et al. 2010). Livestock sector in Ethiopia has not been able to meet the growing demand for animal source foods mainly due to failures to take advantage of potential benefits improvements to technical aspects of dairy production. The increasing demand for milk and milk products needs to be met within the limited land and water resources. The challenge is to provide for the needs of a growing human population and at the same time sustain scarce land and water resources. Successful approaches are likely to bring together positive aspects of sustainable intensification and resource conservation. Increasing demand for milk and milk products and increasing competition for land and water resources, therefore, imply that

livestock production systems in Ethiopia will have to intensify to ensure acceptable livelihoods for its producers (Descheemaeker et al. 2009). Past experience and research findings have shown that agricultural productivity gains are strongly associated with adoption of improved agricultural production technologies (Shaw 1987; Minten and Barrett 2008). Development and effective utilization of new agricultural technologies and practices can shape the extent to which farmers take up business opportunities in the dairy subsector. Several technologies and interventions have been promoted in Ethiopia to enhance the productivity of dairy cattle (Staal 1995; Ahmed et al. 2004). In spite of the higher productivity gains resulting from use of livestock technologies, adoption of the technologies at smallholder farmers' level has been very low. The productivity levels achieved on research stations and a few commercial dairy farms are seldom achieved at smallholder farmers' level. The reasons that farmers are not reaping the benefits of improved technical practices and not taking advantage of business opportunities in the livestock sector in the country remain unresolved. The persistent resistance of subsistence farmers to adopt improved production technologies can sometimes be hidden in higher-order coordination issues. In this paper, we assess innovation constraints, identify the bottlenecks and missing links in dairy subsector development using a systemic innovation policy framework (Wieczorek and Hekkert 2012) and suggest some policy instruments needed to address system weaknesses.

Methods

We use event history analysis to assess the fulfilment of the seven innovation functions needed to build market oriented dairy. The historical event analysis method is a longitudinal research method that is based on the construction of an event sequence and has proven to be powerful in creating insights into the dynamics of innovation (van de Ven 1990; van de Ven et al. 1999). In total, 39 program and policy documents covering 1950's to 2013 were reviewed. The information was obtained particularly from government policy documents, program outcome reports, project and program evaluation reports, peer reviewed journal articles and information from websites of relevant organizations. The occurrence of the events was cross-referenced using published materials wherever possible.

Results and discussion

We find evidence that the major thrust of livestock development in the country over the past five decades has been placed on the technical solutions to breeding, feeding and health constraints. Organizational and marketing issues were treated lightly or totally neglected by most projects and programs implemented in the country (Table 1).

Table 1. Summary of major events that shaped innovation system functions in livestock sector in Ethiopia

Time line	Policies, programs and projects	Focus areas
1950s	Exotic dairy cattle introduced to Ethiopia and Shola milk processing plant	Introduced the first batch of dairy cattle to Ethiopia
1960	Dairy Development Enterprise (DDE)	Set up for collection, processing and distribution of milk for the Addis Ababa market
1958–63	1st Livestock Development Project	Supporting commercial dairy development enterprise around the capital city, Addis Ababa
1964	National Veterinary Institute (NVI)	A primary task of producing vaccines
1967	National Artificial Insemination Service (SNAIS)	AI service
1970–1980	CADU/ARDU	Focus on Production and distribution of cross breed heifers ,AI service, animal health, forage production and marketing
1971	Addis Ababa Dairy Development Project (AADDP)	Launched with the objective of developing commercial dairy production and providing support for smallholder producers in the form of credit, imported cattle and technical services
1971–1975	Wolayta Agricultural Development Unit (WADU)	Focus on bull station and AI services
1973–81	2nd Livestock Development Project	Establishing slaughter facilities for provincial towns and cities
1974–1991	Intensive dairy development effort through producers' cooperatives	Distribution of crossbred dairy cows, AI and milk marketing

Time line	Policies, programs and projects	Focus areas
1972–1981	Addis Ababa Dairy Development Project (AADDP)	Developing commercial dairy production and providing support for smallholder producers in the form of credit, imported cattle and technical services
1972–1985	1st and 2nd Agricultural Minimum Package Projects	Major components include distribution of crossbred in-calf heifers, bull service and AI services and veterinary service
1986–1992	Dairy Rehabilitation and Development Project (DRDP)	Focus on cooperative dairy farm, development through introduction of crossbreds, state farm development and health services
1987–1991	Selale Peasant Dairy Development Pilot Project (SPDDP)	Focus was on dairy stock distribution and cooperative development
1988–1994	Fourth Livestock Development Project (FLDP)	Focus of the project was on feed and forage improvement as well as increased coverage of veterinary services in the highlands of Shoa and Gojam
1991–1994	Smallholder Dairy Development Pilot Project (SDDPP)	Focus on milk processing and marketing
1999–2002	National livestock development project (NLDP)	Aim of livestock health and breed improvement. Focused on establishment of seven regional AI sub centres, establishment of a bull dam farm and training of artificial insemination professionals and forage development throughout the country
2005–2011	SNV Ethiopia's Value Chain Development Program	Aimed to enable small farmers in Ethiopia to adapt their production and arrange for more profitable market outlets for their produce through improving business to business relations based on vertical linkages in value chains
2005–2011	Improving Productivity and Market Success (IPMS) of Ethiopian Farmers (IPMS) project	Aimed at developing a more efficient system for market-oriented agricultural development
2010/11–2014/15	Growth and Transformation Plan	Seeks to bring about an improvement in the livestock sector by enhancing the quality and quantity of feed, providing improved extension services, increasing livestock health services and improving productivity of local cows by artificial insemination while preserving the indigenous breeds
2012–2015	AGP–Livestock Market Development Project	Aims to improve smallholder farmer incomes and nutritional status through investments in livestock value chains including beef, dairy and hides
2012–2016	Market-linked Innovation for Dairy Development (MIDD) program	Aims at dairy value chain development in Ethiopian regions
2013–2018	Livestock and Irrigation Value Chains for Ethiopian Smallholders (LIVES) Project	Aims to contribute to enhanced income of smallholders and other value chain actors through increased and sustained market off-take of high value livestock and irrigated crop commodities.

Most projects have targeted limited technical problems at one or two steps in the value chain. We find that shortage of scientific and technological knowledge is not a big constraint. There are articulate actors who can explain science to a scientist but cannot show proof of concept in farmers' fields. The main reasons for low adoption of dairy technologies and slow response to the growing demand for livestock products can be attributed to the underappreciated problem of coordination failures in dairy value chains. So far, public research and extension systems have not been able to provide the institutional set up to coordinate complementary sources of knowledge and resources along livestock value chains. Little attention has been given to research which looks at the organizational requirements of the innovation process in the livestock sector.

Experience and research findings show that business success is not solely a function of good technologies; it is also about the capability to apply and maintain them in sustainable actions (Gopalakrishnan et al. 2010). Thinking through all activities along the value chain and dealing with all the challenges that will inevitably come at every step of the value chain require organizational innovation. Invention and implementation of organizational models are as important as development of the physical technologies themselves. The lessons from a highly acclaimed Operation Flood India suggest that organizational strategy that is functionally and spatially integrated, that seeks to exploit technological and scale advantages, that aims at a near-saturation coverage of an area and that builds upon a synergy among various activities was perhaps the single most critical factor which influenced its performance (Sambrani 1982; Bellur et al. 1990). This suggests that innovation in institutional arrangements is key to translate technological inputs and services into farmers' practices and to induce innovation in livestock sector.

Conclusions and recommendations

Our findings suggest that the components of most of the projects and programs implemented in the country over the past five decades have been focused on the technical solutions to breeding, feeding and health constraints. Organizational and marketing issues were treated lightly or totally neglected. A suitable combination of technologies, skills and behaviour, processes and organizations are needed to unlock the full potential of dairy technologies. Exploring alternative institutional arrangements for organizing knowledge, skills, services, inputs and outputs in livestock sector should be one of the research priorities. Designing, prototyping and experimenting with alternative institutional arrangements that can effectively coordinate inputs (e.g. existing and new technologies), services, processes and outputs in livestock value chains should be taken as a serious research undertaking. There are promising results emerging from piloting innovation platforms, milk shed hubs, community based breeding schemes and vertically integrated dairy cooperative models. These efforts require proper recognition, resources and rewards. Governments and donors need to encourage the search for new models of institutional arrangements and allocate necessary resources. Monitoring the efficacy of different models of institutional arrangements should also be taken as serious research agenda.

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Water productivity

Improving agricultural water productivity through integrated termite management

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Abstract: Termite infestation is symptomatic of severe land degradation in many semi-arid regions of the Nile Basin. One characteristic of land degradation is low organic matter (OM) reserves in vegetative biomass and soil. One consequence is excessive rainwater depletion through non-productive evaporation and runoff leading to low agricultural water productivity and diminished livelihoods. CPWF research demonstrated that rapid restoration of pasture production is possible by providing manure through night corralling of cattle prior to re-seeding termite affected rangeland in Uganda. In degraded Ethiopian and Ugandan croplands, preliminary results also suggest that application of maize or sorghum stover to growing maize crops reduces termite damage and associate yield losses. Termites appear to prefer feeding on litter, manure and stover rather than on living plant material. We hypothesize that sustainable crop and livestock production requires a minimum threshold of available dry-season 'litter' to avoid termite-driven destruction. We propose an integrated termite management (ITM) approach that involves establishment of sufficient OM reserves to sustain termites and other ecosystems services. One anticipated consequence is enabling termites to resume their beneficial roles in promoting nutrient recycling, infiltration and aeration of soil. In this context, ITM requires an appropriate mix of relevant bio-physical and socio-economic interventions. Besides providing water for animal and crop production, the process of rebuilding OM reserves on degraded termite affected rainfed agricultural land requires additional water. We anticipate that the long-term results of increasing OM reserves will be higher agricultural water productivity, increased crop and animal production and improved livelihoods.

Media grab: Integrated termite management, an ecosystem approach to termite control, helps increase agricultural water productivity, rehabilitate degraded rangelands and enhance agricultural production in East Africa.

Introduction

Better management of African rainfed agriculture affords numerous approaches and opportunities to improve food security and livelihoods while promoting healthy and sustainable agro-ecosystems. Changes for the better require increased water and land productivity and an enabling socio-economic environment for affected people. One widely perceived constraint to rehabilitating degraded land and improving livelihoods is the widespread destructive behaviour of termites. Termites' destructive behaviour is most evident in degraded semi-arid grazing, cropping and forestry

systems, owing to the disruption of the ecological prey-predator relationship between termites and their predators, shifts in termite species composition and depletion of termites' preferred feed resources Mugerwa (2013). The economic and social costs attributed to termites are high, but not well documented. UNEP (2003) and Mugerwa (2013) state that 20–50 out of about 1000 African termite species damage hundreds of thousands structures such as fence posts and houses and generate major losses of agricultural output including 10 to 30% and 30 to 60% for groundnuts and maize, respectively. Termites also account for widespread destruction of grazing land and negate efforts to implement forestry and agroforestry (Nyeko and Olubayo 2005; Mugerwa 2013; Peden 2013). The Macrotermitinae is the family accountable for most agricultural damage in Africa (Abdulahi et al. 2010; Mugerwa et al. 2013). Although distribution of *Macrotermes* species is not well understood, Diga *woreda*, Ethiopia and Nakasongola, Uganda, represent two locations in the Nile River Basin where accelerating agricultural losses associated with termites constrain efforts to improve rainwater management, agricultural production and sustainable land management. This paper summarizes emerging concepts, results and recommendations from CGIAR Challenge Program on Water and Food (CPWF) research on integrated termite management undertaken through the lens of agricultural water productivity.

Termites, organic matter and water productivity

Agricultural water productivity (WP) is the ratio of the set of net benefits from agricultural goods and services to the volume of water depleted in the processes of producing these benefits (Molden and Sakthivadivel 1999). WP includes the crop and livestock water productivity (CWP and LWP). CPWF research concluded that the greatest opportunities for increasing food production arise in rainfed agriculture where current WP is very low (Molden et al. 2007). One key principle underlying this finding is recognition that in degraded agricultural land much water is lost through evaporation and excessive down-slope runoff (Peden et al. 2012). Interventions that divert otherwise depleted water to transpiration promise opportunities to increase agricultural production and enhance the organic matter storage and carbon flow in degraded agro-ecosystems on which production depends. A key requisite step is increasing vegetative cover of trees, pasture, crops and soil organic matter (SOM). However, production of this organic matter capital also requires water. Past research has not adequately addressed the provision of water to replenish OM that is lost from the ecosystem, or what we might call OM water productivity (OMWP). We hypothesize that successful rainwater management must take into account not only water requirements for production of crops, pasture and trees, but also for all OM such as litter and soil OM that sustains ecosystem functioning. This implies allocating water to satisfy production for people and additional water to drive carbon accumulation and turnover in agro-ecosystems.

In healthy tropical ecosystems, organic matter (OM) production and imports must equal or exceed OM losses. Human activity including overgrazing, charcoal production, inappropriate fire regimes and cultivation and export of agricultural and wood products along with *in-situ* respiration leads to long-term loss of the OM capital in supporting agro-ecosystems. In some cases, OM may also be lost when carried away by flood water. In degraded areas of the Nile Basin such as Nakasongola and Diga, *Macrotermes* undermine efforts to replenish depleted OM and thus to rehabilitate the productive capacity of the land.

Donovan et al. (2001) classified *Macrotermes* as generalist feeders, consuming many types of biomass, including detritus or litter derived from vegetative biomass. Litter is their preferred food resource but when detrital production declines, these species switch to foraging on herbaceous producer biomass, causing significant denudation of grassland vegetation (Mitchell 2002). Although behavioural ecologists generally apply the concept of 'switching' to the ingestion of food items by consumers, detritivores (particularly termites) may also show behaviour akin to switching. Switching is characterized by the forager concentrating on more abundant food species, paying little attention to rarer species (Begon et al. 2006). Findings by Mugerwa et al. (2011) support the expansion of the concept of switching to termites. These authors demonstrated that, in litter-deficient grazing lands, subterranean termites resorted to producer biomass, consuming up to 90% of the available biomass. According to this theory of *optimal foraging*, a forager will tend to maximize the net gain of energy from food above that expended in searching for and ingesting it (Smith and Smith

2001). To achieve this, a forager will: 1) prefer the most profitable food items that yield the greatest net energy gain; 2) feed more selectively when profitable food items are abundant; 3) include less profitable items in the diet when the most profitable food are scarce; and 4) ignore unprofitable items, however common, when profitable food items are abundant.

To rehabilitate termite affected degraded land, rainwater management must ensure increased OM storage. In particular, timely production of litter must exceed this threshold to prevent their damaging behaviour. This OM can be produced within the systems or imported in forms such as manure and crop residues from elsewhere. The management objectives are to rebuild ecosystem capacity to satisfy termites' dietary needs such that subsequent termite activity enhances soil fertility, infiltration and aeration that benefit crop production and natural vegetative growth and to eliminate the need for chronic application of chemical pesticides.

CPWF research demonstrated that termite induced damage can be reduced in rangelands and croplands by importing organic matter (Mugerwa 2007; Peden et al. 2012). In highly degraded grazing areas, night corralling of cattle prior to reseeding former pasture deposits manure that attracts termites and enables rapid recovery of graminaceous ground cover. Mugerwa (2007) realized an in increase forage production from nil to about 3000 kg/ha in only one season. Preliminary evidence suggests that this outcome is sustainable with appropriate grazing practices (Peden et al. 2012). We hypothesize that sustainability is achieved in rehabilitated pasture when annual shedding of root biomass before the dry season becomes sufficient to satisfy termites' appetite. In both Nakasongola and Diga, application of maize and sorghum stover, respectively, led to increased maize production that was at least partly due to a shift in termite feeding practices. Clearly, importing organic matter enabled increased production of food and feed for people and animals. However, a broader ecosystems approach that considers a wider range of biophysical and socio-economic a factors is needed, a process we call integrated termite management (ITM).

Potential opportunities and constraints for integrated termite management

Traditional approaches to termite control commonly involve interventions such as manual removal of queens and nests, application of chemical termicides, baiting and use of repellent plant, urine and animal excreta (UNEP 2003; Abdulahi et al. 2010; Mugerwa 2013). Furthermore, chemicals potentially harm non-pest species and interfere with the positive roles termites play in healthy ecosystems. In general, these approaches are costly. Although affected farmers seem knowledgeable about termites and their damaging behaviour, these interventions are frequently ineffective or only helpful for a short time only. Longer-term solutions are needed. Triggering the threshold dependent response of termites to available litter (Figure 1) provides an alternative intervention tied to the complex structure and function of termite affected ecosystems. ITM links this termite feeding behaviour to larger agro-ecosystem process along with associated livelihood strategies.
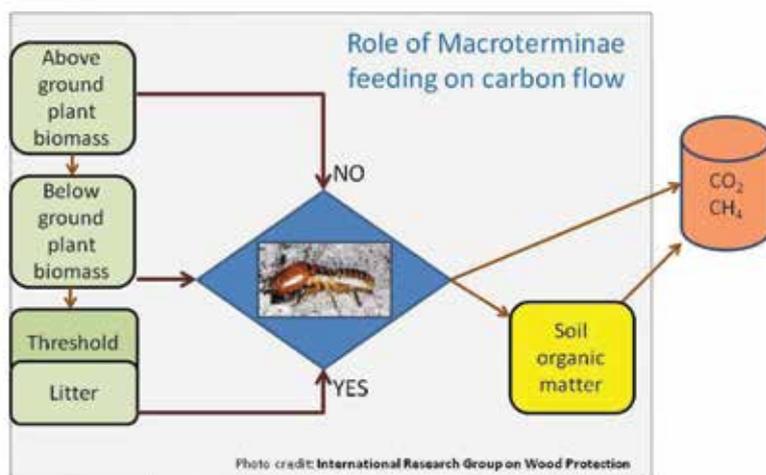
Figure 1. Hypothesized litter biomass threshold below which Macroterminae shift feeding from litter to live plant materials and wooden infrastructure such as fence posts.

Figure 2 proposes a framework that links termite feeding to available litter biomass (Figure 1) and the ecosystem functions that promote increases and decreases thereof. This simplistic model suggests that carbon storage (OM) increases due to photosynthesis and biomass imports and decreases through respiratory loss of carbon dioxide and methane and export of plant and animal material including food, feed and wood products. Selection of appropriate plant species along with good soil, water and vegetation management are the key factors that affect above ground and concomitant below ground biomass production. In turn, accumulated soil OM increases soil water holding capacity and nutrient levels that promote additional primary production. For example, Bationo et al. (2006) call for interventions to increase crop biomass production that can in turn be transformed into soil OM that further sustains and enhances nutrient recycling and productivity.
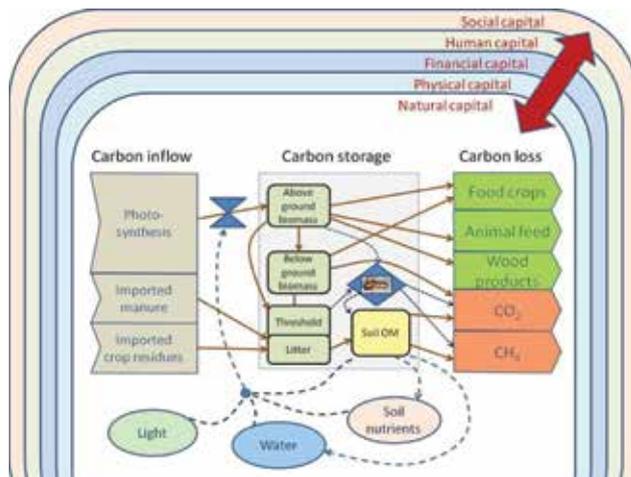
Figure 2. Termite interaction with litter production is one of many important socio-economic and biophysical component processes inherent in degraded agro-ecosystems implying the need for complementary interventions that draw on appropriate natural, physical, financial, human and social livelihood assets.

Termite affected agro-ecosystems are part of the natural capital that sustains human livelihoods. Science-based biophysical interventions are essential for rainwater and land management that promotes increased biomass production and soil OM accumulation. At least for rehabilitation of degraded agro-ecosystems, biomass accumulation must exceed biomass depletion. Key interventions that have been shown to help achieve this include:

- Biomass transfer such as night corralling and import of stover

- Exclosures that prevent overgrazing

- Conservation agriculture that minimizes loss of soil carbon

- Enhancing proliferation of termite predators

- Water harvesting that enables increased CWP

- Use of inorganic fertilizer especially combined with manure to increase crop and forage production

- Selection of appropriate types and varieties of crops and livestock that maximize WP

- Restrictions on grazing pressure, harvesting of wood products and utilization of crop residues to ensure that litter biomass exceeds the required threshold

- Adoption of agroforestry that provides long-term production of litter biomass and

• Demand management of competing uses of biomass to help ensure that in-situ biomass levels maintain levels that promote sustainable ecosystem functioning.

Biotechnical solutions are not sufficient. As depicted in Figure 2, the contextual environment involving people's access to livelihood assets determines farmers' capacity to rehabilitate degraded land. Although context specific, adoption of effective ITM requires farmers' access to appropriate levels of physical, financial, human and social capital and the tradeoffs they make in their attempts to overcome numerous livelihood challenges.

Future research in the Nile Basin and indeed elsewhere in Africa warrants mapping the distribution of termite species that threaten sustainable agricultural production. Wherever they are found in association with severe land degradation, ITM involving allocation of litter biomass along with other proven agronomic practices can help farmers restore agricultural productivity and the sustainability of their natural capital. In this context, ITM can make a meaningful contribution to increasing WP in rainfed agricultural systems. Moreover, we suggest that the process of rehabilitating degraded grazing and crop lands demands investments in water that help rebuild agro-ecosystem structure and function and increase agricultural production.

Conclusions

Farmers' perceive termites as a major constraint to livelihoods in semiarid rainfed agricultural areas of the Nile Basin. In reality these insects are symptomatic of degraded pasture and cropland in which termites consume crops and feed because litter, their preferred source of food, is insufficient. Rehabilitating termite affected agricultural land requires production and imports of organic matter at levels that exceed losses. Research results indicate that import of manure and stover can quickly increase pasture and crop production. Once ecosystems structure and functioning has been reestablished, agricultural production must be undertaken in a manner that does not diminish organic matter reserves. While biophysical interventions underpin efforts to increase agro-ecosystems' natural capital, investments of physical, financial, human and social capital remain vital. Taking an ITM approach where relevant requires an investment in water to produce increased biomass and OM in degraded agro-ecosystems, but will likely result in long-term increases in agricultural WP.

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Enhancing farming system water productivity through alternative land use and improved water management of rainfed agriculture in Vertisol areas

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Abstract: Waterlogged Vertisols are amongst the high potential soils where management interventions could result in positive impacts. This study utilized soil, climate and crop and livestock productivity data and models to demonstrate intensification strategies which increase crop–livestock system productivity and to understand the effects of alternative land use and water management options on water productivity in the Vertisols areas. The areas have been classified into three slope classes including areas where artificial drainage is not feasible, where Broad Bed and Furrows (BBF) can be used to drain the excess water and naturally drained areas, represented by areas with 0–2%, 2–5% and over 5% slope steepness, respectively. Early planting of wheat (*Triticum* spp) using BBF on drainable areas and rice (*Oryza sativa*) or grasspea (*Lathyrus sativus*) on the flat areas were compared with the traditional practices. Yield and biomass data were obtained from research stations in the area whilst the effective rainfall and crop water requirement were estimated using CROPWAT Model. The feed value of the native grass and crop straw was estimated based on previous works. With respect to effective rainfall, the water productivity increase due to BBF over the control ranged from 5 to 200%, with an average increase of 57%. Despite higher water consumption of the rice, feeding its residues to livestock enhanced the overall economic water productivity of the system over the natural grazing or grasspea cultivation. Consequently, use of BBF enables growing high value or food crops of choice that may be sensitive to waterlogging whilst tolerant crops can be grown on flat lands allowing utilization of the full growing period. Coupled with livestock integration into the system, the alternatives can enhance food production and resource use efficiency from these 'marginal' areas.

Key words: Ethiopian highlands, waterlogging, drainage, crop–livestock system, Blue Nile

Media grab: This study has demonstrated that significant agricultural water productivity enhancement can be achieved in both crop and livestock components as well as overall farming system in environmentally constrained areas such as the water logged Vertisols in the Nile Basin.

Introduction

Intensification of rainfed agriculture requires generation and adoption of integrated land, water, crop and livestock management alternatives. However, extreme biophysical variations in the Nile Basin pose daunting challenges to widespread adoption of technologies that were tested under specific conditions. The waterlogged Vertisols that cover about 2.7 million hectares in the basin are among the sites where intensification can significantly improve agricultural productivity as well as system resilience to shocks (Erkossa et al. 2009). One major impediment to intensification in the area is the hydrological properties of the soils, manifested by their slow internal drainage, with infiltration rates between 2.5 and 6.0 cm day^{-1} (Erkossa et al. 2004). The traditional response to the impeded drainage includes planting of local cultivars at the end of the rainy season or leaving it for native pasture. Empirical evidence suggests that traditional management significantly reduces the length of the effective growing period, maximizes evaporation, exposes crops to terminal moisture stress and reduces water productivity (Erkossa et al. 2011). Studies conducted in various agro-ecologies in Ethiopia and elsewhere have shown that surface drainage using Broad bed and furrows (BBF) allows early sowing, enabling the utilization of the full growing period (Astatke and Kelemu 1993) while suppressing evaporative losses (Erkossa et al. 2011). However, the use of BBF is limited to areas having slope of 2–5% as it requires a slope steep enough for drainage. Depending on the growing season temperature, rice (*Oryza sativa*), teff (*Eragrostis tef*) and forage crops can be grown in areas where surface drainage is not an option. The overarching objective of this study was to assess the impacts of alternative land, water and crop management practices on water productivity (WP) of the crop–livestock system and its components.

Materials and methods

Depending on the slope gradient (%), the Vertisol areas have been divided into (Figure 2): i. Non-drainable (0–2%); ii. Drainable (2–5%); iii. Steep enough to drain passively (>5%). The alternative interventions evaluated include early sowing of wheat using BBF for the drainable areas and rice cultivation for the non-drainable areas, provided that the daily minimum temperature during the growing season remains above 10°C. The traditional uses, i.e. late sowing of wheat on flat beds for the former and growing grasspea (*Lathyrus sativus*) or natural pasture for the latter were treated as controls. The common wheat and rice varieties, HAR2029 and X-JIGNA, were used. The Crop Water Requirements under the alternative practices were estimated using the CROPWAT 8.0 model (Richard et al. 1998). The grain yield of wheat was obtained from published literature while the straw yield was estimated using an average harvest index of 0.41 (Birhanu 2010). Similarly, the grain yield of rice was obtained from demonstration fields where the straw yield was estimated using a harvest index of 0.44 (Seyoum 2006). Crop water productivity was estimated as a ratio of the crop yield or its equivalent gross economic value estimated based on farm gate price to the actual evapotranspiration or the potentially available water (effective rainfall). To estimate the livestock water productivity, the feed biomass (crop straws) productivity from the traditional and alternative land and water management were converted to ME in MJ kg^{-1} using literature values on energy content. The number of TLU that the energy per hectare can support under the traditional practices, the alternatives was estimated and linked to the benefit per TLU to calculate total livestock outputs and services per ha. To estimate system water productivity both crop and livestock outputs were converted financial values and the sum was divided by the potentially available or consumed water to produce them.

Results and discussion

Water productivity on drainable areas

Early sowing of wheat on BBF increased average biomass yield by over 63% as compared to the traditional late sowing on flat seedbeds. The increased grain yield may enhance the food security and livelihoods of the households both through improved food availability and increased income through sale of the products. The benefits of additional straw or crop residue production depend on how it is used, which can include: direct incorporation into the soil; feed to the livestock and return the manure to the soil; use as soil mulch, building material or as fuel. It may also be sold. Depending on the decision

of the household on the type of use, the increased biomass production may enhance agro-ecological sustainability through increased soil organic matter or improve household livelihoods as a direct benefit. The effective rainfall during the growing period ranged from the highest of 7990 m³ ha⁻¹ at Pawe to the lowest of 4770 m³ ha⁻¹ at Enewari. Similarly, Pawe exhibited the longest length of growing period (LGP) of 191 days, as opposed to Dogollo that had the shortest (114 days). On the other hand, the highest (3,168 m³ ha⁻¹) and the lowest (2804 m³ ha⁻¹) actual crop water consumption (ETa) were at Bahir Dar and Merawi, respectively. Evidently, advancing the sowing date of wheat using BBF increased consumptive use of water over the traditional late planting on flat beds irrespective of the locations, but the magnitude of the increase varied with location, ranging from the lowest (15%) at Merawi to the highest (177%) at Enewari. This may be related to the extended growing period (184 days) at the latter site, which led to less effective consumption of water by the crop.

Early sowing of wheat on BBF increased the crop water productivity (CWP) with respect to effective rainfall, as compared to late sowing on flat beds, but it was reduced with respect to ETa, indicating that higher water productivity with respect to consumed water does not necessarily mean higher crop yield. While the average increase in CWP due to BBF was about 57%, it ranged between 5% at Enewari in 1986 and 200% at Merawi in 2007. Therefore, advancing the sowing date of wheat on Vertisols using BBF increased the productive use of the potentially available water, most of which otherwise would have been lost to evaporation (Erkossa et al. 2011). The spatial and temporal variation in the effect suggests the need for targeting interventions to optimize the return to available water. On average, the use of BBF increased the gross return (GR) from wheat grain by 50% as compared to that of flat beds with the highest GR of 1282 USD ha⁻¹ at Bahir Dar in 2007 under BBF as opposed to the lowest of 296 USD ha⁻¹ at Merawi during the same year under the traditional method. The use of BBF increased the Gross Economic WP with respect to effective rainfall by up to 183% at Merawi in 2007 despite its increased water consumption. Overall, every cubic meter of water resulted in an average gross return of 0.14 USD from the wheat sown early on BBF, a 36% increase on the previous 0.09 USD gross return obtained when the crop was sown late on flat beds. Similar to the case with crops, the use of BBF significantly improved the value of livestock products and services. The highest value was estimated for Merawi, which is in line with the effect on biomass production.

Water productivity on non-drainable areas

Changing land use from native grass to rice or grasspea on flat Vertisols increased crop water consumption by 152 and 10%, respectively. This is attributed to the fact that rice consumes more water per day for a longer duration (148 days) as compared to grasspea that was sown late and required only 90 days to mature. Consequently, the biomass water productivity with respect to effective rainfall was 0.4, 1.0 and 1.8 kg m⁻³ for native grass, rice and grasspea, respectively. Despite its high biomass production and water productivity, grasspea can be risky both as food and feed due to its high content of anti-nutritional agents, especially β-ODAP neurotoxin, which can lead to a disease known as lathyrism (Sharma et al. 2003) if consumed beyond a limited quantity. The beneficial outputs and services from livestock was the lowest where non-drainable Verstisols are used for rice but this can be improved by supplementing the practice with a second crop like grasspea.

System water productivity

As shown in Figure 1, all proposed alternatives showed higher system water productivity compared to the traditional practices at system level. Despite having the highest water consumption, the highest gross return and system water productivity was recorded under the rice–livestock system, closely followed by the grasspea–livestock system. This can be explained mainly by the high value of rice on the Ethiopian market and the fact that the straw can be fed to the livestock. A number of studies argue that sustainable water use through improved water productivity focuses on producing more agricultural products using the same or lower quantity of water input (e.g. Haileslassie et al. 2011). The decision on whether to go for high value but water depleting crops or a lower value crop which depletes less water is one with economic and political dimensions. However, in this particular situation, the opportunity cost of the extra water consumed by rice is insignificant as it is largely lost to evaporation under the traditional system. The BBF-wheat system also increased both the gross return and water productivity at system scale, confirming the previous findings in which it was recommended as a profitable alternative (Erkossa et al. 2006), even when water consumption is considered.
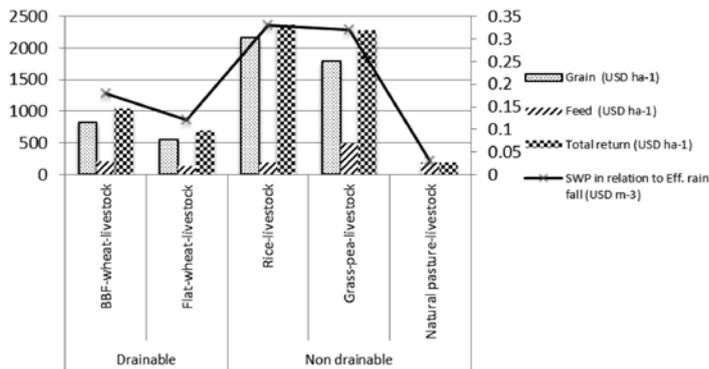
Figure 1. Effect of the alternatives on system water productivity in relation to effective rainfall

Conclusion

Based on primary data generated by the authors, secondary data obtained from published and grey-literature sources and model outputs, this study has demonstrated that significant agricultural water productivity enhancement can be achieved in both the crop and livestock components as well as overall system scales in environmentally constrained areas such as the highlands of Ethiopia. Improving crop productivity on soils which are hydro-physically constrained such as Vertisols, either using surface drainage technologies where the slope gradient is suitable, or growing hydrophilic crops such as rice in areas where drainage is limited by topography have been proven to be superior both in terms of gross return and efficiency of water use. The profitability is even higher when livestock is integrated into the system through using the dry matter as feed, the productivity of which was increased due to the use of the improved land and water management options.

Evidently such interventions enhance the livelihood of subsistence farmers and boost resilience of their environment. With increased market access for the products such as rice and livestock outputs, the widespread use of the alternatives within the basin and beyond can meaningfully contribute to the efforts to ensure national food security and spurs the overall economic growth. In view of ensuring high system productivity of the 12 million hectare Vertisols in the country, these integrated approaches need to be disseminated using a well guided strategy with the involvement of relevant stakeholders. In addition, provision of enabling policy and institutional environment that stimulate the wider adoption of improved management practices need to be in place. In the meantime, further refining of the alternative soil, water, crop and livestock-related technologies through research for development need to be invigorated.

Acknowledgements

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Effects of livestock feed sourcing and feeding strategies on livestock water productivity in mixed crop–livestock systems
of the Blue Nile basin highlands of Ethiopia

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Abstract: Inefficient management and use of water is unanimously the most single constraint of agricultural production of Ethiopia. The study was conducted to assess the effect of livestock feed sourcing and feeding strategies on livestock water productivity (LWP) in mixed crop–livestock production systems of the Blue Nile Basin in Ethiopian Highlands. Three districts representing diverse agricultural farming systems were considered. Each district further stratified to different farming systems. Multi-stage stratified random sampling technique was employed to select farm households. Household survey, group discussions and plant biomass sampling were done to generate data on beneficial outputs, water depleted and feed sourcing and feeding strategies. LWP was estimated as a ratio of livestock's beneficial outputs and services to depleted water. The results indicated that the major feed sources were mainly from crop residues (58.5 to 78.2%), natural pasture (10.9 to 33.4%) and aftermath grazing (9.9 to 24.3%) in study farming systems. The feed source from energy dense (improved forages) was low. The feeding strategies were relatively similar among the study farming systems. No apparent difference ($P>0.05$) was observed in LWP within all districts among the farming systems and the value falls between USD 0.15–0.19 m^{-3}. However, LWP difference was observed within clustered wealth status within all farming systems and lower value of LWP general observed for the poor farm households. Such differences of LWP values can be accounted for by the strategies farm households are following in feed sourcing and how water productive those feed sources are. Hence, in the context of this work, options to improve LWP mainly involve sourcing water productive and higher quality feed.

Media grab: Improving feed sources, feed quality and feeding system increases water productivity and hence LWP

Introduction

Water competition among different uses and users can hinder meeting increasing food–feed demands (Benin et al. 2006). For decades, long irrational communal exploitation of land, has led to competition over land and water and thus caused water scarcity in Blue Nile Basin (WFP 2007). The Nile basin in Ethiopia contains about 27.6 Tropical Livestock Unit (TLU) per km² (Breugel et al. 2007) but livestock's requirements for and impact on agricultural water uses have been largely ignored (Peden et al. 2007; Peden et al. 2008). Globally, current animal production depletes more than 1×10^{12} m³ of water per year only for feed and this is about one seventh of the global water depletion for agriculture (Peden et al. 2007). However, by 2020, livestock will likely produce more than half of the total global agricultural output in monetary value. This will place a significant extra demand on agricultural water resources; especially for livestock feed production. Hence, emerging understanding suggests that better integration of livestock and water development can help improve agricultural water productivity in the Blue Nile basin (Peden et al. 2007). A livestock water productivity framework enables a better understanding of livestock–water interactions. However, little is known about water depleted to produce feed, the efficiency with which feed is converted into animal products and services and the impact animals have on water resources in different landscape of crop–livestock system. Hence, the aim of this study was to assess the effect of current feeding strategies and feed sourcing on livestock water productivity in different farming systems and landscapes of the mixed crop–livestock systems of Blue Nile Basin of Ethiopia.

Materials and methods

Study sites

This research was undertaken in Diga, Jeldu and Fogera Districts, as part of the Nile Basin Development Challenge (NBDC) project. Three study watersheds one from each district were selected. The watersheds identified were; Dapo from Diga, Meja from Jeldu and Mizewa watershed from Fogera.

Stratification, household survey and estimation of LWP

A multi stage stratified random sampling technique was employed to select farm households. Household survey, group discussions, feed resources assessment using harvest index and plant biomass sampling were done to generate data on beneficial outputs, water depleted and feed sourcing and feeding strategies. LWP was estimated as a ratio of livestock's beneficial outputs and services to depleted water.

Results and discussion

Feed sources

Sufficient and quality feed resources availability are some of the major determinants of livestock productivity. In all study systems, majority of sample farmers responded that crop residues, green grass from natural pasture and aftermath grazing are major feed resources. The contribution of each of these feed ingredients to the diet of livestock varies across study systems. Generally, for all farming systems, the crop residues contribution to feed on a dry matter basis ranged from 58.5 to 78.2%. But the point is as to whether these major feed sources; crop residues, influence the livestock water productivity in mixed crop livestock systems of Ethiopia. The grazing land and aftermath grazing contribution on dry matters basis ranged from 10 to 33 and 9 to 24% in study systems, respectively. Decline of areas and dwindling of biomass productivity of grazing lands in the study areas are some of the major concerns. What is encouraging in terms of future improvement of dry matter productivity and associated LWP is the huge yield gaps between these traditional practices and research managed intervention. For example, in Fogera as much as 10.8 t dry matter yield per hectare was reported (Ashagre 2008) from improved natural pasture. By closing yield gaps as high as 100%, improvement in LWP is reported for mixed crop livestock systems of India (Haileslassie et al. 2011). Moreover, the results of this study demonstrated that improved forages production and feed supplementation (e.g. bran, oil cake)

were rarely practised in all study sites. This indicates that to date adoptions of technologies are generally limited to peri-urban and urban areas. The relevant question here is probably as to why policy measures that enhance improved forage production could not be implemented and as to whether policy recommendations, if they exist, are system specific or generalized.

Feeding systems

In teff–millet system of Diga, about 34.3% of respondents practice tethering of livestock on grazing land. However, in Jeldu and Fogera, most of the private grazing lands were grazed by herding and some of it used for hay making. About 95.6 and 96.7%, of respondents practice giving small amount of crop residues to livestock near homestead in farming systems of Jeldu and Fogera, respectively. About 76.1 to 96.8% of respondents did not practice any treatments or improvements made during feeding to increase the quality of straws in all study systems.

Livestock water productivity

Although the magnitude of LWP varies across systems and study sites, differences were not statistically significant. LWP is derived from number of data sets and assumptions. Therefore the reason for similarity or divergence of LWP values among systems can trace back to those data sets. A simple example is the livestock beneficial outputs and the water depleted for feed production in the study system. The beneficial output on TLU basis, for example, does not show many discrepancies among system. This implies that the farming practices from which the beneficial outputs mainly derived is very similar. Probably difference emerges when considered at farmers' wealth category level where difference in land holding is important and thus beneficial outputs from livestock services differed between farm households. One major trend worth mentioning here is that in areas of higher beneficial outputs (e.g. Fogera rice system) as the results of livestock density, the water depletion for feed was very high and this offset the LWP value. Generally, LWP values for the study farming systems falls between USD 0.15 m^{-3} to USD 0.19 m^{-3}. The LWP estimates of this study, for rice system, was comparable with the study of Haileslassie et al. (2009) (USD 0.15 m^{-3}) of Gumera watershed. Cook et al. (2008) also suggests those kinds of variability to the temporal and spatial scales at which livestock production systems are analysed and strong fluctuations in water availability related fluctuations in livestock productivity. Descheemaeker et al. (2010) also suggested that the amount of water used by different feed types and the influence of management practices and agro-ecological conditions lead to variation of LWP value.

The value of LWP (USD 0.25 m^{-3} to USD 0.39 m^{-3}) from a controlled experiment reported by the Geberselassie et al. (2009) shows greater values than this study. This may be due to the difference of feed composition, animal age and weight under considerations. This indicates that there are options to increase LWP by improving feed quality in the study areas. To understand more if there are any LWP differences related to household access to resources, LWP estimates in the study were disaggregated into household clusters. The livestock water productivity, for example, among wealth group within each farming system varies. Generally, the livestock water productivity of poor smallholder is lower than other wealth clusters. The average value of LWP among wealth status in this study lies between USD 0.08 m^{-3} to USD 0.23 m^{-3} per household for all farming systems. The fact that the range among wealth categories is wider than the system scale suggests also higher opportunities to improve LWP by targeting farmer's livelihoods. Such big differences of LWP values among farm households can be accounted for by the strategies farm households are following in feed sourcing and how water productive those feed sources are.

Conclusion

- Currently, in all of the study farming systems, crop residues constitute the major ingredient of livestock diet. Supplementary feeding with high value feed is not commonly practised. Hence, strategic way of feed source diversification (forage production), improvement of quality and improved feeding strategies are important entry for feed productivity improvement and hence LWP values.

- System scale LWP did not show apparent divergences between farming systems as the farm scale did. The farm scale showed a very wide range between the resources of poor and better off farmers. Such big gap of LWP for farm households operating in the same farming system suggests a potential for improvements. Hence, to exploit this potential, policy measures that build farmers' capacity to access key livelihood assets (e.g. land and livestock) is important.

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Hydrological/erosion modelling

Hydrological modelling of sustainable land management interventions in the Mizewa watershed of the Blue Nile basin

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Abstract: The current paper discusses the use of hydrological modelling tool to understand sustainable land management interventions in the Blue Nile basin of Ethiopia. A micro-watershed named Mizewa with a drainage area of 27 km[2] in Fogera district was selected and instrumented with hydrological cycle observation networks in the year 2011. The SWAT hydrological modelling tool was used to simulate landscape-wide Soil and Water Conservation (SWC) investments. Simulations of the selected investments modelled in this analysis suggest that improvements in infiltration, decreases in surface runoff and decreases in erosion are achievable in the watershed. Further simulations suggest that a landscape-wide approach of terrace and bund construction has the greatest effect in terms of decreasing surface runoff, decreasing sediment yield and increasing groundwater flow and shallow aquifer recharge. A comprehensive landscape investment of terraces on slopes greater than 5% and bunds maintained on slopes less than 5% would decrease surface flow by almost 50%, increase groundwater flow by 15% and decrease sediment yield from erosion by 85%. However, constructing terraces in areas with greater than 5% slope (without constructing bunds in areas under 5% slopes) has a similar effect whereby surface flow and sediment yield decreases by 45 and 83%, respectively and groundwater flow increases by 13%. Residue management also has a significant effect on surface flow and erosion in the Mizewa watershed. Average annual surface flow decreased 17 when adopting residue management on all agricultural land and 26% when coupling terracing on steep slopes with residue management in mid-range slopes. These analyses provide the foundation for understanding feasible outcomes given a more comprehensive investment strategy. Results stemming from the current work can be paired with household level socio-economic data in order to assess program investment alternatives taking into account household constraints to Sustainable Land and Watershed Management (SLWM) investment and maintenance on private and public lands.

Media grab: Hydrological modelling techniques can support decision-makings for Sustainable Land and Watershed Management (SLWM)

Introduction

Continuous investments in water resource management in the Blue Nile Basin suggest a need for efficient and effective mechanisms to improve water capture and agricultural output in the highlands of Ethiopia. Ethiopia's unique biophysical variability provides the underlying conditions for abundant fresh water resources; however, deforestation due to farmland expansion and energy needs, fragile soils, undulating terrain and heavy seasonal rains make the highlands of Ethiopia vulnerable to soil erosion and gully formation in the rainy season. During the dry season, water scarcity and low water tables cause previously perennial streams to be intermittent and may affect agricultural yields in the Upper Blue Nile basin.

The Blue Nile is one of the least planned and managed subbasins of the Nile (IWMI 2008). Previous studies have examined the impact of investments in sustainable land and watershed management (SLWM) derived implicitly from economic analyses (Pender and Gebremedhin 2006; Schmidt and Tadesse 2012), but the physical improvements of SLWM investments (i.e. decreased surface runoff and sediment yield and increased groundwater flow during the dry season) require further examination through a hydrological model which takes into account comprehensive landscape investments and their effect on overall water balance. This analysis focuses on the impact of a variety of SLWM investments on runoff and sediment capture and seepage within the Mizewa watershed in Fogera district.

The study utilizes recent hydrological and meteorological data (stream flow, rainfall, weather and groundwater measurements) collected from the previously ungauged Mizewa watershed in order to understand more localized impacts of sustainable land management practices. The Soil and Water Assessment Tool (SWAT) (developed by the US Department of Agriculture; Arnold et al. 1998) is utilized to simulate sediment and runoff processes in order to better understand the physical impact (in terms of hydrological processes and linkages to agricultural yields) of SLWM investments.

Simulated conservation practices are evaluated at the outlet of Mizewa watershed by comparing model simulations with the limited investments that currently exist (status quo) with simulations of a variety of terracing and residue management activities. Results suggest that parallel terrace and bund construction significantly reduced surface runoff and sediment yield and improved groundwater flow. The benefits of residue management practices were more important for less steep areas, while a mixed strategy of terracing on steep slopes and residue management on mid-range slopes decreased surface runoff and sediment yield by 26 and 54%, respectively.

Methods

Study area description and model input data

The Mizewa watershed is situated in Fogera district located in the northeast of the Blue Nile basin near Lake Tana (Figure 1). The watershed modelled in this study encompasses the Mizewa River and is approximately 27 km², with the highest point in the catchment reaching 2391 masl.

This study uses data from recently installed gage stations in the previously ungauged Mizewa watershed in order to understand more localized impacts of sustainable land management practices on runoff and erosion. From June through August of 2011, a network of data gages were installed in the Mizewa watershed including: soil moisture probes, automatic and manual water level gauges, a weather station, manual rain gauges and shallow ground water monitoring devices. The climate monitoring data used in this analysis consists of one automatic weather station and two manual rain gages.
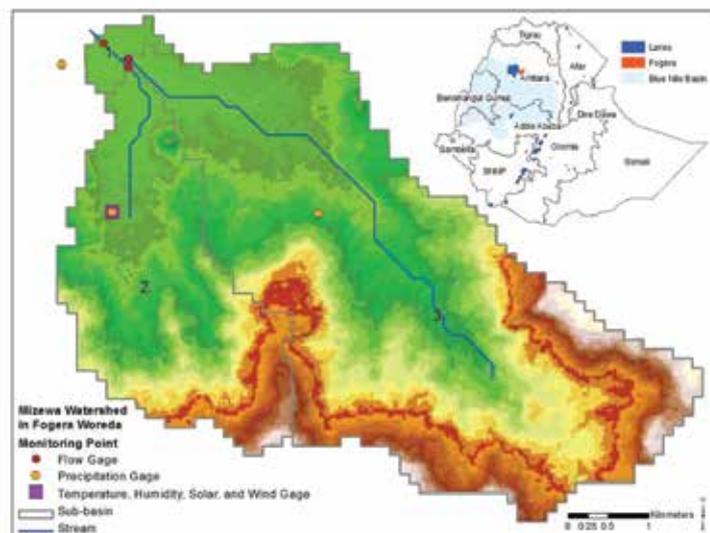
Figure 1. Mizewa watershed, elevation and streambed

Calibration and validation of the SWAT model

Parameter calibration was completed using one year of data collected at the outlet of the Mizewa watershed. A three year warm-up (January 2009–2011) period utilized long-term weather data from Bahir Dar weather station in order to initialize the model. Model predictions are evaluated after the 3 year warm-up period and three months (August 2011–October 2011) of simulation using Mizewa weather stations in order to approach reasonable starting values for the model state variables. Calibration and verification were performed on the simulation period ranging from November 2011 to November 2012. Several statistics including the Nash-Sutcliffe prediction efficiency (ENS), coefficient of determination (R^2), Index of Volumetric Fit (IVF) and graphical plot were used to compare model predictions against the observed values. The model is calibrated at a daily, weekly and monthly time step. Surface and base flow were calibrated simultaneously. Simulated results suggest that temporal dynamics are important in the overall hydrologic behaviour of the watersheds. Similar to findings by Liu et al. (2008), daily flow simulations did not capture interflow that was developing and occurring over longer periods, requiring hydrographs consisting of weekly sums to capture comprehensive stream responses to rainfall events.

Calibrated weekly peak flows are well-represented with exception to the first event whereby the model anticipates time to concentration the first week of July, which results in a lower overall ENS and R^2 value (Table 1, Figure 2). The monthly simulated and observed flow accurately depicts runoff and reveals that hydrologic processes and flow regimes in SWAT have a good fit with observed monthly flow data.

Table 1. Nash Sutcliffe Coefficient and R^2 for calibration and validation of outlet discharge

	Calibration			Validation		
	ENS	R2	IVF	ENS	R2	IVF
Daily	0.39	0.41	99.3	0.24	0.27	74.09
Weekly	0.72	0.73	99.04	0.61	0.69	73.96
Monthly	0.93	0.94	99.35	0.71	0.81	74.09
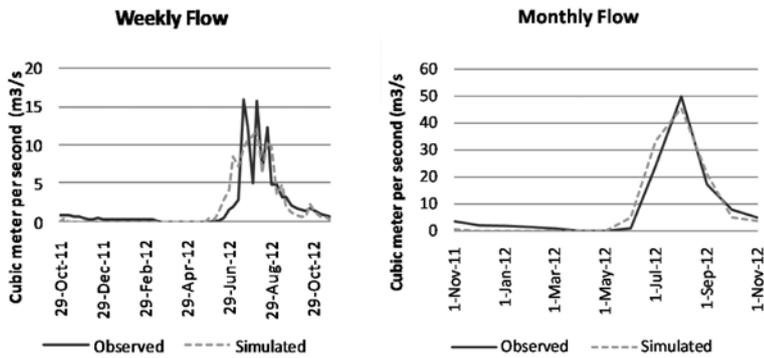
Figure 2. Calibration comparisons between observed and simulated weekly and monthly stream flow

After model calibration, validation was performed using discharge data from the flow measurements collected at the upstream confluence of the Mizewa watershed (associated with sub-watershed number 3, Figure 1). Model validation was completed on the calibrated parameter values to test the accuracy of the model prediction from a different observational dataset than the observed values used in the calibration. The model fit for these data values suggest that the calibrated parameters are appropriate for Mizewa watershed as reported by the predicted and observed data fit using ENS and R^2 to test model validity (Table 1, Figure 3).
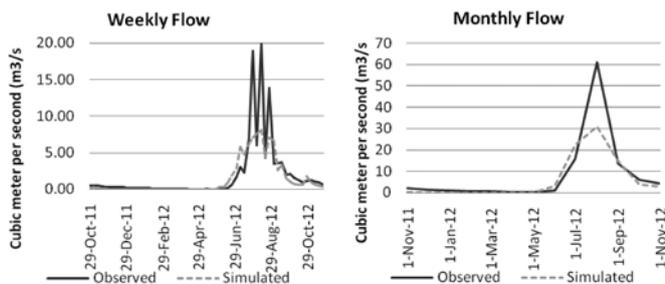
Figure 3. Validation comparisons between observed and simulated weekly and monthly stream flow

Simulating SLWM investments

Given that precipitation data from Mizewa watershed were collected for one year at the time of this study, we use the long-term precipitation data collected in Bahir Dar by the National Meteorological Agency from 1961 to 2011 in order to simulate the effects of SLWM investments. The Global Weather Data for SWAT database supplied data for the other long-term weather input variables (air temperature and solar radiation, wind speed and relative humidity) required for SWAT simulation based satellite data and reported weather data from Bahir Dar and Addis Zemen weather stations.

In the study terraces are modelled under three scenarios: 1) terraces built on only steep land (greater than 20 slope gradient) in the watershed, 2) terraces built on steep and mid-range slope gradients (5–20 degrees) and 3) a mix of terraces and bunds across the entire watershed landscape. Given that terraces and bunds require labour investments, residue management is another strategy that is less labour intensive, but requires grazing limitations on agricultural land. We simulated residue management under two scenarios: 1) assuming that 0.5–1 ton/ha residue is left on all agricultural fields between harvest and planting seasons and 2) assuming that 0.5–1 ton/ha residue is left on agricultural fields with a mid-range slope, while steeper slopes (greater than 20 degree gradient) receive terraces. Although contour farming is often modelled as a low cost intervention, it is a traditional method of soil conservation used in Ethiopia and most farmers in Mizewa have been contour farming for decades, thus we consider this a baseline condition. The key parameters used to model terrace construction are SCS curve number (CN), USLE support practice factor (USLE_P) and slope length of the hillside (SLSUBBSN). The key parameters to adjust when modelling residue management are the curve number (CN2) and Manning's roughness coefficient for overland flow (OV N).

Results and discussions

Simulations of the selected SLWM investments modelled in this analysis suggest that improvements in infiltration, decreases in surface runoff and decreases in erosion is achievable in the Mizewa watershed. Daily average total flow and surface flow decrease compared to the base in each investment scenario, though to varying degrees depending on the magnitude of the investment. Table 2 presents effects of investments on different components of the hydrological cycle.

Table 2. Average annual simulated discharge and sedimentation under different SLWM practices

	Base (mm)	Terrace (slope >20°)	Terrace (slope >5°)	Terrace (slope >5°) Bund (1–5 slope°)	Residue management	Residue management (5–20° slope) Terrace (slope >20°)
Surface flow	45.0	−15.2%	−45.1%	−49.6%	−17.3%	−25.9%
Lateral flow	200.3	1.4%	2.9%	3.0%	0.9%	2.0%
Groundwater flow	72.2	0.0%	13.0%	15.4%	6.2%	4.7%
Stream flow	317.6	−1.2%	−1.6%	−1.7%	−0.5%	−1.4%
Sediment Yield	1.99	−45.4%	−82.5%	−85.0%	−19.2%	−53.9%

Simulations suggest that average monthly runoff during the rainy season is the primary driver to decreased sediment yield and surface flow, as well as increased and prolonged groundwater flow during the dry season. In comparison to the base scenario, surface flow during July (the peak month of the rainy season in Mizewa watershed) decreases from 26 mm to 16.8 mm under the mixed terrace and residue management simulation. Similarly, sediment yields decrease from 1.03 t/hectare in the base scenario to 0.47 t/hectare in the month of July under the mixed terrace and residue management simulation (Table 2). Terracing on greater than 5% slopes and the mixed terracing and bunds simulations suggest similar outcomes, whereby surface flow is reduced by 45 50% (12.4 and 11.3 mm), respectively in July and sediment yield decreased by 82 and 85% (0.17 and 0.15 t/ha).

Conclusions and recommendations

The methods used to represent SLWM in the present study are based on historical and ongoing experimental trials of conservation practices and may not capture the unique processes that occur specifically in Mizewa watershed. Ongoing data collection and further research in the Mizewa watershed after SLWM interventions would allow for more in-depth analysis on specific impact of investments on water balance and discharge in the affected area.

The SLWM scenarios presented in this study are based on hydrologic processes represented in SWAT utilizing the SCS curve number method. Recent literature argues that the SWAT-Variable Source Area (VSA) model, developed by White et al. (2010) and Easton et al. (2010) is a more appropriate framework for watersheds that experience monsoonal climates typical of the Ethiopian highlands. However there are no studies to date that test model parameter adjustments for SLWM investments on experimental plots or fields apart from the conventional SCS curve number method. Thus, it is unclear how to simulate future SLWM investments using SWAT-VSA. A future study could compare parameter modifications using the CN and the VSA model on pre- and post-investment data to assess appropriate value changes for modelling of specific SLWM structures taking into account the spatial complexity of watershed-level management will provide a more comprehensive understanding of how these investments affect agricultural sustainability in the medium to long term.

In order to explore policy options for incentivizing local investment and up-scaling of sustainable land management activities, it is important to understand the watershed system and the potential for improved hydrological performance at a landscape and household level scale. Future analysis would benefit from coupling household level investment choices with more comprehensive landscape wide interventions in order to take into account wider biophysical impacts, as well as household level economic factors. Successful past programs have supported a participatory planning approach that takes into account the relationships between household/village opportunity costs,

perceived risk and changing social and economic dynamics. This analysis provides the foundation for understanding feasible outcomes given a more comprehensive investment strategy. Results stemming from this analysis can now be paired with household level socio-economic data in order to assess program investment alternatives taking into account household constraints to SLWM investment and maintenance on private and public land.

Acknowledgements

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Erosion modelling in the upper Blue Nile basin: The case of Mizewa watershed in Ethiopia

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Abstract: The main objective of this research was to study soil erosion and sediment yield in Mizewa watershed using SWAT model. The study was involved hydrological and erosion modelling using primary data collected in the watershed. Hydrological and meteorological data were collected from the stations installed in the watershed by IWMI in collaboration with Ministry of Water and Energy and National Meteorological Service Agency. Suspended sediment data was collected at Mizewa River in the watershed, used for sediment rating curve development. The land use/ land cover map was prepared using field survey and Land sat image and soil map for the watershed was prepared from Abay basin soil as per FAO world soil database. Sensitivity and calibration analysis was done from one year data. Curve number II (cn2) and USLE_P are the most sensitive parameters for flow and sediment, respectively. The model performance test indicated that the coefficient of determination (R^2) were 0.84 and 0.83 for flow calibration and validation; 0.82 and 0.81 for sediment calibration and validation, respectively; the Nash Sutcliffe efficiency (N_{SE}) were 0.81 and 0.79 for flow calibration and validation; 0.8 and 0.78 for sediment calibration and validation, respectively. PBIAS is also −18 and −13 for flow calibration and validation and −11.5 and −10.5 for sediment calibration and validation, respectively. The average monthly soil loss was estimated in July with pick suspended sediment concentration despite the pick flow and sediment yield at the outlet were recorded in August which is believed to happen due to the sediment data developed by sediment rating curve. The predicted rate of soil loss and sediment yield at the subbasins and watershed outlet were high which considered the watershed as erosion sensitive area according to Setegn (2009) and Hurni (1985) criteria of erosion sensitivity.

Key words: SWAT model, suspended sediment concentration, sediment yield, soil loss and erosion modelling.

Introduction

Soil erosion is a universally accepted environmental problem that threaten man's well-being and his overall development both in its on-site and offsite effects (Hudson 1981). According to studies, Ethiopia is described as the most soil erosion affected country in the world (Beyene 2011) with recorded annual soil loss ranging from low 16 tonnes/ha per year to high of 300 tonnes/ha per year (Hawando 1997). The Lake Tana basin, where Mizewa watershed is located, is ranked as the second serious erosion hazard area of the Blue Nile basin next to the steep slope of West and East Gojam areas; seriously affected by land degradation, soil erosion, reservoir sedimentation, flooding and sediment transport (Setegn et al. 2009). It is also ensured by eyewitnesses that siltation of waterways, reservoirs, irrigation works are critical problems now. Small-scale dams are vanishing due to siltation in the basin. Angereb water

supply reservoir is suffering from sedimentation with an estimated annual capacity loss of 3.3%. Adrako (Ebnat *woreda*) micro earth dam in Ribb watershed (vanished totally in 2008 after 7 years of its construction). Gomit (Estie), Shina (Derra) and Selamko (Debretabor) micro earth dams in Ribb watershed are losing their storage capacity by siltation in a fast rate. Despite the severity of soil erosion and its threatening impacts, studies that characterize erosion rates and erosion prone areas using small watersheds and primary data that are crucial to improve land and water resources management in the study basins are rarely done especially in the study area. Hence the focus of this study is modelling erosion at a micro-watershed scale and understands the dynamics of the hydrological process associated with erosion and its impact on water productivity.

Materials and methods

Study area description

The study area, Mizewa watershed, is located in Fogera *woreda*, northwestern Ethiopia; South Gondar Administrative Zone of the Amhara National regional state to the southeastern shore of Lake Tana in the Tana Subbasin. Geographically, Fogera *woreda* lies between $11^0 58'$ latitude and $37^0 41'$ longitudes; the *woreda* capital, Woreta, is situated on the main asphalt road, 625 km from Addis Ababa, 55 km north of the Regional capital, Bahir Dar to Gondar. Mizewa watershed is located at about 15 km east of Woreta–Gondar asphalt road at which the outlet point that provides a good point of flow monitoring, lies at $11°55'77''$N, $37°47'54''$E on the bridge of Woreta–Woldiya road, in which the Awuramba community and Woji village are elements.

Data collection and analysis

The input data used for SWAT simulation are daily river flow and sediment yield, climatic data, Digital Elevation Model (DEM) and the soil map data. River flow data were collected from IWMI developed from rating curve that provide data at two locations on Mizewa River. A daily suspended sediment concentration data was collected at the watershed outlet and Site 2 upstream from the outlet, using simple grabbing technique, analysed in the laboratory for suspended sediment concentration (g/l), from which the sediment rating curve was developed that used to develop the sediment yield data.

Sediment rating curve equation is given as: $Qs = aQ^b$ where, Qs is the sediment yield, Q discharge, a and b variables.

The climatic data includes short period data that was collected from meteorological stations established in the watershed by IWMI and long year data, collected from National Meteorological Agency Bahir Dar branch, used for user weather generator development. Digital Elevation Map (DEM), soil map data were collected from the Ministry of Water and Energy, Abay Basin office.

Hydrological and erosion modelling- the SWAT model

SWAT predicts the hydrology at each HRU using the water balance equation

$$SW_t = SW_0 + \sum_{i=1}^{t}(R_{day} - Q_{sur} - E_a - W_{seep} - Q_{gw} \quad ....2.1$$

Where SWt is the final soil water content (mm), SW_0 is the initial soil water content (mm), t is the days (days), R_{day} is the amount of precipitation on day i, (mm), Q_{surf} is the surface runoff (mm) on day i, Ea is the evapotranspiration on day i, (mm), W_{seep} is the seepage from the bottom soil layer (mm) and Q_{gw} is the groundwater flow on day i (mm).

Surface runoff Volume: SWAT calculates it using curve number method

The SCS curve number equation (SCS 1972) is given as:

$$Q_{surf} = \frac{(R_{day} - I_a)^2}{R_{day} - I_a + S} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.2$$

Where Q_{surf} is the accumulated runoff or rainfall excess (mm), R_{day} is the rainfall depth for the day (mm), I_a is the initial abstractions (surface storage, interception and infiltration prior to runoff (mm) and S is the retention parameter (mm).

Pick runoff rate is an indicator of the erosive power of a storm and is used to predict sediment loss, determined by a modified rational method embedded in SWAT.

$$q_{peak} = \frac{\alpha_{tc} * Q_{surf} * Area}{3.6 * t_{conc}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots \qquad \ldots\ldots\ldots\ldots\ldots\ldots .2.3$$

Where q_{peak} is the peak runoff rate (m³/s), α_{tc} is the fraction of daily rainfall that occurs during the time of concentration, Q_{surf} is the surface runoff (mm), Area is the subbasin area (km2), t_{conc} is the time of concentration for the subbasin (hr).

Erosion and sediment yield simulation: the soil erosion caused by rainfall-runoff and sediment yield in each HRU of the watershed with the Modified Universal Soil Loss Equation (MUSLE) (Williams 1975), a modified version of the universal Soil Lose Equation developed by Wischmeier and Smith (1965, 1978) and finally summarized in each subbasin.

MUSLE: The modified universal soil loss equation (Williams 1995) is given by:

$$sed = 11.8. (Q_{surf} . q_{peak} . area_{hru})^{0.56} . K_{USLE} . C_{USLE} . P_{USLE} . LS_{USLE} . CFRG \quad 2.4$$

Where, Sed is the sediment yield on a given day (tonnes), Q_{surf} is the surface runoff volume (mm H_2O/ha), q_{peak} is the peak runoff rate (m³/s), $area_{hru}$ is the area of the HRU (ha), K_{USLE} is the USLE soil erodibility factor (0.013 t m² hr/(m³-t cm), C_{USLE} is the USLE cover and management factor, P_{USLE} is the USLE support practice factor, LS_{USLE} is the USLE topographic factor and CFRG is the coarse fragment factor.

SWAT model set up

SWAT model setup involves project definition, watershed delineation, HRU analysis, model parameter sensitivity analysis and calibration. Mizewa watershed was delineated from Amhara DEM 30 m resolution using SWAT 2009 interfaced with ArcGIS 9.3 with discretization of 3 subbasins followed by land use and soil map preparation. The land use of Mizewa watershed was prepared from field data of land cover and Land sat image using ERDAS Imagine9.1 and GIS software. The soil map of Mizewa was prepared from Abay basin soil as per the FAO world soil data base standards (Berry 2003). Two soil classes, Haplic Luvisols (88.48%) and Eutric Fluvisols (11.52%) of the watershed area were found. The soil and soil water parameters were defined using FAO Harmonized World Soil Database (HWSD) and Soil Plant Air Water (SPAW) Hydrology softwares. The soil erodibility factor (USLE_K) was calibrated using the Hurni, (1985) adopted values (0.28 for Eutric fluvisols and 0.25 for Haplic Luvisols) (Hurni 1985). Three land slope classes and 13 HRUs were also identified.

Sensitivity analysis and model calibration and performance test

Sensitivity analysis was done using both observed flow and sediment data separately to determine sensitive parameters that were adjusted during calibration. In this particularity, a one year observed flow and sediment data (8/30/2011 to 8/31/2012), collected at watershed outlet and was used for sensitivity analysis. The model was calibrated for flow and sediment data collected at the outlet of the watershed and validated by the data with the same time series but different spatial location (site 2).

The coefficient of determination (R^2), the Nash Sutcliffe efficiency (NSE) and PBIAS were used for model performance test.

$$R^2 = \frac{\left(\sum_{i=1}^{n}(o_i - \bar{o}_i)(P_i - \bar{P}_i)\right)^2}{\sum_{i=1}^{n}(o_i - \bar{o}_i)^2 \sum_{i=1}^{n}(P_i - \bar{P}_i)^2} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots 2.5$$

$$E_{NS} = 1 - \left[\frac{\sum_{i=1}^{n}(O_i - P_i)^2}{\sum_{i=1}^{n}(O_i - \bar{O}_i)^2}\right] \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots 2.6$$

$$PBIAS = \left[\frac{\sum_{i=1}^{n}(O_i - P_i) * (100)}{\sum_{i=1}^{n}(O_i)}\right] \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots 2.7$$

Where R^2 is coefficient of determination, ENE is Nash Sutcliffe simulation efficiency, PBIAS is per cent bias, n is the number of observations during the simulation period, Oi and Pi are the observed and predicted values at each comparison point I, $\bar{o}_i$ and $\bar{P}_i$ are the average values of observed and predicted data respectively. $\bar{o}_i$ and $\bar{P}_i$ are the average values of observed and predicted data respectively.

Result and discussion

Sediment rating curve and measured sediment yield

Sediment rating curve of the watershed was developed by conducting regressions of SSC/sediment yield (Tone/day) to discharge. It is a graph of equations relating sediment discharge/concentration to stream discharge from which a one year sediment load of Mizewa watershed was estimated from the stream flow records.

The sediment rating curve of Mizewa watershed generally represents a functional relationship of the form

$$Q_s = 45.25Q^{1.798} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots 3.1$$

Where Qs is the suspended sediment in tonnes per day Q is discharge in m³/s

From the rating curve developed, a one year sediment yield (8/30/2011 to 8/31/2012) at the outlet and at site 2 was estimated that used to model calibration and validation.

Sensitivity analysis

During sensitivity analysis, 270 and 70 iterations have been done for flow and sediment, respectively; 26 and 7 parameters were tested for flow and sediment sensitivity analysis, respectively, but 10 parameters for flow and 5 for sediment were found to be the most sensitive with their effect on the simulated result when their value is changed and selected for calibration. Curve number II (Cn2) was the most sensitive parameter for flow and USLE equation support practice (USLE_P) was the most sensitive parameter for sediment.

Model calibration

Flow calibration

The curve number II (Cn2) (%), threshold depth of water in shallow aquifer required for base flow occurrence (Gwqmn) mm, base flow alpha factor (Alpha_Bf) days, channel effective hydraulic conductivity (Ch_K2)mm/hr, ground water delay (GW_Delay)days, soil evaporation compensation factor (Esco), Manning's in value for main channel (Ch_N2), soil available water capacity (Sol_Awc)mm/mm, Soil depth (Sol_Z)mm and the saturated hydraulic conductivity (Sol_K)mm/hr were the sensitive parameters calibrated for flow using both autocalibration and manual calibration methods. The coefficient of correlation (R^2) of flow calibration is 0.84 and Nash Sutcliff coefficient (N_{SE}) is 0.81, the model performs good. The PBIAS test (−18%) depicted that, the model overestimated the result but it is acceptable.
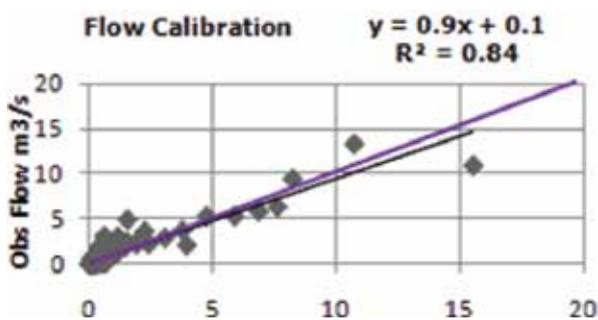
Figure 1. Scatter plot of flow calibration
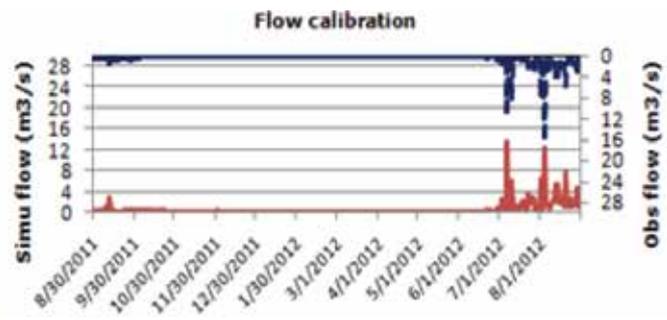
Figure 2. Line graph of flow calibration

Sediment calibration

USLE equation support practice (USLE_P), Slope, cropping practice c factor (USLE_C), linear parameter for maximum sediment yield (SPCON) and Exponential parameter for maximum sediment yield in channel sediment routing (SPEXP) are the calibrated sediment sensitive parameters with corresponding actual values of 0.85, 0.15, 0.35, 0.95 and 0.95, respectively. The coefficient of determination (R^2), Nash Sutcliff efficiency (N_{SE}) and PBIAS during calibration were found to be 0.82, 0.8 and −11.5%, respectively which are quite satisfactory for soil erosion modelling. Negative PBIAS value indicates an overestimation, though it is in the acceptable range.
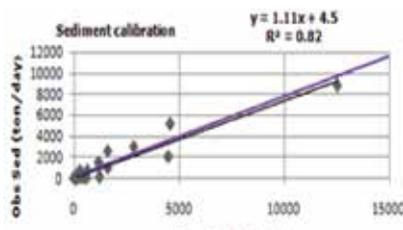
Figure 3. Scatter plot of sediment calibration
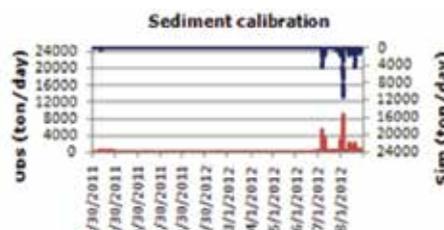
Figure 4. Line plot of Sediment calibration

The Model was also validated for both flow and sediment with the data at different spatial location but similar time series with that of calibration data. The R^2, NSE and PBIAS values are 0.83, 0.79 and −13 for flow validation and 0.81, 0.78 and −10.5 for sediment validation respectively.

Simulated soil loss in subbasins and sediment yield at the outlet

Table 1. Soil loss of Mizewa watershed at the outlet

Months	Subbasin1 Soil loss (ton/mon/ha)	Subbasin2 Soil loss (ton/mon/ha)	Subbasin3 Soil loss (ton/mon/ha)	Average soil loss (ton/mon/ha)
Sep	0.31	0.35	0.17	0.27
Oct	0.07	0.00	0.00	0.02
Nov	0.00	0.00	0.00	0.00
Dec	0.00	0.00	0.00	0.00
Jan	0.00	0.00	0.00	0.00
Feb	0.00	0.00	0.00	0.00
Mar	0.00	0.00	0.00	0.00
Apr	0.00	0.00	0.00	0.00
May	0.00	0.00	0.00	0.00
Jun	5.86	7.20	6.02	6.36
Jul	13.57	25.60	32.55	23.90
Aug	10.50	7.70	12.87	10.35
Annual (ton/ha/yr)	30.30	40.84	51.60	40.91

Table 2. Simulated sediment yield at the outlet

Months	Observed Sed. Yield (ton/mon/ha)	Simulated Sed. Yield (ton/mon/ha)	Deviation	Deviation %
Sep	0.20	0.24	0.04	16
Oct	0.03	0.02	0.00	-11
Nov	0.02	0.02	0.00	3
Dec	0.01	0.01	0.00	10
Jan	0.01	0.01	0.00	-10
Feb	0.00	0.00	0.00	14
Mar	0.00	0.00	0.00	-9
Apr	0.00	0.00	0.00	**
May	0.00	0.00	0.00	**
Jun	0.02	0.02	0.00	16
Jul	3.50	4.16	0.66	16
Aug	7.67	8.30	0.63	8
Annual	11.45	12.78	1.34	10
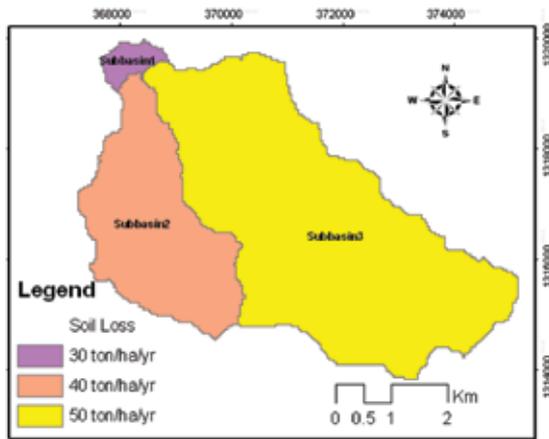
Figure 5. Map of soil loss at the subbasins

Conclusion and recommendations

Modelling was conducted extensively in a micro-watershed scale using primary data collected in the watershed with full control over it which is impractical in most of the synonymous works but vital to accurately characterize the watershed. The land use map was prepared fully from the field survey in combination with the land sat image. The soil map of the watershed was also prepared carefully calibrating all the parameters as per the FAO world soil database. The model performance test for both calibration and validation indicated that the agreement between measured and simulated result is acceptable. Mizewa is considered as erosion sensitive area as rate of soil loss (40.9 t/ha per year) is more folds of the soil formation rate of the region (11 t/ha per year), stated in many literatures. The surface runoff (335.70 mm or 24%) of the simulated precipitation is high and a very high soil water storage as simulated by the model are responsible for high erosion potential of Mizewa watershed.

The hydrological and meteorological data of the watershed used as the model input was short duration which may have increased uncertainty. Thus long duration time series records of discharge, suspended sediment and climatic variables are essential in order for a model to give appropriate simulation.

Acknowledgements

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Understanding runoff generation processes and rainfall runoff modelling in the Meja watershed of Ethiopia

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Abstract: Understanding the basic relationships between rainfall, runoff, soil moisture and ground water level are vital for an effective and sustainable water resources planning and management activities. But so far there are no hydrological studies in Meja watershed that aims to understand the watershed characteristics and runoff generation processes. This study was conducted to understand runoff generation processes and model rainfall runoff relationship in Meja watershed having a drainage area of 96.6 km^2. The watershed is one of the three research sites of International Water Management Institute (IWMI) developed in early 2010 in the upper Blue Nile Basin of Ethiopia. In the study, primary data of soil moisture, shallow ground water level, rainfall and runoff were collected from the hydrological monitoring network in the watershed. Hydrological models like HBV and RRL SMAR were configured to understand the relationship between rainfall and runoff in the watershed. Relationships between rainfall, soil moisture, shallow ground water level and discharge were developed to understand runoff generation processes in the watershed. According to one year and three months data, there is no strong daily rainfall and runoff relationship ($r^2 < 0.5$) in Meja and Kolu which is nested sub-watershed; this may be due to abstractions such as irrigation and human interventions in the watershed. Ground water level and runoff has strong relationship ($r^2 > 0.65$) in monthly basis of Kolu nested sub-watershed but there is moderate relationship of rainfall and ground water level. There is strong linear relationship of rainfall and monthly averaged volumetric soil moisture in most layers of Meja and its nested sub-watersheds. The general relationship between runoff and monthly averaged soil moisture at different layers in Meja watershed and Kolu is strong and linear. Analysis of rainfall runoff models indicated better performance of HBV than RRL SMAR model.

Key words: Runoff generation processes; Rainfall Runoff Process; Meja watershed; HBV model; RRL SMAR model

Introduction

Watershed based planning and management requires thorough understanding of the hydrological processes and accurate estimation of runoff. The determination of runoff is essential to address soil and water conservation practices in the watershed. Information pertaining to occurrence of runoff further helps in integrated soil and water management practices such as prioritizing watersheds, erosion control and selection of sites for conservation

measures. (Zemadim et al. 2011). In the study area, i.e. Meja watershed, there hasn't been any hydrological monitoring stations until recently in 2011. To study the biophysical conditions of the watershed and improve rainwater management strategies, International Water Management Institute (IWMI) pioneered the establishment of hydro-meteorological stations. There are no hydrological studies in the catchment so far that aims to understand the watershed characteristics and runoff generation processes. Therefore the purpose of this research is to understand runoff generation processes and to model rainfall runoff relationship and to get an alternative mechanism for estimating runoff, soil moisture and ground water level by using statistical analysis and rainfall runoff model.

Materials and methodology

Data collection and analysis

Rainfall data was collected from the field using nine ordinary rain gauges and one automatic weather station. Areal rainfall was determined using thiessen to account for the spatial variability. Runoff data was collected using current meter and water level recording instruments called stage boards. Water level conversion to discharge values was obtained by use of the established stage discharge rating curve. Soil moisture data was collected using profile probe called PR2/6 that measures the soil moisture at 6 depths. The nominal sensing depths in cm are 10, 20, 30, 40, 60 and 100. Rainfall runoff and soil moisture data were collected from 15 July 2011 up to 30 September 2012. Ground water data was collected from 15 July 2011 up to 30 August 2012 from three tube wells Kolu 2 (C45113), Kolu 5 (C45171) and Serity 2 (C45182). Readings of weather conditions were recorded using Campbell scientific automatic weather station. Relationship of rainfall with runoff, rainfall with soil moisture, rainfall with groundwater level, soil moisture with runoff, groundwater level with runoff was conducted using excel sheet of statistical analysis techniques such as regression analysis, Linear correlation coefficient and coefficient of determination. For the part of the modelling, HBV and RRL SMAR models have been used. In Ethiopia HBV and SMAR model are applied in highlands of Blue Nile Basin and gives good result and the models are conceptual and needs small amount of data. (Semu 2007) For this reason, the two conceptual models were selected in this study. Rainfall, runoff and potential evapotranspiration data are required for simulation.

Results and discussions

Rainfall, soil moisture, ground water level and flow relationship

There was runoff in the absence of rainfall during October, November, December, January, February and March. During this time, runoff was affected by other factors such as soil moisture and groundwater flow or base flow. Meja watershed requires only few storms at the beginning of wet season to satisfy the watershed and began producing runoff but stream flow did not immediately return to dry season levels instead it steadily decreases.

There is moderate relationship between rainfall and runoff in daily analysis. Coefficient of determination of rainfall and runoff in Meja watershed in daily basis is 0.48 and correlation coefficient is 0.7; this indicates presence of moderate relationship. In monthly basis, the relationship between rainfall and runoff is strong. According to the figure, coefficient of determination between rainfall and runoff in monthly basis is 0.94 and correlation coefficient is 0.97 which indicates strong relationship so that monthly rainfall runoff relationship is better than daily relationship.
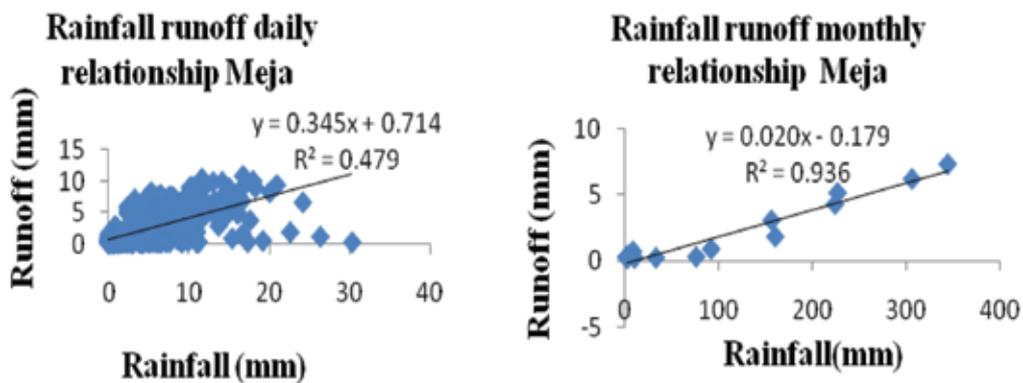
Figure 1. Daily and Monthly rainfall runoff relationship in Meja

There is strong relationship between rainfall and ground water level in Kolu. Coefficient of determination between ground water level at Kolu 2 and rainfall at Kolu site in monthly basis is 0.80 and correlation coefficient is 0.94 and coefficient of determination between ground water level in Kolu 5 station and rainfall at Kolu site is 0.45 and correlation coefficient is 0.67 which indicates strong relationship. There is moderate relationship between rainfall and ground water level in Serity. Flow has strong relationship with ground water level and soil moisture than rainfall, so that there is higher horizontal permeability than vertical hydraulic permeability and also there is high contribution of sub surface and ground water flow to the stream.

The following figure helps to visualize each layer of volumetric soil moisture measurement with rainfall amount at Meja watershed. When the depth from the ground surface increases, volumetric monthly soil moisture also increases but the relationship between rainfall and soil moisture decreases. There was high amount of volumetric soil moisture in 600 mm layer than 100 mm layer. This may be because of capillary rise of ground water at 600 mm and there is more influence of rainfall at 100 mm.
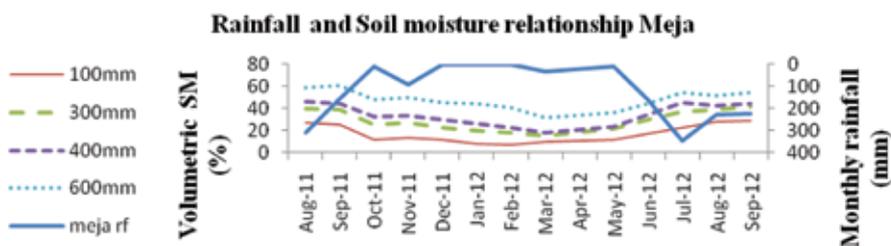
Figure 2. Rainfall and different layers of volumetric soil moisture pattern of Meja watershed

Rainfall runoff modelling

The available data set was split into two. The data range from 15 July 2011 to 5 May 2012 was used for calibration and the rest of the range between 6 May 2012 and 30 September 2012 was used to validate the model without further fine tuning the model parameters. HBV model in Kolu during calibration and verification period was performed satisfactorily and in Meja the model performed very good during calibration and verification period. SMAR model in Kolu and in Meja indicates satisfactory performance during calibration and verification period so that HBV model performed better than RRL SMAR in Meja and in Kolu.

Conclusion

Understanding the runoff generation processes in Meja and its nested sub-watersheds was conducted by using the data collected from the field and analysing by drawing the relationships between rainfall and runoff, rainfall and soil moisture, rainfall and groundwater, soil moisture and runoff, ground water and runoff, soil moisture and ground water and by applying statistical techniques such as coefficient of determination and correlation coefficient.

According to a one year and three months data, there is no strong rainfall and runoff relationship ($r^2 < 0.5$) in daily basis of Meja and Kolu which is nested sub-watershed; this may be due to abstractions such as irrigation and human interventions in the watershed.

Ground water level and runoff has strong relationship ($r^2 > 0.65$) in monthly basis of Kolu nested sub-watershed but there are some conditions that interrupted this general relationship, such as decrease of runoff when water table rises and increases of runoff when water table falls. In Kolu and Serity, rainfall has moderate relationship with ground water level. This indicates presence of high horizontal hydraulic permeability than vertical hydraulic permeability. In Kolu site, there is strong relationship of rainfall and soil moisture. In 600 mm layer, soil moisture has strong relationship with ground water than rainfall but unlike this in 100 mm layer soil moisture has strong relationship with rainfall than groundwater level. The general relationship between runoff and monthly average soil moisture at different layers in Meja watershed and Kolu nested sub- watershed of Meja is strong. There is direct relationship between runoff and soil moisture in all layers. There is strong relationship of soil moisture and ground water level in Kolu and Serity.

Further to the data analysis of understanding runoff generation processes, hydrological models like HBV, RRL and SMAR were configured to understand the relationship between rainfall and runoff in the watershed. In both models the same input data for the same period of time were used for model calibration and verification purpose. Calibration and validation of watershed parameters was done by manual and automatic procedures. Based on the efficiency criteria such as coefficient of determination and Nash Sutcliff criteria, HBV model performs better than SMAR. SMAR model couldn't capture low flow in Meja and Kolu. This in accurate result of SMAR model in Kolu nested sub-watershed that may be due to inability of the model to simulate runoff in very small watersheds like Kolu.

Recommendation

- There is not enough current meters reading, but in order to develop accurate rating curve and rating equation, there must be full measurement of flow during high flow and low flow period. Generally rating curve should be modified using full current meter reading.

- In order to know more on runoff generation processes, study on the aquifer behaviour and soil texture sample test is required.

- In order to know or confirm whether there is blockage or capillary barriers, dye tracer experiment must be done.

- There must be high temporal resolution of data measurement specially soil moisture and groundwater in order to understand influence of soil moisture and groundwater on runoff generation processes and on the understanding of hydrological processes.

- In order to get accurate understanding of soil moisture dynamics, interception and evapotranspiration conditions must be determined.

- In order to get accurate result on runoff generation mechanism or occurrence of surface runoff source areas, it is wise to conduct study using subsurface saturation and surface runoff sensors.

- Abstractions such as irrigation abstractions and other human activities must be included in the study of rainfall runoff relationship of the watershed.

- SMAR and HBV model can be applied in Meja watershed but in the nested catchments such as Kolu, HBV model is recommended.

- The models must be tested using long period of data.

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Rainwater, land and water resources management

Prioritizing rainwater management strategies in the Blue Nile basin

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Abstract: Most farmers in the Blue Nile Basin depend on unreliable rainfed agriculture and are vulnerable to climate variability. Lack of appropriate rain water management in these areas prevents smallholders from addressing the consequences of flooding during the rainy season and droughts during the dry season. This is in turn a major contributory factor to food insecurity and poverty. Addressing these issues entails designing, targeting and prioritizing rain water management strategies. In support of this, we developed a generic methodology for out-scaling and prioritizing interventions in agricultural systems. The methodology entails a multi-stage and iterative process of (1) diagnosis and selection of options, (2) characterization of the options, (3) identification of the recommendation domains and out-scaling potential of these options, (4) assessing the impacts along different dimensions and on different groups of people. This paper describes how we applied this methodology in the Blue Nile Basin. We consulted several national stakeholders and identified the 'best-bet' options as they are currently being promoted by the SLM program. A next step entailed the description and characterization of the options. Previous knowledge about bio-physical and socio-economic conditions influencing suitability was collated, while field studies were undertaken to increase our understanding of adoption of these options. Matching this characterization data with a spatial database allowed us to map the suitability and feasibility of rainwater management options and strategies. For the last stage, the impact assessment, we identified the most-likely-to-be-adopted strategy for each of the watersheds based on the feasibility maps. We translated this into maps compatible with the SWAT model. Results from the impact assessment should eventually feed back into the assessment of alternative options. The framework is applicable in many different forms and settings. The steps can be gone through qualitatively in a multi-stakeholder setting while the process can also be done quantitatively. It has a wide applicability beyond the Blue Nile Basin.

Media grab: When designing rainwater management strategies, it is important to combine multiple practices across the landscape and look at their potential impacts beyond the local level.

Introduction

Most farmers in the Blue Nile Basin depend on unreliable rainfed agriculture. Lack of appropriate rain water management in these areas prevents smallholders from addressing the consequences of flooding during the rainy season and droughts during the dry season (Johnston and McCartney 2010). As a result, farmers and livestock keepers in the Blue Nile basin face a wide variety of challenges. Amongst others, they have to deal with widespread food insecurity, high poverty levels, land degradation and declining soil fertility, low and variable yields (de Fraiture

et al. 2010). Some of these challenges are limited in their geographical spread while others are common to many smallholders in the region.

A wide variety of rainwater management practices (RWPs), ranging from soil and water conservation structures and biological measures over forestry and agroforestry to area enclosures, have been developed and promoted by the Ethiopian Government and NGOs (Merrey and Gebreselassie 2011). Many of these RMPs have been promoted with relatively low success. Too often, practices did not suit the socio-economic and institutional context of the communities resulting in high dis-adoption rates (Merrey and Gebreselassie 2011). In addition, implementing single rainwater management practices might not lead to the expected overall benefits. Indeed, some practices might have positive or negative impacts on downstream farmers. In order to takes these synergies or trade-offs into account, rainwater management should be optimized at landscape scale. They need to be matched to the local context and combined across the landscape so that together they reach the overall objective of sustainable landscape productivity while also addressing water depletion, land degradation and profitability.

Addressing the multitude of challenges thus entails designing, targeting and prioritizing location-specific rainwater management strategies (RMSs). A strategy is therein defined as a combination of different practices across the landscape. This paper describes a generic methodology supporting this process, with an example application in the Blue Nile basin.

Methods

Deciding which rainwater management practice to implement where entails a multi-stage and iterative process including the following four steps.

A first step involves the diagnosis and selection of options. Depending on the local environment, land use and current problems encountered in the landscape, different RWPs are needed. We consulted several national stakeholders and identified the 'best-bet' RWPs that are currently being promoted by the SLM program. In different landscape zones, different objectives need to be met and therefore different RMPs are required. In the uplands, the objective is mainly to increase water infiltration, while in the midlands erosion control and soil moisture maintenance is more important. In the lowlands, the focus is often on more efficient use of surface water. Regardless of the landscape zone, fodder quantity and quality need to be improved on grassland, whereas on heavily degraded land, rehabilitation is the major objective. By maximizing the potential synergies and minimizing negative trade-offs between these individual RMPs the aim is then to optimize the multiple objectives at the landscape scale. Each landscape has different characteristics and therefore the water productivity or water availability maximization might call for different combinations of RMPs. We therefore combined or 'mixed and matched' different practices and came up with a variety of potential strategies at the landscape scale.

A next step entailed the description and characterization of the options. A comprehensive database describing the selected practices in terms of their purpose and the bio-physical, socio-economic and institutional conditions that influence their suitability, adoption and success was compiled. Previous knowledge about bio-physical and socio-economic conditions influencing suitability was collated. This was mainly based on the 'Community Based Participatory Watershed Development' (CBPWD) guidelines from the Ministry of Agriculture and Rural Development produced in 2005, but complemented with livestock-based interventions. In addition, adoption studies, which responded to the knowledge gap around socio-economic factors influencing applicability of RMPs were carried out. The adoption model used was of the following form: $P(Y = 1) = \Phi(X'\beta)$ where Y is the binary variable that captures the adoption of a given RMP, Φ is the cumulative normal distribution, X the vector of explanatory variable and β the regression coefficient. The estimation of the econometric model results into an estimated coefficient $\hat{\beta}$ that can be used to predict the model:

$$\hat{y} = \Phi(X'\hat{\beta}).$$

A third step entails the delineation of recommendation domains and out-scaling potential. Based on the characterization of options, areas where the options are likely to be applicable can be identified. It is however important to note that the impact of a technology intervention is not only dependent on the suitability of the technology to the bio-physical environment, but also to the adoption pathway of this technology (Thornton et al. 2006). We therefore applied 3 consecutive sub-steps to produce feasibility maps for the selected RMSs:

a.   Creation of suitability maps: we matched the conditions favouring the successful implementation of an option, identified in step 2, to a spatially referenced database. This involved transforming the previously identified characteristics for a technology into variables for which spatial data exists or can be collected. The application of GIS overlays then results in the delineation of geographical areas where this specific strategy is likely to have a positive impact.

b.   The suitability maps are made on the basis of the bio-physical characteristics. This, however, doesn't give any information about where they are likely going to be adopted. We therefore used small-area estimation to come up with watershed level 'willingness to adopt' maps, i.e. maps that predict locations where the socio-economic criteria are more in favour of adoption of a given technology or practice. The small-area estimation technique is a technique that is usually applied for poverty mapping (Davis 2003; Hyman et al. 2005). It uses the output from the adoption studies and extrapolates results from the linear econometric model based on a farm household survey to broader scales by predicting the model with full coverage census data. We therefore made use of the IFPRI rural economic survey based on the census data, which constitutes of data at *woreda* (district) level. For market access, a zonal statistic was performed on the GIS layer with travel time to markets (Nelson 2008) to get an average at *woreda* level. Three promising RMPs for the Ethiopian Blue Nile have been chosen to illustrate the approach, namely, orchards, terraces and river diversions. These three RMPs are amongst the most promoted RMPs by GIZ and are also commonly chosen by stakeholders and communities in participatory processes.

c.   A simple multiplication of suitability with willingness-to-adopt yields practice-specific feasibility. The resulting feasibility maps indicate the likely adoption rates of the practice in suitable areas only. A geographical information system (GIS) was then used to overlay the practice-specific suitability maps with a landscape delineation layer. This allowed us to compute the total suitable area for each practice within the landscape. For a landscape to be considered suitable for a given RMP, a certain minimum threshold of suitable area needs to be met. As such suitable landscapes can be identified for single RMPs as well as combinations of RMPs, i.e. 'strategies'. The feasibility of the strategy in a suitable landscape is defined by the lowest practice-specific willingness-to-adopt.

A last step involves assessing potential impacts of alternative strategies. It is thereby important to assess the impacts (i) for different stakeholders, (ii) at different spatial and temporal scales and (iii) in terms of different metrics, such as yield increases, economic returns, food security and income, environmental sustainability, social and cultural acceptability. In order to do so, scenarios of alternative options need to be constructed and compared in reference to a baseline. For this paper, we demonstrate this by the construction of a 'most likely to be adopted SLM practices' scenario that was fed into a SWAT modelling exercise.

Results and discussion

The database describing 83 different RMPs can be found on http://nilebdc.wikispaces.com/ rainwater+management+practices. It describes each RMP in terms of their purpose and therefore indirectly links them to a specific landscape zone and an envisioned impact there. In addition, factors influencing their bio-physical suitability and likeliness to be adopted are included. Based on this information bio-physical suitability maps were constructed. A few examples are shown in Figure 1.
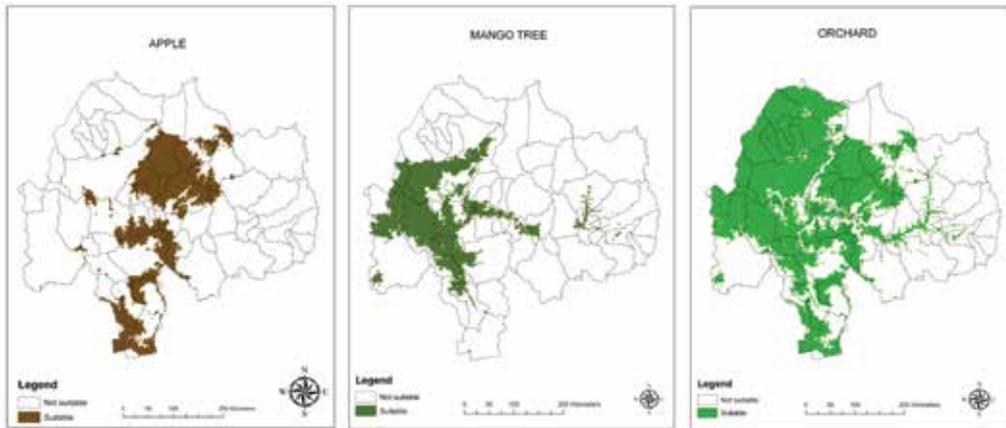
Figure 1. Suitability maps for apple trees (a), mango trees (b) and orchards (c)

The adoption studies indicated that the willingness to adopt orchards, soil and water conservation structures and irrigation from the river are influenced by very different factors. Farmers who have bigger plots size, who hire labour and have access to advise are more likely to adopt orchards. Orchards are also found further away from markets. Soil and water conservation seems to be adopted by smallholders with smaller holdings, with off-farm jobs and who hire labour. Also access to advice through the extension services increases their adoption rate. Farmers with more but smaller plots and bigger land pressure (household size / landholding) are more likely to irrigate from the river. Female headed households are less probable to irrigate from the river. As travelling time to markets increases, the adoption of irrigation from the river decreases. Figure 2 shows how these adoption factors are expressed geographically through applying the factor weights to spatially-explicit census data. An example for orchards is shown. In addition it shows the associated feasibility map, which is the result of multiplying suitability and willingness-to-adopt.
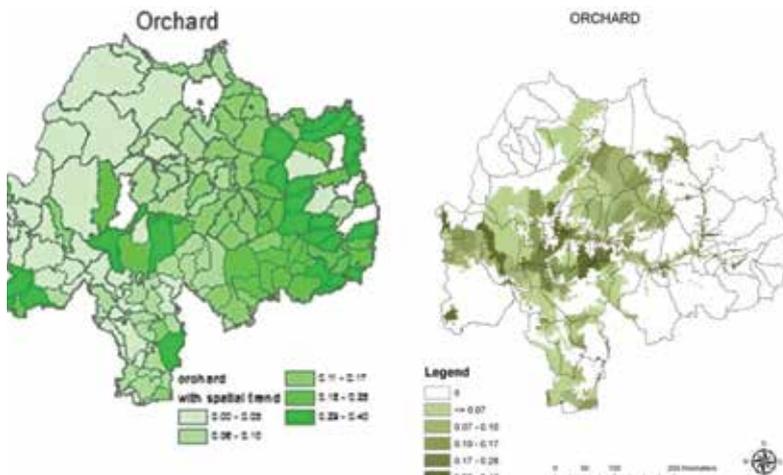
Figure 2. Willingness-to-adopt (a) and feasibility (b) maps for orchards

Based on such feasibility maps for the RMPs, the likely-to-be-adopted RMS was identified for each watershed. For more than half of the watersheds, not a single strategy, combining practices for the 3 zones, was found suitable. In the other watersheds, one of the following strategies was possible. Their location is shown in Figure 3.

1   Orchard, multipurpose tree, strip, river diversion, well, gully rehabilitation, water harvesting
2   Orchard, multipurpose tree, strip, river diversion, gully rehabilitation, water harvesting
3   Multipurpose tree, terraces, strip, river diversion, gully rehabilitation, water harvesting
4   Multipurpose tree, strip, wells, water harvesting
5   Multipurpose tree, strip, river diversion, gully rehabilitation, water harvesting
6   Multipurpose trees, orchard, terraces, strips, river diversion, gully rehabilitation, water harvesting
7   Orchards, multipurpose tree, strip, well, grazing land management, gully rehabilitation, water harvesting
8   Multipurpose tree, strip, river diversion, well, grazing land management, gully rehabilitation, water harvesting
9   Orchards, multipurpose tree, strip, river diversion, well, grazing land management, gully rehabilitation, water harvesting
10   Multipurpose tree, terraces, strip, river diversion, well, grazing land management, gully rehabilitation, water harvesting

Figure 3. Map showing the likely-to-be-adopted strategies

These strategies were then fed into the SWAT model with the aim of assessing the likely impact of full implementation of SLM-promoted landscape level strategies. The assessment will go beyond the local scale and cover potential basin-wide impacts. It will look at both short- and long-term impacts. This will provide an important piece of information to take into account for further planning. In principle, different scenarios of potentially useful practices and strategies can be taken through this process. The projected impacts of different strategies at different timescales, on different stakeholders, locally, upstream, downstream and in the overall basin can then feed into discussions about the prioritization and final design of RWM interventions.

Conclusion

In this paper, we demonstrated the application of a generic four-step framework that explicitly links the prioritization of rainwater management interventions with impact assessment, targeting and out-scaling. We've shown a quantitative implementation of the framework. The same four steps can, however, also be run through with several stakeholder groups and in either qualitative or semi-quantitative fashion. Also, the framework has an application domain far beyond rainwater management. The same generic steps of (i) diagnosis and selection of alternative options, (ii) characterization of the options, (3) identification of the recommendation domains and (4) impact assessment are important in any prioritization exercise. As such the framework provides a comprehensive step-by-step guide for designing and planning rural development interventions.

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Rhetoric vs. realities—An assessment of rainwater management planning and implementation modalities in Oromia and Amhara regions, Ethiopia[5]

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Abstract: This paper is the first in a series of three interrelated papers and focuses on planning and implementation modalities of Rainwater Management (RWM) Strategies. It is part of the NBDC project '*On integrated RWM strategies—technologies, institutions and policies*'. The project is underpinned by the recognition that integrated RWM needs to combine technologies, policies and institutions and be developed through multi-stakeholder engagement to foster innovation. Three *woredas* were selected for the research—Jeldu and Diga in Oromia Region and Fogera in Amhara Region. The research on planning and implementation of RWS is guided by the hypothesis that there is a gap between available policy and guidelines and specific planning and implementation procedures. Research findings conclude that RWM planning and implementation is still rather top–down and technology-oriented instead of people-centred. Local processes are not in place to take account of different livelihood strategies and constraints, cultural, social or institutional dynamics as well as power relations and gender issues. The research concludes with six recommendations, largely aimed at Ethiopian policymakers and implementing agencies, suggesting an alternative approach to RWM planning and implementation processes which would help improve the impact, sustainability and local ownership of interventions. The paper outlines RWM strategies which are developed with true participation of farmers and other stakeholders; are based on evidence of what works and why; take into account specific socio-economic and ecological niches; work across relevant sectors; and support local opportunities for innovation.

Introduction

Smallholder rainfed farming is the backbone of the Ethiopian agriculture sector, the dominant contributor to national GDP and at the heart of the country's current national economic growth strategy. Considerable potential exists for enhancing food production and rural livelihoods through better rainwater management (RWM)—interventions which enable smallholder farmers to increase agricultural production by making better use of available rainwater while sustaining the natural resource base in rainfed farming systems.

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5. This paper is a summary of a longer research report authored by the same authors and published in the CPWF Research for Development Series, No. 5.

Ethiopia has invested extensively in RWM interventions, in particular soil and water conservation and afforestation, over the last 40 years, but often with disappointing impact for multiple reasons. Given this limited success in natural resource conservation, a new approach is clearly needed, but what should it be? This question is at the centre of the Nile Basin Development Challenge (NBDC) program, part of the larger 'Challenge Programme on Water and Food'. The two key elements of the NBDC approach are (1) viewing RWM as a landscape-scale issue, whereby watersheds are conceived as socio-agro-ecological systems with social, economic and institutional networks that may cross-cut hydrological boundaries; and (2) recognizing that improving RWM successfully and on a sustainable basis, requires a focus on institutions as well as technologies and a new approach to planning, implementation and monitoring of interventions.

The NBDC program is implemented through five related projects. The Nile 2 project (N2), '*On integrated RWM strategies—technologies, institutions and policies*', is centred on field research in three pilot learning sites. The starting point for research in N2 is that integrated RWM strategies need to combine technologies/practices, policies and institutions and need to be developed through innovative approaches that bring together different stakeholders. Because policies and institutions can foster or discourage the adoption of productivity-increasing, resource-conserving strategies by farmers, the project also examines the extent to which policy change and institutional strengthening and reform could be combined with new technologies to spur widespread innovation.

Research questions

A central mechanism for stimulating innovation within the NBDC is the use of '*innovation platforms*' at district and national levels. The diagnosis of RWM planning and implementation modalities was in part designed to inform the development of innovation platforms (see also Paper by Aklilu Amsalu et al. and by Beth Cullen et al.) by providing a baseline understanding of existing RWM strategies and institutional arrangements at local level. There are various elements to this. First, we were interested in how RWM interventions are planned and implemented at local level and how different actors are involved in this process. Second, we were interested in what government's role in planning and implementing RWM means for local 'innovation capacity'. Finally we wanted to understand the diversity of local livelihood strategies and how these might intersect with formal and informal approaches to RWM in our study sites.

Approach and methods

Three *woredas* (districts) in the Blue Nile Basin of Ethiopia were selected for intensive study as part of the larger project. These are Jeldu and Diga in Oromia Regional State and Fogera in Amhara Regional State.

Jeldu (West Shewa Zone, Oromia Region) is characterized by a mixed crop–livestock system. Potato and barley are dominant crops especially in the highland part of the *woreda*. Some of the current drivers of change in Jeldu include land degradation (soil erosion), seasonal migration of youth to towns and market constraints.

Diga (East Wollega Zone, Oromia Region) is characterized by a mixed crop–livestock farming system with a lowland-dominated agro-ecology including maize, sorghum, coffee, vegetables, mango and sesame. In comparison with the other research sites, natural vegetation is still comparatively widespread, although deforestation is increasing. In-migration and movement from the highlands to the lowlands in order to access fertile farmland are important driving forces.

Fogera (South Gondar Zone, Amhara Region) is characterized by a mixed crop–livestock farming system. Rice production is an important strategy for market integration in Fogera, accounting for more than 20% of the arable land. Expansion of rice production, enhanced markets and conflict over grazing land are some of the many drivers of change in the *woreda*.

Data collection, analysis and write-up of site reports were carried out between November 2010 and December 2011. The final analysis and writing has been done during 2012 and has been influenced and informed by subsequent research in the three sites.

In each of the three study *woredas*, five *kebeles* were identified for in-depth primary data collection. *Kebeles* were sampled purposively to capture a range of agro-ecologies (highland/midland/lowland), presence/absence of RWM interventions and high/low levels of natural resource degradation.

A broad suite of methods and tools for data collection was used, including:

- Community resource mapping and participatory timelines;

- Focus group discussions (male and female groups separately for livelihoods analysis and a mixed group focusing on innovation capacity; each group captured a range of ages and wealth status);

- Key informant interviews with a broad range of stakeholders; and

- Secondary data collection from *kebele* and *woreda* offices.

At each site, a team consisting of researchers from a nearby Agricultural Research Centre and a regional University (Adet Research Centre and Bahir Dar University for Fogera, Bako Research Centre and Wellega University for Diga and Holetta Research Centre and Ambo University for Jeldu) were responsible for carrying out data collection, analysis and write-up of site reports. The research teams were supported by researchers from ILRI, IWMI, ODI and Addis Ababa University, who also developed question guides and tools for data collection and analysis, provided feedback on site reports and wrote the synthesis report (Ludi et al. 2013).

Findings

Past interventions, politics and policy in relation to RWM

Land degradation in Ethiopia presents a major challenge in terms of agricultural productivity, food security and rural livelihoods. Various land and water management programs have been implemented on farms and community lands over the past four decades, undertaken by government agencies in collaboration with national and international organizations. However, success to date has been limited. Reasons identified include: top–down planning and implementation; standardized intervention packages based on inadequate scientific and technical knowledge; use of quota systems; lack of an integrated or systematic watershed approach; limited consideration of variations in agro-ecological conditions; and coerced participation with little regard for the views of the people (Merrey and Gebreselassie 2011: 54). These programs were therefore widely perceived as government-imposed activities (Keeley and Scoones 2000: 103). Although participating farmers received food rations in return for their work, the structures created often served no positive purpose and at the end of the Derg government, a large proportion of these were either deliberately destroyed or abandoned (Merrey and Gebreselassie 2011: 54).

When EPRDF came to power in 1991, the new government committed itself to a decentralized political system and a new Constitution. Since then there has been a gradual shift towards more participatory community-driven approaches, increased emphasis on 'awareness raising', consultation and building projects from the 'bottom–up' (Keeley and Scoones 2000: 107). Added to this was growing talk of 'sustainability', 'integrated natural resource management' and a commitment to involve farmers in agricultural development activities, including an appreciation of their knowledge (ibid. 108). Current RWM programs are now taking a more systematic approach with an emphasis on consultation and planning on a watershed basis. Soil and water conservation or sustainable land management programs also focus more on enhancing farmers' incomes and food security. As Merrey and Gebreselassie (2011: 55) assert, 'Improved water and land management should be a means to improving peoples' lives, not an end in itself'. However, 'top–down blueprint approaches remain pervasive with agricultural extension largely focused on technology transfer' (*ibid.*, 41). Programs remain quota driven and focused on the promotion of 'best practice' packages. There is also considerable

evidence that many of the soil and water conservation structures promoted to date have low or negative returns and are often not perceived positively by farmers (Merrey and Gebreselassie 2011).

Planning of RWM

The rationale for focusing on planning and implementation of RWM was based on the recognition that a number of national and regional policies and strategies in relation to RWM exist. These include very detailed guidelines, for example for participatory community watershed management (e.g. Desta et al. 2005). However, planners, in particular at lower administrative levels, do often not have sufficient tools and skills available to engage at a landscape level for effective integrated and multi-sectoral planning and implementation of RWM. In sum, a major hypothesis guiding this research was that there is a gap between available policy and guidelines and specific implementation. The baseline study also assessed the effectiveness of RWM planning in terms of its being evidence-based, tailored to social and ecological niches, cross-sectoral and participatory.

The research concluded that there are five issues with the current planning process that need to be addressed if improving RWM is to become an integral part of sustainable agricultural development:

1   The discrepancy between policy and practice. While participation is a central plank of policy and land users are considered to be the main driver of planning and implementation of RWM at local level; in reality plans are too often guided by quotas supplied by higher-level administrative units.

2   Notions of participation. There is a very different understanding of the word 'participation' among different actors. Often, participation in the context of RWM planning and implementation tends to mean mobilizing farmers to implement something, rather than providing incentives to engage in voluntary collective action and involving them in decision-making (Harrison 2002). Although at *kebele* level, planning processes attempt to be participatory and land users are involved in discussing problems and identifying priority RWM interventions, these plans do not necessarily get picked up sufficiently in planning of activities at higher administrative levels.

3   Incentives for DAs. Although at local level, DAs try to reconcile as much as possible plans developed at local level with those plans received from the *woreda* to take account of local realities, in the end *woreda* plans with set quotas tend to be approved for implementation because quotas are used for performance monitoring. If DAs do not meet their quotas there are repercussions for their performance rating and their prospects of promotion. In general, DAs could play a more effective role in local planning if they were better connected with higher levels of government in terms of support and two-way communication.

4   Failure to anticipate conflicts. Because plans are developed without sufficient recognition of local realities, conflicts at local level can arise. Most prominent are examples related to small-scale irrigation where downstream water use was insufficiently recognized, but also conflicts within watersheds when, for example, areas previously used for grazing livestock were closed off for rehabilitation, increasing pressure on existing grazing land.

5   Missed opportunities for sustainability. Developing plans without sufficient local participation misses opportunities to tap into local cultural practices and institutions which would make it easier to implement RWM and could enhance the sustainability and ownership of interventions.

Overall, the research has identified a key dilemma: national plan, output targets and a generally top–down planning focus vs. devolution, decentralization and participation in planning and co-development of innovations at the lowest possible level. This needs to be resolved if RWM interventions are to be owned by farmers, be sustainable and make a meaningful contribution to improved environmental management and better livelihoods. These features of the planning process have direct implications for the way in which RWM is implemented and the effectiveness of interventions on the ground. This is clearly evident in the discussion of findings on implementation which follows below.

Implementation

Despite several decades of intensive investments in RWM and natural resource management across Ethiopia, the impact on livelihoods and natural resources quality and quantity in many areas is rather disappointing. This should not distract, however, from the numerous sites across the Ethiopian Highlands where RWM and NRM has been more successful and is reported to have led to increasing household wellbeing, increasing community resilience and improved availability of a variety of natural resources. Many land and water management technologies and approaches are not achieving their full impact, mainly because of low levels of ownership and sustainability, but also because where degradation of natural resources is less advanced, the benefits of natural resource conservation are more difficult to detect. Approaches to NRM and RWM have historically been technology-oriented and top–down in approach with insufficient regard for the needs, aspirations, constraints and livelihood realities faced by farming communities. In addition, many RWM investments were seen as an end in themselves rather than a means to achieve improved household wellbeing and increased community resilience—as has been recognized by some programs such as 'MERET'. It is of critical importance that RWM strategies adopt a people-centred approach which takes into account local livelihood strategies and constraints, cultural, social and institutional dynamics as well as power relations and gender issues. It is essential to gain an understanding of these aspects because they feed into development planning for sustainable land use and livelihoods.

The research found that there is a long tradition of RWM interventions in the study sites, particularly those implemented by farmers on their own land. Other interventions which are more labour and cost-intensive and need coordination across several farms or a watershed are much less likely to be sustainable. There are at least six reasons for the poor sustainability of these interventions:

- Lack of relevance to local priorities. As discussed, plans are not necessarily congruent with local needs assessment.

- Weaknesses in technical design. In some cases, DAs lack the required technical skills, or do not have access to information about the range of possible technologies or practices.

- Lack of voluntary collective action. Compulsory campaigns to implement RWM do not inspire ownership and maintenance after construction.

- Lack of clear governance arrangements for interventions on communal land. Although farmers would not necessarily be motivated to sustain interventions on their own land unless they perceived them to have clear value (both direct financial and non-financial), the weak enforcement of rules for management of communal resources (and low penalties for violations) creates a disincentive for individuals to invest in managing these better.

- Poor follow up and monitoring. There is very little follow up by DAs and *woreda* experts as performance monitoring is based on outputs, i.e. quota achievement and not on outcomes or sustainability/longevity of interventions.

- Focus on isolated technical interventions. There is typically a narrow focus on isolated technical interventions, such as bunds or ponds and very little attention to supporting needed interventions such as changing patterns of water use or land management.

This research did not assess in detail the performance of particular interventions and practices and their contribution to enhanced crop productivity, water productivity or livelihoods, nor issues around land management and how this could be integrated with the application of specific RWM technologies. These are key issues which need to be better researched and understood in order to develop more effective RWM strategies and implementation approaches. Strengthening monitoring and evidence collection functions of *kebele* and *woreda* officials on the impact and effectiveness of RWM interventions would make a huge contribution.

Livelihood issues and RWM

Our research has highlighted many specific livelihood issues and several underlying institutional processes which need to be considered if RWM activities are to be successful. Key among these is active involvement of community members in the process of RWM activities right from the start. Development agenda and interventions introduced by outsiders may conflict with local knowledge and priorities which address specific needs and circumstances. Community perspectives should therefore be integrated with plans of action for long-term sustainability. Better understanding of current knowledge and practices, coping mechanisms, capacity for innovation and mechanisms for community mobilization, as well as understanding the reasons for resistance to certain interventions, could lead to a much better understanding of how, where and what to promote when it comes to RWM.

There are potentially exciting opportunities for co-development of plans and interventions which incorporate local perspectives as well as develop farmers' capacity to innovate. Care must be taken not to idealize indigenous knowledge, but multi-stakeholder participatory processes involving external agents and community members can be used to assist local communities to organize and assess their own knowledge and resources whilst also identifying and integrating appropriate outsider knowledge and technologies. Further, it is 'not narrow disciplinary research that is necessary for addressing land degradation and its impacts, but interdisciplinary communication and transdisciplinary collaboration (Ludi 2004: 387). This includes multi-disciplinary research, research partnerships between researchers and research organizations from Ethiopia and from abroad and genuine collaboration of researchers and the concerned society. Not focusing on either participatory approaches or scientific methods alone, but combining the two knowledge systems equitably will be the key to finding options for sustainable land management and sustainable livelihoods.

However, it is also important to bear in mind that not everyone may want to share their knowledge. People may have good reasons for not wanting to make their perspectives and knowledge known or widely available. People in rural areas work long and exhausting hours and have little time to carry out project tasks, particularly if they cannot see tangible benefits. If farmers already have to do compulsory work on resource conservation activities such as watershed protection or tree planting, as well as being required to attend political meetings, 'sensitization' sessions and trainings, they may not be willing to participate in additional planning events. This is particularly relevant if their experiences of 'participation' are already negative. Therefore, it will be important to develop mechanisms for collaboration between various stakeholders which enable different knowledge and perspectives to be exchanged, shared and translated into action. As Teshale et al. (2001) highlight, 'While devolving the responsibility for resource planning and management to local communities may be a necessary condition for meeting the objective of sustainable development, it is important—particularly in the case of developing countries—that this is complemented with capacity building initiatives at local and national levels in an integrated framework' (2001: 34).

Conclusions and recommendations

The study concludes with six recommendations, which are largely for Ethiopian policymakers and implementing agencies. They are also currently being tested and demonstrated through an action research process in the three research sites under the NBDC program and the results are being shared through various consultative platforms at local, regional and national levels. Together they represent an approach to improving the RWM planning and implementation processes in rural Ethiopia such that impact, sustainability and local ownership of interventions are prioritized and strategies are based upon meaningful participation of farmers and other stakeholders, a growing base of evidence about what works and why and increasing opportunity for true innovation at all levels. Although such processes are not always straightforward and this does represent a major shift away from current practice, some of the foundations of this approach are in fact already present in existing policies and implementation guidelines.

The six main recommendations are:

- Shift the focus of targets from outputs to outcomes;

- Enhance monitoring and evidence collection on RWM with a focus on impact and sustainability;

- Revitalize and capitalize on the DA system;

- Strengthen local institutions' roles in RWM;

- Move towards more meaningful participation;

- Open lines of communication to foster innovation capacity.

By the completion of the NBDC, we hope to have provided evidence that adoption of these recommendations can contribute significantly to achieving the long-term goals of sustainable productive agriculture and natural resource conservation in the Ethiopian Highlands; they can be implemented at a large scale; and their implementation will result in positive benefits at landscape and watershed as well as community and farm levels.

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Integrated termite management in degraded crop land in Diga district, Ethiopia

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Abstract: Termites are a major pest in the semi-arid and sub-humid tropics. They pose a serious threat to agricultural crops, forestry seedlings, rangelands and wooden structures. In Ethiopia the problem is particularly serious in the western part of the country, specifically in Wollega Zones of Oromia Region. In the past, several attempts were made to reduce damage caused by termites, including extensive termite mound poisoning campaigns. These interventions not only had a negative effect on the environment, but were also largely ineffective. Based on previous work in Uganda showing that adding organic matter to the soil diverts termites from the plant and functions as alternative feed source, a project was commenced by the Challenge Program for Water and Food (CPWF). In partnership with IWMI and Makerere University, ILRI and Wollega University took the lead in working with local stakeholders to identify sustainable solutions to address the termite problem in Diga, Ethiopia. The research consisted of two major activities; 1) a baseline study to better understand the relation between land use, water, termites and local institutions; and 2) the design and testing of identified interventions. The baseline findings indicated that termite damage depends on various biophysical and socio-institutional factors, which requires an integrated, but also targeted, termite management approach; two termite species are locally recognized, but level of knowledge highly varies among farmers within and between *kebeles*. Various trials were designed for on-farm experimentation using cattle manure and crop residues as alternative feed source for termites in combination with other cultivation techniques. The result obtained indicated that application of cattle manure and crop residues increases the organic matter content of the soil by 24.5 and 13.9%—grain yield of maize by 38.8 and 16.7% and reduces termite count per plant by 29.6 and 21.6% as compared to the control treatment, respectively. The results are in line with farmers' own evaluation of the trials. Results and implications are discussed.

Media grab: Integrated Termite management provides a promising approach to rehabilitate degraded crop–land; it is based on local and scientific knowledge and requires active involvement of local stakeholders, especially farmers.

Introduction

In Ethiopia, termites are one of the major threats to agricultural crops, forestry seedlings, rangelands and wooden structures. The problem is severe in the western part of the country including Wollega area (Abdulahi et al. 2010). In the past, several attempts were made to reduce damage caused by termites, including extensive termite mound

poisoning campaigns. These intervention approaches not only had a negative effect on the environment, but were also largely ineffective. In addition, farmers also employed several cultural practices to reduce the damage caused by termites. These control measures includes queen removal, flooding and smoking. However, none of these cultural practices are effective so far to control termites especially for that of non-mound forming once.

A multi-partner research project was designed to understand the problem along with the wider biophysical and socio-economic contexts and identify appropriate combinations of technical and institutional options for control through a process of shared learning and innovation. To this effect, a baseline study was conducted to understand the relation between the termite problem and land use; also perceptions and knowledge of termites, the severity of the problem and control strategies were explored. Based on the findings of the baseline study and previous work in Uganda (see Mugerwa 2007; Peden et al. 2009), participatory on farm trials were designed to test various options to minimize termite damage and improve soil fertility. This paper summarizes the main findings and implications of the baseline study and the on farm trials.

Methods

The study site, Diga District, is located in East Wollega Zone of Oromia Regional State to the west of Addis Ababa, Ethiopia. In case of rainfall pattern, the *woreda* is predominantly mono modal and it receives rain from mid-March through November. The dry season extends from December to Mid-March. According to the Diga *woreda* Agricultural office termites are problem in 13 of the 21 *Kebeles* in the *woreda*. Two *kebeles* namely, Lelisa Dimtu and Bikila were selected for the study, with Bikila representing the upstream catchment and mid-highland and Lelisa Dimtu representing the down-stream and lowland areas.

For the baseline study, primary and secondary data were collected using various tools at *woreda* and *kebele* levels. Key informant interviews (KIIs) were conducted with *woreda* level key staff of office of agriculture, Wollega University and Mekane yesus church. Similarly, KII were conducted at *kebele* level with the development agent, the *kebele* chairman, *kebele* manager and elders. At each *kebele*, one focus group discussion (FGD) was conducted with 8–12 farmers to understand their knowledge, attitude and practices in terms of the termite problem, its causes and consequences, copping strategies, controlling mechanisms etc. Also a household survey (HS) was conducted among 28 households in each *kebele* (56 in total) to collect household level quantitative data. Besides, secondary data was collected through document and literature review. The qualitative data of the baseline were analysed through, categorization, summarization and interpretation in line with the research questions while the quantitative data was analysed using SPSS. Simple descriptive statistics, using percentages and means, were employed to summarize the quantitative data.

Based on the baseline data and previous work on termite management in Uganda, integrated termite management trials were designed to evaluate the effect of cattle manure and crop residues on soil fertility and termites' damage. Maize, the main staple crop in the area was used as the test crop. The experiment consists of six treatments arranged in randomized complete block design; treatments were replicated on 6 farms in Lelisa Dimtu and 4 farms in Bikila, with each farm being used as a replication. Treatments consisted of: control, intercrop only, crop residue, crop residue + intercrop, cattle manure and cattle manure + intercrop. Haricot bean was used as intercrop. The spacing used for maize was 75 cm between rows and 25 cm between plants for both sole and intercrops and for haricot bean the spacing was 25 cm between rows and 12.5 cm between plants. The net plot size was 5m × 6m (30 m^2). The space between two plots was 2 m. Crop residue (sorghum) was applied during planting under soil by chopping with the rate of 2 t ha^{-1} (6 kg per plot). Similarly for cattle manure half the recommended rate which is 2 t ha^{-1} (6 kg per plot) was applied during planting in rows. Recommended rates of inorganic fertilizer DAP 100 kg / ha (0.3 kg/plot) and Urea 200 kg/ha (0.6 kg/plot) was applied at planting and at active growth stage of maize plant, respectively. Farmer groups of 10–15 farmers were established in each *kebele* to discuss progress at regular intervals and to evaluate the trials in each farm according to various socio-economic criteria (i.e. labour requirement, presence of weed, cost of required materials and accessibility of materials, termite infestation and yield.

Data for the trials were recorded for agronomic (crop and soil fertility) and termite data to evaluate the overall performance of the trials. Biological data recorded was subjected to analysis of variance table (ANOVA) by SAS software version 9.01. Treatment that showed significant differences were separated by least significant differences (LSD) at 5% significant level. Matrix ranking (from least to highly preferred) was used by the farmers groups to evaluate the trails of the selected farms in their *kebele* for each socio-economic criteria.

Result and discussion

Relation between termites, land use, water and livelihoods

Based on the baseline survey, the problem of termite is very serious in the study area for the last 10–15 years and its severity increases over time. Farmers mentioned several reasons for increased termite infestation in the area; soil degradation, deforestation and overgrazing were mentioned as main ones (see Table 1).

Table 1. Farmers' perception on causes of termite infestation based on the baseline survey (n=56)

Factors	Kebele		Total
	Bikila	Lelisa Dimtu	
Soil degradation	12 (23.5%)	16 (33.3%)	28 (28.3%)
Deforestation	13 (25.5%)	11(22. 9%)	24 (24.2%)
Over grazing	8 (15.7%)	12 (25.0%)	20 (20.2%)
Population pressure	6 (11.8%)	6 (12.5%)	12 (12.1%)
Drought	6 (11.8%)	2 (4.2 %)	8 (8.1%)
God	3 (5.9%)	1 (2.1%)	4 (4.0%)
Excess rainfall	3 (5.9%)	0	3 (3.0%)

*More than one answer per respondent possible.

Farmers reported that there is feed shortage in dry season due to termite damage and shortage of grazing land, while there is overgrazing of the existing rangelands due to uncontrolled grazing. According to farmers, overgrazing not only affects the feed availability in the area but also reduces the population of black ants which feed on termites. Farmers use cattle manure for improving soil fertility. However, due to the decrease in the number of livestock, the amount of manure incorporated into the soil is decreasing which also affects the soil fertility in the area. Farmers reported that due to the effects of termites, the land was becoming less productive over the years and cost of production was also increasing due to increased demand for inorganic fertilizers to improve the poor soils.

The impact of termites on soil fertility and the degradation of land are closely related to limited access to and use of water resources. Rainfall in the area is mono-modal in nature and farmers rely on this rain for crop production. However, farmers' livelihoods are threatened by the variability in the amount and distribution of the rainfall. Even-though there are a number of permanent rivers that cross the district there are no irrigation facilities in the *woreda* except for few farmers who practice small scale irrigation. In addition there is limited rain water harvesting practices in the *woreda* to conserve the excess rain in the rainy season for both animals and crop production. Recently soil and water conservation practices started in the district to rehabilitate the degraded lands and to conserve the soil from runoff. Still these practices are not sufficient to conserve the soil due to the sloppy nature of the area.

The decreases in crop production and productivity due to land degradation added up with the direct damages caused by termites on crops have affected farm income and household food security. The frequently mentioned reasons for facing food shortage in ranking order were poor soil fertility (22%), termite damage (21%), land shortage (12%), oxen shortage (10%) and wild animal damage on crops (7%). Moreover, termites do not only threaten food security, but also affected farmers' security directly though damaging their houses.

Farmer perceptions of termites and control methods

Farmers differentiated two types of termites. The local names given to the two types of termites are *Werrartu* (meaning *'invaders'* in Afan Oromo*)* and *Marimartu* (meaning *'common to the area'* in Afan Oromo*)*. The *Marimartu* have mounds and stay in some places whereas, the *Werrartu* are non-mound forming and migratory type. However, only about a third of them knew that there are different types of termites. About a third believed that termites improved soil fertility as the mounds help decompose crop residues. Some farmers also reported that the queen can be used for livestock fattening purposes. In general, famers in Lelisa Dimtu (lowland) had better knowledge of termites compared with their colleagues in Bikila. This could be related to the knowledge and information diffused in Lelisa Dimtu *kebele* during the Derg time as the area was a state farm at that time.

It was reported by farmer and key persons that termites damage almost all crops and trees. However, there is a difference in terms of tolerance to termite attack. For instance, maize, teff, coffee, sugarcane and eucalyptus are reported to be most susceptible. On the other hand, sorghum, finger millet, sesame and common bean, are more tolerant. It was reported that tuber and vegetables have higher tolerance to termite attack and that improved crop varieties are more susceptible than the local ones.

From soil fertility management practices farmers reported that corralling, compost and manure were the most effective practices not only for improving soil fertility but also to decrease termite infestation. Crop residues are used for various purposes including feed, soil fertility, cooking, lighting and house construction.

The farmers employed some cultural practices to reduce the damage caused by termites. These control measures includes queen removal, flooding and smoking. However, none of these cultural practices are effective so far to control termites especially for that of non-mound forming once. In addition to these control measures chemicals were used by the agricultural office of the *woreda* in areas where the severity was very high. But, the farmers reported that they have limited access and capacity to use chemicals. Moreover, chemicals are usually not effective in the long term (termites come back) and have negative effects on the environment.

In the study area there are formal and informal institutions that have role in soil, land and termite management. The formal structure of *woreda* government has various departments dealing with soil and water conservation, land administration and pest/management. There are also development agents at *kebele* level who are part of this formal structure and organize the implementation of these activities. At community level there are formal institutions such as cooperatives and local institutions such as Edir, Equb, Debo, Wenfel etc. These institutions can potentially support various collective action and resource sharing and provision arrangements such as finance, labour and information etc.

Although termite management is mainly seen as a male activity, in general women have a substantial role in termite related practices, such as soil fertility and land management activities. Especially, in terms of the use of manure and crop residues, it is often women who decide. Moreover, many of these practices are applied on crop land directly near the homestead, which is often the domain of the woman; hence it important to keep these gender aspects into account when designing interventions.

Testing the effect of cattle manure and crop residues

Based on the findings of the baseline discussed above, on farm trials were designed with the involvement of local stakeholder to test various options that have been practised by farmers in the area and other options proved to be effective in other areas. The trials are planned to be conducted for two consecutive years. The following section summarizes the findings of the first year trials.

From the result obtained application of cattle manure and crop residue improves the fertility of the soil, grain yield and reduces termite count per plant (see Table 2). Organic matter content of the soils increased by 13.9 and 24.5% following the application of crop residue and cattle manure, respectively. High significant differences ($P<0.01$) were obtained among treatments for days to maturity and grain yield of maize. The grain yield of maize was improved

by 16.7 and 38.8% due to crop residue and cattle manure application as compared to no application, respectively. Similarly, days to maturity of maize crop were increased by 16.4 and 22.0% due to addition of crop residue and cattle manure as compared to their control treatment, respectively. On the other hand, application of crop residue and cattle manure reduces the number of termites observed on the crop at maturity by 21.6 and 29.7% as compared to the control treatment, respectively. The results indicate that adding cattle manure is preferred over adding crop residues; it may be that cattle manure does not only act as alternative feed source for termites, but—compared to crop residues—also provides easier access to nutrients (see higher level of organic matter) to the plant resulting in more vigorous and healthy plants. Intercropping had a positive impact on organic matter and yield when compared to the control and increased yield when applied in combination with crop residues, but in combination with cattle manure it reduced yield. In general, intercropping seems to have a positive effect on the termite number per plant. This last aspect is difficult to explain as the intercrop was supposed to be tolerant to termites and have a negative effect on termite number—unless, termites are pushed away from the tolerant intercrop (haricot bean) towards the more sensitive test crop (maize).

Table 2. Effect of treatments on organic matter content (%OM), days to maturity, grain yield (GY, t/ha) and termite count per plant.

Treatment	% OM	Days to Maturity	GY (t/ha)	Termite count/plant
1. Control	6.92	98.7	5.66	37
2. M+IN	7.2	112.0	7.03	40
3. M+CR	7.83	113.8	6.02	23
4. M+CR+IN	8.25	122.5	7.57	35
5. M+CM	9.7	121.3	9.58	20
6. M+CM+IN	8.67	131.8	8.92	32
Mean	8.09	116.7	7.5	31.2
LSD	1.74	20.7	1.68	NS

Where, M- maize, IN-intercropping, CR-crop residue, CM-cattle manure, LSD-least signficant diffrence.Ns- non-signficant, OM- organic matter

Based on various socio-economic criteria, farmers also evaluated the trials themselves through ranking (see Table 3). Farmers ranked the trials in the following order of preference from highly preferred to least preferred: cattle manure + intercropping, crop residue + intercropping, cattle manure, intercropping, crop residue and control, respectively. In cases, cattle manure and crop residue with intercropping were selected as best treatment for grain yield. So among the criteria's used for the evaluation by the farmers' grain yield, termite damage and availability of the treatment materials were the best for ranking the treatments.

Table 3. Average ranking by famers of treatments according to various socio-economic criteria

Treatment	Labour	Costs	Access to materials	Termites infestation	Yield	Overall assessment
1. Control	6	6	1	2	5	6
2. M+IN	5	5	2	2	4	5
3. M+CR	4	4	5	1	5	5
4. M+CR+IN	2	3	6	6	3	3
5. M+CM	3	2	3	5	2	4
6. M+CM+IN	1	1	4	6	2	2

Where, M- maize, IN-intercropping, CR-crop residue, CM-cattle manure; 1: highly prefered; 6: least preferred

The data obtained from the farmers' evaluation are in general in line with the earlier research findings. Because cattle manure application and addition of crop residue improves the grain yield of the crop if there is high decomposition through organic matter improvement. However, the results do show that intercropping of maize with common bean needs high labour to intercrop to implement on large scale production. In addition for the women, application of crop residue (sorghum Stover) is not appropriate treatment than cattle manure because it is used as a main source of fuel in the area.

Conclusions and recommendations

Termites are symptoms of land degradation and poor soil fertility, which is caused by a variety of factors (overgrazing, deforestation, soil erosion). To address this, we need to address the underlying factors and an ecosystem approach towards termite management and rehabilitation of degraded land.

The results of crop trials indicate that adding cattle manure and crop residue increase yield and reduce termite numbers per plant. Adding cattle manure seems more effective compared to the adding crop residues. However, we need more insight in the underlying mechanisms to explain the relation between reduced termite numbers and increased yield, as well as the difference between adding cattle manure vs. crop residues. More work should be done in the future on intercropping on how it affects the termite population, possibly by using different types of intercrops (see Sileshi et al. 2005 for different effects on termite damage based on legume species). Furthermore, we need to realize that data are based on a limited set of farms over one season. More replicates are needed before strong conclusions are drawn.

The farmers' preferred options based on socio-economic criteria seem largely in line with the biophysical data. However, more information is needed on the trade-offs between resource at the farm level (e.g. in terms of labour, money, manure, use of crop residues). Also the interactions between farms and between crop and grazing land may are important issues to take into account.

Integrated Termite Management approaches will need to take both biophysical and socio-economic factors into account. This requires capacity building among both farmers and extension workers in terms of the underlying factors and how they are related. Furthermore, farmers need to have an incentive to work on land degradation and termite infestation; we need to make clear what the costs are and what they can gain by working on these issues. Increased income resulting from higher production for feed or markets/food can work as a 'pull' factor that makes other things happen. The added value of 'feed' to cattle through better management of grazing areas may be an incentive, which lead to more cattle and manure, which in turn can be applied to crop land and improved food security

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Sustainable intensification of small-scale agriculture in the upper Blue Nile basin: Multi-criteria optimization of rainwater management strategies

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Abstract: Using a multi-criteria optimization technique for system analysis, this paper quantitatively characterizes baseline production activities, resource management and environmental relationships of the mixed crop–livestock farming system at the Jaba micro-watershed, upper Blue Nile Basin, to get insights that inform sustainable intensification of small-scale agriculture. The paper characterizes and models system relationships at a landscape scale under the business as usual land use and resource management scenario (including rainwater management), in the light of social, economic and environmental sustainability indicators (employment, farm income and sediment loss and water generation, respectively). The analysis is based on optimization technique that weighs the socio-economic and environmental costs and benefits of current land use and resource management practices at spatial and temporal scales, using farm level survey data. The results show that, under the business as usual scenario, the crop sub-sector will remain the major source of farm income and rural employment. Agricultural income, though trending positively, will not significantly drift from its current level, indicating the limited possibility for rural income growth from agricultural activities under the current pattern of land use, resource management and socio-economic circumstances. Land has the highest shadow price (while such price is low for labour), showing that land scarcity, unlike abundant labour, limits the possibility for extensive farming and agricultural income growth in the area. The environmental cost of agricultural income growth is considerable, showing a clear trade-off between agricultural income growth and the natural resource base that supports agriculture. The socio-economic and biophysical consequences of alternative innovations towards such end can be simulated by introducing respective scenarios into the quantified baseline relationships. The social, economic and environmental consequences of alternative rainwater management strategies can be simulated for technology selection, prioritization and targeting.

Key words: Sustainable intensification; integrated innovations; system analysis; landscape; optimization; upper Blue Nile.

Media grab: There is a need for land use change in the Upper Blue Nile Basin to get poverty reducing and ecologically sustainable outcomes from small-scale agriculture.

Introduction

Rainfed areas have potential for intervention schemes that can be operated locally and targeted at smallholder farmers to improve livelihood resilience (FAO 2008). One of such schemes is rainwater management (RWM), which refers to capturing, storing and using rainwater for productive and consumptive purposes (Rockstrom et al. 2007). Rainwater management provides adaptive mechanism to upgrade rainfed agriculture and to improve livelihood resilience in areas where water related constraints to food production are important sources of risk (Oweis and Hachum 2009). It improves resilience of rural livelihoods in the event of climate change and rainfall variability. Provided that it is complemented with other interventions, there is optimism that better management and use of rainwater provide a dependable option for productivity growth and livelihood resilience in rainfed agriculture, including reduction in crop failure risk due to short dry spells (de Fraiture et al. 2009; Zemadim et al. 2011).

Rockström et al. (2010) suggest for a paradigm shift in agricultural water management in favour of a focus on a catchment scale, which offers the best opportunities for water-related investments to build resilience in small scale agricultural systems and to address trade-offs between water for food and other ecosystem functions and services. There is a growing shift of focus towards watersheds (landscapes) as entry points for water governance and management. As a result, watersheds have become increasingly useful planning and intervention units for integrated management of land and water resources (Argent et al. 1999). Integrated watershed management (addressing social, economic and ecological aspects as multiple objectives pursued in a watershed) has recently become a useful concept of analysis for environmental management and sustainable development (Pastakia and Oza 2011). The approach promotes the use of soil, water and vegetation resources to obtain optimum and sustainable benefits without undermining the capacity of the natural resources and the ecosystem to regenerate and sustain itself. The concept underscores the importance of considering the economic, social and ecological costs and benefits in assessing alternative management strategies.

Method

Optimal RWM strategies in a landscape can be identified using multi-criteria optimization techniques which identify and quantify RWM strategies that enable achieving multiple objectives in a landscape. Optimization techniques applied to natural resource management permit identifying the optimal values for decision variables (land use types and soil and water management practices) that lead to the achievement of a management goal (Quintero et al. 2006). The optimal relationships and benefits identified for a base period can serve as baseline scenarios to be compared against simulated results for alternative management scenarios.

This paper applies the concept of landscape approach to RWM in a crop–livestock mixed rainfed agriculture as adaptive strategy to build livelihood resilience. Using a multi-criteria optimization technique, the paper quantifies optimal socio-economic and biophysical relationships for Melka micro-watershed located in the Blue Nile subbasin, Ethiopia. Alternative RWM scenarios can be developed and their impacts can be simulated *ex-ante* to guide decision-making at farm, community, watershed and policy levels. The costs of environmental services, such as payment for environmental services, can be estimated to inform management options. The paper contributes to the environmental management and climate change adaptation literature by applying the concept of landscape approach to RWM for upgrading rainfed agriculture.

The optimization model uses income, employment, sediment and water generation as important socio-economic and biophysical indicators to address the social, economic and environmental objectives pursued in a watershed. It is necessary to optimize indicators on each of these objectives in order to make production, development and livelihoods sustainable. Technologies and livelihood development strategies that fail addressing such issues are unlikely to be sustained in the long-run. The model was conditioned in such a way that available land resource in the three zones of the watershed is fully utilized for agriculture, grazing and tree planting purposes as important land use types. Consequently, the model optimizes activities on 7.94 ha in the upper zone, 8.80 ha in the middle zone and 3.92 ha in

the lower zone (a total of 20.66 ha). Such land sizes in each zone at which the model optimizes are the same as the land size used in the model's land size input. This is an indicator that the model reproduces the baseline situation and is valid for simulation.

Results and discussion

At optimal level, the baseline activities in the three zones of the micro-watershed generate a total net income of USD 404,790 over a 10 years period (2011/12–2020/21) for the rural dwellers. Agriculture will continue as the major source of rural income. Annual income generated from agriculture will be irregular, though trends positively. Crops are the major sources of agricultural farm income, followed by dairy and meat products. Income generated from dairy and meat products is more stable than that from crops. Moreover, agriculture will remain the major source of employment opportunities. The sector will generate a total of 3847 employment opportunities for contracted labour over the ten years period.

Production activities will generate water and sediment as positive and negative externalities, respectively. The annual average level of water and sediment produced as a result will remain steady around 13235 mm and 2538 (t/ha), respectively. As can be seen, the environmental cost in terms of sediment loss is high, showing a clear trade-off between income generation and resource conservation.

The baseline results in the Jaba micro-watershed show an important feature that income generated in the coming ten years will basically remain where it is today, except minor rise. Maintaining the current crop–livestock mixed farming system and land use pattern will ensure achieving only the current income level, with no meaningful shift to high level rural income. Under such scenario, per capita income level will perhaps decline as a result of a rising population size in the area. This suggests the need for alternative management practices that enhance productivity growth in the micro-watershed.

The optimal net farm income level for the business as usual scenario provides a benchmark for comparative analysis purpose on the feasibility and marginal impact of alternative management practices. The optimal levels of farm income and environmental externalities imply that alternative management practices in the micro-watershed (rainwater management, soil conservation, land use change etc.) will be economically feasible and environmentally sustainable if the net income they generate exceeds or is equal to the baseline income level and the negative (positive) environmental externalities are reduced to below (increased to above) the baseline average.

Income growth in a watershed can be constrained both by resource limitations and high production costs. Acquiring additional resources and undertaking extra activities are costly to farmers. Identifying the resources that constrain income growth in a watershed and the real value of such resources helps devising mechanisms that help cost reduction and productivity growth per unit resource. Shadow prices provide estimate of additional costs required to acquire a unit of extra resource (land, energy, protein etc.) and to produce a unit of extra output (crop, milk, meat etc.). Accordingly, the scarcest or constraining resources tend to have high shadow prices. Such resources have high limiting role against income growth. Provided that the optimization model is based on real socio-economic and biophysical data, the calculated shadow prices reflect the real market value of resources and cost of activities.

Land is the scarcest resource and most important constraint in Jaba micro-watershed. As a result, income growth in the micro-watershed will be limited because of land scarcity. Acquiring a hectare of land for different activities costs USD 23813 in the upper zone, USD 17495 in the middle zone and USD 24272 in the lower zone. Labour is not a limiting factor of production in the area and has a shadow price USD 1.77/man-day. Energy supply (shadow price USD 145/thousand megacal) is more limiting than protein supply (shadow price USD 0/ton) for livestock production. Meat production is more expensive than dairy production, which, in turn, is more expensive than crop production.

Conclusion and recommendation

Optimization results for the business as usual scenario in Jaba micro-watershed mimic reality on the ground. They show that agriculture will continue as the major source of rural income in the coming years and as the major employment provider. Much of agricultural income will be generated from the crop sub-sector, followed by income from the livestock sub-sector. Agricultural income will be sustained around its current level, without showing major positive change. Agricultural income enhancing efforts in the area will be constrained by land shortage as the most important limiting factor. This is reflected in the high shadow price for land, while it is low for labour. This suggests the need for interventions that promote intensive (land saving) agriculture combined with more labour use. Potential impact of alternative RWM and land use practices as intensification and climate change adaptation strategies can be assessed by extending the analysis of this paper to such scenarios.

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Evaluation of rain water management practices for sediment load reduction in the (semi) humid Blue Nile basin

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Abstract: With the construction of the new Renaissance Dam at the Ethiopian Sudan border, reducing sediment load in the Blue Nile is becoming increasingly important. Past attempts of decreasing sediment concentrations have been only partially successful. In this paper, we will examine the temporal distribution of sediment generation within small watersheds and systematically compare this with the observed sediment concentration at various watershed scales using the Parameter Efficient Distributed (PED) model. The model is based on the concept that runoff and erosion are generated mainly from areas that become saturated during the rain storm. These runoff source areas consist of shallow soils over a dense hardpan or areas where the water table is close to surface. Saturated areas are also prone to gullying. Simulation of watershed evaluations indicate that most erosion occurs from degraded areas, from temporarily saturated agricultural land and from gullies in the saturated bottomlands near the river. In addition, we found that the annual runoff and sediment concentrations increased significantly in the Blue Nile basin at the border with Sudan. The model results would indicate that rehabilitating the degraded and bare areas by planting permanent vegetation and preventing further incision by gullies would be extremely effective in decreasing the sediment concentrations. Reduced tillage would likely result in less sediment transport but would increase use of pesticides and the cattle cannot graze freely anymore. Tentatively, we conclude that decreasing upland erosion might decrease sediment concentration downstream, since there is relatively little sediment storage in the main rivers of the Blue Nile basin.

Introduction

The Nile is the longest river in the world. Without the Nile, major portions of Sudan and Egypt would run out of water. Eighty five per cent of the roughly 85 km^3 (on the average of 25 mm over the whole Nile basin) entering Lake Nasser originates from the Ethiopian highlands.

The highlands are becoming more populated and in an attempt to increase prosperity (and thereby assure food security), the Ethiopian Government is both encouraging management practices for increased rain water productivity and increasing irrigated agriculture. Consequently, there is a growing anxiety downstream in Sudan and Egypt about climate, landscape and human induced changes in discharge and sediment load especially with respect to the newly built Grand Ethiopian Renaissance Dam and other planned dams on the Blue Nile.

Several researchers have utilized past rainfall and discharge records as an effective method to study the effect of climate on hydrology (Yilma and Demarce 1995; Conway 2000; Tekleab et al. 2010). Conway, (2000) and Tesemma et al. (2010) indicated that there was no significant trend in the basin wide annual, dry season, short and long rainy season rainfall in the past 40 years. However using statistical tests by Tesemma et al. (2010) and Gebremicael et al. (2013) researchers, found that the discharge during the rainy phase of the monsoon for the Blue Nile at the Sudanese border have increased during the last 50 years. In addition Gebremicael et al. (2013) reported a significant increase in sediment concentration in the past 30 years.

Since it appears that sediment concentration are increasing in time, the objective of this paper is to examine the cause of this increasing trend in the Blue Nile basin and propose effective management practices to reverse this trend. In order to understand erosion at different scales, three watersheds with vastly different areas were investigated: Anjeni (113 ha), Gumara (1500 km^2) and the Ethiopian Blue Nile (18,000 km^2)

Study areas

The **Anjeni** watershed covers 113.4 ha with a mean annual rainfall of 1690 mm with a low variability of 10%. Agriculture is the dominant land use activity. Starting in 1986 and continuing in 1987, graded Fanya-Juu (throw uphill) bunds were installed to terrace the hillslopes. Rainfall, discharge and sediment concentration were made available by ARARI for the period of 1 June 1984 to 31 December 1993.

The **Gumara watershed** is located east of Lake Tana. Its drainage area is about 1500 km^2. Discharge and precipitation data are available for the period of 1981 through 2005. Rainfall was on the average 1400 mm/year and varied between 1100 mm/year in 1983, 1984, 2002 and 2004 and 1700 mm/year in 1994 and 1997. Twenty seven sediment samples were taken for the period of 1982 to 2005 to determine the relationship between sediment load and discharge.

The18,000 km^2 **Blue Nile River** emanates from Lake Tana and flows nearly 850 km to the Sudan-Ethiopian border, with a fall of 1300 m. From approximately 30 km downstream of Lake Tana and into Sudan, the river flows through deep rock-cut gorge. Annual average precipitation varies from nearly 1400 mm north of Lake Tana to over 1800 mm on the higher elevations.

Rainfall-runoff-and erosion simulation

Parameter changes in time in mathematical constructs (i.e. models) relating rainfall, runoff and sediment concentrations can show whether the landscape is changing affecting these parameters. This is different from statistical tests in which rainfall and discharge are considered independent of each other.

The runoff and erosion model used here is the Parameter Efficient Distributed (PED) model that was validated by Steenhuis et al. (2009), Tesemma et al. (2010) and Tilahun et al. (2013a, b) for the Blue Nile Basin. In the PED model, various portions of the watershed become hydrologically active when threshold moisture content is exceeded. The three regions distinguished in the model are the *bottom lands* that potentially can get saturated, *degraded hillslopes* and *permeable hillslopes*. Each of the regions is the lumped average of all such areas in the watershed. In the model, the permeable hillslopes contribute rapid subsurface flow (called interflow) and base flow. For each of the three regions,

a Thornthwaite Mather-type water balance is calculated. Surface runoff and erosion are generated when the soil is saturated and assumed to be at the watershed outlet within the time step. The percolation is calculated as any excess rainfall above field capacity on the permeable hillslopes. Zero and first order reservoirs determine the timing when the percolate reaches the outlet. Based on the work of Hairsine and Rose (1992) and Ciesiolka et al. (1995), sediment concentrations are obtained as a function of the surface runoff per unit area and a coefficient that decreases linearly from the transport limit at the start of the rainy monsoon phase to the source limit after about 500 mm rainfall. Subsurface flow is sediment free except for the Gumara. Equations are given in Tilahun et al. (2013a, b).

Results

In order to fit the PED model, we varied only the fractional areas of the degraded and permeable hillsides. The remaining landscape and erosion parameters were kept constant (Table 1). The input parameters (Table 1) were fitted to a portion of the rainfall, discharge and sediment concentration record.

Anjeni: In the 113 ha Anjeni watershed, Fanya-Juu bunds were installed during starting at the end of 1985. We divided up the record in four periods: *I*) prior to Fanya-Juu bunds installation in 1984–1985; *II*) during installation 1986–1987; *III*) immediately after Fanya-Juu installation was completed in 1988 and 1989 and terraces were likely being formed and *IV*) post installation from 1990 through the end of 1993. Cumulative discharge and sediment load for each of the periods is depicted as the red line in Figures 1a and 1b, respectively, clearly showing that sediment losses were small only from July 1986 through the end 1989 shortly after the graded Fanya-Juu were constructed.

The first step in the application of the PED model was fitting the landscape parameters that were kept constant (Table 1). We took arbitrarily the period of 1984 through 1985 for calibration and found as expected almost the same values as Tilahun et al. (2013 a, b) for the same watershed.

The fractions of the degraded and permeable hillsides were fitted with the PED model for three of the four periods omitting period II when the bunds were being constructed in 1986 and 1987. Depending for what period the hillslope parameters were calibrated, various line colours were used for the predicted discharge (Figure 1a) and sediment cumulative load (Figure 1b).

Period I (1984–1985) prior to Fanya Yuu installation: Using the hillslope parameters in Table 2 where 15% of the area is degraded and, 50% of the area contributed to the interflow and baseflow (second column Table 2), the observed cumulative discharge (Figure 1a) and the sediment load (Figure 1b) in 1984 and 1985 were simulated well with a Nash Sutcliffe value of 0.86 for daily discharges for 1984–1986 period. Consequently, the total area that contributed water to the gage is 67% (consisting of 65% hillside, Table 2 and 2% saturated area, Table 1). The rain falling on remaining 33% of the area is leaving the watershed either by evaporation or deep percolation. Applying the two hillslope fraction of 15 and 50% to the remaining periods, the PED model over- predicted the soil loss greatly especially for the period 1988–1989 after the graded Fanya-Juu were installed and terraces were being formed (purple line in Figure 1b). The daily discharge was marginally over-predicted (purple line Figure 1a) but consistently with decreased Nash Sutcliffe values of 0.68 and 0.79. In other words, sediment load was reduced by the installation of the Fanya-Juu and only for a few years after installation.

Period III (1988 and 1989) immediate after installation of Fanya-Juu: Construction of the bunds (Figure 2a) began in 1986 and it took some time before they were all installed as indicated by the high sediment concentrations early in 1986. In 1988 these bunds were effective. Accordingly, in order to fit the cumulative discharge and soil loss data for 1988–1989, we assumed that the Fanya-Juu became quite effective as all water was infiltrating and sediments was deposited behind the Fanya-Juu bunds. Decreasing the fraction of degraded area to zero (Table 2) and increasing the permeable hillsides to 56% (Table 2) in the discharge in a good fit (Figures 1a) with Nash Sutcliffe value of 0.91 for the period 1988–1989 This parameter set fitted the observed cumulative load (black line in Figure 1b) amazingly well without changing any of the sediment transport properties in Table 1. This hillslope parameter set for any other period reduced the Nash Sutcliffe

values for daily discharge to 0.79. By comparing black line (indicating what the loss would have been in the case that the Fanya-Juu practices would have remained effective) and red lines in Figure 1 we find that the Fanya-Juu and the terraces that formed behind them reduced the discharge marginally and sediment load in the watershed significantly.

Period IV (1990 to 1993) post installation of Fanya-Juu We are not sure why in 1990 the discharge increased slightly compared to the period before and sediment concentrations became much higher (compare the black and green line in Figure 1. The increase in runoff could be simulated by assuming that a greater portion (10%, Table 2) of the watershed started to contribute to surface runoff. This increase in degraded area could also simulate the increase erosion (Figure 1b, green line). There are two likely scenarios why this might have been the case. The sediment that was not in the runoff 200 ton/ha (obtained by adding the difference is soil loss between the observed soil loss (red line) and what the soil loss would have been if no intervention would have taken place (the purple line) for periods II and III in Figure 1b) or 13 cm of soil over the whole watershed in 4 years (1986–1989) filled up some of the storage behind the bunds. Figure 2b shows the terraces as they are today in the watershed. A second scenario is that the extra water that infiltrated and increased the water table and saturated the soil in the bottom part of the watershed (as shown by Tebebu et al. 2010 and 2013) can result in gully formation and results in soil loss. This is corroborated by the local informants who indicated that the gully started around this time. Now in 2013, this gully has greatly expanded (Figure 2c, note the size of the people)!

Gumara: For the 1500 km^2 Gumara watershed, similar to the Anjeni watershed, we divided the rainfall and discharge data into several consecutive periods, kept the landscape parameters constant (Table 1), increased the portion of degraded land area and decreased the permeable hillsides by a comparable amounts (Table 3). The periods considered are 1981–1985, 1987–1992, 1994–1999 and 2000–2005.

The watershed parameters in Table 1 for the Gumara were in general the same as for the Anjeni watershed with the exception of a much shorter half-life of the first order linear reservoir than for Anjeni and in the same order as other watersheds in the region . In addition, the sediment transport capacity of the degraded areas was much higher and might have been caused by the sandy nature of some of the sediments in the river which were suspended during high flow. The degraded area was increased from 5% in 1980's to 15% in the 2000s (Table 3). The daily discharge values had Nash Sutcliffe values varied between 0.52–0.73 and are equivalent with those obtained with SWAT (Setegn et al. 2009). Monthly values Nash Sutcliffe were above 0.80. The predicted and observed sediment losses for the two periods are reasonably close (1981 to 1992, Figure 3a, red line) and (1993–2005, Figure 3b, red line) with good R^2 values and a slope close to 1. As for Anjeni, we did not change the sediment transport properties to obtain these results. By using the hillslope parameters of last period (2000 to 2005) for predicting the discharge in the two first periods, the Nash Sutcliffe values are either larger or remain the same (last row, Table 5) and the sediment concentration are greatly over predicted (blue line in Figure 3a) and similarly by using the calibration for the early period with 5% degraded area, the sediment concentration are severely under predicted (blue line Figure 3b)

Blue Nile at the Sudan Border. We have reported the predicted recharge and sediment concentration for the Blue Nile at the Ethiopia Sudanese border before (Tesemma et al. 2010; Steenhuis et al. 2013; Tilahun et al. 2013a b) and only a short summary is presented. Similar to the Gumara watershed, we found that the best fit between predicted and observed discharge amounts was obtained by increasing the fraction of degraded area in the watershed from 10% in 1964 to 18% in 1993 to 22% 10 years ago in 2003 (Steenhuis et al. 2013). In addition, similar to the results above, the PED model predictions provided a good fit for the 10 day averaged sediment concentrations (solid green line in figure 4a for 1993 and solid black line for 2003 in Figure 4b) with Nash Sutcliff values greater than 0.94 (Steenhuis et al. 2013). Sediment concentrations are increasing because by interchanging the calibrated degraded areas (i.e. using the 22% degraded area for 1993), the observed sediment concentration are over-predicted in 1993 (black line, Figure 4a) and under predicted in 2003 (green line, Figure 4b).

Discussion and conclusion

It is obvious from the results that the discharge and soil loss are increasing with time throughout the Nile basin (Figures 1, 3 and 4). This is consistent with the findings of Gebremicael et al. (2013) who had access to the 1972 and 2003 daily sediment concentration data at the Egyptian Sudan border in which the concentrations in the beginning of the rainy season are 2 to 3 times greater in 2003 than in 1972.

Given that the degrading areas are responsible for large amount of the soil loss, we will define now management practices that can be employed to reduce soil loss. According to the analysis of Gebremicael et al. (2013), 1% of the Blue Nile basin is bare and these are obvious the very hotspots that should be treated first. These hotspots likely include gullies and hillsides where all top soil is removed. Tebebu et al. (2013a, this proceeding) lists measures that can be tried to halt gully expansion. The bare land area where the top soil is removed is a likely candidate for planting trees that can in time improve the soil. However, these bare areas cover only 1% of the land while the amount of degraded land in the PED model varied between 5–20%. So where do the other degraded areas occur in the landscape producing runoff and soil loss? It is likely that the agricultural land that have a hardpan at very shallow depth surface and farmers have installed the local graded furrows to carry off the excess water are likely an additional source of erosion. Since there is more rain than evaporation during the rainy season, the only way to prevent saturation of the top soil is to open the old flow paths through the soil as proposed by Tebebu et al. (2013b, this proceeding) or potentially by adding charcoal and growing deep rooted crops as proposed by Bayabil et al. (2013, this proceeding). It is obvious that terraces are not effective in humid climates when they are not drained.

Reduced tillage or 'no-till' might reduce soil loss since the transport of the soil will remain at the lower source limit However, this practice is unlikely to be popular given the importance of crop residues for fodder and fuel, in addition to the inherent increase in pests associated with no-till and the implications for pest management.

This indicates why sediment concentrations have been increasing over time despite the investment of millions and perhaps billions of Ethiopian birr in soil and water conservation practices. The structural Fanya-Juu practice tested here in the Anjeni watershed was effective for less than four years; thereafter it contributed only slightly less sediment than before (Figure 3). Fanya-Juu terraces may in fact be more successful than other structural practices installed in Ethiopia, because as Haile et al. (2006) reported, 40% of all erosion is caused by practices installed incorrectly.

By understanding the cause of the increase in sediment concentrations, we can devise measures to reduce the load (Merrey and Gebreselassie 2011). The above analysis finds that the increase in degraded lands is related to the increase sediment loads. On the other hand, Gebremicael et al. (2013) and many others correlate land use change seen in satellite imagery to an increase in sediment load. These findings may be mutually reinforcing, because as shown by Bayabil et al. (2010) land use is directly related to the watershed hydrology. For example lands that become degraded and cannot support crop growth become grass land (Hanson et al. 2004). Findings of Balthazar et al. (2013) in the Ethiopian highlands support our hypothesis that degraded land are an important driver of soil loss: 'Statistical analyses have shown that 41% of the observed variation in SSY (area-specific sediment yield) can be explained by surface vegetation cover (expressed as a percentage of poorly vegetated areas)…..' Gebremicael et al. (2013) also noted that the degraded areas increased during their 40 year period of observation. Finally, our findings are in agreement with Garzanti et al. (2006) that write based on their findings and that of Nyssen et al. (2004):' Sediment loads of the Nile may thus have doubled during the past century, largely as a consequence of increasing land degradation in Ethiopian highlands, fostered by extensive deforestation by a rapidly expanding population'.

Reduced tillage or 'no-till' might reduce soil loss since the transport of the soil will remain at the lower source limit. However, this practice is unlikely to be popular given the importance of crop residues for fodder and fuel, in addition to the inherent increase in pests associated with no-till and the implications for pest management

Finally, in many river basins reducing the upland sediment load has no effect on the siltation of reservoirs, because the eroded sediment from the upland areas that remains in the river channels, is still prone to transport during storm flow. The Blue Nile in Ethiopia is exceptional in terms of the large volume of sediment transported. This is due

largely to high gradients which carry all its sediment downstream, as soon as sufficient rainfall in the rainy monsoon phase transforms the almost dry river channels to flood conditions. As our results show, this results in sediment concentration peaks before the peak of the discharge in all of the three basins, of greatly different scales, that we modelled. If sediment was not limiting in the river channel, sediment concentration and peak concentration would have coincided for the Gumara and the Blue Nile at the Sudan border.

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Hydraulic properties of clay soils as affected by biochar and charcoal amendments

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Abstract: Understanding soil hydraulic properties is crucial for planning effective soil and water management practices. A study was conducted to evaluate the effects of different biochar and charcoal treatments on soil-hydraulic properties of agricultural soils. Biochar and charcoal treatments were applied on 54, undisturbed soil-columns, extracted from three-elevation ranges, with replications along three transects. Daily weight losses of freely draining soil-columns and soil moisture contents, at five tensions, were measured. In addition, field infiltration tests and soil analyses for particle size distribution, bulk-density and organic carbon content were conducted. Moreover, five-year event precipitation data, from the watershed, was analysed and exceedance probability of rainfall intensity was computed. Results show treatments reduced soil moisture contents, for most of the cases. However, treatment effects were significant only at lower tensions (10 and 30 kPa) and within two days after saturation ($p<0.05$). On the other hand, relative hydraulic conductivity (K_r) coefficients, near saturation, of amended soils were higher than the control. Acidic to moderately acidic soils with high average clay (42%) and low organic carbon contents (1.1%) were dominant. Infiltration rate ranged between 1.9 and 36 mm/h, with high variability (CV = 70%). At the same time, storms with short duration (< 15 min) and high average intensity (6.3 mm/h) contributed for 68% of annual precipitation (1616mm/year). Dominant soil properties and rainfall characteristics suggest that infiltration could be a major problem on considerable number of fields, in the watershed. This implies, on such fields, constructing physical soil and water conservation structures alone will not reduce runoff and erosion effectively, unless soil infiltration and permeability rates are enhanced through integrated soil management approaches.

Media grab: Biochar and charcoal amendments can ameliorate soil-hydraulic properties of degraded soils. However, treatment effects may vary depending on dominant soil textural composition and organic carbon content.

Introduction

Despite continuous soil and water conservation efforts, since the 1980s, land degradation and drought (Amsalu and Graaff 2006) remain major threats to the predominantly rain-fed, smallholder, farming livelihood in the Ethiopian highlands. In most areas, efficiencies of soil and water conservation structures were below satisfactory This was mainly due to inappropriate planning (Mitiku and Stillhardt 2006, Kato et al. 2011) mainly physical conservation structures. In addition, there were no previous studies conducted, with the objective of developing integrated soil management practices, tailored to address ecological and hydrological constraints.

Recently, biochar and charcoal additions on degraded soils have been suggested to improve soil physical and hydraulic conditions. In light of this, recent studies reported charcoal and biochar amendments significantly improve soil physical and hydraulic properties of degraded soils: such as moisture retention (Lehmann et al. 2006; Laird et al. 2010; Spokas et al. 2010; Karhu et al. 2011) and hydraulic conductivity (Asai et al. 2009).

However, negative results, from biochar and charcoal addition were also documented; such as reduced moisture retention (Tryon 1948) and crop yield (Kishimoto and Sugiura 1985). This indicates that the effect of biochar and charcoal, on soil physical and hydraulic properties, is highly affected by inherent field soil properties: such as textural composition and soil carbon levels (Tryon 1948, Rawls et al. 2003).

As a result, this study was conducted with two major objectives (1) to determine dominant soil physical and hydraulic properties in the watershed; and (2) to evaluate the effects of biochar and charcoal amendments on soil-hydraulic properties of cultivated soils.

Methods

This study was conducted in the Anjeni watershed, in the northern Ethiopian Highlands, at 10°40' N and 37°31'E geographic coordinates. The watershed area covers 113 ha with elevation ranges between 2407–2507 m.

Column studies were conducted, on 54 soil-cores, to evaluate the effects different biochar and charcoal amendments on moisture retention and drainage characteristics of agricultural soils. Six soil-cores were extracted adjacently from three elevation ranges (Low, Mid and High) with replicate transects (n = 3) along the toposequence. Five treatments (two biochars and three charcoals) and untreated control were randomly applied to soil-cores; Measured data include daily weights, from saturation to drying, of 54 undisturbed soil-columns (amended with five biochar and charcoal treatments and non-amended control) and soil moisture contents, at five tensions, using a pressure plate apparatus. In addition, infiltration tests (at 48 locations), laboratory analyses, on 50 soil samples, for selected soil properties (particle distribution, bulk density, organic carbon and pH) were conducted. Soil moisture retention characteristic curves (SMRC), effective saturation (S_e) and relative hydraulic conductivity (K_r) were predicted using the van Genuchten (1980) closed form soil-hydraulic equation. Moreover, five-year event precipitation data, from the watershed, were analysed and dominant storm characteristics (duration and intensity) were calculated. Similarly, watershed soil depth data was obtained from Mengistu D.A. (unpublished).

Statistical analyses and model optimization were performed using R statistical programing software for Windows, version 2.15.2. Moisture data, from saturation to dryness, violated normality and equal variance assumptions of parametric statistical test procedures; as a result, data sets from each tension were analysed separately, using Two Way ANOVA tests, with treatment (main factor) and elevation (block factor). Moreover, TukeyHSD mean comparison tests were performed for factors with significant variance tests. Non-linear least square (nls) curve-fitting package, in R, was used during model optimization.

Moisture retention data, observed at different pressures, were fitted to a set of equations according to the van Genuchten (1980) soil characteristic model.

$$\theta_{(\psi)} = \theta_r + (\theta_s + \theta_r)\left[\frac{1}{1+(\alpha\psi)^n}\right]^m \qquad (1)$$

$$S_e = \frac{\theta_{(\psi)} - \theta_r}{\theta_s - \theta_r} \qquad (2)$$

$$K_r = S_e{}^l\left[1 - \left(1 - S_e^{\frac{1}{m}}\right)^m\right]^2 \qquad (3)$$

where θ*r* and θ*s* are residual and saturated gravimetric soil moisture contents (g/g) and θ*(ψψ)* and $(\psi)(\psi)$ are moisture content and tension respectively with $\alpha\alpha$*, n and m* are curve-fitting parameters. $\alpha\alpha$ is proportional to the inverse of air entry value; and *n and m* are related to the pore size distribution of soils. *m* was assigned a value of one minus the inverse of *n* (i.e. *m = 1-1/n*). $S_e S_e$ and $K_r K_r$ represent effective saturation and relative hydraulic conductivity of soils respectively. $K_r = k/K_s K_r = k/K_s$, where *k* is the unsaturated conductivity and $K_s K_s$ is the saturated hydraulic conductivity. ll is a dimensionless model fitting parameter assigned a fixed value of 0.5.

Results and discussion

Soil properties show considerable variation along the elevation gradient. Soil depth varied the most (CV = 37%) and differences between mean soil depth values, along the topo-sequence, were significant (p< 0.00). Unexpectedly, a positive correlation was observed between soil-clay levels and elevation gradient (Figure 1). Overall, acidic to moderately acidic soils (data not show) with low carbon and high clay levels, on average 42 and 1.1%, respectively, were predominant in the watershed. In agreement with our results, Vancampenhout (2005) concluded that soil organic carbon levels, in the Ethiopian highlands, were generally low.
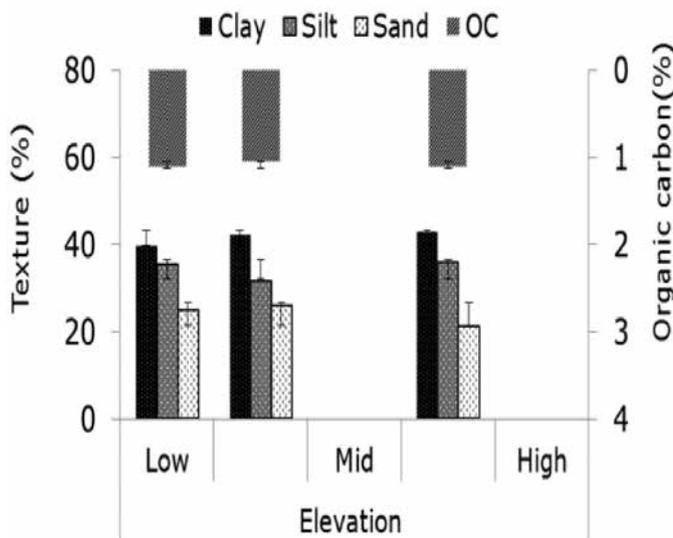
Figure 1. Summary results of soil properties at three elevation ranges

Rainfall intensity and soil infiltration rate

Summary result of event precipitation data, show annual rainfall was high, on average 1616.32mm/yr. However, rainfall distribution was not uniform; mainly three months (June, July and August) contributed 65% of annual precipitation (data not shown). Moreover, storm intensities varied between 0.24 and 444 mm/h (data not shown); but storms, with short durations (< 15 min) and high average intensity (6.3 mm/h) were dominant; accounted for 68% of annual precipitation (Figure. 2a). Average storm intensity decreased sharply, with a slight increase in duration. For example, average intensity of storms, with duration between 30–60 min, was one-third of average intensity of storms, with duration <15 min (Figure. 2a). On the other hand, steady infiltration rate (f_s) was observed between 1.9 and 36.4 mm/h; with median of 8.9 mm/h (Figure. 2b). Steady infiltration varied highly (CV = 70%); but showed a decreasing pattern as elevation increased (data not shown).
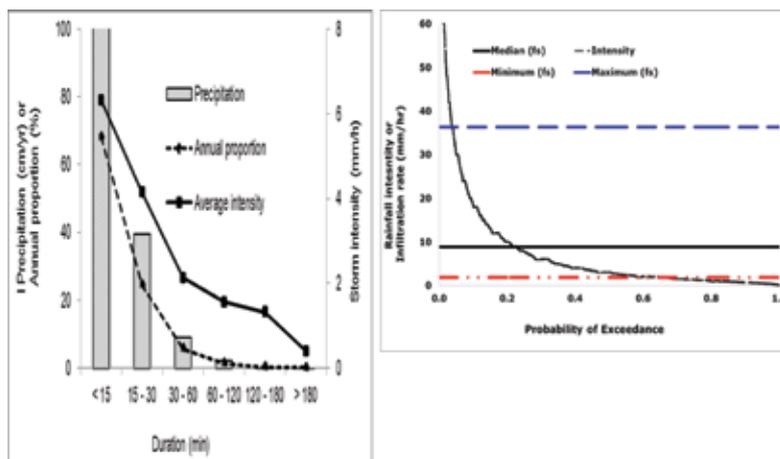
Figure 2. Annual rainfall characteristics (a); and Exceedance probability of rainfall intensity (b)

The probability that storm intensity is equal or greater than the median infiltration rate was 21% (Figure 2b). Thus, much of the runoff generated during the intense storms infiltrates before reaching the outlet

Effects of biohcar and charcoal on soil moisture detention

Statistical analyses of moisture data, from pressure plate, show that treatment effects were statistically significant (p < 0.05) only at lower tensions (–10 and 30kPa) Table 1. Furthermore, mean comparison tests show Croton, Eucalyptus and Oak treatments (at 10kPa) and Croton (at 30kPa) resulted in a significant soil moisture content reduction (p<0.05). Contrary to this, Corn biochar did not reduce moisture content, at all tensions; rather, though not statistically significant, it increased moisture retention at high tensions (Table 1). In agreement with our findings, Rawls *et al.* (2003) suggested increased impacts of organic matter near field capacity than wilting point.

Similarly, Foley and Cooperband (2002) reported that effects of organic amendments were significant only at lower tensions (30 kPa). Not only treatment effects were significant, but also block effects (elevation) was significant at lower and higher tensions: 10, 30 and 1500kPa (p<0.05). Specifically, mean moisture retention, at high elevation, was significantly low compared to low elevation, which could due soil clay content difference, (Table 1).

Table 1. *Summary of treatment effects on soil moisture retention (ANOVA results) at different tensions*

	Tension (kPa)				
	10	30	100	500	1500
Treatment effect					
Control	0.34 (0.01)a	0.32 (0.01)a	0.27 (0.01)a	0.22 (0.00)a	0.20 (0.00)a
Acacia	0.32 (0.00)a	0.31 (0.01)a	0.27 (0.01)a	0.21 (0.00)a	0.19 (0.00)a
Corn	0.34 (0.01)a	0.32 (0.01)a	0.28 (0.01)a	0.22 (0.00)a	0.21 (0.00)a
Croton	0.31 (0.00)b	0.30 (0.00)b	0.28 (0.01)a	0.22 (0.00)a	0.20 (0.00)a
Eucalyptus	0.32 (0.00)b	0.31 (0.00)a	0.27 (0.01)a	0.21 (0.00)a	0.20 (0.00)a
Oak	0.31 (0.00)b	0.30 (0.00)a	0.27 (0.01)a	0.22 (0.00)a	0.20 (0.00)a
Block effect					
Low	0.33 (0.00)a	0.32 (0.00)a	0.28 (0.00)a	0.22 (0.00)a	0.21 (0.00)a
Mid	0.32 (0.00)ab	0.31 (0.00)ab	0.27 (0.01)a	0.22 (0.00)a	0.20 (0.00)a
High	0.31 (0.00)b	0.30 (0.00)b	0.27 (0.01)a	0.21 (0.00)a	0.19 (0.00)b

Values are averages of replications (n = 9) and values inside parenthesis are standard errors. Different letters in the same column and treatment group, represent significant difference between treatments (p<0.05)

In agreement with our findings, Tryon (1948) reported that charcoal addition on clay soils decreased average moisture content by 11.1% and residual moisture content by 3.8%. On the contrary, the same study reported that charcoal increased moisture retention of sandy soils. Likewise, Rawls et al. (2003) reported organic matter addition decreased moisture retention of clay soils, but decreased moisture retention of sandy soils. Similarly, water-holding capacity of medium textured, boreal agricultural soil was increased by 11% shortly after biochar addition (Karhu et al. 2011).

This highlights that effects of organic amendments, including biochar and charcoal, on soil hydraulic properties, is highly affected by inherent soil properties: such as textural composition and carbon levels (Tryon 1948, Rawls et al. 2003). Moisture content reduction, on clay soils, from biochar and charcoal addition could be due to different factors: hydrophobicity of biochar and charcoal materials (Tryon 1948), improved macrospore networks, that release water easily and hence difficult to detect (Dexter 2004).

Biochar and charcoal characterization

As presented in Table 1, corn biochar affected moisture retention of soils differently than Oak biochar, Acacia and Eucalyptus charcoals, hardwood treatments. This could be due to differences in treatments composition. Overall, base cation contents of the two biochars were high; nevertheless, Corn biochar contain higher amounts of each element, particular K^+ (Table 2). Moreover, Rao and Mathew (1995) reported that high valiancy cations increased clay flocculation and hydraulic conductivity. High Monovalent Cation Adsorption Ration (MCAR) clay dispersion can cause clay dispersion. Corn biochar has the highest MCAR 17.5 and 12.6 times higher than Acacia and Eucalyptus.

Table 2. Total elemental analyses results of biochar and charcoal treatments

	pHKCl	Biochar Ca2+	Mg2+	K+	Na+			pHwater	Charcoal Ca2+	Mg2+	K+	Na+	
		(mg/Kg)				MCAR			(mg/Kg)				MCAR
Corn	9.4	7317	8031	25707	1112	9.83	Acacia	8.2	15.9	11.7	60.1	2.9	0.56
Oak	7.5	1023	25	1664	229	3.23	Eucalyptus	8.7	13.5	1.6	51.3	5.9	0.78

Data for Corn and Oak. Biochars were taken from Edres et al. (2012).

This suggests that lower moisture retention with charcoal treated soils could be enhanced drainage and hydraulic conductivity due to increased clay particle aggregation Rawls et al. (2003).

Effects of biochar and charcoal on soil hydraulic parameters

The van Genuchten (1980) moisture characteristic model fitted observed data well; with coefficients of determination (89 to 94%) and root mean square error of (0.01 to 0.02) respectively (Table 3). However, as shown in

Table 3, the model under predicated residual moisture content, for most treatments, compared with predicted value for the control and observed data at 1500kPa (estimator of residual moisture content). Of all five model fitting parameters, variability of α (inverse of air entry pressure) was high (CV = 41%, Table 3).

Table 3. Summary results of van Genuchten model fitting parameters and efficiency.

Treatment	θ_r (g/g)	θ_s	α (1/m)	n	m	RMSE (%)	R^2
Control	0.18	0.34	0.23	1.59	0.37	0.02	89.90
Acacia	0.17	0.33	0.17	1.65	0.39	0.01	94.36
Corn	0.17	0.35	0.27	1.51	0.33	0.02	89.01
Croton	0.12	0.31	0.13	1.57	0.33	0.01	90.90
Eucalyptus	0.19	0.32	0.10	1.96	0.48	0.01	94.24
Oak	0.16	0.32	0.20	1.50	0.32	0.01	90.93
CV (%)	26.58	4.94	34.02	17.31	16.65	38.73	2.27

Treatments effect on soil saturation (Se) and relative hydraulic ponductivity (Kr)

Treatments effect of on effective soil saturation (Se) and relative hydraulic conductivity (Kr), at different tensions (logarithmic scale), from saturation to dryness, are depicted on Figure 3. With increase in tension ($\geq$ 1.5 cm) differences between treatment S_e coefficients were increased. Between tensions (1.5–4 cm), all treatments, except Corn biochar, increased effective soil saturation (Se) compared with the control Figure 3(a). However, at high tensions ($\geq$ 4cm), S_e coefficient for Eucalyptus decreased sharply, below the control. On the contrary, at similar tensions ($\geq$ 4cm), Corn biochar slightly increased S_e. On the other hand, differences between treatment K_r coefficients were relatively high at low tensions ($\leq$ 3cm); high coefficients were observed for Acacia, Croton and Eucalyptus charcoals, whilst coefficients of Corn and Oak biochars were low compared with the control Figure 3(b).
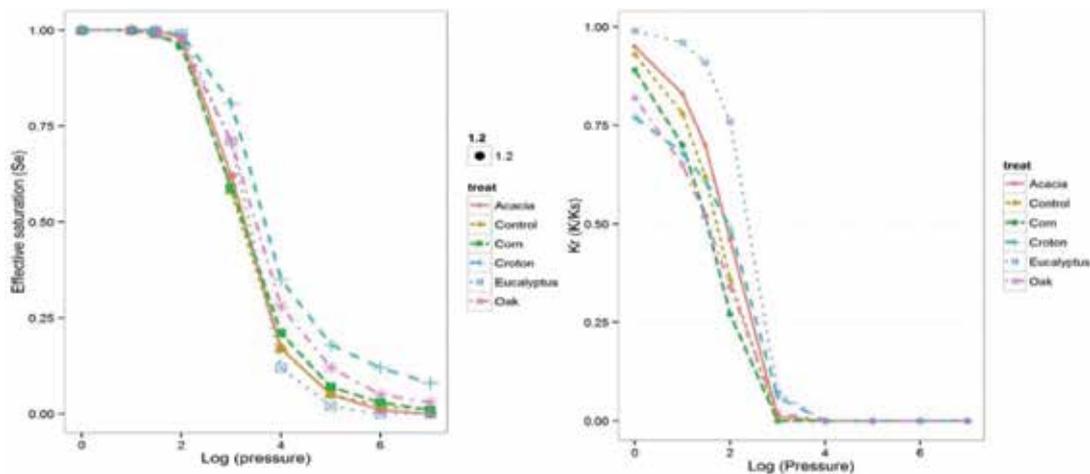
Figure 3. Treatments effect on effective soil saturation (a) and relative hydraulic conductivity (b), at different tensions (log scale).

Conclusion

This study evaluated the effects of biochar and charcoal amendments on soil-hydraulic properties; and results were discussed with respect to dominant field soil physical and infiltration rates as well as rainfall characteristics.

Results show all charcoal treatments and Oak biochar decreased moisture retention for most of the cases. However, treatment effects were significant, only at lower tensions (10 and 30kPa). Moreover, observed effects of biochar and charcoal treatments, were in conformity with dominant soil textural composition and organic carbon level. Hence, it is presumable that biochar and charcoal treatments could restore soil health of degraded fields; nevertheless, research is needed to select best performing treatments, based on inherent soil properties and intended impact on soils.

Overall, findings from this study underscored the significance of considering soil physical and hydraulic conditions when planning soil and water management practices.

Acknowledgements

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Local knowledge of the impacts of eucalyptus expansion on water security in the Ethiopian highlands

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Abstract: Lack of long-term hydrological monitoring makes it difficult to determine impacts of changing land use on the water dynamics for many catchments in Africa. Here we use local ecological knowledge (LEK) to explore the impacts of rapid expansion of eucalyptus agroforestry on water security in the Ethiopian highlands. Local knowledge about the impacts of changes in tree cover was collected from farmers (n = 30), extension staff (n = 2) and timber merchants (n = 2) in five *kebeles* within the Jeldu *woreda*. Jeldu has undergone significant land use change over the last forty years. The area was heavily deforested 20 years ago and farmers associate this time with a major change in the water dynamics. Recently the development of a new road to Goja, the main town, opened up the area as a source of timber for Addis Ababa. This has resulted in a substantial expansion of eucalyptus plots adjacent to roads on the upper plateau and in riparian areas where growth is accelerated. Poorer farmers have been displaced on to the sloping land (which used to be woodland) where there is now evidence of rapid soil degradation. The key findings were that farmers identified significant trade-offs at the plot scale between eucalyptus and adjacent crop fields. They also identified indicators suggesting the sudden increase in eucalyptus cover had accelerated declines in water availability at landscape scales. The study showed the value of using LEK for exploring immediate landscape scale dynamics in the absence of hydrological monitoring. Whilst there is a degree of uncertainty surrounding the impacts of eucalyptus, this research demonstrated local awareness associated of problems associated with unregulated expansion of eucalyptus woodlots on the water regulating capacity at immediate landscape scales in the Ethiopian highlands.

Media grab: Local knowledge of farmers highlights negative impacts of eucalyptus on water security in the Ethiopian highlands

Introduction

Ethiopia is entering a period of increasing water scarcity due in part to poor water resource management and environmental degradation caused by deforestation (Tadesse 2009). As natural vegetation is cleared for agriculture and other types of development there are often negative impacts on water regulation and sediment transport (Wood and Armitage 1997). Integrating trees back into agriculturally productive landscapes (through agroforestry

interventions) can address these issues (Schroth and Sinclair 2003). In common with many parts of Ethiopia, the Jeldu *woreda* lost much of its natural tree cover in the 1980s. Since that period eucalyptus (*Eucalyptus globules)* has been used to address local timber and fuel security. Recent improvements in infrastructure have opened up the *woreda* as an area for supplying timber to local towns and Addis Ababa. Eucalyptus enjoys a mixed reputation in Ethiopia but there is increasing recognition of its potential negative impacts on stream flow (cf. Albaugh et al. 2013).In the absence of long-term monitoring, this study used local knowledge (knowledge held by farmers and resource users concerning their daily interactions with their natural environment, based primarily on experience and observation) to explore the impacts of land use change. The objective of this study was to explore local knowledge of the impacts of changes in tree cover (particularly eucalyptus expansion) in a head water area in the Ethiopian highlands.

Methods

Study site: The Jeldu *woreda* is in the Eastern Blue Nile catchment, in Oromia Region (9°15'54" N; 38°04'54" E) and represents a high to intermediate rainfall (1200 mm year-1), high altitude (2500–3200 masl), rain-fed, mixed crop–livestock system. The most common crops were potato, wheat and barley (Bayala et al. 2011). Potato was the most widely grown crop both for consumption and cash generation for small households. The *woreda* has nine *kebeles* (administrative units), of which five were selected as study sites; two located in the upper plateau (Seriti Dhenku, Chilanko) two on valley sides to valley bottom (Kolu Gelanand Shikute) and one in the lowland zone of the *woreda* (UrgaEreri). The main town of Goja is in the Chilanko *kebele* which sits on a plateau with a new road running along the central spine. The river Meja runs along the southern edge of the *woreda* down into the Blue Nile.

Local knowledge about impacts of changing tree cover on water security was acquired using systematic methods. Knowledge elicitation involved a combination of participatory mapping and semi-structured interviews coupled with formal representation using knowledge based systems software that allowed evaluation of knowledge as it was acquired (Sinclair and Walker 1998; Walker and Sinclair 1998). Detailed knowledge was acquired by repeated interviews with a purposive sample of 30 farmers in five *kebeles*, mainly in the headwater areas (n = 17). Repeated interviews with the same people were important for obtaining deeper explanatory knowledge and resolving inconsistencies. Two types of farmer were interviewed—model farmers (farmers who were part of collectives) and non-model farmers. In addition, scoping interviews were held with local timber merchants (n = 2) and development agents (n = 2).

Results and discussion

Land use change

Farmers identified two main phases of land use change in the *woreda*. Twenty years ago, land adjacent to the road was used for arable production and the steeper slopes were covered with natural woodland. As the population expanded into the area and requirements for timber and fuel increased, much of this woodland was cleared and then converted into arable land.

The recent development of a new road to Goja, the main town of Jeldu *woreda*, opened up the area as a source of timber for Addis Ababa (Figure 1). This had resulted in a substantial expansion of eucalyptus plots; with 75 and 80% of the eucalyptus being exported to Addis Ababa. Timber merchants from the local town of Ginchiwere arranging short-term leases of fields from farmers and taking harvests from these plots every 3–7 years for fuel wood and timber. These leases tended to be with non-model farmers. As formal credit and saving institutions were scarce in the area, farmers also used eucalyptus woodlots as insurance against critical cash shortages, particularly as the eucalyptus was said to require less labour compared to arable production. Eucalyptus expansion was only viable in the upland *kebeles* (nearer Addis Ababa) as the cost of fuel for transportation made it less cost effective in other parts of the *woreda*. The eucalyptus plots needed to be located near to roads (for ease of extraction) or planted adjacent to the streams (to enable faster and straighter poles—which were more valuable for timber and had shorter rotations). Eucalyptus had expanded to cover approximately 20–40% of the land area in the upper *kebeles*. As a result of this, some non-modal farmers had been displaced onto the steeper slopes (see Figure 1).
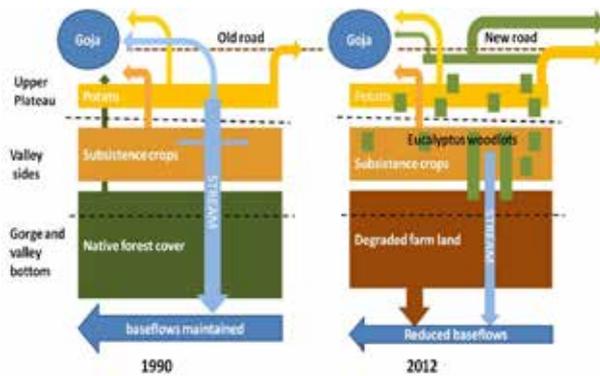
Figure 1. Changes in land use in the Jeldu woreda between 1990 and 2012.

Impacts at plot and farm scale

Farmers had detailed understanding of trade-offs between eucalyptus and their crops through their daily interactions. Small-scale eucalyptus woodlots compete with crops for green water (rainfall that is stored in the soil and is available to plants). Farmers recognized that eucalyptus grew fast (in relation to other tree species) and observed lower yields in areas immediately adjacent to their crops. The area affected increased with the maturity of the trees. Rising prices for potatoes had resulted in some model farmers removing eucalyptus. Although the area of effect was smaller for juvenile eucalyptus farmers said this was the time of greatest requirements for water.

Impacts on immediate landscape in upland-midland kebeles

Farmers described a number of impacts associated with the initial loss of tree cover 20 years ago. One impact was that water availability had decreased. The farmers across the *woreda* provided indicators of this. The farmers knew that 14 years ago the water driven grinding mill in Kolu Gelan closed because of insufficient water supply. Farmers also reported that drops in base flow had caused the water level to remain low enough for people to cross the river Meja all year round (even in heavy rain)—20 years ago farmers could only cross the river until June (at the beginning of rain season). The loss of original tree cover has also destabilised the slopes and contributed to substantial erosion/nutrient loss. The farmers estimated that the fields in these areas would be exhausted within five years. There was a widespread belief that the loss of tree cover had affected rainfall patterns. Farmers stated that deforestation had caused decreased air humidity because of less evapo-transpiration from vegetation canopies; this resulted in a drier atmosphere that led to reduced rainfall. Where there was no vegetation, any moisture-carrying wind would pass over the area and not settle. Lack of vegetation cover resulted in increased wind speed, which cleared rain-forming clouds.

In the *kebeles* in the headwater areas, farmers identified a secondary impacts associated with the increase of eucalyptus. Eucalyptus woodlots planted near springs had caused them to dry up during the dry season and had further reduced overall stream flow—to the point that farmers had to use small check dams to allow livestock to drink. Some springs were always seasonal but the duration of dry periods had increased during the period that the eucalyptus cover had expanded. Farmers had to move further down the slope to collect water as the springs on the upper slopes had dried up. This had caused a noticeable decrease in drinking water availability in Goja town (the water available in dry season was no longer sufficient to support Goja's population). Eucalyptus was also associated with decreased water quality from the headwaters. The increase of overall eucalyptus cover was associated with a decrease in rainfall.

The knowledge of landscape processes was less immediately obvious to farmers. Eucalyptus expansion had been very rapid and unplanned. Farmers agreed that it took longer for them to be aware of the implications of this and by that time the eucalyptus was well established. Model farmers had more opportunity to diversify and were more likely to remove eucalyptus. Non-model farmers, although aware of the potential problems, were committed to eucalyptus in the short term.

Impacts on immediate landscape in lowland *kebele*

Farmers in the lowland *kebele* were aware of the impacts of loss of tree cover from 20 years ago but were less aware of the impacts of eucalyptus. The main problems identified by farmers in this area related to decreased water quality. There had been a noticeable increase in sedimentation of the river during the wet season which had reduced water quality downstream. Increased sedimentation had also added to destabilization of the riverbank of Meja causing loss of agricultural land through bank collapse. Farmers did not volunteer information of eucalyptus in these areas

Potential solutions

Given growing awareness of the problems associated with unplanned eucalyptus expansion, farmers' attitude was that an increase in native tree cover (especially around riparian areas and springs/headwaters on the upper slopes) would bring protection to and maintain springs and streams.

Farmers were able to identify a number of native tree species that could potentially displace eucalyptus. There was an interest in species that were reasonably fast growers or had other qualities that made them suitable for their farms; for example, farmers wanted species that could grow on degraded soils, comparable to eucalyptus.

An immediate recommendation from farmers was to return to *Hagenia abyssinica*. This is a relatively fast growing tree (providing timber in about 10 years compared to seven years for eucalyptus). It was preferred by farmers especially because of its ability to improve soil fertility through leaf fall and decomposition and was considered 'water friendly' by farmers, making it more appropriate for riparian areas although it would struggle on degraded soils.

Table 4. Alternative tree species suggested by farmers

S/N	Local name	Latin name	Most appropriate uses
1	Heto	Hagenia abyssinica	T, SC
2	Wadesa	Cordia africana	T, MP
3	Lafto	Acacia sieberiana	FW, SF, CC
4	Garbi	Acacia lahai	FW, SF, CC
5	Shewshewe	Chamae cytisuspalmensis	FD, SF
6	Bekenisa	Croton macrostachyus	T, FW

T = Timber, SC = soil conservation, MP = Multipurpose, SF = Soil Fertility, FW = Firewood, CC = Charcoal, FD = Fodder.

Conclusions and recommendations

These insights demonstrate the value of local knowledge to explore impacts of environmental change in unmonitored catchments. The farmers interviewed in Jeldu had detailed explanatory knowledge of the impacts of changing tree cover on their water security. At an immediate landscape scale (within the sub catchment), there were clear indicators of increased water stress—caused by a combination of reduced tree cover, unplanned eucalyptus expansion and increased population. The beneficiaries of the eucalyptus largely lay outside the *woreda* in the towns on the roads to Addis Ababa. Conversely the dis-benefits of the decreased water security flowed downstream to the west of Jeldu into the Blue Nile. Whilst there is a degree of uncertainty surrounding the impacts of eucalyptus, this research identified clear issues associated with unregulated eucalyptus expansion on the water regulation at immediate landscape scales in the Ethiopian highlands.

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Institutions, adoption and marketing

Assessment of farmers' rainwater management technology adoption in the Blue Nile basin

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Abstract: Agricultural productivity in Ethiopian highlands is constrained mainly by high climate variability. Although use of soil and water conservation technologies is recognized as a key strategy to improve agricultural productivity, adoption of technologies has been very low as farmers consider a variety of factors in their adoption decision. This study assesses the adoption pattern of interrelated rainwater management technologies and investigates factors that influence farm household adoption and scaling-up of rainwater management technologies and draws recommendations for policy. Our results show that rainwater management technologies are interdependent to each other implying that technology adoption decisions need to capture the spillover effect on the adoption of other technologies and have follow a multi-dimensional approach. Moreover, our results suggest that instead of promoting blanket recommendations, it is important to understand the socio-economic, demographic characteristics and biophysical suitability of the rainwater management technologies. Although impact of gender is likely technology-specific and generalization is not possible, our result indicates that male-headed households have a comparative advantage in rainwater management technologies adoption in the Nile Basin and suggests the need to address the constraints of women farmers to give them an opportunity to actively participate in rural economic activities.

Media grab: Since rainwater management technologies do not stand alone, it is important to understand their interdependence and not to make blanket recommendations.

Introduction

Like in many sub-Saharan Africa economies, agriculture is the main sector of the Ethiopian economy. In sub-Saharan Africa, water scarcity and land degradation affect the performance of agriculture and people's livelihoods. Agricultural productivity is low, dominated by low input low output rainfed mixed crop livestock production in the Ethiopian Highlands (Merrey and Gebreselassie 2011). In the Blue Nile Ethiopian highlands, agricultural productivity is constrained by high climate variability, rather than low water availability where rainfall distribution is extremely uneven both spatially and temporally, which has negative implications for the livelihood of the population (FAO 2005). Drought frequently results in crop failure, while high rainfall intensities result in low infiltration and high runoff causing soil erosion and land degradation and contribute to low agricultural productivity and high levels of food insecurity (Lautze et al. 2003; Deressa 2007). High population growth and cultivation of marginal land coupled with lack of effective rainwater management strategies have aggravated poverty and environmental fragility (Tamene and Vlek

2008). Use of soil and water conservation (SWC) technologies, referred here as 'rainwater management interventions' (RWM), are widely accepted as a key strategy to improve agricultural productivity by alleviating growing water shortages and the effects of drought and worsening soil conditions (Kurukulasuriya and Rosenthal 2003). It has been demonstrated that access to RWM interventions can help farmers in the Blue Nile Basin to decrease poverty levels by approximately 22% (Awulachew et al. 2012) and provide a buffer against production risk in particular in the face of increasing variability due to climate change (Kato et al. 2009). However, even if technologies are appropriate to the biophysical setting, they are not always adopted (Guerin 1999; Amsalu and Graaff 2007) as farmers consider a variety of factors in their adoption decision (McDonald and Brown 2000; Soule et al. 2000). In fact, there is no consensus on factors that influence the adoption and scaling-up of rainwater management technologies, which this study is aiming to contribute to the existing literature in filling knowledge gap. This study has been carried out in the framework of the Nile Development Challenge (NBDC) program that aims at improving rural livelihoods and their resilience through a landscape approach to rainwater management in the Ethiopian part of the Blue Nile Basin. The study specifically assesses the adoption pattern and factors that influence farm household adoption and scaling-up of rainwater management technologies and draws recommendations and policy implications.

Methodology

Recent empirical studies (Moyo and Veeman 2004; Marenya and Barrett 2007; Nhemachena and Hassan 2007; Yu et al. 2008; Kassie et al. 2009) argue that farmers usually consider a set of possible technologies and try to select the one they assume can maximize their expected utility; hence the adoption decision is inherently multivariate. Most of previous studies on technology adoption, however, assume a single technology without considering the possible correlation/interdependence between different technologies (Yu et al. 2008) possibly masking the reality that decision-makers often faced by a set of choices. The conceptual framework of this study is based on the premises that farmers are more likely to adopt a mix of rainwater management technologies as a coping mechanism to climate change and agricultural production constraints implying that technologies can be adopted simultaneously as complements or substitutes. When technologies are correlated, a univariate model is not appropriate, because it excludes useful information contained in interdependence and simultaneous adoption decisions; hence, failure to capture such interdependence will lead to biased and inefficient estimates. To fill this gap, we used a multivariate probit (MVP) model (as specified in Cappellari and Jenkins 2003; Kassie et al. 2012) as follows:

$$Y_t^* = \beta_t X_t' + \varepsilon_t , \quad t = 1, \ldots m \quad and$$
$$Y_t^* = 1 \quad if \quad Y_t^* > 0 \quad and \quad 0 \quad otherwise$$

Where (X_{ht}') represents the choices of rainwater management technologies. The assumption is that farm household has a latent variable that capture the choices associated with the rainwater management technology. The estimation is based on the observed binary discrete variables that indicate whether or not farm household has adopted a particular rainwater management technology (denoted by 1 for adoption and 0 for non-adoption). The unobserved characteristics are captured by the error term denoted by, ε_t while β_t is a parameters to be estimated. In general, multivariate probit model is used to estimate correlated binary outcomes jointly where the source of correlation can be complementarity (positive correlation) and substitutability (negative correlation) between different technologies (Belderbos et al. 2004). A multi-stage stratified random sampling was used to draw a household survey data from 671 sample households in seven watersheds in the Blue Nile Basin.

Results and discussion

Our result shows significant joint correlation and interdependence between rainwater management technologies. Differences in the estimated coefficients across equations also support the correctness of differentiation between technology options. Household demographic characteristics, off-farm participation, migration, ownership of livestock, ownership of land, access to credit, access to market, social capital and watershed location captured by *woreda* fixed

effects are the main determinants of adoption of rainwater management technologies. The suitability of rainwater management technology is likely to be influenced by landscape, land degradation and land use patterns.

As presented in Figure 1, some technologies are more suitable in flat, gentle slope or steep slope lands. Similarly, the level of land degradation is more likely to influence where a specific rainwater management technology can be adopted, which also indicates the biophysical suitability.
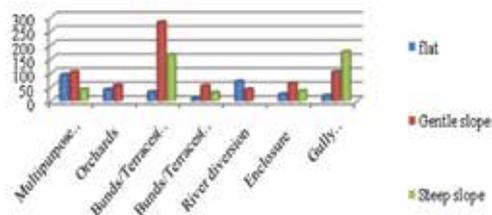
Figure 1. Adoption of rainwater management technologies by landscape

For example, Figure 2 shows that except bunds/terraces, most of the rainwater management technologies were adopted in degraded lands, probably because these technologies are used as *ex-post* land rehabilitation and resource conservation measures. Finally, the type of land use is likely to influence the suitability of technologies and adoption decisions of farm households (see Figure 3).
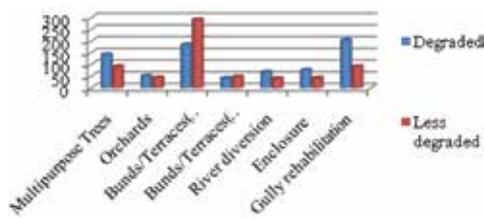
Figure 2. Land degradation and adoption of rainwater management technologies
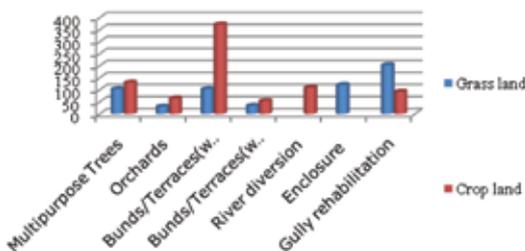
Figure 3. Adoption of rainwater management technologies by land use

Conclusion and recommendations

The main conclusion and recommendation of this study is as follows: (i) rainwater management interventions should focus not only on the engineering and biophysical performance of conservation measures, but also on the socio-economic and livelihood benefits; (ii) adoption of rainwater management technologies are interdependent, hence, any intervention towards promoting of rainwater management technologies need to consider such interdependence; otherwise failure to capture such interdependence may lead to mask the reality that farmers often faced by a set of choices and the results in poor performance of the technologies; (iii) targeting women groups to address their constraints to actively participate in rural economic activities can have positive impact on the adoption and scaling-up of rainwater management technologies leading to improved livelihoods; (iv) farmers with better experience and information are most likely to take initiatives in adopting and testing new technologies; therefore, using such models farmers can help to promote successful and proven technologies; (v) in addition to the socio-economic and demographic characteristics, it is important to understand the biophysical suitability of technologies instead of

promoting blanket recommendations for the adoption of rainwater management technologies; (vi) externally driven technical solutions are rarely sustained by farmers unless consideration is given to socio-economic, cultural and institutional, as well as biophysical and technical factors.

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Is 'social cooperation' for traditional irrigation what 'technology' is for motor pump irrigation?

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Abstract: This paper calls attention to the importance of social cooperation in irrigation farming. It argues that a mere focus on the technical aspect of irrigation, disregarding its social aspects undermines the long-term benefits of irrigation to rural livelihoods. This assertion draws on lessons from small-irrigation practices in Fogera, in the Blue Nile Basin of Ethiopia, where I conducted fieldwork-based qualitative research. In recent years irrigation farming has drawn a growing interest among farmers in rural Fogera. Farmers practise small-scale irrigation that includes traditional irrigation and motor pump irrigation. Farmers assert that irrigation has brought farming benefits through cultivation of more crops as well as new crops that serve food and cash purposes. Such benefits have particularly spurred the enthusiasm for motor pump irrigation. However, the practice of motor pump irrigation largely relies on the motor-pump technology, overlooking the social scheme of irrigation. While traditional irrigation involves more social cooperation involving joint activities, water allocations and irrigation schedules, lack of social cooperation and such institutional conditions is widespread in motor pump irrigation. Local classification of irrigation practices also associate the mechanism of irrigation use and management including water use regulations and water use turns with traditional irrigation in contrast to motor pump irrigation. The neglect of social cooperation within current practices of motor pump irrigation will have significant adverse implications on long-term practices. Farmers have been already concerned about how competitions for water are growing, limiting the duration of water availability and creating water shortage. The study suggests that while farmers' willingness to practise motor pump irrigation in Fogera has been stimulated by its livelihood benefits, sustained benefits of this irrigation scheme require social cooperation and feasible institutional conditions that can mediate water usage across user villages.

Key words: Social cooperation, technology, traditional irrigation, motor pump irrigation, Fogera, livelihood

Media grab: Sustained benefits of irrigation depend on pertinent social cooperation including institutional arrangements that guide water use and management.

Introduction

Smallholder farmers in Ethiopia essentially depend on rainfed farming for their livelihood. The reliance on rainfed farming has been problematic, as rainfall is often unpredictable and highly variable. This calls for alternative water access, particularly irrigation so that small-scale farming can be viable in the face of rainfall uncertainties.

Irrigation has become an important government agenda for agricultural development. Its importance for agricultural productivity and food security has been alluded in key government policy documents (MoFED 2006; MoFED 2010). It has also been promoted by development organizations (FAO 1999; IFAD 2012). Thus, there has been increased attention paid to the importance of irrigation. In this regard, assessing the role and performance of irrigation will be instrumental in guiding policy and development orientations pertaining to irrigation practices.

Several studies highlighted the role of irrigation for increased productivity, poverty reduction and improved economy (FAO 1999; Fitsum et al. 2010; You et al. 2010; Tilahun et al. 2011). However, what makes irrigation farming, its productivity and benefits enduring and sustainable is still a crucial issue that requires thorough and holistic investigations. Studies which reflected on the issue of how to ensure irrigation productivity and its contributions emphasized on technological efficiency and complementary agricultural inputs. They indicated that ensuring irrigation productivity and its contributions depends on the right choice of irrigation technology and how irrigation investment is accompanied by complementary agricultural inputs such as fertilizer, improved seed and high value crops (FAO 1999; Fitsum, et al. 2010; You et al. 2010; Tilahun et al. 2011).

There seems to be little attention paid to the social aspect of irrigation, how the presence or absence of pertinent social conditions can hinder or facilitate irrigation. This paper argues that sustained benefits of irrigation depend on pertinent social cooperation including institutional arrangements that guide water use and management. It examines the practices and implications of disengaging the social aspect of irrigation from the technology. Focusing on small-scale irrigation in Fogera, the paper examines differing practices of traditional and motor pump irrigation, involving differential focus on social cooperation and technology, thereby analysing the implications of social cooperation including the lack of it for sustained benefits of irrigation for rural livelihood.

Methods

This paper is based on a wider local study on livelihoods and rain water management in Fogera, in the Blue Nile Basin of Ethiopia, where I conducted fieldwork-based research in three *kebeles*: Dibasifatira, Alember and Kokit in 2012. The study employed qualitative and participatory methods of data collection including in-depth individual interviews, key informant interviews, group interviews, observations, focus group discussions, trend analysis, participatory mapping, participatory problem identification and priority rankings. Data analysis involved pertinent forms of qualitative coding and analysis which proceeded through building categories, themes and patterns.

Results and discussion

This section presents results and discussions of the study which are organized under different topics and subtopics with interrelated themes. These include: small-scale irrigation and livelihood, traditional irrigation: history, expansion and collective action; motor pump irrigation: history, expansion and pumping water.

Small-scale irrigation and livelihood

Agriculture is the main livelihood of people in rural Fogera. Farmers practise plough-based farming with the help of oxen as the main draught power. They have long relied on rainfed farming for their livelihood. In recent years, irrigation farming has drawn growing interest among such farmers. They now practise small-scale irrigation which largely includes traditional irrigation, locally referred to as *mesno* and motor pump irrigation. Rivers and streams including Rib, Mizwa, Narza, Alemayehu and Kechin have facilitated farmers' small-scale irrigation practices. Irrigation is being incorporated into local farming practices, with a total of 4682 hectares of land that has been cultivated through irrigation in the three *kebeles* of Kokit, Dibasifatira and Alember (see Table 1 below).

Table 1. Irrigation cultivation in selected kebeles of Fogera

Kebele	Cultivated land (ha)	Cultivated with irrigation (ha)
Kokit	2635	2413
Dibasifatira	2614	2153
Alember	2882	116

Source: *Kebele* agriculture offices (Fieldwork in Fogera 2012).

Irrigation has brought changes in local land use practices. In particular, it has stimulated intensive cultivation. Farmers have been able to practise multiple cropping through improved land uses. Many people in rural Fogera assert that irrigation has significantly contributed to improve the livelihoods of farmers who have been involved in irrigation farming. Being able to produce a variety of crops as well as new crops is an important aspect of the improvement mentioned by many farmers. Such farmers emphasized that they used to cultivate mainly rainfed crops such as teff and millet, while they now have been able to shift from producing such one season crops into two season crops. Thus, irrigation has enabled them to produce a variety of crops including onion, emmer wheat, chickpea, grass pea, tomato, lentils and fenugreek.

Irrigation users described improved livelihood in terms of acquiring more food, cash and assets. Overall, local users appreciate the contributions of irrigation for their livelihoods. In describing such appreciations, a farmer in Dibasifatira said, '*A farmer who now uses water is a flower.*' He was referring to how farmers with irrigation do well in making a living. However, the benefits of irrigation are not equally distributed among members of the rural community. There have been differential impacts of irrigation, partly depending on ecological factors which can facilitate or hinder irrigation practices. There are variations in irrigation infrastructure which relate to the topographical heterogeneity of the area (Eguavoen et al. 2012). The gains and losses of intensification have also involved differential impacts on local land use practices. While irrigation has facilitated intensive cultivation, in some instances this has been practised at the expense of other land uses, particularly grazing fields.

Traditional irrigation: history and expansion

In Fogera traditional irrigation is practised through river/stream diversions and the construction of a small dam. The history of traditional irrigation dates back to the Imperial regime. A key informant in Fogera recalled that *mesno* was practised during the Imperial regime of Haileselassie and it was administered by *dagna* (judge). Studies conducted in another northern part of the country, namely South Wello, revealed that irrigation during the Imperial regime was limited, largely controlled by landlords, while it increased during the Derg and further expanded during the present regime (Mengistu 2001; Pankhurst 2002).

In Fogera, although traditional irrigation was practised in the past, its expansion is a recent phenomenon. Local people largely indicated that the wider practice of *mesno* has emerged since the turn of this century. A combination of factors including increased rainfall uncertainty, growing realization of the importance of irrigation and extension support has reinvigorated local interest in experimenting traditional irrigation. While farmers would often perform agriculture following the rains, they now seem to have opted for irrigation as an alternative option. In explaining about this shifting endeavour, a key informant in Dibasifatira said that '*When the rain stopped in September, we would also stop cultivation. The canal came about 11 years ago. When the rain decreased, we tried the canal. We learned to use it thereafter.*'

There has been heightened interest to practise traditional irrigation. Farmers are eager to take advantage of streams and rivers that pass through their villages. During interviews, such farmers passionately reported about their recent experiences and accomplishments by emphasizing how they have managed to make use of hitherto 'idle' water sources. This situation reflects how local perceptions of irrigation have changed recently, farmers attaching more value to its importance. This was also captured during focus group discussions with farmers. For instance, during a focus group discussion in Dibasifatira, participating farmers strongly shared the view of their colleague who emphasized that '*In the past, the water would just go through cutting the land. Today, we are questioning her where it is going.*' While discussing how they are now determined to utilize available water, focus group discussion participants in Alember also underlined that '*Today there is no water that freely goes around the field. If found, it will be diverted.*'

Traditional irrigation and collective action

In rural Fogera, social cooperation is an important defining feature of traditional irrigation against motor pump irrigation. Traditional irrigation involves social cooperation from the onset of the scheme through water use and irrigation schedule. Local users pool their labour, ideas and commitment together to work on *mesno* facilities that involve river diversion, dam construction and preparation of water channels. The social cooperation and coordination that such activities entail are more appreciated when considering that this is not a onetime activity. It is a work that requires continuity, in some cases involving the doing and dismantling of traditional dams. Users build a small dam from soil by digging the earth. Key informants indicated that they are often cautious about the potential adverse impact of this small dam, particularly during the rainy season in that it may overflow and inundate the surrounding area. They have carefully managed to practise this irrigation scheme by dismantling the dam once the period of irrigation (October to January) is over and rebuilding it after the rain stops.

In many respects, the users' readiness to forge social cooperation reflects their understanding of traditional irrigation as a social undertaking. The social trust embedded in their joint efforts also has a significant implication for collective action in irrigation use and management. This was evident during fieldwork from farmers' remarks regarding water use norms and practices. For instance, in response to whether users adhere to norms of shared water use or tend to be self-centred, disregarding others, a farmer in Alember emphatically stated that '*We have equally worked together to bring the water and we all have to use it equally.*' Thus, water usage is regulated involving water use turns and irrigation schedules depending on water availability.

Key informants explained that people who worked together during initial preparations jointly discuss and arrange irrigation schedules and water use turns. Then, individuals use water based on turns and specified schedules. The system of usage is coordinated by water judges. Several water judges from each user village constitute a water committee which includes 5–6 members. Such collective arrangements have greatly facilitated the viability of traditional irrigation, involving significant contributions for long-term practices. The practice of irrigation schedule along water use turns is instrumental in avoiding destructive competitions and ensuing conflicts over water use. Local users also seem to be aware of the negative implications of uncoordinated water use practices. For instance, a key informant in Kokit stressed that '*irrigation has to be used on the basis of turns so that people should not fight.*'

However, this does not necessarily suggest that irrigation water use will involve no competitions and conflicts in the presence of such water use arrangements. But, they can be mediated by the local arrangements in place. Traditional irrigation users in Fogera indicated that competitions and conflicts can arise between users over scheduled water turns. Individuals may violate the turn system to pursue their own advantages at the expense of other users. Yet the water committee will intervene and address such situations.

Scholars maintain that the rule of exclusion/inclusion is an important principle that guides collective use and management of natural resources (McCay and Acheson 1987; Ostrom et al. 1999). This is fairly reflected in traditional irrigation practices in Fogera. However, the local notion of inclusion/exclusion does not focus on restricting or denying access to water. It intends to facilitate social cooperation that enables irrigation use. In the local context, who should be included for water access in irrigation schedules depends on whether they have participated in joint activities during the preparation of the traditional irrigation scheme. In principle, those who have failed to participate in such joint activities will be excluded. However, this customary principle is flexible in that such individuals can be included later if they pay some fines. The fine represents a form of punishment for failing to take part in the social cooperation required for irrigation usage, while the individual will ultimately get access to irrigation water.

Motor pump irrigation: history and expansion

The history of motor pump irrigation in Fogera dates back to the period of cooperative farming during the previous socialist regime of Ethiopia. The initial experience of motor pump irrigation in the area can be traced to a cooperative farm which operated in the area over two decades ago. A key informant in Kokit recalled that '*During the Derg in 1979/80, they organized us under a cooperative farm in Shega Kebele and gave us Motor. We used the motor to cultivate*

rice and we got good harvest.' Nevertheless, several key informants indicated that the recent practice of motor pump irrigation was introduced less than 10 years ago. It was introduced through 'investors' who collaborated with local farmers in share-cropping arrangements. A key informant explained:

> *'Initially, traders were coming from Wereta town with motors to work with farmers here. The farmers would contribute labour and land, while the others would contribute motor, seed and fuel. Later they would share the harvest equally. After two years, the farmers became free from dependence. They were able to buy their own motors and became self-sufficient.'*

Interviews conducted with farmers suggest that use of the motor pump technology has expanded in the past three years. Eguavoen et al. (2012) also noted the recent increase in the use of pumps. My study found that the recent expansion and wider practice of the technology is largely attributed to enabling institutional factors, shading light on the importance of such factors for the dissemination and adoption of agricultural technologies. Access to credit to buy the motor pump has been available through the Amhara credit and saving institution in conjunction with the agricultural office. The latter delivers the motor pumps, while the former supplies the credit to buy the motor pump. This inter-institutional coordination along with access to credit forged an enabling institutional factor in terms of facilitating access to the motor pump technology and its wider practice.

Sharecropping has been another important social factor in terms of enabling farmers to have access to motor pumps and pursue irrigation. Farmers have figured out how to draw experiences from their traditional sharing and exchange arrangements pertaining to farming practices. Farmers have long engaged in sharecropping arrangements, involving those without plough-oxen and others with oxen and landless and land owners. This relationship has been extended to motor pump irrigation in that farmers who have no motor pump engage in sharecropping arrangements with motor pump owners. In this arrangement, the former contribute land and labour, while the latter provide the motor with fuel and seed and they share the harvest equally.

Pumping water

Current practices of motor pump irrigation in Fogera suggest that the conception of this irrigation scheme is reduced to pumping water, disregarding pertinent forms of social cooperation required for successful irrigation practices. A household often relies on the household labour force to transport the motor pump and the pipe to a convenient water point where it arranges the implement to pump out water and irrigate a farming field. For instance, farmers in Kokit draw water from Rib River and irrigate their plots around the river path. Motor pump users in Dibasifatira pump up water from Mizawa and Narza rivers and irrigate their lands in the vicinity of these rives.

A household may constitute a self-sufficient production unit, depending on labour and economic capacity, to work on a non-irrigated farm field. This situation differs in the case of irrigation farming in that irrigation essentially requires social cooperation beyond the household level. However, in Fogera, irrigation with the motorized implement is largely practised on individualized household basis, lacking coordination and restrictions. What I have learned about motor pump irrigation during my fieldwork in rural Fogera suggests that more importance is given to acquiring the technology, the motor pump, disregarding the social cooperation and institutional conditions that facilitate irrigation use across households and cross-cutting village and *kebele* boundaries.

Lack of institutional conditions that guide motor pump irrigation is widespread among motor pump users. Local people associate the presence of a system that coordinates water use and irrigation schedules with traditional irrigation in contrast to motor pump irrigation. They link the latter with a situation of uninhibited usage. Interviews conducted with different farmers indicated that current motor pump irrigation usage lacks any mechanism of water allocations and irrigation schedules. For instance, a farmer in Dibasifatira pointed out that '*There is no water use turn*

with motor irrigation. Water is used as one wants to use. People stop when the water stops.' Similarly, a farmer in Kokit indicated that '*Motor irrigation has no water committee. It has no turn. It is possible for everyone to irrigate as he wants to do.*' This was also revealed through focus group discussions where farmers indicated that motor pump irrigation usage is devoid of water use turns and irrigation schedules.

Besides, motor pump users pumping water from the lower part of a river insist that users in the upper village use the water as they want and complain about the lack of mechanism to check and deal with water blocking. In describing such problems of irrigation use, a development agent at the *kebele* level said, '*There are too many motors now. Everybody has motor pump and it is difficult to follow up. If we try to follow up our kebele, it will be difficult for us to follow up things in another kebele.*' This situation reveals the lack of inter-village coordination for water use. This gap in social cooperation goes beyond inter-village relations in that irrigation use cross cuts *kebele* boundaries, thereby requiring social coordination among inter-*kebele* water users.

Farmers have been already experiencing the consequences of lack of social coordination in current motor pump irrigation practices. Motor pump users have been concerned about how competitions for water use are growing, limiting the duration of water availability and creating water shortage. While describing this frustrating situation, a middle-aged woman in Kokit emphatically stated: '*Now the motors are randomly placed in every direction that there is shortage of water.*' During interviews as well as focus group discussions, farmers largely identified shortage of water as a growing problem. They indicated that the amount of water available for irrigation is decreasing from time to time. Rivers are also getting weaker and drying before their regular seasonal period. For instance, during a group discussion, farmers in Dibasifatira indicated that '*There are so many motors now that the Narza River we use for motor irrigation has dried. Before the presence of many motors we could use it from October to February. Now it stopped at the start of January. As a result, the crop we planted, wheat, failed.*'

Conclusion and recommendations

In recent years farmers in rural Fogera have been more involved in small-scale irrigation practices that include traditional *mesno* irrigation and motor pump irrigation. Farmers assert the importance of irrigation for their livelihood. This has spurred the enthusiasm for motor pump irrigation. Farmers have even drawn lessons from their traditional sharing and exchange practices and incorporated the use of the motor pump into local share-cropping arrangements. This shows farmers' willingness to utilize existing local practices so that they can adopt the use of a new technology they consider worth embracing. Indeed, motor pump irrigation has contributed to improve the livelihoods of farmers who have been able to use this technology. However, the study indicates that current motor pump irrigation practices undermine the sustainability of its benefits. Motor pump irrigation, unlike traditional irrigation, involves little social cooperation. While traditional irrigation is perceived as a social undertaking, this notion is undermined in motor pump irrigation by the undue focus on the motor pump technology and individualized activities of water pumping. Thus, current motor pump irrigation practices lack pertinent forms of social cooperation including mechanisms of water allocations and irrigation schedules. Consequently, farmers have been experiencing water shortage and increased competitions, threatening the livelihood benefits they seek from the enterprising of motor pump irrigation.

The study suggests that sustained benefits of this irrigation scheme as well as its long-term practice require pertinent forms of social cooperation and institutional mechanisms that coordinate and mediate water use and irrigation management across users' villages, cross-cutting *kebele* boundaries. This calls for collective action and feasible institutional arrangements to guide motor pump irrigation use and management. Traditional irrigation practices also need to be encouraged and supported. In particular, they require support to strengthen their institutional capacity for irrigation use and management. It is important to conduct more research regarding the performance of small-scale irrigation practices, with a holistic approach to understanding the multi-contextual factors that influence long-term benefits and how institutions can shape water use and improve irrigation performance.

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Factors in the suboptimum performance of rural water supply systems in the Ethiopian highlands

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Abstract: Access to safe drinking water services in the Ethiopian Highlands is one of lowest worldwide due to failure of water supply services shortly after construction. Over hundred water supply systems were surveyed to find the underlying causes of failure and poor performance throughout the Amhara Regional State. The results show generally that systems with decision-making power at the community level during design and construction remained working longer than when the decisions were made by a central authority. In addition, the sustainability was better for water systems that were farther away from alternative water resources and contributed more cash and labour. The results of this study of the importance of decision-making at the local level in contrast to the central authority is directly applicable to the introduction of rain water management systems as shown by earlier efforts of installing rain water harvesting systems in the Ethiopian highlands.

Media grab: Hundred surveyed water supply systems provided evidence for the importance of full community involvement both to lighten the burden of the overworked *woreda* staff, achieving greater quality of construction and sustained operation. Great poverty prevented payment and caused failure.

Introduction

Ethiopia has adopted the millennium development declaration and is devoted to the achievement of the millennium development goal (MDGs). Among the MDGs the most important development objectives are reducing poverty by enhancing economic growth, increasing agricultural production and improving rural water supplies.

Rural water-supply schemes in Ethiopia are partially or fully funded from governmental and nongovernmental resources. Many governmental organizations (GOs), non-governmental organizations (NGOs), donors and international non-governmental organizations (INGOs) through bilateral or multilateral projects and programs have

been working for two decades in Ethiopia to increase coverage and to provide safe water supplies and sanitation to underserved populations in poor and remote rural areas in the highland.

In Africa and other developing countries, sustainability of rural water supply is quite low with 30 to 60% of the schemes becoming non-functional within 5 years after implementation. Failure of water supply systems in sub-Saharan Africa includes lack of community participation, lack of recovery of operation and maintenance costs, poor training, disinterested users committees (Carter et al. 1999; Mengesha et al. 2003; Carter 2009), weak administrative support (Bhandari and Grant 2007), non-suitability of the technology for its intended use (e.g. hand pumps cannot provide sufficient water for cattle in Mali, Gleitsmann et al. 2007) and finally limited sustainability of imposed community management structures (Harvey and Reed 2006: Deneke et al. 2011).

Despite the many efforts in Ethiopia, the failure of both constructed water supply points and rain water management structures have common key factors in sustainability. The factors for either system poor sustainability in the Ethiopian highlands are not very well known and no information is available how these factors vary spatially. Since rainwater management structure have only recently been implemented we made an in-depth analysis on how the sustainability of developed rural water supplies is affected by available alternative water resources, operation and maintenance practices, Water Use Committees (WUCs), community participation and project cost. Detailed surveys were carried out in five *wordeas* and a more general survey in the remaining part of Amhara. In this paper, an overview is given of the survey results of the performance of the more than 100 water point. More information can be found by searching http://soilandwater.bee.cornell.edu/research/international/eth_pubs.htm and includes the full report to WaterAid-Ethiopia, briefing notes and theses.

Material and methods

Several studies on rural water supply systems are combined in this overview. They can be divided in two studies (A and B). Study A was carried out by five master's students in the Cornell/BDU program on Integrated Water Management. In-depth surveys, consisting of formal interview, focal group discussion and field observation were conducted of 80 water supply systems in five districts (*woredas*): Achefer, Mecha, Libokemekem, Quarit and Semada (Figure 1). In order to understand better why systems failed water system selection was changed slightly during the study. In the initial survey the selection of water supply systems was random in the Achefer, Libokemekem and Semada *woredas*. In the follow-up survey in Mecha and Quarit *woredas*, water supply points were selected randomly with the restriction that half of the water points were functional and the other half were non-functional. From 12–20, water supply systems per *woreda* were investigated (Table 1). In all *woredas*, households were randomly selected with 160 households (HHs) in all districts except in Libokemekem (200 HHs) and Quarit (180HHs) (Table 1). Study B was intended to obtain a broad overview of all water supply systems in the Amhara region in the Ethiopia highlands and consisted of a survey of 32 water supply schemes located in 29 different *woredas* (Figure 1). The survey was done by faculty members of School of Civil and Water Resources Engineering at Bahir Dar University and was funded by WaterAid Ethiopia.

Table 1. Description of study areas (Source: PCC 2008 and WaterAid Ethiopia)

Study area Name	Area (km2)	Population size 2007 census	Zone	% of rural population	Site selections
Achefer	2500.00	173,211	West Gojam	93	Randomly 16 villages
Libo Kemekem	1706.20	198,374	South Gondar	89	Random 20 villages
Mecha	1612.50	292,250	West Gojam	92	8 villages functional 8 not functional
Semada	2281.72	228,271	South Gondar	96	Randomly 16 sites
Quarit	613.6	166,848	West Gojam	98	6 villages functional 6 not functional
Amhara Region	161,828	17,214,056	11 zones	89%	32 sites selected
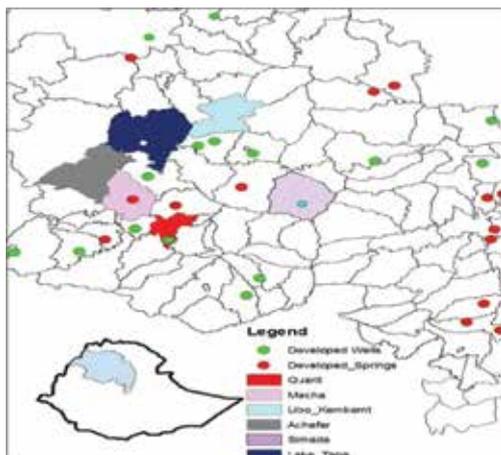
Figure 1 Map with locations of water supply points (red and green points) studied at regional level and Woredas (shaded area) where studies were conducted.

Data collection by formal surveys and focal group discussios was done in Study A from July to November in 2008 for Achefer and Libo-Kemekem districts and for the remaining districts, from September to December 2010. Surveys for Study B were conducted from October 2010 to March 2011.

Results and discussion

Functionality of schemes**:** In Study A (Table 1), water supply schemes consisted of hand dug wells, shallow wells and natural (or gravity) springs. The hand pump wells were less than 30 meter deep with the exceptions of the Semada district where the depth was 60 m. In study B in addition to the same types of water supply systems, 2 boreholes were surveyed.

In the Achefer, Libokemekem and Semada *woredas* (Figure 1), where water supply systems were selected at random (Tables 2 and 3), about two thirds were operational, one tenth completely not functioning and the remainder needed major repairs. The percentage of failed and broken water supply systems is nearly equal to that reported by African Development Fund in 2005.

Table 2. Functionality of schemes with technology type in the three districts where water points are selected randomly. HDW is hand dug wells

Study areas	Type of scheme	Number of water supply schemes	Functional	Non-functional	Functional with breakage
Libokemekem	HDW	16	13	3	0
Achefer	HDW	8	7	0	1
	Springs	8	2	0	6
Semada	HDW	6	5	0	1
	Springs	10	4	1	5
Amhara Region	HDW	15	6	3	6
	Shallow well	3	0	2	1
	Springs	12	6	1	5
	Borehole	2	2	0	0
Total		80	45	10	25

Table 3. Distribution of water point types where they are selected randomly for functional and non-functional categories

Study areas	Type of scheme	Number of water supply schemes	Functional	Non-functional	Functional with breakage
Mecha	HDW	14	8	0	6
	Springs	2	0	2	0
Quarit	HDW	8	5	3	0
	Springs	4	0	3	0

Amount of water use per day: The average water use from functional systems in study A was between 10 and 15 l/day per capita which was significantly less than the WHO guidelines of 20 l/day, (Minten et al. 2002; Mengesha et al. 2003; Collick 2008). In the Achefer and Semada *woredas,* we found that an increase of household by one person decreases significantly the per capita water consumption by 1.5 l/day. In addition in Achefer *woreda* increase in travel by 1 km to the water source decreased water use by 6.2 l/day per capita. Thus, both large family size and improved sources of water force households to use unimproved water sources when at closer distance than the improved source.

Alternative sources: Generally in most watersheds, several sources are available for obtaining drinking water. In the Amhara region (study B), we found that besides the improved sources, 65% of the villages had unprotected alternative source. In addition 24% of the village had choice between two improved sources. In Semada *woreda*, about 68% of the 160 respondents had more than one source. The availability of alternative unprotected spring water sources affects the sustainability of developed scheme. For example in the Mecha *woreda,* we found that approximately two thirds of the systems failed for households that used spring water before the new system was installed. In contrast, less than 20% was in need of repair for households that used traditional hand dugs in the back yard before the improved system was installed. These results are directly related to the belief of the rural population that the quality of water is good from spring and poor from hand dug wells. Thus for spring users there is no need to use water from a protective source and once the system is broken there is very little incentive to repair it. The opposite is true for communities that used water from the traditional hand dug wells and consequently more improved sources remain operating. Similarly to Semada *Woreda* in the Achefer villages the functionality was inversely related to the availability of alternative drinking water sources. It was found that in a village without alternative sources, none of the water system was completely broken.

Operation and maintenance: Surveys in Libokemekem, Semada, Quarit and Mecha *woredas* were directed towards understanding the various aspects of willingness to pay for operation and maintenance (O&M) of water facilities. The percentage of payers was in the order of 30% except in the Quarit district in which the functional system had great number of users contributing. In almost all cases, the amount collected did not cover the cost of maintenance. An interesting fact and often overlooked in reasons for failure of water systems is that the cash for obtaining water was just too costly for the poor families and therefore obtained lower quality water from traditional sources to save money.

WUCs: Water Use Committees (WUCs) were instituted in many villages for governing water systems (for example 90% in Semada, 100% Achefer and 62% Mecha of the villages had WUC's). The idea of water point management through WUC is reasonable taking into account both the scattered rural settlement pattern and the small number of *woreda* level experts relative to the number of water supply systems. In the Quarit *Woreda*, for example, only five experts (1 office head, 1 planning and documentation expert, 1 operation and maintenance expert, 1 pump attendant and 1 water quality expert) for the total of more than 200 water supply points. In many cases the WUCS were ineffective, had unclear responsibilities and authority in part due to outsider initiated institutional structure dominated by local administrators from government rather than local indigenous institutions as described in Deneke et al. (2011). This is demonstrated in Semada *woreda* where 47% of the respondents did not know the existence and/or the role of water user committee. Well-functioning WUCs are important because for instance in Achefer *Woreda*, there was a direct and statistically significant (p<10%) relationship between trust of WUCs and the amount of cash contributed.

Community participation: In Ethiopia, just like other African countries, the degree of community participation is extremely important This is well demonstrated in the surveys in the study of the Quarit and Mecha *woredas* (Figure 2).

The functionality of the system was much greater when either the community of a local leader had the responsibility for selecting the water points rather than the implementer. This is also the reason that the number of operational systems was much greater in the Mecha compared to Quarit system because local communities and leaders were more involved in the selection process.
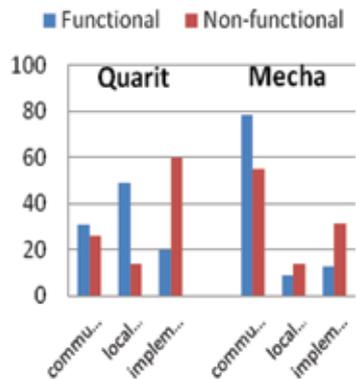
Figure 2 Community, local leader and implementer's share of responsibility in site selection in Quarit and Mecha Woredas

Project cost: Participation of households during water source installation is an important indicator for future project sustainability. This was well demonstrated in the Achefer *Woreda* where there was no complete failure and where for over 75% of the systems labour was provided for site clearing and construction and material were given such as wood. In addition 10 to 12%, the project cost was covered by the community. There was a similar situation in Mecha district in which nearly half of the community contributed cash, labour and local materials in case of the functional water points. In non-functional water point, majority of the community participate by providing only food and local beer for labourers.

Conclusions and recommendations

Despite many years of development efforts, both access to safe water supplies and well-maintained rainwater management systems in the Ethiopia highlands continues to be challenging. There are many parallels between the implementations of rural water systems and rainwater management systems. Success of either system depends largely on effective community participation in assuring that the systems function to the satisfaction of the users.

In case of water supply systems, 10 and 20% have failed completely. This will in near future be increased by 35% unless immediate solutions are devised by understanding the factors for unsustainability.

The availability of alternative water sources was an important factor in the failure of the system. Labour shortages often forced the family members to obtain water from a water point that was closest to the home. It is important for the sustainability of the system to consider providing sufficient water at a fair distance from their house by improving unprotected alternative sources near the houses.

The members of the community have often insufficient cash resources for payments. Therefore most cash collected for O&M should be spent on maintenance rather than operation such as payment for guard. Operation payments could be in kind by through participation of all households.

For the sustainability of the water points, the degree of participation of community or local leaders should be high. Although in all cases the communities requested for the water supply system and provided some level of services, only in the currently operational systems local traditionally community leadership participated in the selection of site, project scheduling and important decisions during construction.

The final important factor in success of the water systems was the functioning of the Water User Committees (WUCs). In most cases in failed systems, WUCs was found to be selected for formality to fulfil the requirement of implementers. They weren't fully recognized by the community and the communities did not trust them. It might

be preferable to use local indigenous institutions as described in Deneke et al. (2011) or local traditional leaders to assure WUCs that are trusted by the communities, so that payments will make for repair and systems can be repaired when broken.

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Impacts of brokerage institutions on the marketing of horticultural crops in Fogera district, Ethiopia

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Abstract: Fogera District, where the study focused, is endowed with diverse natural resources. It has huge potential water sources which are suitable for irrigation during the dry season for the production of horticultural crops mainly vegetables. However, there is a great market problem in the area associated with the nature of horticultural crops such as perishablity and seasonality in production. Moreover, the area is characterized by the existence of strong brokerage activity with their economic role not known. Thus, the main objective of this study was to analyse the economic roles played by the brokerage institutions in smallholder market linkages to market outlets in horticultural marketing and determinants of decisions on whether to use brokerage institutions or not under imperfect market condition in Fogera District, in northwestern Amhara Region particularly focusing on onion and tomato. Both secondary and primary data were collected for the study. Primary data were collected from a very wide number of respondents at all stages of the market channel where brokers are expected to play role. Two stage sampling techniques were used to select the sampled farmers. Descriptive and econometric statistical models were employed for data analysis using STATA software. The study implemented the Propensity Score Matching (PSM) model. The result of the study showed that the brokerage institutions are characterized as urban, peri-urban and farmer brokers. There was significant brokerage activity only for onion marketing and in the case of tomato marketing the brokers act as rural assemblers. Most of the horticultural trading in the area is undertaken by credit and thrust based and in this arena brokerage institutions are playing most important role by linking smallholder farmers to market outlets. Logistic regression estimation of Propensity Score Matching model revealed that age, education level, distance of residence from development agent office, distance of residence from Woreta market, distance of residence from main asphalt road, access to cell phone (mobile phone) and number of regular wholesaler customers significantly affected the participation decisions of the smallholders in the brokerage institutions services. Kernel Matching with band width of 0.25 was found to be the best matching algorithm. The result of the study also revealed that smallholder farmers using brokerage institutions have got 4393.62 ETB higher net income and 13.55% of greater marketed surplus than those smallholders who do not use. Generally, the brokerage institutions are playing significant and important role in forming market linkages between smallholders and wholesalers under imperfect market conditions with their limitations. Therefore, the study highly recommends the formalization of the brokerage institutions through licensing, training and continuous follow up in the district considering the experience of ECX.

Key words: Fogera, Brokerage institutions, STATA, PSM, ECX

Media grab: Most of the horticultural trading in the district is undertaken by credit and thrust based and in this arena brokerage institutions are playing most important economic role for smallholder farmers. Thus, this study highly recommends the formalization of the brokerage institutions considering the experience of ECX.

Introduction

Ethiopia has highly-diversified agro-ecological conditions which are suitable for the production of various types of fruit and vegetables. Amhara Region is one of the potential areas in the country. Fogera District is endowed with diverse natural resource, with the capacity to grow different annual and perennial crops. Two major rivers are of great importance to the *Woreda*, Gumara and Rib. They are used for irrigation during the dry season for the production of horticultural crops mainly vegetables. Efficient coordination in traditional markets is a prerequisite for a successful smallholder commercialization towards rural transformation, poverty reduction and agrarian change in the developing countries. However, it is often staggered by the problem of market imperfection and institutional underdevelopment that increase transaction cost and risk faced by smallholders. There are no producer organizations, such as cooperatives to coordinate horticultural marketing purpose in Fogera on behalf of farmers, against a growing demand for the products in different parts of the country. Because of this, success in horticulture crop production as high value crops is not necessarily translated into a market success in the area. Such institutional bottlenecks against an emerging horticultural market have created a fertile ground for a strong presence of brokers in the horticultural market of Fogera.

Though road infrastructure and use of mobile telephones among farmers for market access and information exchange is reasonable, direct linkage of farmers to the wholesale market (the major market for the horticulture crops produced) is very limited. As a result, the majority of smallholders opt to use brokers to sell their products to wholesalers, who distribute products to different consumer and seasonally deficit producer markets in the country. Given the large volume of horticulture products in the area, combined with seasonal glut and high perishability, efficient market coordination and logistics are necessary to link Fogera horticulture farmers with the wholesale markets and to enable them generate sufficient economic incentives. In rural areas where producer organizations are absent and market institutions are underdeveloped, posing a challenge for smallholder market linkage, brokers could fill the coordination gaps and logistical constraints to facilitate exchange. Fogera provides a useful case in this regard where the brokerage institution, which dominantly exists informally, plays an important role in coordinating the horticultural marketing activities, starting from the farm. According to Amhara Regional Agricultural Research Institute and Amhara Regional Bereau of Agriculture (2008) participatory rural appraisal report, one of the priority research problems in horticultural marketing in the *woreda* was the role and functions of informal brokerage activity in the area.

However, the brokers at Fogera horticulture market (who play a market coordination role by constituting an important element of the 'invisible hand'), are not closely studied, known and described in terms of their impacts, limitations and constraints to improve their efficiency and impact as an important intermediary in the horticultural supply chain of the area. Perhaps, this is a result of the less recognition the brokerage institution receives. This paper is intended to contribute to filling this knowledge gap in the area by addressing the following objectives.

The general objective of the study was:

• To assess the economic roles played by the brokerage institution and identify determinants of decisions on whether to use brokers or not under imperfect market condition in the study area.

The specific objectives of the study were:

• To identify the determinants of farmers' decision whether to use brokerage institutions or not as a means of market linkage to wholesalers; and

• To measure the impact of brokerage institutions on smallholder horticulture producers

Methodology

Description of the study area

Fogera District is one of the 106 *woredas* of Amhara Regional State and found in South Gondar Zone. It is situated at 110 58 N latitude and 370 41 E longitude. Woreta is the capital of the *woreda* and is found 625 km from Addis Ababa and 55 km from the Regional capital, Bahir Dar. The District is divided into 27 rural Peasant Associations and 3 urban *kebeles*.

Methods of data collection and sampling procedures

Both primary and secondary data were used for this study. The primary data for the study were collected from market actors starting from production to the end retailers which were conducted through interview and discussion. A semi-structured questionnaire and check-list were used for data collection. Field trips were made to undertake Rapid Market Appraisal (RMA). The questionnaires were pre-tested and its contents were refined. The researcher has made personal observations and informal discussions with farmers, development agents, district agricultural experts of Ministry of Agriculture and Rural Development using checklists. Multi-stage random sampling techniques were employed. The sample has covered farmers, brokers, rural assemblers, wholesalers and retailers on proportionate to size basis and research objectives using sample size determination formula.

Methods of data analysis

Both the descriptive statistics and econometric methods were used for the analysis of the data. Descriptive statistics such as percentages, frequencies, standard deviation, independent sample t-test and chi squared test were used. To measure the impacts of brokerage institutions this study used with and without approach which best suits the purpose of this particular study i.e. brokerage institution participants and non-participants comparison using Propensity Score Matching (PSM) model.

Results and discussions

Demographic and socio-economic characteristics of sampled households

This study is based on information collected from 143 sampled farm households in Fogera District. Family size ranges from 2 to 14. The sample is composed of 63 male headed and 4 female- headed non-participant households and 67 male-headed and 9 female-headed participant households. There is significant difference between participant and non-participant farmers with respect to sex. This indicates female-headed households tend to participate in the brokerage institutions to sell the horticulture product. Because, direct linkage to the wholesalers needs high communication ability, networked interaction, labour intensive and mobility from place to place but females in the area cannot undertake this because they are very busy undertaking house works and also social taboos hinder them.

Labour supply conversion factor (person day equivalent).

There is a significant difference in age. This is because aged people are weak in communication and interaction which needs moving from place to place and labour intensive. Thus, they tend to participate in the brokerage institutions. The level of education of the household heads is statistically different for the two groups and non-participants were better-off in their level of education. Educated people have greater communication and negotiation ability in addition they have no problem of calculating the transaction and profit. Thus, educated households tend to do not participate in the brokerage institutions in order to remove the *commission payment* and maximize their profit. There was significant difference on irrigable land holding between the non-participant and participant households. This might be due to the reason that households who have higher irrigable land size have the opportunity to produce more which

in turn gives an incentive for them to attract wholesalers because wholesalers think of the reduced transaction cost in which they can have full of the car at a time from one producer. The livestock ownership was not significantly different between participant and non-participant households. The minimum amount owned by a household is 0 while the maximum was 17.68 TLU which indicates that there is a high degree of disparity in the ownership of livestock between the sample households.

Table 1. Descriptive statistics of sample households on pre-intervention characteristics

Pre-intervention variables	Sampled households (143)		Participant (N = 76)		Non participant (N = 67)		Difference in means		T-Value
	Mean	Std. Er	Mean	Std. Er	Mean	Std. Er	Mean		
Age	39.60	0.99	42.54	1.64	37.01	1.09	−5.52	1.93	−2.86***
Sex	1.91	0.02	1.87	0.04	1.95	0.03	0.08	0.05	1.70**
Marital status	0.96	0.02	0.95	0.03	0.96	0.02	0.01	0.03	0.16
Education level	2.53	0.29	1.52	0.36	3.42	0.41	1.9	0.56	3.42***
Family size	3.31	0.11	3.36	0.15	3.26	0.15	−0.10	0.22	−0.47
Family size	6.13	0.21	5.94	0.29	6.29	0.30	0.35	0.42	0.83
TLU	5.67	0.25	5.97	0.38	5.40	0.34	−0.57	0.51	−1.11
Land size	1.57	0.09	1.43	0.08	1.69	0.16	0.27	0.19	1.43
Irrigable land	0.97	0.09	0.77	0.06	1.16	0.15	0.39	0.18	2.2**
Experience in production	8.97	0.32	9.18	0.48	8.79	0.42	−0.39	0.64	−0.61
Distance to extension	3.49	0.30	4.41	0.55	2.69	0.26	−1.71	0.59	−2.92***
Cell phone	0.43	0.04	0.18	0.05	0.64	0.06	0.47	0.07	6.32***
Distance to district (Woreta)	12.43	0.63	14.64	1.1	10.49	0.63	−4.15	1.22	−3.40***
Distance to asphalt road	2.49	0.22	3.76	0.36	1.37	0.18	−2.39	0.39	−6.16***
Number of customers	1.52	0.20	0.85	0.19	2.12	0.32	1.27	0.38	3.29***
Number of trading contacts	8.07	0.59	7.95	0.74	8.17	0.92	0.22	1.20	0.18

Source: Author's survey 2011/12.
*** and **means significant at the 1 and 5% probability levels, respectively.

Institutional and social capital aspects

All of the households have access to formal credit sources such as Amhara Credit and Saving Institutions (ACSI). Only 13.2% of households are member of cooperatives. In all of the *kebeles* of the district there are development agents. However, there is significant difference in distance from residence to development agents between participant and non-participant households. Telecommunication facility is the most important service in marketing of horticultural products by providing recent information and reducing the transaction cost of trading. There was significant difference between the participant and non-participant households with respect to cell phone ownership. Higher percentage of mobile phone ownership helps the non-participant households to easily call and find the wholesalers for selling their horticulture product. There are two main asphalt roads from Bahir Dar to Gondar and from Woreta to Debre Tabor. There is significant difference between participant and non-participant households with respect to distance of residence to Woreta (District) market and main asphalt road. The reason is that when the households are far away from the main asphalt road and Woreta town, the transaction cost of finding market information and wholesalers is very high. Thus, the households tend to use brokerage institutions in order to reduce the transaction cost.

Table 2. Descriptive statistics of sample households (for dummy variables)

Pre-intervention variables	Category	Participant (N = 76)		Non participant (N = 67)		Total		χ^2
		N	%	N	%	N	%	
Sex	Female	10	13.16	3	4.48	13	9.09	2.88*
	Male	56	86.84	64	95.52	130	90.91	
Cell phone	No	62	81.58	43	64.18	105	73.43	31.56***
	Yes	14	18.42	24	35.52	38	26.57	

Source: Author's survey 2011/12.
*** and *means significant at the 1 and 10% probability levels, respectively.

Social capital plays very significant role in transaction. There is significant difference between the participant and non-participant households with respect to the number of regular wholesaler customers and number of trading contacts to main (Woreta) market in marketing of horticultural products. Social capital reduces the transaction cost by reducing the negotiation and information searching costs. High social capital means less probability of participation in the brokerage institutions. Since, non-participant households have higher social capital which reduces the transaction cost, they tend to directly contact to wholesalers to sell their product than using brokerage institutions.

Propensity score matching model

Only six of the fifteen explanatory variables which are theoretically supported to influence the decision to participate in the brokerage institutions for linkage in the logit model have significant effect on the participation decision of the household.

Table 3. Logit results of households' brokerage institution participation

Variables	Coefficients	Std err	Z value
Age	0.056**	0.028	2.03
Sex	−0.157	0.996	−0.16
Marital status	−0.308	1.410	−0.22
Education level	−0.163*	0.086	−1.90
Family size1	−0.052	0.282	−0.19
TLU	0.109	0.098	1.11
Land size	0.183	0.586	0.31
Irrigable land	−0.022	0.574	−0.04
Experience in production	−0.021	0.065	−0.33
Distance to extension	0.156*	0.087	1.81
Cell phone	−1.710***	0.554	−3.09
Distance to district	0.006	0.038	0.16
Distance to asphalt	0.631***	0.172	3.67
Regular customer	−0.331**	0.164	−2.02
Trading contacts	−0.027	0.042	−0.65
Constant	−2.479	2.458	−1.01
Sample size (N)	143		
LR chi^2 (15)	84.88		
Prob > chi^2	0.00		
Pseudo R^2	0.42		
Log likelihood	−56.394		

Source: Own estimation result.
***, ** and *means significant at the 1, 5 and 10% probability levels, respectively.

Labour supply conversion factor (person day equivalent)

The interest of the matching procedure is to get a household from non-participants in brokerage institutions service with similar probability of participation or using brokerage institutions given the explanatory variables. Age of the household head significantly and positively affected the probability of participation in using brokerage institutions service of the household. It coincides with the hypothesis that as the age of the household head increases, the household decides better to participate in brokerage institutions. This is due to the fact that aged people have weak communication and information searching ability in order to directly contact to traders/wholesalers to sale the onion. In other words, the younger the household head is, the more likely will be the probability of not participating in the brokerage institutions for linkage in the marketing of onion.

Education level of the household has a negative significant effect on the participation decision of the household in brokerage institutions. People with higher education level are good at communication, information searching, negotiation and undertaking transaction which leads to direct contact to traders to sell their product. This indicates that educated people have less probability of using brokerage institutions for linkage to wholesalers than uneducated people (illiterate and adult education). In Fogera *Woreda,* the most determining factor for direct linkage of farmers to

wholesalers is the thrust between them during transaction. The transaction can be undertaken if there is strong thrust between them in weighing and payment. If the household head is uneducated he has no knowledge about weighing and preferred to use brokerage institutions for market linkage than direct linkage to wholesalers as he is more familiar with the broker who lives in the residence and trustful on the broker. Payment place is also the most important issue for farmers and wholesalers. Farmers prefer to receive their payment at the farm while wholesalers prefer to pay at Woreta town this disagreement made uneducated farmers to sale their product using brokerage institutions while educated farmers have no problem of payment place rather the price itself. Thus, there will be easy agreement between farmers and wholesalers and they tend to directly contact to wholesalers to sell their product without using brokerage institutions.

Distance of residence of the household to development agent's office has a positive significant effect on the participation decision of the household in the brokerage institutions. Households which are far from the development agent office have higher probability to use brokerage institutions for linkage to the market outlet than households which are near to development agents. The reason for this fact is that when distance of the household's residence to the development agents increase, the household cannot have easy access for extension services related with product marketing techniques, market information and market linkages which lead the household to participate in brokerage institutions service for linkage than direct contact to the wholesalers. The two most important factors which affects households decisions whether to use brokerage institutions or not in Fogera *Woreda* are transaction costs and the issue of obtaining secure market outlet for the product. Having Cell phone (Mobile phone) or not has a negative significant effect on the participation decision of the households whether to use brokerage institutions or not for linkage to the traders/wholesalers. Households who have mobile phone have a higher probability of not using brokerage institutions for market linkage than those who do not have. Mobile phone makes communication and information searching very easy as a result it reduces the transaction cost of finding wholesalers. Therefore, it facilitates the direct contact of households to the traders.

Distance of residence of the household to the main asphalt road has a positive and significant effect on the participation decision of the households in the brokerage institutions. Households which are far from the main asphalt road have higher probability to use brokerage institutions for linkage to the market outlet than households which are near to the main asphalt road. The reason for this fact is that when distance of the household's residence to the main asphalt road increases, the household cannot access information about the wholesalers and there will not be thrust between the wholesalers and the farmers in the transaction processes (payment become very difficult for the wholesalers at the farm which is distant from the asphalt road, the wholesaler do not thrust the farmer whether he has quality onion or not in the area and if there is no quality onion there will be high transaction cost for wholesaler to come out of the farm to the main road. On the other side, the farmer also do not have thrust on the wholesaler in order to receive the payment for his product from the wholesaler in the Woreta town) which leads to higher probability of using brokerage institutions for market linkages in which the brokerage institutions are known and the transaction is safe from any default.

Number of regular customers (wholesalers) of the households has a negative and significant effect on the participation decision of the household in brokerage institutions service. Households having large number of regular wholesalers have lower probability of participating in the brokerage institutions for market linkage than those who have lesser number of regular customers. This is due to the fact that households prefer direct market contact to the wholesalers as they have larger number of regular customers who can purchase the product. Thus, there is no information problem and higher transaction cost to access them. In addition, direct contact removes the *FERQ* which is advantageous for both producers and wholesalers. However, if the households have less number of regular wholesaler customers, wholesalers cannot purchase all of their products because they are few which needs searching another market outlet or wholesaler. This in turn leads to higher transaction cost of searching information and wholesalers. As a result, the households prefer to use brokerage institutions for market linkage under this condition.

Common support condition and matching using matching algorithms

The next step in propensity score matching technique is the common support condition. Only observations in the common support region matched with the other group considered and others should be out of further consideration. The predicted probability for those who are participating in the brokerage service ranges from 0.060 to 0.999 with the mean probability of participation being 0.725. On the other hand, the probability of not participating of the non-participant households in the brokerage institutions service ranges from 0.003 to 0.895 with mean of 0.242. From the result, observations with the predicted probability between 0.060 and 0.895 are in the common support region with the possibility of getting good match from the other group. Observations with predicted probability of less than 0.060 and greater than 0.895 have been disregarded out from further analysis. In an impact assessment study, households should have their good match from the control group. This will be maintained through balancing the covariates of the participant group to the covariates of the non-participant group. Against the unmatched sample, matched samples using kernel with band width of 0.25 satisfy the property of balanced matching for all of the covariates. The three criteria were implemented to each matching algorism to identify the best matching technique. Kernel matching algorism with a band width of 0.25 was found to be the best estimator by balancing all the observable covariates, ends with low pseudo-R^2 and large number of observations in the common support. Accordingly, the research used it for measuring the impact.

Impacts of the brokerage institutions

The study describes the impacts of brokerage institutions in linking smallholder horticultural crop (onion) producers with market outlets (wholesalers) in terms of net return, percentage of marketed surplus, land allocated to onion production, amount of onion produced and sensitivity of the impacts.

Table 4. Impact of brokerage institutions

Outcomes	ATT	Std.Err[1]	T-value
NRO	4393.62	1781.51	2.53**
PMS	13.55	13.84	2.86**
AOP	−5.084	36.72	−0.25
LAOP	−0.053	0.22	−0.24

1. The bootstrapped SE is obtained after 100 replications.
**, significant at 5% probability levels; Source: Own estimation result.

Impact on net return from onion production (NRO)

Brokerage institutions in Fogera *Woreda* create linkage between farmers and the market outlet (wholesalers). Thus, farmers using brokerage institutions have easy access to wholesalers which reduces the transaction cost of searching traders, market information, loss due to perishablity and transportation cost which in turn reduces the overall marketing cost. As net return is revenue reduced the total cost, a reduction in marketing cost means a reduction in total cost which leads to high net return. Smallholder farmers using brokerage institutions have got 4393.62 ETB higher net incomes from onion production than those farmers who do not use brokerage institutions for linkage to the market outlet. This indicates that brokerage institutions are playing a significant and positive role in linking smallholder farmers to the market outlets.

Impact on percentage of marketed surplus (PMS)

Smallholder's use of brokerage institutions is highly associated with the issue of obtaining secure market for their product in all the production years. According to *Woreda* Experts and Development Agents, there is significant fluctuation either increasing or decreasing in horticultural production every year following the increase or decrease in price of the previous year, respectively. In 2011 production year, it was very good year for horticultural production and onion production was high in the area following the high price incentive in 2010. Thus, in 2011 the price of onion has reached to 0.25 ETB for kg of onion because the supply was much more than the demand and even most of the farmers specially farmers who do not use brokerage institutions do not sell much of their product. Following this,

the farmers reduced allocation of more land to onion production and the supply in 2012 become very low relative to demand. Based on the monitoring of the study area for about four months (January, February, March and April), the price score for a kg of onion was between 4.00–7.00 ETB.

In 2011, due to the high supply of onion, lower demand compared to production and perishable nature of the product brokerage institutions played great role in linking their smallholder customer farmers (broker users) to the market outlets and the percentage of non-marketed onion from total production was lower than 27.27% while farmers who do not have the experience of using brokerage institutions specially those whose residence is far from the main asphalt road were unable to sell their product and the non-marketed onion from total production has reached to up to 79%. This is due to the fact that brokers have much higher regular wholesaler customers than farmers who do not use brokers, more information and very high communication capacity which leads them to control most of the wholesalers coming to the area. In addition, in the time of much supply brokerage institutions provide service first for their very experienced farmer customers that is based on experience in transaction. The result of the study revealed that smallholder farmers who participated in brokerage institutions for linkage have 13.55% of greater marketed surplus than those smallholders who do not participate. This implies that brokerage institutions have significant and positive impact on marketed surplus in Fogera District.

Impact on amount of onion Produced (AOP) and land allocated to onion production (LOAP)

The result of the study indicated that brokers have no significant and positive impact on the amount of onion produced and land allocated to onion production. The reason is that higher land allocation and high production is affected by other factors like previous year price.

Sensitivity analysis

Rosenbaum (2002) proposes using Rosenbaum bounding approach in order to check the sensitivity of the estimated ATT with respect to deviation from the CIA (Conditional Independence Assumption). The basic question to be answered here is whether inference about treatment effects may be altered by unobserved factors or not. Result of sensitivity analysis using Rosenbaum bounding approach.

Outcomes	$e^\gamma = 1$	$e^\gamma = 1.25$	$e^\gamma = 1.5$	$e^\gamma = 1.75$	$e^\gamma = 2$	$e^\gamma = 2.25$	$e^\gamma = 2.5$	$e^\gamma = 2.75$	$e^\gamma = 3$
NIO	5.0e–12	6.4e–09	6.9e–07	0.000018	0.000192	0.001141	0.004497	0.013149	0.030763
PMSU	P<0.000	P<0.000	P<0.000	1.1e–16	8.0e–15	2.3e–13	3.3e–12	2.9e–11	1.8e–10
AOP	P<0.000	P<0.000	P<0.000	P<0.000	P<0.000	P<0.000	P<0.000	P<0.000	P<0.000
LAOP	P<0.000	P<0.000	P<0.000	P<0.000	P<0.000	P<0.000	P<0.000	P<0.000	P<0.000

Source: Own estimation.
e^γ (Gamma) = log odds of differential due to unobserved factors where Wilcoxon significance level for each significant outcome variable is calculated.

The first column of the above table shows those outcome variables which bears statistical difference between treated and control households in our impact estimate above. The rest of the values which corresponds to each row of the significant outcome variables are p-critical at different critical value of e^γ. Result showed that the inference for the effect of the brokerage institutions is not changing though the participants and non-participant households in the brokerage institutions has been allowed to differ in their odds of being treated up to 200% ($e^\gamma = 3$) in terms of unobserved covariates. That means for all outcome variables estimated, at various level of critical value of $e^\square$, the p- critical values are significant which further indicate that the study has considered important covariates that affected both participation and outcome variables. The study couldn't get the critical value e^γ where the estimated ATT is questioned even if the research have set largely up to 3, which is larger value compared to the value set in different literatures which is usually $e^\gamma = 2$ (100%). Thus, it is possible to conclude that the research impact estimates (ATT) are insensitive to unobserved selection bias and are a pure effect of brokerage institutions in the area.

Conclusion and recommendations

The overall analysis of the study can be concluded that brokerage institutions are characterized as farmer, peri-urban and urban brokers including farmers, youth brokers (school dropout and high school complete youngsters) and traders of cereals like rice. The brokerage institutions have strong chain in the *Woreda* and most of the transactions are undertaken by them and are playing role by searching different market outlets to almost all parts of Ethiopia. Since brokerage institutions are well informed by buyers and producers, who are residents of the *Woreda*, educated and youngsters, they have easy information access and play significant role by providing market information, linking smallholders to wholesalers, creating economies of scale from many smallholders, easily bargain with both smallholders and wholesalers and act as a collateral for both of actors which helps the smallholders and wholesalers to reduce transaction cost under market imperfections. If brokerage institutions were not there, it was very difficult for wholesalers coming from the area to find smallholder producers. Therefore, empirically the idea that brokerage institutions are not important along the value chain is highly challenged here and brokerage institutions are the most important actors in the marketing of perishable products like onion which implies that greater attention should be given for them in order to sustain production and market linkages.

Brokerage institutions are source of secure market for smallholder producers because they have many regular wholesaler customers coming from the different areas of the country. Thus, if a farmer has regular customer of broker and plan to produce onion he is secured for the market because of brokers. This in turn implies that brokerage institutions form market outlets for the smallholders. Finally, the study recommends that a formalized and upgraded brokerage institution is commendable only as a *third pillar* for a better market coordination in the area. That is to say, in the best circumstances, even a formalized and upgraded brokerage institution should be considered only as a complement to, rather than as a substitute for, improved market institutions and effective producer organizations. The formalization activity can be adopted from the Ethiopian Commodity Exchange (ECX) experience. The study also recommends the ECX to include the horticultural crops such as onion in its commodity crop services. In addition, the study recommends training to farmers on marketing and weighing, standardization of weighing and provision of market information for the farmers in order to increase the benefit and income of farmers which helps them to come out of poverty.

Acknowledgements

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Posters

Management practices and agro-ecological effects on crop water productivity in Meja watershed, Ethiopia

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Abstract: Mixed crop–livestock farming system is a major livelihood strategy in most sub-Sahara African countries. Low water use efficiency and water scarcity characterize the dominant rainfed agricultural production system in the densely populated highlands of Ethiopia. Improving water productivity in the rainfed system is among the ways of overcoming the water scarcity challenge. This study was conducted in *Meja* watershed, located in Jeldu district, West Shewa in the Ethiopian part of the Blue Nile Basin to estimate economic crop water productivity based on agro-ecology and crop management practices. The watershed was classified into three landscape positions (local agro-ecologies) and major crops representing at least 70% of each landscape position were identified through discussion with farmers and development agents. Five farmers field were randomly selected for each major crop and crop management practices implemented by the farmers were monitored and yield (grain or tuber and straw) was measured at harvest. The local market value of the crops and the production cost was estimated based on the local market value for labour and other inputs. CROPWAT model was used to estimate effective precipitation based on weather data generated using NewLocClim and crop characteristics. The result indicated that the landscape positions, crop variety and management practices significantly influenced the net economic water productivity. The net economic crop water productivity for barley, wheat, tef, sorghum and maize grains and fresh potato tubers were 3.31, 2.45, 3.09, 3.01 and 5.20 and ETB 13.56 m⁻³, respectively. Similarly, physical water productivity of the crops ranged from 0.47 for teff to 9.98 kg m⁻³ for fresh potato tubers. Hence, farmers can enhance economic benefit from the land and water resources they are endowed with rainfed by using improved agronomic practices that could raise grain/tuber and biomass yield. Enhancing improved input use, improving access to market for outputs and integrating livestock with crops may further augment the benefit at system scale.

Key words: Meja watershed, Ethiopia, water use efficiency, water scarcity, crop management

Introduction

Mixed crop–livestock farming system, which is characterized by a strong complementarity in resource use (Devendra and Thomas 2002), is a major livelihood strategy in most sub-Sahara African (SSA) countries (Steinfeld et al. 2006) including Ethiopia and supported the livelihoods of approximately 80% of the population (Thornton et al. 2002). In

this system, achieving higher production and improved rural livelihoods is highly restricted by underdevelopment, rapid population increase, land degradation, climate uncertainty and associated water scarcity (Singh et al. 2011). Among others, the problem of water scarcity has been aggravated and seriously hampered crop productivity in rainfed agriculture mainly due to non-water related factors. Among water related factors, increasing competition for water among agricultural and other economic sectors as well as household consumption and environmental demand (Molden et al. 2007), increasing temporal and spatial variability of rainfall resulting in amplification of extreme events (IPCC 2007), poor land and inefficient rainwater management systems implemented by most smallholder farmers (Rockström and Steiner 2003; Wani et al. 2003; Zemadim et al. 2011) and decreasing potential of irrigation water withdrawals due to its stressing effect in many of the world's major river basins (Molle et al. 2007). These factors reduced water available for agricultural sectors. Among non-water related factors, land degradation, poor soil fertility, soil salinity, lack of improved varieties, low rate of fertilizers used, poor weed management, unsecured land ownership, limited access to capital for investment, limited skill and abilities are the determinant factors for low crop productivity (Kijne et al. 2003; Mulugeta 2006; Singh et al. 2011). Generally speaking, water available for agricultural sector is continued to be reduced despite the increasing food demand (Kijne et al. 2003) due to increasing human population. One of the best solution to alleviate this problem lies on improving crop water productivity (Cai et al. 2010). Hence, technological interventions that could significantly increase crop water productivity and improve rural livelihoods in different landscape positions at farm and watershed levels are highly required. The Ethiopian Institutes of Agricultural Research (EIAR 2004) also recommended that water productivity improvements in crops, livestock and fishery can effectively address food insecurity and poverty. In line with this, the major objective of the study was to estimate net economic water productivity of major crops based on agro-ecology and management practices. Therefore, the study result would confidently serve as a valuable input for the concerned governmental, NGOs, policymakers and others at local, regional and country level to design and implement appropriate technological intervention strategies to the study area in particular and upper Blue Nile Basin in general so as to address the problem of water scarcity and food insecurity.

Materials and methods

Description of the study area

Meja watershed is located in Jeldu district, West Shewa in the Ethiopian part of the Blue Nile Basin. Mixed crop–livestock farming system is the most common livelihood strategy in the area (Zemadim et al. 2011). It was estimated that about 4769 households were living in the watershed from which 16% were females and the average family size of the district was six. The watershed was predominantly characterized by subsistence, low yielding rainfed agriculture, lack of appropriate soil and water conservation practices and increasing human and livestock population pressure (Berhanu Ayana 2011). The watershed covers an area of about 85.36 km^2 with an altitude ranging from 2440 to 3200 masl (Zemadim et al. 2011). Barley is the dominant crop cultivated followed by wheat, potato and enset (false banana), respectively. Farmers used both traditional and improved farm inputs to treat soil fertility problem and enhance crop yield. Cattle, sheep and equines were the dominant livestock species reared by farmers (Berhanu Ayana 2011). Small-scale irrigation through traditional diversion of the major river is common along the downstream regions. The area receives bimodal rainfall pattern with main rain from June to September and short rain from March to May having mean annual rainfall varies from 900 to 1350 mm (Zemadim et al. 2011). The mean maximum and minimum annual temperature ranges from 17°C to 22°C. Farmers obtained income mainly from the sale of barley, potato, green maize, eucalyptus and livestock products.

Sampling, data collection methods and determination of crop yield

The watershed was classified into three landscape positions (local agro-ecologies) and major crops representing at least 70% of each landscape position were identified through discussion with farmers and development agents in the district. Five farmers field were randomly selected for each major crop and crop management practices implemented by the farmers were monitored and yield (grain/tuber and straw) was measured at harvest. The sampled crop fields were continuously monitored in 10–20 days intervals and detailed data on crop management and agronomic practices including tillage frequency, crop rotation patterns, types of precursor crops, planting dates, seeding rates, types and

rates of fertilizer applied, methods of sowing, weed control method, date to flowering, date of maturity and harvesting dates were recorded. Above ground biomass and grain yield were also estimated using quadrate sampling technique at the time of harvesting. Samples for grain and straw were brought to laboratory and forced to dry in the oven at 65°C for 24 hours and grain moisture content was adjusted to 12%. Finally, average productivity of each crop in kg ha⁻¹ was determined.

Simulating effective precipitation

The other input data required for CWP analysis is amount of rainwater consumed to produce crop products. Weather data required for simulation of crop water requirement was generated by using New-LocClim model from FAO data base due to absence of weather station in the area. Effective precipitation (m³) was simulated by CROPWAT model using imported weather data and both crop and soil water characteristics of the study area. According to Singh et al. 2011, rainfed crops use infiltrated rainfall that forms soil moisture in the root zone which accounts for most of the crop water consumption in agriculture. As compared to other components of water, effective precipitation is more affected by crop management practices. As a result of this, effective precipitation was preferable to be utilized for CWP analysis of this particular study.

Estimating crop water productivity

Both physical and economic water productivity with respect to effective precipitation were determined as a ratio of unit mass of agricultural output (kg ha⁻¹) and economic return in ETB to effective precipitation (m³) (Kijne 2003; Steduto et al. 2007) using the following procedures:

- WP of GY or FTY (kg m-3) = GY or TY (kg ha-1) ¸ Effective Precipitation (m³ ha-1)   (A)

- WP of SY (kg m-3) = SY (kg ha-1) ¸ Effective Precipitation (m³ ha-1)   (B)

- EWP of Grain (ETB m-3) = GY (ETB) ¸ Effective Precipitation (m³ ha-1)   (C)

- EWP of Straw (ETB m-3) = SY (ETB) ¸ Effective Precipitation (m³ ha-1)   (D)

The net economic crop water productivity was determined by subtracting costs of production (ETB) from monitory values of BM, GY or FTY through the following course of action:

- GEWP (ETB m-3) = above ground BM for cereals and total BM for potato in kg ha-1 ¸
  Effective Precipitation (m³ ha-1) or (C + D)   (E)

- Net economic crop WP = GEWP (ETB m⁻³) – Q (ETB)   (F)

Where WP, EWP, GEWP, ETB, Q, BM, GY, FTY, SY refer to Water productivity, economic water productivity, gross economic water productivity, Ethiopian birr, Costs of Production, Biomass, grain yield, fresh tuber yield and straw yield, respectively.

Data analysis

In order to test whether there is significant mean net economic biomass, grain or tuber water productivity difference among the three agro-ecological zones or not, comparison of means was employed. The null hypotheses for such test would be: H_O: $x_1 = x_2 = x_3 = \ldots = x_k$ where x_1 to x_k represent sample means of the 1 to k groups (Storck et al. 1991) and the most appropriate statistical technique to test such hypothesis is the analysis of variance (Norusis 1987). Analysis of variance is used to examine the degree of variability in the mean net economic biomass and grain or tubers water productivity results. Based on the variability, some conclusions about the means were drawn. Again,

one-way analysis of variance (multiple comparisons) test was also applied to justify the differences among mean net economic biomass and grain or tubers water productivity magnitudes of the major crops with respect to each local agro-ecology. In addition to this, several management practices that could affect crop water productivity in the study watershed were considered to test their degree of association with net economic biomass and grain or tuber water productivity. The Pearson's correlation analysis was employed to test the existence and strength of relationships between the selected crop management practices and net economic biomass, grain or tuber water productivity across the three local agro-ecological zones by using SPSS software. Based on the results and level of significance, the possible effects of those management practices on EWP magnitude of each crop was presumed.

Results and discussion

Physical crop water productivity

Productivity is a ratio between a unit of output and a unit of input and the term water productivity is used exclusively to denote the amount (physical) or value (economic) of product over volume or value of water depleted or diverted (Renault and Wallender 2000; Kijne 2003; Steduto et al. 2007). For this particular study, the amount of product and individual net monetary value over volume of effective precipitation was considered. Hence, the average rainwater productivity result of barley grain was 0.78 kg m^{-3} while that of wheat (0.83 kg m^{-3}) in the upper zone and 0.98 kg m^{-3} in the middle zone. WP of teff in the lower zone (0.64 kg m^{-3}) was more than twice of that of middle zone (0.29 kg m^{-3}). Similarly, the WP of sorghum in the lower zone (0.71 kg m^{-3}) was better by 17% than that of the middle zone (0.52 kg m^{-3}). WP of maize was 1.14 kg m^{-3} and that of fresh potato tuber was 9.98 kg m^{-3} in the upper zone (Table 1). These cereal crops WP results are strongly agreed with research output by Droogers et al. (2001) and Cai and Rosegrant (2003), in that the value of WP index for cereals ranged from 0.50 to 1.50 kg m^{-3} depending on variety, soil, climate and management. According to FAO (2011), the world average WP of barley, wheat and fresh potato tubers range from 1.20 to 1.40 kg m^{-3}, 1 to 1.20 kg m^{-3} and 4 to 11 kg m^{-3}, respectively. Likewise, the average WP of sorghum at global level also ranges from 0.80 to 1.30 kg m^{-3} (Steiner 1986). Thus, the average WP results of barley, wheat and sorghum were by far lower than that of the global average while that of fresh potato tubers falls within the range of world average. There is no well-defined study on teff WP in Ethiopia and elsewhere in the world except Araya et al. 2010 and Alemtsehay et al. 2011, who tried to estimate normalized WP test to use in AquaCrop simulation. However, its average WP result (0.47) was extremely lower even as compared to all other cereal crops considered for this study. Therefore, WP of the dominant food crops like barley, wheat, teff and sorghum needs to be improved so as to bring sustainable livelihood improvement in the area and beyond.

Table 1. Physical crop water productivity across Agro-ecology

Agro-ecology	Crop	Productivity (kg ha^{-1})				Effective Precipitation (m^3)	Physical WP (kg m^{-3})	
		Grain	Straw	Biomass	Fresh Tuber		Biomass	Grain and fresh tuber
Upper Zone	Barley	3487	5937	9424	–	4463	2.11	0.78
	Wheat	3629	10544	14173	–	4364	3.25	0.83
	Potato	–	1360	54600	53240	5334	10.24	9.98
Middle Zone	Wheat	3569	7167	10735	–	3947	2.72	0.90
	Teff	1093	3336	4429	–	3713	1.19	0.29
	Sorghum	3050	17435	20485	–	5878	3.49	0.52
Lower Zone	Teff	1631	3799	5430	–	2550	2.13	0.64
	Sorghum	3802	20799	24601	–	5391	4.56	0.71
	Maize	5986	22129	28115	–	5274	5.33	1.14

Source: Field measurement 2011, CROPAT model and own calculation.

Net economic crop water productivity

Water productivity calculated in terms of net value output gives better picture of the net gain from a unit of water in production than gross value output (Mulugeta 2006). The results also help to make comparison of economic benefit

of one crop with other crops and also assist farmers to make proper decision to invest on more valuable crops at the expense of others. Economic value of the crops and production costs i.e. seed, fertilizers, labour, agrochemicals and other inputs were determined based on their local market value. The result indicated that potato has extremely high cost of production (ETB 25,551 ha^{-1}) as compared to other cereal crops whereas sorghum has the least cost of production (Figure 1B). The net economic water productivity of sorghum, teff, wheat, barley and maize grains were ETB 3.10, 3.27, 3.49, 3.73 and 5.54 m^{-3}, respectively, while that of fresh potato tubers was ETB 15.17 m^{-3} (Figure 1A). Regarding economic benefit of food crops, potato tuber has the highest economic value followed by maize, barley and wheat while that of sorghum has the least value in the study district. In terms of net economic BM water productivity (food and feed), barley, wheat, teff, sorghum, maize and potato has ETB 4.77, 4.78, 4.97, 6.63, 7.09 and 13.56 m^{-3}, in that order (Figure 1A). Here, potato again ranks first followed by maize, sorghum and teff whereas barley was the lowest. Thus, it is possible to say that potato is the most appropriate crop in economic water productivity than all other crops in the upper zone of the study watershed. Similarly, wheat is more appropriate in the middle zone and that of teff in the lower zone. Generally speaking, net economic benefit obtained from BM (food and feed) is by far better than that of food crop indicating the need to integrate crop with livestock. Several research results confirmed that crop–livestock interactions increase productivity and the income of farmers and improve system resilience and environmental sustainability (Devendra and Thomas 2002; Parthasarathy Rao et al. 2005). Therefore, if farmers integrate crop with livestock, they will generate better economic benefit from available land and water they are endowed with rainfed and also bring sustainable livelihood improvement in the long run.
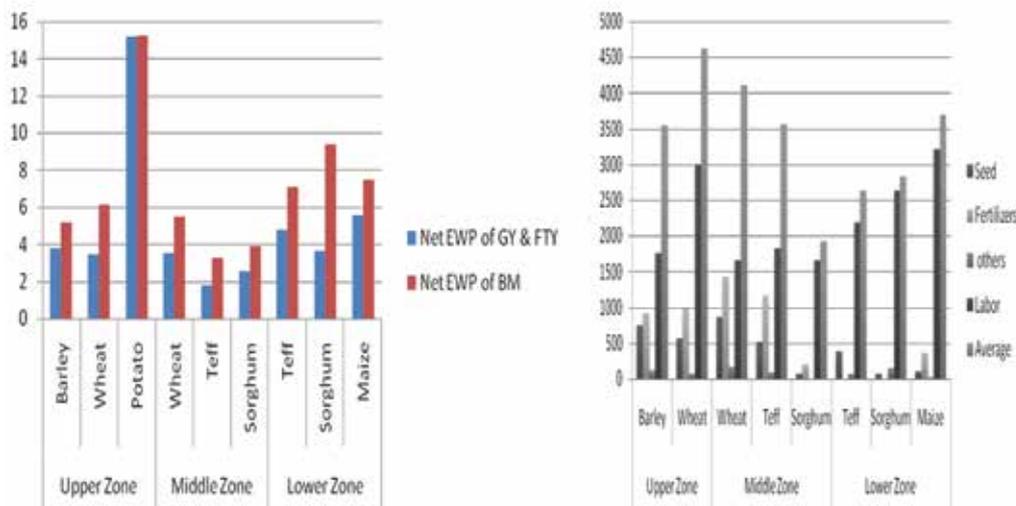
Figure 1. Net economic water productivity of biomass, grain and fresh tuber yield in ETB m^{-3}(A) and costs of production in ETB ha^{-1} (B).

Effect of agro-ecology on physical and net economic CWP

The ANOVA test result indicated that there was significant mean of both physical and net economic CWP variation (at p = 0.014 and P = 0.001, respectively) between the three local agro-ecological zones. However, one way ANOVA (multiple comparisons) test result showed that the variation was significant for both variables only in between upper and middle and upper and lower zone indicating that treating the middle and lower agro-ecological zones independently is not necessary but rather treating them as one. Therefore, the three local agro-ecological systems arbitrarily classified by the local people should be corrected to only two zones (upper and middle) having no lower zone and the whole watershed, except few areas around the outlet, fall in the upper zone. Ecologically, the upper zone was highly degraded and more populated than the other two zones. The severity of land degradation due to high human and livestock population pressure, poor land and water management practices (Berhanu Ayana 2011 and Zemadim et al. 2011) increased surface runoff and reduced infiltration resulting in low water productivity. In addition, barley was a dominant crop in the district in general and in the watershed in particular but, its total BM water productivity was found to be the lowest. Therefore, technological interventions that could increase soil water availability, improve productivity and enhance economic benefit are required mainly here. Most of the soil and soil nutrients washed away by erosion from the upper zone deposit in the middle and lower zones. This aspect was

validated by both net economic and physical WP results of wheat, teff and sorghum grains. It tended to increases as we move from upper through middle to lower zones (Figure.1A).

Effects of management practices on physical and net economic CWP

The aspects like physical and economic crop water productivity in a system depend on many factors and the management practices prevailing in the watershed is one.

Several management practices were considered and investigated their relationship with both physical net economic WP. The result showed that rate of UREA and DAP application, seeding rate, crop variety, precursor crop, method of sowing and harvesting date significantly affected both parameters (Table 2) indicating that improving rate of application of both types of fertilizers, using improved method of sowing and proper seeding rate based on crop type, variety, location in a landscape position and other physiographic conditions could considerably increase CWP in the area. This finding strongly agreed with research outputs of Toung 1999; Rockstrom and Steiner 2003; Kijne et al. 2003; Molden et al. 2003 and Mulugeta 2006 in that any management practices used to enhance crop yield significantly increased crop WP. Hence, farmers should implement improved management and agronomic practices so as to increase CWP.

Table 2. Some management and agronomic practices and their degree of association with CWP

Variable	Net EWP WP of grains or fresh tubers		Physical WP of grains or fresh tubers	
	Pearson's corr. coeff. (r)	Significance (p-value)	Pearson's corr. coeff. (r)	Significance (p-value)
UREA (kg ha^{-1})	+0.562**	0.000	+0.681**	0.000
DAP (kg ha^{-1})	+0.740**	0.000	+0.849**	0.000
Seeding rate (kg ha^{-1})	+0.851**	0.000	+0.950**	0.000
Crop type	–	–	−0.377*	0.011
Crop variety	−0.359*	0.016	−0.382**	0.010
Precursor crop	−0.434**	0.003	−0.438*	0.003
Tillage frequency	–	–	+0.302**	0.044
Method of sowing	+0.706**	0.000	+0.671**	0.000
Harvesting date	−0.577**	0.000	−0.531**	0.000

*Significant at the 0.05 level and ** at the 0.01 level (2-tailed).

Conclusions and recommendations

The study revealed that farmers tried to implement different crop management practices which were not appropriate such as inappropriate crop rotation systems, maximum tillage, inadequate rainwater management systems, improper seeding rates, inappropriate fertilizer rate, traditional methods of sowing (88%) and harvesting (100%), delayed harvesting, poor weed control methods were mostly practised. Among this, rate of fertilizers applied, seeding rate, crop variety, types of precursor crops, method of sowing and harvesting date as well as landscape positions significantly affected both physical and net economic water productivity of food crops. Water productivity results in kg m^{-3} of barley, wheat and sorghum grains were by far lower than that of the global average while that of fresh potato tubers falls within the range of world average. Even though there is no well-defined study on teff water productivity in Ethiopia and elsewhere in the world, its average water productivity result (0.47kg m^{-3}) was the least as compared to all other cereal crops under study. Therefore, water productivity of the dominant food crops like barley, wheat, teff and sorghum needs to be improved so as to bring sustainable livelihood improvement in the area and beyond. In terms of economic benefit (ETB m^{-3}) of food crops, fresh potato tuber has the highest economic value followed by maize, barley and wheat while that of sorghum has the least value in the study district. With respect to net economic biomass water productivity (food and feed) maize, sorghum and teff were the leading whereas barley was the least. Thus, it is possible to say that potato is the most appropriate crop in both economic and physical water productivity than all other crops in the upper zone of the study watershed; wheat is more appropriate in the middle zone and that of teff in the lower zone. Generally, net economic benefit obtained from biomass (food and feed) is by far better than net economic benefit of that of food crop. Therefore, if farmers integrate crop with livestock, they will generate better economic benefit from available land and water they are endowed with rainfed and also bring sustainable

livelihood improvement in the long run. In addition to this, the one way ANOVA (multiple comparisons) test result shows that there was significant variation of both variables only in between upper and middle and upper and lower zone indicating that treating the middle and lower agro-ecological zones independently is not necessary but rather treating them as one. Therefore, the three local agro-ecological systems arbitrarily classified by the local people should be corrected to only two zones (upper and middle) having no lower zone and the whole watershed, except few areas around the outlet, fall in the upper zone.

Hence, some of the recommendations include implementing improved technology at both farm and watershed level such as using improved crop varieties, improving rate of fertilizers use, using improved crop ration, appropriate seeding rate, improve method of sowing and timely harvesting, diversifying rainwater management systems, crop diversification and integrating crop with livestock could significantly improve both the quantity and economic vales of crops. Moreover, given the high current and potential productivity of potato in the upper part of the watershed and poor market linkage, all local and regional actors need to facilitate the development of value chain for this essential product. Furthermore, scaling up and implementing these findings to the whole basin could help to address the problem of water scarcity and food insecurity so as to bring sustainable livelihood improvement in the long run.

Acknowledgements

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Characteristics and on-site financial costs of erosion in the Meja watershed of the Abay basin, Ethiopia

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Abstract: Most soil erosion studies conducted in Ethiopia are focused on quantification of sediment and lack specific information on temporal and spatial variability of sediment and its associated plant nutrients loss. This study was, therefore quantified and characterized runoff and sediment along with estimated the on-site financial cost of erosion in terms of its concomitant crop yield loss due to the nitrogen and phosphorus lost in consequence of erosion. Data on discharge and runoff samples for sediment concentration and nutrient content was collected at three monitoring stations (Melka, Galesssa and Kollu) in Meja watershed in Jeldu district, in the Ethiopian part of the Blue Nile Basin. Daily samples collected during the rainy season were analysed in the laboratory of Ambo University for sediment content of runoff, particle size distribution of the sediment and nitrogen and phosphorus content of both the sediment and runoff. Preliminary results indicate that both runoff volume and sediment concentration vary with space and time. While the maximum runoff volume was recorded in the middle of the rainy season, sediment concentration decreased towards the end of the rainy season in response to increased ground cover. The average suspended sediment concentration during the rainy season was 3.0 ± 1.1, 2.2 ± 1.3 and 1.4 ± 0.9 g L^{-1} while the total sediment yield ranged from 74 t km^{-2}, 248 t km^{-2} and 604 t km^{-2} at Melka, Galesssa and Kollu, respectively. The financial cost of erosion was estimated at 595, 510 and 2475 ETB ha^{-1} from Melka, Kollu and Galessa, respectively.

Keywords: *Ethiopia, discharge, sediment concentration, nutrient loss, Nile basin*

Introduction

The study site, head of the Nile basin is heavily affected by water erosion, resulting in significant loss of top fertile soil and plant nutrients during the flood period. This poses threat to the development of sustainable agriculture and crop water productivity of the area. Consequently a considerable area of cropland is currently unable to provide reasonable crop yield.

Though there are many works on land degradation in the highlands of the country like the study watershed, but still a tangible change is not seen. This is because most of the researches on erosion are focused on quantification of soil

loss at runoff plot or basin scale with little attention to the nutrients loss despite its importance makes still a challenge for the soil water productivity more than ever.

This study was, therefore conducted with the objectives of (1) Quantifying suspended sediment concentration loss with runoff from the watershed (2) Analysing the spatial and temporal load–discharge variability of sediment and plant nutrient loss (3) Characterizing of sediment and runoff water samples for selected physical and chemical parameters (4) Estimating the economic effect of erosion due to the loss of major plant nutrients in the watershed

Methods and materials

Description of the study area

The study was carried out at Meja micro watershed in Jeldu district in the southern part of upper Blue Nile Basin; Central highlands of Ethiopia (9°02'47" to 9°15'00" N and 38°05'00" to 38°12'16" E).
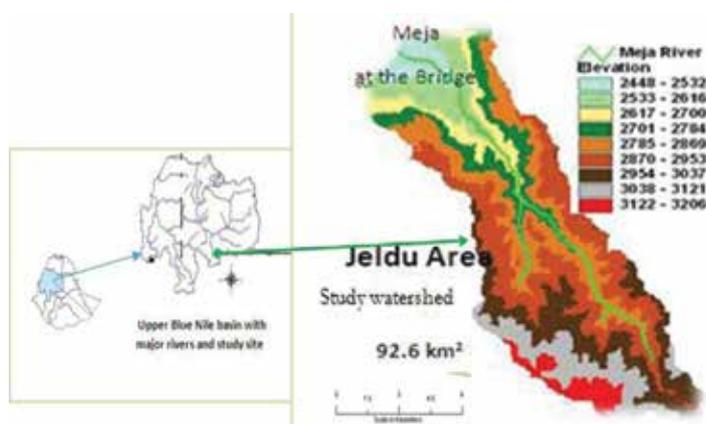
Figure 1. Location of the study watershed and the major contributory river to Abay basin

The watershed has an undulating terrain with altitude ranging from 2900–3200 meters above sea level (Birhanu et al. 2011). Agriculture is the major livelihood of the people. The watershed is drained by Meja River which drains to the Guder river one of the major tributaries of Abay.

Monitoring stations selection, data collection and laboratory analysis

For monitoring runoff, sediment and nutrient losses; three monitoring stations were selected based on the land use and land cover conditions (LULC) of the micro watersheds and availability of hydrological gages.

The rivers discharge was measured directly by Area—velocity method and the Q-d rating curves were developed for each station to have continuous discharge data for the whole study period (Graf and Altinakar 1998).

Depth-integrated runoff sampling was carried out twice every day from the beginning of July up to the offset of September and to minimize cost and to get sufficient sediment sample, the 10 consecutive days samples were bulked as a representative sample. Then the total sediment load that losses in each station was determined by measuring instantaneous discharge, Q (m^3s^{-1}) and instantaneous suspended sediment concentration, SSC (gL^{-1}) for the bulked samples of each decades.

The bulked sediment samples was also analysed for sediment texture, organic carbon (OC), total nitrogen, available P, NH_4-N and NO_3-N using Hydrometer (Bouyoucos 1962), Walkley and Black (Jackson 1967), Modified Kjeldahl digestion (Dalal et al. 1984), Olsen (Olsen 1954), Magnesium oxide-Devarda's alloy, (Maiti 2004) methods respectively.

For the runoff sample UV-Spectrophotometer method was used to determine the dissolved nitrate, phosphate and ammonia (Patnaik 2010) at Ambo University. The on-site financial cost of erosion was calculated by considering only inorganic form of available nitrogen (NH_4-N and NO_3-N) as a source of nitrogen fertilizer and P_2O_5 as phosphorous fertilizer both in the sediment and dissolved in runoff water using productivity change approach (PCA).

Result and discussion

Sediment concentration and its spatial and temporal variability

The mean average suspended sediment concentration (SSC) during the rainy season was $3.0+1.1$ g L^{-1} from the watershed (at Melka) while $1.4+0.9$ and $2.2+1.3$ g L^{-1}, at Galesssa and Kollu sub catchment monitoring stations respectively. While the mean specific sediment yield (SSY) was ranges from 448 t km^{-2} at Galessa, 604 t km^{-2} at Kollu and 74 t km^{-2} at Melka. The analysed data's revealed that SSC were significantly varied between stations and sampling time. For example from the regression analysis between both SSC and sampling time (decade) indicated that it was strong relation in each station with ($R^2 = -0.71$, -0.90 and -0.64 at Melka, Kollu and Galessa respectively).

The graph also confirms that most peaks in SSC to all stations were observed at the beginning of the rainy season. It is most probably because in the study watershed the land tillage and sown was at the beginning of sampling. This is because SCRP data indicates that an erosion loss is highest-flying during ploughing and the first month after planting of the crop fields (EHRS 1986).
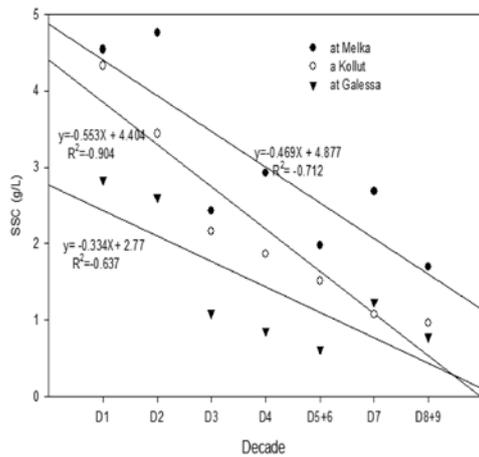
Figure 2. Regression lines between suspended sediment and sampling period

The parametric test between SSC and monitoring station also shows that there was statistically significant at $p< = 0.05$ among stations. Though it needs detail research about these differences; human activities and/or LULC, the physiographic feature and soil type of the upper sub catchments of erosion contributing areas of the monitoring stations was play great role for such variation.
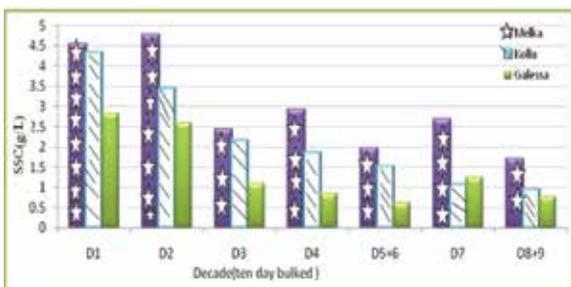
Figure 3. Spatial variability of SSC among the three monitoring site

Texture of the sediment

The average texture of the catchment soil is silt clay (IWMI 2011). Yet, as per the texture analysis of sediment it was more of clay; which implies that the suspended sediment collected that moved along with run-off came from fine-grained fertile and productive soils and fine soil particles was play great role in the process of erosion in the watershed. Here also the mean correlation test analysis of sediment texture with those eroded parameters; it has a significant strongly correlated with all nutrients and sediment loss in all stations at 0.01 level of significant (having R^2 = 0.83 and –0.89 with % of clay and sand respectively.

Plant nutrient losses in the watershed

Analysis of sediment and runoff samples from the three monitoring sites indicated that there was a significant amount of plant nutrients mainly TN, NH_4-N, NO_3-N, Available phosphorus (Pav) and organic matter was lost associated with the sediment and runoff water during the time of runoff.

Table 1. Estimated monitory values of available nutrient lost due to erosion in three stations

Station			Total lost during the study period from in the watershed							
			In Sediment (g/kg)					Dissolved in runoff water (g/L)		
			TN	NH4-N		P-P2O5	SOC	NH3-N	NO3-N	P-PO4
Kollu		Total	14.80	3.46	1.35	2.08	810.23	1.20	4.53	2.37
		Mean	2.11+1.51	0.49+0.31	0.19+0.02	0.30+0.16	31.88+21.9	0.17+0.14	0.65+0.51	0.34+0.24
Melak		Total	10.08	1.32	0.42	1.44	14.18	1.12	2.92	0.82
		Mean	1.44+1.53	0.27+0.19	0.27+0.16	0.21+0.12	2.3+2.0	0.16+0.06	0.46+0.25	0.22+0.14
	Galessa	Total	18.54	1.48	0.20	0.73	76.78	1.32	6.12	1.37
		Mean	2.65+2.57	0.21+ 0.2	0.03+0.02	0.10+0.09	10.97+8.45	0.19+0.13	0.87+0.56	0.20+0.17

As shown in Table 1, there is a variation in nutrient concentration in sediment and runoff between the stations and sampling period. The statistical significance difference test in nutrient concentration among stations at 0.05 level of significant showed that there is significant difference for NO_3, NH_4, TN and OC at Melka and Kollu with that of Galessa (p-value = 0.06). The higher TN and OC level at Galessa than Kollu is most probably the addition of manure from livestock that visit the upper catchment for grazing.

The mean statistical significance difference test in nutrient concentration between sampling periods at 0.01 significance level showed that there is significant difference for NO_3 and NH_4 in all the three stations (p-value = 0.06) from the onset of July (D1) to the mid of August (D4). But the general trend in each station, highest concentration was at the start of the rainy season to all stations.
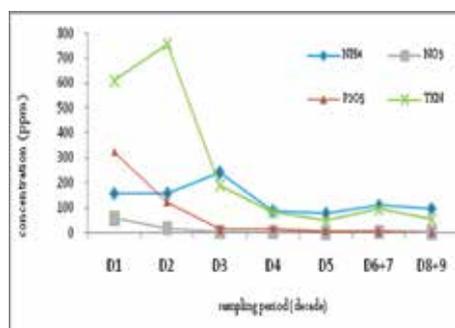

Figure 4. Temporal variability of nutrient loss concentration

On-site financial cost of erosion in the watershed

Table 2. Estimated monitory values of available nutrient lost due to erosion in three stations

Monitoring station	Total lost fertilizer (kg/ha)		Estimated optimum total grain and/or tuber yield (kg)/ha with lost		Assumed grown crop	Seed and/ or tuber cost (ETB*/kg)	Subtotal lost benefit (ETB/ha)	
	N	P	N	P			N	P
Melka	9	6	32	47	Barley	7.5	240	356
Kollu	17	5	25	43	Barley	7.5	187	323
Galessa	3	3	210	340	Potato	4.5	945	1530

* Ethiopian birr 17.85 = USD 1.

Here based on the Jeldu district bureau of agriculture and rural development (2011), Potato (*Solanum tuberosum*) for Galessa and Barley (*Hordeum vulgar*) for Kollu and Melka are the major crops for the upper sub catchments of the stations. Similarly the yield of these crops with N and P fertilizers response was from the calibrated curve developed using the experimental data of Holetta Agricultural Research Center (HARC). So that the total benefits that the farmers lost due to erosion can be calculated as:

Lost benefit (ETB*) = Grain cost (ETB*/kg) × Estimated optimum total grain yield (Kg)/ lost nutrient;

which is summarized in the following table

So that the loss of N and P nutrients because of erosion was a potential to reduce income of farmer's by Ethiopian birr (ETB) 595/ha, 510 and 2475 from Meja, Kollu and Galesssa sub catchments respectively in the watershed as a result of erosion only in one particular rainy season.

Conclusion and recommendation

Analysis of sediment and runoff samples indicated that the loss of sediment and plant nutrients associated with runoff during the rainy season was one of the challenges for sustainable crop–water productivity for Meja watershed. From the general observation; both SSC and nutrient concentration were highly variable both in time and location situations. The general trend shows their concentration was lower towards the end of the rainy season in all the three stations while the spatial distribution of sediment and nutrient loss showed that the lower and middle part of the watershed was relatively severed than the upper catchments of Galessa. Thus, it is possible to conclude that the economic impacts of erosion through the depletion of top fertile soil and plant nutrients have profound implications in the current as well as the future survival of the people which adds another stress on insufficient food production to the poor of Meja watershed.

Therefore based on available data on sediment and nutrient loss in this study; who involved in planning, design and environmental related activities in Meja watershed and similar areas in the basin, the researcher recommend any interventions better to give priority to those erosion prone identified areas and when erosion is more hazardous. Further work is therefore needed to determine the dynamic watershed response of runoff and erosion process to specify different land use scenario especially for eucalyptus plantations on their land and Runoff water harvesting should be an opportunity cost to maximize production and simultaneously to minimize erosion risks.

Acknowledgements

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Assessment of rainwater management practices and land use land cover changes in the Meja watershed of Ethiopia

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Abstract: Poor rainwater management (RWM) practices and resultant problems of land degradation and low water productivity are severe problems in the rural highlands of Ethiopia. The current study was undertaken at Meja watershed, which is located in the Jeldu district of Oromia region. The study investigated rainwater management practices and associated socio-economic and biophysical conditions in the watershed. The existing RWM interventions, their extent and the nature of changes in land use and land cover (LULC) conditions were mapped and evaluated. Results indicated that over the two decades between 1990 and 2010 there was an increase in the extent of cultivated land and large expansion in eucalyptus plantation at the expense of natural forest and grazing lands. Results indicate that, with few exceptions of RWM interventions practised, there were mainly poor and inefficient rainwater management practices. The overall effect leads to inadequacy of water for household consumption, livestock and for intensifying agricultural production via small scale irrigation systems. Deforestation and poor resource management resulted in soil degradation, reduction of hydrological regimes and water productivities in the watershed.

Introduction

Water is one of the most useful natural resources for life and livelihood of human beings. Water is becoming a limiting factor for sustainable development in many parts of the world. Globally, the gap between demand and availability of water has become wide, necessitating immediate measures to be taken for its sustainable utilization and efficient management, especially in the developing world.

Rainwater is the main source of water and its current use efficiency for crop production ranges between 30 and 45% (Wani et al. 2003). According to Wani et al. (2003) 300 to 800 mm of seasonal rainfall is lost annually as surface runoff or deep drainage. Watershed is a logical unit for efficient rainwater management in the dry regions. Along with water, other natural resources such as soil, vegetation and biota can also be managed efficiently by adopting integrated watershed management (IWM) approach. The major advantages of adopting IWM approaches are the involvement of those most affected by the decisions (i.e. the stakeholders) in all phases of the development of their watershed

and holistic planning that addresses issues which extend across subject matter disciplines (biophysical, social and economic) and administrative boundaries (village, *woreda* etc.) (UNEP 2002). So, watershed development seeks to manage hydrological relationships to optimize the use of natural resources for conservation, productivity and poverty alleviation. Achieving this requires the coordinated management of multiple resources within a watershed, including forests, pastures, agricultural land, surface water and groundwater, all linked through hydrology (World Bank 2007).

Water harvesting involves on farm-water harvesting and building small dams to capture runoff from upper watersheds after heavy rains. Reducing erosion minimizes silt in runoff water and in water harvesting ponds, thus lengthening their lifespan. Water harvesting in turn benefits farms further down the slope by providing irrigation, either via surface water or by recharging groundwater. These interventions are designed to eventually raise the productivity of all natural resources in the watershed. Soil becomes more productive for agriculture, water for irrigation and pastures and forests for more biomass. All livelihood activities that depend on these resources may be enhanced and employment may increase as agriculture becomes more productive and additional labour is needed for harvesting and other operations (Kerr 2002).

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The watershed under study being characterized by high rainfall is prone to sheet and rill erosion as well as to the formation of big and active gullies. Moreover, the current land use land cover change pattern characterized by the absence of natural forest/vegetation in the area has negatively influenced the infiltration of water into the soil profile. Poor land management practices and ineffective and inefficient rainwater management practices are characteristics of the watershed. Therefore, the adoption of sustainable participatory integrated watershed management as the platform for integrated land and rainwater management and improving the livelihood of community in Jeldu district is crucial. The objective of the present study was, therefore, to assess the major potentials and constraints for sustainable rainwater management through participatory integrated watershed management approach and to assess the land use land cover change pattern in the watershed.

Materials and methods

Description of the study area

The study was conducted in the Meja watershed which is located in Jeldu district, West Shewa zone of Oromia Regional State, Central Ethiopia (9°02'47" to 9°15'00" N and 38°05'00" to 38°12'16" E). The district has an undulating terrain nature with an altitude ranging from 2900–3200 meters above sea level. Rainfall pattern is bimodal with the main rainy season from June to September and the short rainy season from February to March. The mean annual rainfall of the area ranges from 1800 to 2200 mm. The maximum and minimum temperature of the area ranges from 17 to 22°C. The farming system of the area is mainly rain-fed. The soil type is characteristic of clay and clay-loam type, but the riverbed has a loam and sandy-loam type of soil (Hurst et al. 1959 cited in Dereje 2010). *Eucalyptus globules* is the main tree planted in the area.
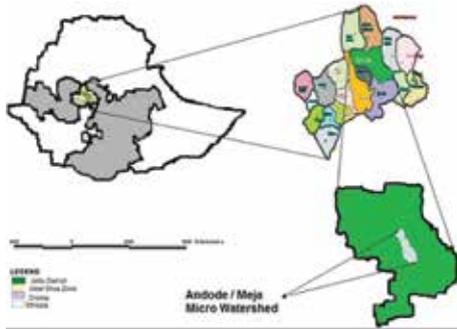
Figure 1. Location of map of study area

Socio-economic survey

Socio-economic study was conducted to assess biophysical, socio-economic constraints and rainwater management practices in the watershed. Structured and semi-structured interview questionnaires, group discussions with men and women representatives and key informant interviews were employed to gather relevant information. Moreover, discussion was held with government administrators at various levels and natural resource management officers to get the necessary information on history of the area, population dynamics, socio-economic activities and participation of the local people in conservation efforts.

Total number of households of the micro-catchment was registered from available secondary sources. The number of sample household farmers selected for the interviews was determined by using the formula developed by Kothari (2004).

$$n = \frac{Z^2 pqN}{e^2(N-1)+Z^2 pq}$$

Where: n = sample size

Z = 95% confidence limit (interval) under normal curve that is 1.96

P = 0.1 (proportion of the population to be included in the sample that is 10%)

q = None occurrence of event = 1–0.1 that is (0.9)

N = Size of population.

e = Margin of error or degree of accuracy (acceptable error term) (0.05)

In the catchment, sample households were selected using simple random sampling techniques from the list of households.

Identifying, assessing and mapping of existing RWM interventions

An inventory of past and recent RWM interventions in the study area was conducted through a review of the literature, interviews with key stakeholders and a field survey of RWM practices. During the field survey, data were collected through observations and interviews with farmers using a semi-structured questionnaire. The field survey was focused on the type of RWM practices, year of construction, farmers' experiences and constraints, duration of water storage, water uses and application methods. This enabled the bottlenecks and successes of RWM interventions to be identified. To map the existing RWM interventions in the watershed, transect walks through the catchment

were conducted. The geographic locations of all the traditional RWM interventions were taken using Atlas Global Positioning System (GPS) and recorded in a recording sheet. The data were then processed using ERDAS imagine 9.1 and Arc GIS softwares to produce the map of RWM interventions.

Data base for land use land covers change

To assess the changes in LULC, multi temporal satellite images of 1990, 2000 and 2010 were used. In addition, household surveys were conducted to acquire data relating to the socio-economic conditions of rural households which would help to explain the changes observed in the LULC. The satellite images were systematically processed. This comprised of georeferencing, mosaicing, interpretation, classification (supervised), digitization and mapping (Daniel 2008). Global Positioning System (GPS) readings of the watershed boundary under study were collected for delineating the watershed. Ground control points were also collected from different land use types in the micro-catchment with GPS that was used for georeferencing the satellite images of the area. An automatic classification method was applied to identify and delineate the different LULC units for the satellite image. Then, satellite images were mosaiced and georeferenced to UTM coordinate system. Supervised classification was employed by using training sites (samples) on the image which were representative of each identified land cover category. Based on the predefined areas representing specific signatures the software classified the remaining pixels using classification decision rule. The interpretation and classification based on the satellite images was checked against ground data using ground truthing technique. The maximum likelihood classification method was applied for identifying land use and land cover types for the study area as a whole. Finally, the land use and land covers map of each year was produced and the LULC change was summarized.

Data analysis

Data obtained from the household questionnaire survey was analysed using statistical package for social sciences (SPSS) version 15.0 and the results are presented with descriptive statistics; tables, graphs and percentages. The qualitative information generated by the informal discussions was used to substantiate results from the questionnaires.

Results and discussion

RWM interventions practised in the study area

The survey results revealed that different types of RWM practices exist which a positive effect in increasing the amount of water has stored in the soil profile. The common traditional RWM interventions in the study watershed are the use of earthen/soil bunds, gully plugging, deep tillage, vegetative barriers, contour farming. Likewise, Alem (1999) cited in Girma (2009) reported the use of soil bunds, stone bunds and grass strips as commonly practised interventions used for controlling erosion as well as for *in-situ* water conservation in the central Rift Valley of Ethiopia. The current study also revealed that there were also few other RWM practices designed to store water for later use for supplementary irrigation and as a source of drinking water for people and livestock. The observed structures during the field survey included: ponds (3.2%), roof rainwater harvesting (35.5%), open wells locally called 'Ella' (3%) and check dams for stream stabilization and diversion (43.5%). Most of these RWM interventions were constructed individually by farmers where farmers contributed labour during the construction. The respondents with corrugated sheet of house commonly use roof rain water harvesting for water storage during the wet season.
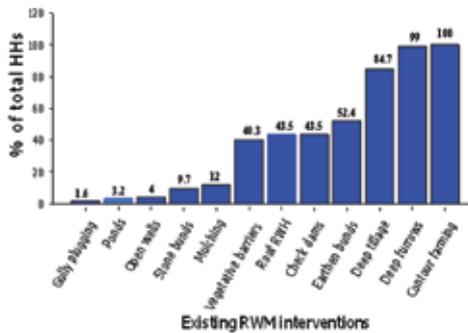
Figure 2. Existing RWM interventions in the watershed area

Only 3–7% of the respondents use ponds as a rainwater management intervention. In the study watershed, four ponds that are intended to store water for later use were identified of which three were constructed by community during the Derge regime (about 28 years ago). One pond was constructed privately in the recent time (3 years ago) in Tullu Gurra *kebele*. The private pond had a circular shape and was 3 m wide and 2 m deep whereas the community ponds which were found in Sariti and Tulu Gura *kebele* were circular in shape and about 6–9 m wide and 2–3 m deep.

Currently the community ponds were neglected without maintenance with grass growing in it and filled with sediment. The privately constructed pond was also not properly protected as it was filled with broken woods, leaves and grasses. Even though the ponds were not properly protected, they are still used mainly for livestock and small scale irrigation to grow potatoes, onion and vegetable and tree seedlings. A success story with the privately constructed pond was that the owner prevented the pond from drying off by diverting the stream which was about 180 m away from the pond and he was able to produce cabbage, onion, potatoes and seedling of eucalyptus tree on his farm in the dry season and was able to secure food at his household level (Figure 3). The report of Alem (1999), cited in Girma (2009), indicated that ponds were the main RWH structures in the Ethiopian Rift Valley where groundwater was deep and other sources of water were not available. According to his report, farmers used ponds to collect water for growing vegetables and fruits around homesteads for markets and home consumption.

(a)   *(b)*

Figure 3. Privately constructed pond in Tulu Gura kebele (A) and unprotected community pond in Sariti kebele (B) of the watershed under study

The survey results showed that none of the ponds were performing as intended in terms of storing/retaining harvested runoff. The owners indicate that the poor performance was a consequence of high water losses arising mainly through seepage, evaporation, siltation problems occurring as a consequence of lack of maintenance. The same problems were reported by Girma (2009) in his study on identification of potential rainwater harvesting areas in the central Rift Valley of Ethiopia using a GIS based approach. In general, the ponds were left unprotected allowing livestock to drink directly from the pond and silt, leaves, grasses and woods were being accumulated in it. For well-functioning of such ponds, there had to be full participation of the entire community. Thus strong community organization was required to mobilize labour for operation and maintenance.

About 43.5% of the respondents practised perennial stream or river diversion by locally constructed check dams from locally available materials such as soil, stone, wood and leaves. Most of these structures were constructed privately in the upper parts of the watershed on nearby spring or streams for household consumption and for livestock. One locally constructed check dam diverted from Laga Shasi stream in Chillanko *kebele* was among a productive check dams observed in the study watershed. The check dam was constructed from eucalyptus tree. The diverted water was used for potato cultivation in the upper part of the watershed (Figure 4). The potato grower said that he had used the same stream for potato, onion and cabbage cultivation

for about 16 years. However, he was no longer able to use it because of the reduction of the flow of the stream. This forced him to irrigate the current potato field by share arrangements with the owner of the land. Most of the respondents complained about the scarcity of water in the stream and short durability of the locally constructed check dam.

Figure 4. Privately constructed local check dam (left) and potatoes farm (B) being cultivated using the dam in Chillanko kebele

On the other hand, it was never tried to divert the big Meja River in the upper part of the watershed by constructing local check dams since it flows in a deep gorge. This prevented farmers from diverting water from the Meja River for irrigation. To solve these problems two respondents were using motor to cultivate potato and onion in the upper part of the watershed. The use of water pumps enabled them to maximize their yield and secure food at the household level. According to the perception of the owners of the water pumps, buying the fuel, spare parts and maintenance of the motors were among the major challenges they face.

In lower part of the watershed the use of check dams (Figure 5) were largely practised to divert perennial streams and Meja River. The terrain nature was suitable for wide range of small scale irrigation systems for production of potato, maize, barley, onion and cabbages. According to the respondents, the major limitation to use irrigation was the scarcity of water. The most widely used water sources for small scale irrigation systems in this lower part of the watershed were the Meja River, the Laga Kile and the Laga Jeba streams. With the help of these water sources, the beneficiary households were able to produce crops twice a year from their farm land.

(A)   (B)

Figure 5. Irrigated maize and onion farms in Kolu Galan kebele (A) and locally constructed Meja check dam in Tulu Gurji kebele (B) in the watershed

Lega Jeba stream originated from Kollu Galan *kebele* and diverted from the upper part of the stream to serve as source of water for production of maize, potato and onion for about 200 households downstream. The power of the flow of the water from diverted stream decreases as it moves away from the point of diversion. At the diverting point the discharging rate, measured by volumetric method (Majumdar 2002) of the water, was 33 seconds with 44 micro seconds for 10 ml of water while it was 3 minutes with 32 seconds on average at the farm land site. This difference in discharging rate at both sites probably indicated water loss or existence of seepages along the course of the irrigation line. This showed that the required amount of water could not reach the farm land to be used for agriculture.

The Meja River which is the largest and only river in the study area is originated from Galessa area. It passes the watershed under study from top (around Sariti and Hinto Dale *kebele*) to bottom (Chobi Sirba and Kollu Galan *kebele* up to bridge on Chobi road). There were four check dams locally constructed mainly from stones, soil and woods at Bicho (one check dam), Tullu Gurji (two check dams) and Kollu Galan (one check dam) *kebele* at intervals along the

course of Meja River every year during the dry seasons. The check dam in Tullu Gurji was constructed for small-scale irrigation purposes serving about 400 households which were organized into 5 zones from two *kebele* partly found in the watershed. These 5 zones were about 5 *gashas* (200 hectares) in area as reported by the respondents in the study watershed. The length of the check dam was approximately 12 m and was constructed by the communities from the 5 zones. Maize, potato and onion were the main crops cultivated in the irrigation system. As in the case of Laga Jaba, there was also water committees which were even further organized in hierarchical manner for wise use of Meja water for irrigation system. Most of the respondents mentioned that the main problems in using the Meja River were the difficulty to construct a dam, maintenance problem and scarcity of water for those farmers located furthest from the diversion. There was also the problem of breaking down of the check dams by water force every year during summer season.

The survey data showed that 4% of the sampled households had private open wells in their garden constructed by an expert paid by the owners themselves. The open wells, which the people call '*Ella*', were circular in shape and are on average about 1 m wide and 9 m deep (Figure 6). As most owners responded, the open wells were full of water during the rainy season and with very little water during the dry season. They used rope for lifting mechanisms without pulley system. All of the surveyed households with the open wells used water for washing and cooking purposes. They also use the stored water to irrigate small plots in the garden to produce vegetables for home consumption and to raise vegetable seedlings. One of the respondents in the Sariti *kebele* complained about the insufficient amount of water in the well during dry season even for household consumption and the problem of cleaning it without the expert. The other respondent in Hinto Dale *kebele* raised the problem associated with lifting mechanism in that the rope sometimes cut and fetching materials such as buckets left in the well.

Figure 6. Privately constructed open well in Hinto Dale Kebele in the study watershed

Fifty two point four (52.4%) and 9.7% of the respondents in the study watershed used earthen bunds and stone bunds on their farm land, respectively (Figure 7). Most of the earthen bunds were constructed during the Derge regime (about 28 years ago) by the community. The earthen bunds varied in length and height (on average about 50 m in length and 50–75 cm in height) and were constructed horizontally on the land which is prone to soil erosion by runoff water. High labour and the lengthy time required for construction were the reasons for not constructing the structure at the household level according to 11.3% of the respondents. Eight per cent (8%) of the respondents, however, reported lack of information and training about the structure for not being constructed at household level. The earthen bunds were mainly constructed for increasing the time for water infiltration into the soil and for runoff protection purposes. Besides this, most respondents used the structure as boundary for separation of pieces of plots from one another (wheat plots from Barley ones) and also for separation of land of one owner from another. In some places of the study watershed some of these structures were broken down by excessive runoff water and by livestock trampling. The stone bunds observed in the study watershed were constructed horizontally (in average 20 m in length and 1.25 m in height and used for similar function as that of earthen bunds. They were constructed in the current time privately.

Earthen bund (A)   Stone bund (B)

Figure 7. Earthen (A) and stone (B) bunds used in the watershed under study

The undulating terrain nature and the high potential of rainfall in the study area were responsible for the formation of runoff following heavy rain. Following roads, furrows and rill erosion, there were a number of gullies being formed in the study watershed. According to the surveyed households, there were only 1.6% gully plugging structures constructed privately in Tullu Gurra and Bicho *kebele* from locally available structures such as wood, leaves, soil and stone in the past summer (Figure 8A). Even these existing structures, observed by walking through the catchment, were not fully constructed and hence runoff water may easily break them down. This implied that such type of gully erosion management by gully plugging needs community participation so as to fully construct and easily control the erosion problem in the area.

(A)   (B)
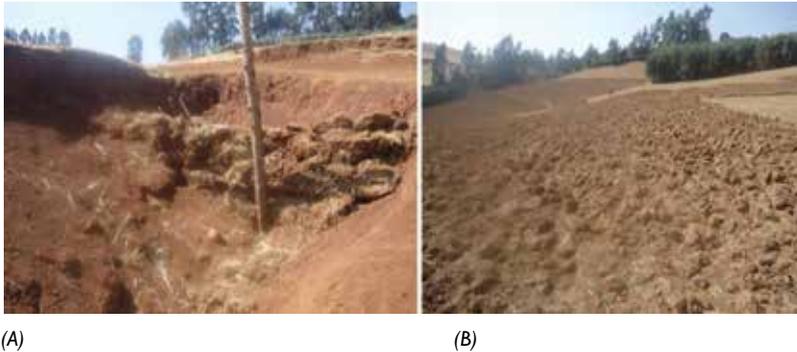
Figure 8. Gully plugging (A) and deep tillage (B) used in the study watershed

According to most respondents, they practised deep tillage (about 15–20 cm deep by local ploughs) on their farm land on which they grow crops starting in October every year. This practice was common and used by the farmers mainly for preparing the land for crop production and for increasing the time for infiltration of rainwater into the soil profile (Figure 8B above). Deep furrows were on average 25 cm deep and constructed mostly by farmers themselves for diverting runoff to reduce the washing out of their farm land. This practice was also very common and adopted from parents and neighbours. The main problems in using deep furrows were that most farmers did not take care of the runoff water once it passed from their farm and they paid no attention to the direction of the furrows as downward directed once were further responsible for gully erosion formation.

Respondents of 40.3 and 12% in the study watershed have used vegetative barriers and mulching, respectively, as options for RWM methods. Mulching method was commonly practised during growing seedling of pepper and eucalyptus trees around springs, streams and homestead areas. It protected the soil from raindrop impact and reduced the velocity of runoff. Maintaining crop residues or mulches on the farm controls effectively soil erosion and has considerable potential for the restoration and maintenance of soil fertility and moisture (MoARD 2005). Most farmers planted eucalyptus trees on steep area around streams and rivers for runoff and land sliding protection while others simply planted on their crop land in order to sell the tree when it was matured. So eucalyptus tree plantation by the farmers was very common in the study area not only for run off protection but also for 'Hatena' purpose to attain food security situation at their household level by selling.

All respondents used contour farming for managing rainwater in order to increase their soil moisture content and soil productivity. According to all respondents, the use of these methods was adopted from their parents and neighbours. Contour farming reduced soil erosion and conserves soil moisture by minimizing the rate of runoff.

Map of selected RWM interventions practised

The most and widely used RWM interventions in Jeldu district are contour farming (100%), crop rotations (100%), deep furrows (99%) and deep tillage (84.7%). The other existing RWM practices in their order of prevalence are earthen bunds (52.4%), check dams (43.5%), roof rainwater harvesting (43.5%), vegetative barriers (40.3%), mulching (12%), stone bunds (9.7%), open wells (4%), ponds (3.2%), intercropping (2.4%) and gully plugging (1.6%). The map of some of the selected RWM interventions and other information were given in Figure 11.

Land use land covers distribution

The four major LULC types identified in the study watershed were riverine trees/vegetation, farm land, grazing land and tree plantation. Riverine trees include trees grown along river and stream courses, including indigenous tree species and exotic trees such as eucalyptus and junipers trees. Tree plantations mainly refer to eucalyptus trees that are not found near river courses. Lands that are used for growing annual crops such as wheat and barley including fallow land and homestead area (including settlement) were categorized under farm land in this study watershed. The proportions and distributions of LULC types in hectare and per cent for 1990, 2000 and 2010 years are given (Table 1).

Table 1. Land use land covers distribution (1990, 2000 and 2010)

Land use/land cover categories	1990		2000		2010	
	Area (ha.)	Area (%)	Area (ha.)	Area (%)	Area (ha.)	Area (%)
Farm land	5147.55	61.87	5697.36	68.48	5854.54	70.37
Grazing land	1206.99	14.5	301.41	3.62	285.13	3.43
Plantation	951.57	11.44	1261.26	15.16	2018.61	24.26
Riverine trees/ vegetation	1013.76	12.19	1059.84	12.74	161.59	1.94
Total	8319.87	100	8319.87	100	8319.87	100

Source: Field survey 2010.

Land used for farm land covers the highest proportion in the three periods considered in the study watershed. It covered 61.87% of the total area in 1990, followed by grassland (14.5%), riverine trees/vegetation (12%) and eucalyptus plantation (11.44%). In 2000, the coverage of farm land increased to 68.48% of the total area followed by Eucalyptus plantation which accounted for 15.16%. While riverine trees/vegetation and grazing land covered 12.74 and 3.62%, respectively. In 2010, 70.37% of the total land use and land cover was covered by farm land and the remaining area of 24.26, 3.43 and 1.94% was covered by eucalyptus plantation, grazing land and by riverine/vegetation, respectively (Table 1).

The highest percentage in area coverage of the farm land use type in the classification within the three periods considered indicated that the conversion of the grazing land and forest land into cultivated land, fallow and homestead areas was the long lasting problem in the study watershed. The same pattern of changes in area coverage of farm land was reported by Daniel (2008), in that land used for growing annual crops was more important in the Upper Dijo River catchment and increased in area coverage from 1972 to 2004 periods. The above analysis indicates that the pressure on the land is immense. Farming constitutes the major livelihood phenomena in the study watershed. With little or no rainwater management practices in the area, land and water resources management would be a great challenge.

Figure 9. Map of existing rain water management interventions practised in the study watershed

Pattern (nature) of changes in land use and land cover

An important aspect of change detection was to determine what was actually changing to what i.e. which land use class was changing to the other. This information would also serve as a vital tool in management decisions. This process involved a pixel to pixel comparison of the study year images through overlay. The loss or gain by each class of LULC between 1990 and 2010 particularly in the change in hectares was given in Table 2.

Table 2. Pattern of LULC changes between 1990 and 2000 and between 2000 and 2010 in the study watershed

Land use/land cover categories	Change b/n 1990 and 2000		Change b/n 2000 and 2010		Average rate of change (1990–2000)		Average rate of change (2000–2010)	
	(ha)	%	(ha)	%	ha/year	%	ha/year	%
Farm land	+549.81	+10.7	+157.18	+2.8	+49.98	+0.97	+14.29	+0.25
Grazing land	−905.58	−75.0	−16.28	−5.4	−82.33	−6.82	−1.48	−0.49
Plantation	+309.69	+32.5	+757.35	+60.5	+28.15	+2.95	+68.85	+5.46
Riverine trees/vegetation	−11.72	−1.6	−840.25	−83.9	−1.07	−0.10	−76.39	−7.62

It can be observed from Table 2 that farmland increased by 10.7 and 2.8% between 1990 and 2000 and between 2000 and 2010, respectively in the study watershed the cause of which is high population growth which demands more land for cultivation in the watershed under study. Eucalyptus plantation showed similar patterns of change, which increased from 32.5 and 60.5% between the 1990 and 2000 and between the 2000 and 2010 periods, respectively. Even if the area coverage of farm land was large from the beginning, its rate of expansion was lesser (0.97%) between 1990 and 2000 and 0.25% between 2000 and 2010 when compared to that of eucalyptus plantation (2.95% between 1990 and 2000 and 5.46% between 2000 and 2010). In contrast, grazing land and riverine tree/vegetation cover showed a reverse trend, reducing by 75 and 1.6%, respectively, between 1990 and 2000 and 5.4 and 83.9%, respectively, between 2000 and 2010. In general, the pattern showed that more land being used for farmland followed by eucalyptus plantations at the expense of grazing land and riverine trees/vegetation. Likewise, Daniel (2008) indicated that the pattern of land use and land cover changes between 1972 and 2004 in the Upper Dijo River catchment showed a tendency towards more land being brought under annual crops, while at the same time tree plantations became more important at the expense of shrub-grassland and riverine trees.

Land use land cover change detection results indicated that over the past 20–30 years there was gradual reduction and even near to the year of the present study almost a total disappearance of natural forest (1.94%) in the study watershed (Table 2). The main reason for the disappearance of natural forest in the study watershed was the conversion of forest to farmland (98.4%). As a result crop fields had taken the major areas even in hilly areas in the study watershed. Due to poor and inefficient utilization of RWM practices in the area, the expanded farmlands were highly prone to sheet and rill erosion as well as for the formation of big and active gullies which in turn led to low agricultural productivities in the study watershed.

The change detection result also revealed that there was reduction of grazing land in the study watershed within the periods considered. The shortage of grazing land for livestock was the main cause for increased crop residue removal for livestock feed purpose from crop fields which in turn resulted in soil fertility problems in the study watershed. Stream course deforestation for grazing purposes and other associated problems such as drying of streams and land sliding caused by livestock trampling were also consequences of grazing land reduction considered over the periods in the study watershed. Generally, variations in soil properties, livestock, agricultural and water productivities in the watershed under study were attributed to the observed differences in the LULC.
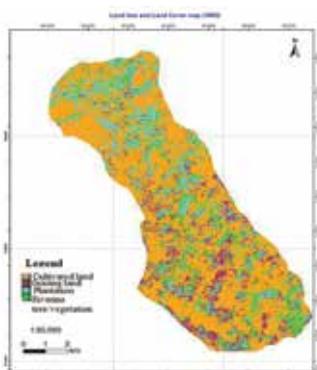

Figure 10 Map of LULC of the study watershed derived from landsat image of 1990
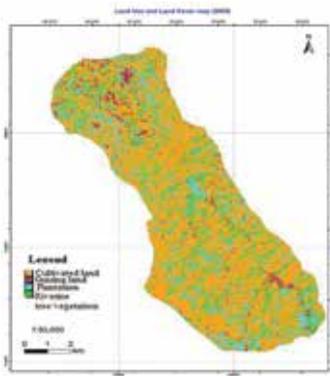
Figure 11 Map of LULC of the study watershed derived from landsat image of 2000

Figure 12. Map of LULC of the study watershed derived from landsat image of 2010

Conclusion

Inefficient applications of rainwater management practices in terms of both in *in-situ* rainwater conservation methods and via RWM for storing water for later use in water storage structures such as ponds were the main causes for water scarcity and water productivity problems in the watershed under study. Most respondents (66%) did not practise RWM interventions. Few RWM interventions such as check dams (43.5%) and ponds (3.2%) were implemented privately and in groups with valuable agricultural products being obtained with the use of these interventions to sustain food at household levels. However, the insufficient amount of water at the water sources (structures) and in diverted irrigation line are the main problems challenging the intensification of agricultural production via small scale irrigation systems in the watershed. Land conversion even at the steep slopes into cultivated land and the expansion of such land is a long time problem in the study watershed. The expansion of cultivated/arable land at the expense of forest and grazing lands was the main cause for the accelerated soil erosion, sedimentation, soil fertility loss and a resultant reduction in crop and livestock production and productivity in the study watershed. Therefore, strategies to secure food among the expanding population in the study areas will have to seek a sustainable solution that better addresses integrated rainwater and watershed management efforts.

Acknowledgements

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Synthesis of local knowledge on drivers of tree cover change in the Blue Nile basin

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Abstract: The quantity and position of trees in a landscape can have significant impacts on farm soil and water resources. Here we present a synthesis of local knowledge studies conducted in three micro-catchments of the Blue Nile Basin (Diga, Fogera and Jeldu *Woredas*) exploring natural and anthropogenic drivers of tree cover change. In total more than 90 purposively selected farmers were interviewed, whilst focus group discussions and feedback sessions were held with larger groups. Local knowledge revealed that all three sites suffered from rapid deforestation of native tree cover over the last 20 years. All three systems were recognized by farmers as declining in agricultural productivity. The decline of native forest in Jeldu was found to be more rapid than the other two sites, partially due to market pressures from the capital city. Fogera and Diga were found to have remnant native forest still present, although certain tree species had disappeared completely due to over-exploitation for their products. This was associated with population expansion which has driven land cultivation into more marginal land (such as steeper slopes and marshy lowlands), resulting in land degradation and heightened pressure on common grazing land. The farmers demonstrated detailed agro-ecological knowledge on how the physical attributes of trees impacted on water and soil resources. Farmers were able to describe the impacts of loss of native tree cover on erosion control, river bank stabilization, protection of headwaters and water quality improvements. There were knowledge gaps on how to integrate native trees into the cereal and horticultural cropping systems. The research findings suggest some potential policy changes and intervention strategies to reach farmers and increase understanding of the functions of trees in watershed management according to on-farm niches and ecosystem service provisioning.

Media grab: Local knowledge enhances our understanding of drivers of tree cover change in the Blue Nile Basin

Introduction

Ethiopia is entering a period of increasing water scarcity due in part to poor water resource management and environmental degradation caused by deforestation (Tadesse 2009). This research was aimed at understanding farmers' knowledge of both past and present trees and other woody perennials in three micro-catchments of the Blue Nile Basin, in order to identify potential entry points that could be used in initiating community-driven tree

conservation/reintroduction into local agro-ecosystems. The aim was to take an initial step towards participatory design of agroforestry-based soil and water conservation strategies in the study areas, as a response to the current widespread context of poverty and environmental degradation (Bayala et al. 2011). In order to do this effectively, we needed to understand what farmers already know and practice on their farms as well as the key drivers of tree cover change in each site.

Methods

This study was conducted using the Agro-ecological Knowledge Toolkit (AKT5) methodology and software. This involves a four-stage process described as 'scoping', 'definition', 'compilation' and 'generalization'. The major focus of knowledge collection comprises an iterative cycle—that is eliciting knowledge from a small purposive sample (Table 1). Open-ended questions were used in semi-structured and depth interviews to gather local knowledge about ecosystem services of trees within farming systems and the wider landscape. Focus group discussions (FGDs) included exercises such as pair-wise ranking of major drivers of land cover change and participatory mapping of historical land cover change. Transect walks were also carried out in selected *kebeles* to gain a deeper understanding of changes in the landscape that were discussed during FGDs. Participants were selected purposively in order to gain insight into the knowledge held by people of different strata (age, wealth, gender and location in the landscape). Elevation was chosen as the main means of stratifying informants across the research area in order to capture as much agro-ecological knowledge held by communities living under different environmental conditions (e.g. varying types and extent of tree cover and water contexts). Although there was a criteria to guide selection of respondents, attention was always given to ensuring the willingness of interviewees. Interviews were processed and relevant statements entered into knowledge bases and analysed using AKT5 software. Causal diagrams were generated to show relationships between tree cover change and important biogeochemical processes within the landscapes, with a special focus on watershed management services of past and present vegetation.

Table 1. A breakdown of first and second interviews and FGDs conducted in the three study sites

Breakdown of interviews	Jeldu	Diga	Fogera
Name of *kebeles* covered	Seriti Dhenku, Chilanko, Kolu Gelan, Shikute and Urga Ereri (5)	Arjo and Gudisa (2)	Tihua Ena Kokit, Alem Ber Zuria and Dibasifatira (3)
Total farmers	30	40	29
Total experts	4	4	5
Second interviews	6	8	6
Focus group discussions	2	2	3

Results and discussion

Local knowledge revealed that all three sites suffered from rapid deforestation of native tree cover over the last 40 years. All three systems were recognized by farmers as declining in agricultural productivity. The decline of native forest in Jeldu was found to be more rapid than the other two sites, partially due to market pressures from the capital city. Fogera and Diga were found to have remnant native forest still present, although certain tree species had disappeared completely due to over-exploitation for their products. This was associated with population expansion which had driven land cultivation into more marginal land (such as steeper slopes and marshy lowlands), resulting in land degradation and heightened pressure on common grazing land.

Tree cover in Jeldu

The tree cover in Jeldu had transitioned from native cover (originally Moist Dega vegetation: *Hagenia abyssinica, Juniperus procera* and *Podocarpus falcatus*) to sparsely spread native trees across the farming landscape and a rapid expansion of *Eucalyptus globulus* woodlots. In Jeldu, farmers reported that the loss of native forest cover had led to observable movement of headwaters down the slopes as the springs on the upper slopes gradually dried up.

Water security had also been affected by fluctuations in rainfall patterns. Increased utilization of river and streams for irrigation had led to a decrease in flow out of the catchment. The increase in *Eucalyptus globulus* had, according to farmers, led to a reduction in base flow of the River Meja. Farmers were found to have less rich agro-ecological knowledge on the services of native trees because of their low frequency but a high awareness of interactions of eucalyptus with crops, soil and water.

Tree cover in Diga

Native forest in Diga was originally Wet Weyna Dega vegetation (*Acacia, Cordia africana*). Remnant forest trees appeared at higher frequency than in Jeldu and retained as riparian cover and coffee shade. There was still a noticeable expansion of *Eucalyptus* spp. especially in Gudisa which borders the town of Nekemte. Farmers in Arjo in the low altitude range had extensive knowledge linking the loss of forest cover on the higher slopes to a decrease in base flow. They were able to explain mechanisms by which deforestation has led to increased erosion, increased fertility loss, increased soil deposition (which had dried the headwaters of streams), decreased rainfall and decreased water quality (Figure 1).
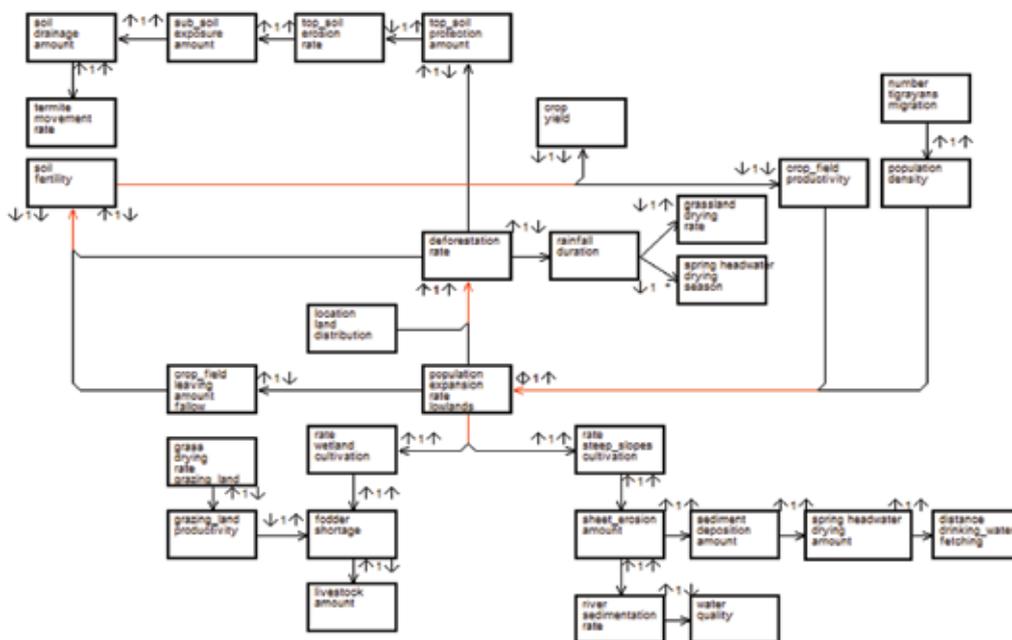

Figure 1. Local knowledge about drivers of tree cover change in Diga lowlands. Nodes represent attributes of objects, processes or actions (boxes with straight edges). Arrows connecting nodes show the direction of causal influence. The first small arrow on a link indicates either an increase (↑) or decrease (↓) in the causal node and the second refers to the effect node. Numbers between small arrows indicate whether the relationship is two-way (2), in which case an increase in A causing a decrease in B also implies that a decrease in A would cause an increase B, or one-way (1), where this reversibility does not apply.

Tree cover in Fogera

In Fogera, the trees naturally regenerating on community grasslands (mainly *Acacia spp.*) formed most of the remnant native forest species found on farmland. The trees were prone to overgrazing (leading to insufficient tree regeneration) and unsustainable management, mainly attributable to a lack of regulation of this community resource. Farmers were explicit about the many forest products which had been overharvested in the past (fibre, roots and leaves) for a variety of household needs (timber, tool construction, fuel, medicine and aromatic material) which had resulted in a decline in species diversity.

Trees for ameliorating environmental degradation

Farmers demonstrated detailed agro-ecological knowledge on how the physical attributes of trees impacted on water and soil resources. Farmers were able to identify tree species which ameliorate the effects of a wide range of environmental degradation issues (Table 2). The tree species known to fulfil these functions were mostly seen at low

frequency in the sites, or known to be extinct from the area. Local knowledge on their regulating services, as well as their utilities had been retained; however, there were found to be knowledge gaps on how to increase native tree cover in the cereal and horticultural cropping systems and manage them to reduce competition.

Farmers in the Diga midlands appreciated the fertile and productive soil that resulted from the forest canopy to grow coffee. The coffee plots were usually located next to streams or water bodies, on steep lands without terracing. In the lowlands, coffee was also being grown under *Mangifera indica* although farmers stated that the productivity was lower than that of coffee produced under traditional shade trees.

In Diga and Fogera, native tree species of high potential value (*Cordia africana, Croton macrostachyus, Acacia* spp.) and exotic fruit trees were planted or retained around the settlements and within croplands. The farmers were found to have two main objectives: to provide essential goods (e.g. timber, fencing material, fodder, fruits) and to conserve the soil fertility (mainly through leaf-litter).

One of the significant findings was the consistency in which farmers linked particular tree species to hydrological processes that influenced their interaction with agricultural crops. *Eucalyptus spp.* was reported to compete with crops for greenwater and to reduce the flow from adjacent headwaters. *Syzygium guineense* was associated with a high water-table and ease of accessibility of groundwater. Farmers reported in both Diga and Fogera that they would use *Syzygium guineense* as an indicator of a high water table when digging a well.

Table 2. A sample of native multipurpose trees across study sites, their uses and landscape niches.

S/N	Site	Latin name	Most appropriate uses	Niches
1	J	*Acacia lahai*	FW, SF, CC	Field
2	J,D,F	*Acacia sieberiana*	FW, SF, CC	Field
3	D	*Albizi aschimperiana*	FW, SF, CC	Riverbank
4	J	*Chamaecytisus palmensis*	FD, SF	Live fence
5	D,F	*Combretum spp.*	T, MP	Forest
6	J,D,F	*Cordia africana*	T, MP	Field
7	J,D,F	*Croton macrostachyus*	T, FW	Field
8	J	*Dombeyatorrida,*	FW, SF	Field
9	J,D	*Ekebergi acapensis*	T, SC, FW, FD	Field boundary
10	J,D	*Erythrina abyssinica*	SC, SF, FW	Live fence
11	J,D,F	*Ficus spp.*	SC, FW, FD	Riverbank
12	J, D	*Hagenia abyssinica*	T, SC	Field
13	J,D	*Myrica salicifolia*	FW	Live fence
14	J	*Nuxia congesta*	FW, CC	Live fence
15	J,F	*Oleaeuropaea ssp. africana*	T, FW, CC	Forest
16	J	*Strychnos spinosa*	FW, CC, FD	Field boundary
17	D,F	*Syzygium guineense*	SC, MP	Riverbank
18	J,D	*Vernonia amygdalina*	FD, MP	Live fence

Site: J = Jeldu, D = Diga, F = Fogera.
Most appropriate uses: T = timber, SC = soil conservation, MP = multipurpose, SF = soil fertility, FW = firewood, CC = charcoal, FD = fodder.

Policy was seen by farmers as a major constraint to integrating native trees on cropland and many of the species had protection under Ethiopian forest policy; this would need to be addressed if farmers are to be encouraged to utilize them as alternative timber and fuel sources to eucalyptus, as well as to retain them on fields and manage them to reduce shade and competition with agricultural crops.

Conclusions and recommendations

The results suggest that farmers in all three sites had a significant understanding of interactions between trees, soil and water. Although farmers understood the various functions of trees in watershed management according to on-farm niches and ecosystem service provisioning, there was still a critical gap in understanding the logistics of integrating them at a higher frequency into the current agricultural systems. Such gaps in knowledge should be addressed through technical training and awareness raising activities. In order to fulfil project goals of improving watershed management in the Blue Nile Basin, farmers' knowledge about native trees needs to be taken into account when designing tree interventions and promotion of agroforestry species by local government nurseries.

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Determinants of smallholder farmers' participation in sesame production: Evidence from Diga, Ethiopia

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Abstract: Considering that agriculture remains a key sector in Ethiopia, commercialization of the sector necessitates improving participation of smallholder farmers in markets, hence improving their incomes and livelihoods. Promoting smallholder commercialization through cash crop production is one avenue of such efforts. The main argument for smallholder commercialization through cash crop production is that it can allow households to increase their income directly. Sesame in Ethiopia can be taken as a good example in this regard. Although Diga has a potential land and the area is among the few areas which are agro-ecologically suitable for sesame production and productivity in the country, smallholder farmers are not participating actively in its production (constrained by a number of factors). This study assesses factors determining smallholders' participation in sesame production in Diga, West Ethiopia. Using structured questionnaires, the data was collected from a random sample of 120 smallholder farmers and analysed by using a double hurdle approach. After all, this study highlighted that access to credit, farm landholding size, family labour, household assets (oxen, donkey), access to family food for the whole year and proximity to extension service centres significantly influence smallholders' decision probability of participating in sesame production. On the other hand, access to credit, number of oxen owned and number of active family labour significantly determine the level of smallholders' participation in sesame production. The implication is that production potential due to favourable agro-ecological condition is necessary but not sufficient for smallholder farmers to participation in sesame production. Indicating household specific and institutional factors also influence their decision. Thus, if active participation of smallholder farmer is required in the field, institutional innovations should be developed and strengthened—in a way to involve all smallholder farmers.

Media grab: In addition to rainwater, other internal and external factors influence smallholder's decision to change the available sesame production potentials and opportunities into livelihood advantages

Introduction and background of the study

In Ethiopia, smallholder agriculture represent about 95% of the total agricultural output. In addition to producing staple crops, smallholders produce large share of export potential crops such as sesame. Sesame is an important crop to Ethiopian agriculture, it is quite extensively cultivated and it yields in relatively poor climatic conditions. In the recent years, it is an important component of Ethiopia's agricultural exports. Different reports indicate that Ethiopia is among the top-five sesame producing countries in the world, ranked in fourth place in 2011/2012 (FAOSTAT 2012). As a smallholder farmer's crop and an export potential crop, it is an opportunity for smallholder farmers to produce sesame and change the available potential into the livelihood improvement.

However, in addition to the limited availability of agro-ecologically suitable areas for sesame production and productivity in the country,[6] smallholder farmers' production and marketing participation did not match the available potential. The extent of cultivation is poorly known and there is little information on yields or productivity in the country. That is, even in areas where the agro-ecology is favourable for sesame production, smallholder farmers' participation is far below the available potential. For example, in Diga *woreda* (part of East Wellega), there is suitable agronomic conditions for growing sesame and there is high potential arable land to do so. This is an opportunity for smallholder farmers in this area, since sesame is an export potential cash crop with high demand and price at both local and international markets. Despite the available potentials and opportunities, many smallholder farmers are not participating in its production and marketing in this area. Currently only about 29% of the potential arable land was cultivated under sesame in this area. This indicates that there are external and internal (household specific) factors that constrain some households from participation in the activity. In addition, the extent to which the participant farmers participate varies significantly and the overall participation is incomparable with the available potential. Due to these factors, smallholder farmers in Diga *woreda* are differently responding to the available potential and thus obtain different welfare benefits from the available opportunities.

Based on this statement, certain key questions became relevant: What factors, other than agro-ecology influence smallholder farmer's participation decision to produce sesame in Diga? What factors determine the level of production participation in this area? The objective of the current paper is to address the foregoing questions, among others. Specifically, the paper is intended to assess the determinants of smallholder farmer's participation decision in sesame production, taking Diga as case study. In addition, the paper tries to identify factors influencing the extent of smallholders' participation in sesame production.

The study settings

Study area and data sources

This study is based on primary data collected from 120 farm household heads randomly selected from Diga district, part of East Wellega, Oromia Regional State. Diga is located in southwest of Blue Nile basin. Agro-ecologically, the district is divided into two; namely midland which comprises about 40% and lowlands accounting for the remaining 60% .The area is one of the major sesame producing areas in Ethiopia, known for the production of high oil content sesame. Though seasonal water scarcity during the dry seasons is a problem, the area receives high amount mono-modal rainfall from mid-March through September. Mixed crop–livestock farming system is the common livelihood strategy of the community. Crop production is primarily characterized by rainfed system. Thus, the performance of the sector and the overall livelihood of the populations in this area are highly dependent on the time onset, duration and amount of rainfall. This implies that livelihood strategy in the area should focus on rainfed crops like sesame if encouraging and linking smallholder farmers to market as a pathway to come out of poverty in the area is required.

Method of analysis

Double-hurdle model was employed to analyse the above discussed farm household decision problem. This model assumes farmers faced with two hurdles in any agricultural decision-making processes (Sanchez 2005; Humphreys 2010). Accordingly, the decision to participate in an activity is made first and then the decision regarding the level of participation in the activity follows. In this study, thus, double-hurdle model was chosen because it allows for the distinction between the determinants of production participation and the level of participation in sesame production in two separate decisions. Double hurdle estimation procedure involves running a probit regression to identify factors affecting the decision to participate in the activity using all sample population in the first stage and a truncated regression model on the participating households to analyse factors affecting their of level of production participation, in the second stage.

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6. *While there is some potential to grow sesame in different parts of the country, its production is mainly concentrated in the northern and northwestern regions of Ethiopia—Humera, Metema and East Wellega (ECX 2010).*

Results and discussion

Determinants of sesame production participation decisions (Probit regression)

Table (1) presents factors influencing smallholders' probability decision to participate in sesame production. Eleven variables were considered and regressed as explanatory variables in influencing decision probability of farmers in this regard. The regression result revealed that farm landholding size is one of the determinant factors in influencing decision of farmers to produce sesame in Diga. The findings by Poulton et al. suggests that land is an important factor in influencing farmer's decision to produce any cash crop (Poulton et al. 2001), hence support the current finding.

Table 1. Probit regression, reporting marginal effects (Probit Regression Result)

Prodpart (D.V.)	Coefficients	Robust S.E.	Z-value
Age of hh head	0.0000284	0.0000905	0.54
Education level	0.129457	0.626501	0.69
Family labour	0.0009162**	0.0021514	2.07
Land size	0.0069887***	0.0160255	3.08
Number of oxen	0.0014022***	0.0033945	2.88
Number of donkey	0.0013355**	0.0032398	2.06
Non-farm income	0.0686414	0.001387	1.34
Access to credit	0.0075744**	0.0163355	2.39
Access to family food	0.0133033**	0.0287685	2.69
Distance to extension	−0.0000356*	0.0000832	−1.91
Distance to market	−7.35e–06	0.0000202	−0.83

Obs. P 0.7583333

Pred. P| 0.9995549 (at x-bar)   Number of obs = 120

Wald chi^2 (9) = 24.62   Prob > chi^2 = 0.0000

Log pseudo likelihood = −12.431611   Pseudo R^2 = 0.8127

NB: (^) dF/dx is for discrete change of dummy variable from 0 to 1

z-value correspond to the test of the underlying coefficient being 0 and thus

*, ** and *** indicates significance of the coefficients at 10%, 5% and 1% levels, respectively.

Source: survey estimation result 2012.

In addition, this result revealed that family labour is one of the critical variables in influencing decisions of households to produce sesame in the study area, ceteris paribus. Thus, farmers who have more access to family labour are more likely to participate in such activity. The possible reason is that labour markets are highly imperfect in this area while sesame productions—from land preparation to its harvest—require labour and lack of such access has a great impact on farmer's decision to produce the crop. This indicates that farmers who have access to more family labour are likely to produce sesame under ceteris paribus assumption.

Furthermore, access to credit is one possible solution for such related problems. These farmers reported that, even if they have access to labour from market, they lack cash to hire that labour. Based on the result, we obtained the evidence that support such positive linkage between access to credit and probability to produce such export potential cash crop—sesame. This result indicates that access to credit is an important factor in influencing the probability of participation in sesame production. Access to household assets such as oxen and donkey also determines the probability of farmers' decision to produce sesame significantly. Thus, these two household assets are among the factors that influence farmers' decision to produce sesame in the study area.

Determinants of the level of sesame production participation

This section focuses on analysing factors affecting farmers' participation decision in sesame production by employing a truncated regression model. The regression result indicates that the estimated coefficient of three variables found to be statistically significant in determining the size of land allocated to sesame production.

As the case of production decision, the survey result revealed that farmers' access to credit reflects positive and statistically significant impact on the level of sesame production participation. This implies again that smallholders' access to credit is one of the major factors in determining the extent of land allocated to sesame production, in

addition to influencing their decision to produce the crop. In addition, the finding by Burke suggests that credit prevalence is an important determinant factor in all stages of the farmer's production and marketing decisions (Burke 2009). Furthermore, the number of active family labour significantly and positively determines the extent of smallholder's participation in sesame production. Thus, the number of active family labour is among the significant factor explaining farmers' decision regarding the extent of sesame production participation in the study area.

Table 2. Determinants of the extent of sesame production participation (Truncated regression)

Cultivated land (dependent variable)	Coefficients	R.S.E.	t-value
Sex of hh head (SEX)	0.0739903	0.0738267	1.00
Number of active family labour (FAMLAB)	0.0984799***	0.0317001	3.11
Total land size (TLS)	0.0955035	0.0708308	1.35
Access to non-farm activity (NONFRM)	−0.0628714	0.016872	−0.62
Number of oxen owned (OXEN)	0.0564588*	0.0312789	1.81
Access to credit (CRDT)	0.2072571**	0.076324	2.72
Educational level of hh head (EDCN)	0.0177086	0.0144058	1.23
Sesame production problems (PROBLEM)	−0.0502468	0.060166	−0.47
Constant	−0.0833815	0.633525	−0.51
Wald chi^2 (8) = 85.19 Prob > chi^2 = 0.0000 Log pseudo likelihood = −106.78			

*, ** and *** indicates significance of the coefficients at 10%, 5% and 1% levels, respectively.
Source: author computation 2012.

This study also gives evidence that shows the number of oxen owned has a positive and significant impact on the level of sesame produced by sampled farmers. The result from this regression, coupled with result obtained from the previous probit regression, confirms the key role of having more oxen in sesame production participation in the study area.

Conclusion and recommendations

 A key premise of smallholder commercialization as a development agenda is that markets provide increased incomes to households who are able to maximize the returns to land and labour through market opportunities. Promoting smallholder commercializing through cash crop production is one avenue of such efforts. This study assesses factors determining smallholders' participation in sesame production in Diga, West Ethiopia. This study highlighted that access to credit, farm landholding size, family labour, household assets (oxen, donkey), access to family food for the whole year and proximity to extension service centres significantly influence smallholders' decision probability of participating in sesame production. On the other hand, access to credit, number of oxen owned and number of active family labour significantly determine the level of smallholders' participation in sesame production. The implication is that production potential due to favourable agro-ecological condition is necessary but not sufficient for smallholder farmers to participation in sesame production. Indicating household specific and institutional factors also influence their decision. Thus, if active participation of smallholder farmer is required in the field, institutional innovations should be developed and strengthened,—in a way to involve all smallholder farmers.

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On-site financial costs of soil erosion by runoff from the Mizewa catchment of the Blue Nile basin

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Abstract: This study was conducted in Mizewa watershed which is located in Blue Nile Basin (BNB) to estimate on-site financial cost of erosion in terms of yield reduction taking maize as representative crop. For this purpose, discharge measurement and runoff sampling was made during the rainy season of 2011 at the outlet of three sub watersheds within Mizewa catchment; lower Mizewa (MZ0), Upper Mizewa (MZ1) and Gindenewur (GN0). The samples were filtered to separate the sediment which was subsampled for determination of suspended sediment concentration (SSC), sediment fixed NO_3^-, NH_4^+ and available phosphorous (P) contents. The filtered water was used to assess dissolved nitrate and dissolved phosphate. The on-site financial cost of erosion was estimated based on productivity change approach (PCA) focusing on available NP losses. The result revealed that the SSC and its NP content varied in space and time, in which higher and lower SSC occurred towards the beginning and end of the rainy season, respectively. The mean seasonal discharge was found to be 2.12±0.75, 1.49±0.52 and 0.57±0.20 m³/sec at MZ0, MZ1 and GN0 stations in that order while the corresponding sediment concentration was 510±370 mg/l, 230±190 mg/l and 370±220 mg/l. This led to the total suspended sediment loss (SSL) of 4 ton/ha/year, 2 ton/ha/year and 3 ton/ha/year from the respective subwatersheds. The on-site financial cost due to N and P lost associated with SSL was estimated to be USD 200/ha, USD 186/ha and USD 227/ha from MZ0, MZ1 and GN0 watersheds, respectively. The study revealed that the economic impacts of soil erosion which is variable based on the characteristics of land resources and management practices are immense and deserve due attention. The result may help in sensitizing both farmers and decision-makers about the risk of soil erosion and in targeting management practices to overcome the challenges.

Keywords: Blue Nile basin, soil erosion, runoff, sediment concentration, Nutrient loss.

Media grab: Information on suspended sediment and plant available nutrients loss in runoff with their economic cost can provide crucial evidence to inform the land users and policymakers to take actions in management of land resources.

Introduction

Blue Nile Basin is heavily affected by land degradation problems. Overpopulation, poor cultivation and land use practices are the major cause, which result in significant loss of soil fertility, rapid degradation of the natural ecosystems, significant sediment and nutrient depositions in lakes and reservoirs (Tamene et al. 2006). To supplement rainfed agriculture with irrigation, a massive surface water harvesting effort has been undertaken in the dry lands of Ethiopia including BNB in the last few years. However, most of the water harvesting schemes is under serious siltation and dry up (Amanuel 2009) due to upstream land degradation mainly soil erosion. Circumstances in turn have led to reduction of productivity because of risky land use exercise and this has significant on-site economic costs to land users and the country as a whole. The cost price of loss of only available N and P, eroded from the 13 small catchments, was estimated at €34.2 million (Haregeweyn et al. 2008) in March 2006 for the Tigray, Northern Ethiopia. Therefore, it is essential to design and implement suitable land management practices for optimum utilization of land resources (soil and water), even if, limited information on financial on-site costs for loss of suspended sediment and plant available nutrients in runoff provide crucial evidence to inform land users and policymakers to take actions. This study tried to estimate productivity losses and corresponding economic and financial costs of suspended sediment and plant available nutrients lost along with runoff in Mizewa catchment as an input to the Nile Basin Development Challenges Program on Water and Food being implemented in the BNB.

Methods

The study was conducted at Mizewa catchment, northwest Ethiopia, drained by Mizewa River, a tributary to the Rib River that feeds to Lake Tana and covering a total area of 2664 ha which is located between latitude 11.88°–11.94°N and longitude 37.78°–37.86°E. Chromic-Luvisols, Chromic-Vertisols and Leptosols are the most common soil types with basaltic rock formation (Setegn et al. 2009). Mixed crop–livestock farming system with maize, rice, finger millet, teff, groundnut and barley are the principal crops grown in the area (Birhanu et al. 2012). Urea and DAP are the commonly used chemical fertilizers. Mizewa lie between 1852 m and 2360 m, dominated by hill to rolling undulating plain land forms and characterized by unimodal rainfall (mean 1204 mm) pattern, peaks around August 20th. Mean annual temperature ranges from 16.73°C to 19.32°C.

Flow height (h), surface flow velocity (Vs) measurement and suspended sediment sampling were conducted at the three monitoring stations three times a day at morning, mid-day and evening from 8 July 2011 through 16 October 2011 to calculate discharge (Q), suspended sediment concentration (SSC), suspended sediment loses (SSL), nutrient concentration (NC) and nutrient loss (NL). Data on maize grain yield (GY) response to fertilizer additions were obtained from previous research results under similar agro-ecological conditions. Surface flow velocity was measured using floating approach using a plastic bottle and converted to the average velocity (V) using Graff (1996) method.[7] Record of h was converted into flow cross-sectional area (A) using an empirical relationship[8] between h and A.

The volume of water (Q) passing a cross section per unit of time was calculated using the area-velocity method[9] (Hudson 1993). Sample runoff sediment was bulked into one as decade (D) according to the date of sampling starting from 8 July 2011 in order to have enough sediment for laboratory analysis and to reduce cost of laboratory. A composite sub-sample of one litter was taken from bulked samples for analysis. In the laboratory, the decade runoff sediment sample was filtered using Whatman No 42 filter paper to have SSC. The filtered water was analysed for dissolved nitrate and phosphate. The sediment left on the filter paper was air dried and weighted to analyse sediment fixed NO_3^-, NH_4^+ and available P concentration. In laboratory, Gregorich and Ellert (1993) method was applied for NO_3^- and NH_4^+ analysis and Olsen et al. (1954) procedure was applied for available P. Dissolved nitrate and dissolved Phosphate were determined using spectrophotometer (Bache and Williams 1971).

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7. $V = 0.6*Vs$.

8. $A = 5.5h2+3.6h$ for MZ0 ,$A=2.9h2+0.95h+0.05$ for MZ1 and $A=9.95h2+7.44h$ for GN0.

9. $Q = V*A$.

Load of sediment (SSL), load of dissolved NO_3^- and dissolved PO_4^{3-} load was product of Q (m^3/decade) and their concentration in mg/l. Sediment bounded losses of NH_4^+, NO_3^- and available P was the product of mg/kg of each species with SSL mass in kg/decade. Seasonal losses were the sum of 10 decades of each species. Conversion of NO_3^- and NH_4^+ to elemental available nitrogen was done using multiplier coefficient 0.23 and 0.78, respectively, while available elemental P and dissolved Phosphate were converted to phosphorous oxide (P_2O_5) using conversion factors 2.29 and 0.75 in order.

Productivity change approach (PCA) technique Bojo (1995) was used to estimate on-site financial cost of plant available nutrient losses through runoff soil erosion. This was calculated taking the loss of available NP nutrients and put a value on it using the equivalent net maize grain yield loss. Effect on crop yield was simply calculated as the net grain yield lost between potential grain yield due to lost available NP on fitting curve[10] and mean grain yield with no NP fertilizers.

Statistical comparisons were performed using SPSS 16. Analyses were performed to make comparison within groups of runoff sediment and nutrient loss between sites and decades. Significance differences in sediment load, rate of discharge and nutrient loss between sites was determined by t-test at 95% confidence limit.

Results and discussion

Runoff volume and suspended sediment lost

The average discharge was 2.12±0.75, 1.49±0.52 and 0.57±0.20 m^3/sec with total flow volume of $18.34 \times 10^6\,m^3$, $12.87 \times 10^6\,m^3$ and $4.92 \times 10^6\,m^3$ per season at MZ0, MZ1 and GN0 rivers, respectively. Peak daily discharge was observed in D5 for the three stations (Figures 1.a, 1.b and 1.c) may be due to excess in saturation and full vegetation coverage of land. Mean flow rate was statistically significant between sites (t = 2.68, P≤0.025 between MZ0 and MZ1, t = 6.58, P≤0.000 between MZ0 and GN0, t = 5.54, P≤0.000 between MZ1 and GN0 rivers).

Note: D=decade=ten consecutive days during monitoring season.
D1: July 8-July 17
D2: July 18-July 27
D3: July 28-August 6 D4: Aug 7- Aug 16 D5:Aug17- Aug 26

D6:Aug27-Sep 5 D7:Sep6- Sep 15 D8:Sep16- Sep 25
D9:Sep26-Oct 5
D10: Oct16 – Oct 15

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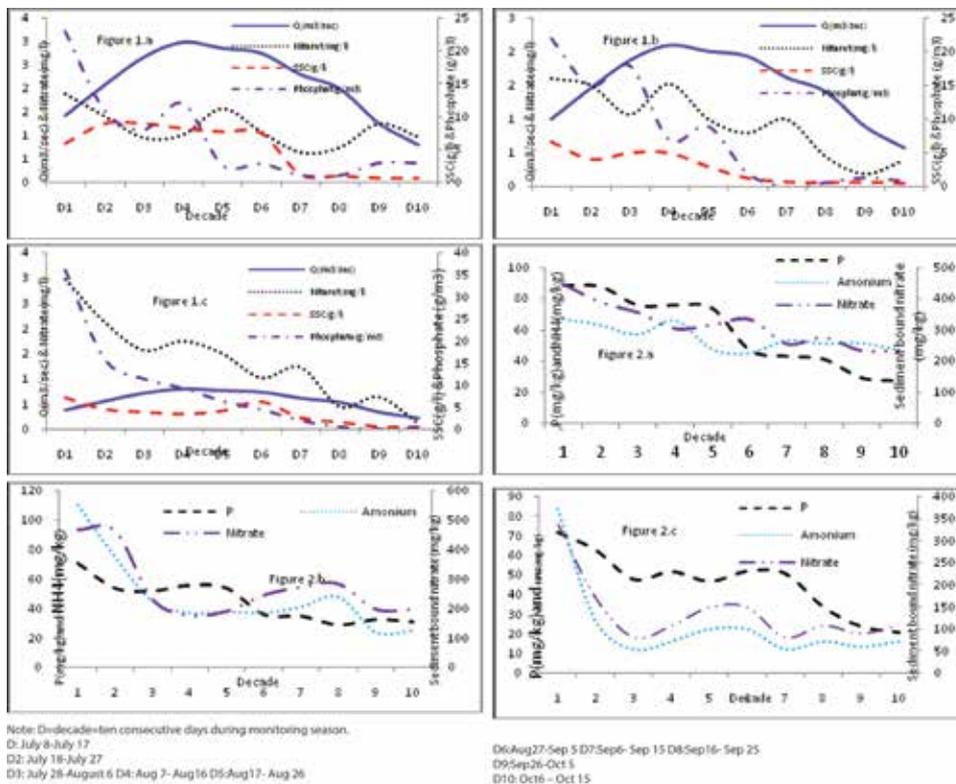
10. $GY = -0.29N_2 + 58.6N + 2537.3 (R2=0.75)$ and $GY = -0.55(P_2O_5)2 + 82.25\,P_2O_5 + 2690.7\,(R^2=0.88)$ regression equations between GY of maize to N and P_2O_5.

Figure 2. Sediment bounded available P, NO$_3^-$ and NH$_4^+$ as a function of time at (a) MZ0 (b) MZ1 and (c) GN0 station during monitoring time.

Mean SSC during the rainy season was 510±370 mg/l, 230±190 mg/l and 370±220 mg/l from MZ0, MZ1 and GN0 stations respectively and significant variations was observed between time and space (Figures 1.a, 1.b and 1.c). In MZ0 mean SSC varied from 67 mg/l to 900 mg/l per decade. SSC coefficient of variation between periods was 73, 82 and 61% for MZ0, MZ1 and GN0 stations, respectively implying that SSC in MZ1 was more variable over time than MZ0 and GN0 rivers. Statistical test for temporal and spatial variability of mean SSC (mg/l) over decades has shown that there is a significant variation between periods (F = 4.51 and p≤0.0032) and sites (F = 5.61 and p≤0.013).

Plant available N and P lost

Significant plant available nutrients were lost in associated with runoff and sediment (Table 1). Mean area specific plant available NP losses were 2.3 kg N/ha and 4.0 kg P$_2$O$_5$/ha from MZ0, 1.6 kg N/ha and 4.1 kgP$_2$O$_5$/ha from MZ1 and 2.3 kg N/ha and 4.8 kgP$_2$O$_5$/ha from GN0 catchments during monitoring period. Statically, there was a clear difference in the concentration of sediment nitrate (F = 6.23, p = 0.006) and NH$_4^+$ (F = 3.85, p = 0.034) across stations during the study period. Figures 2.a, 2.b and 2.c show that; there was no temporal variation in available plant nutrient concentration regardless of the stations except only for soluble phosphate (F = 10.47, p≤0.000). This available nutrient species composition and magnitude varied widely within the watershed which could be caused by several factors that needs further research and detail data to come up the with control variables for these differences among stations.

Table 1. Soluble and sediment fixed plant available nutrients looses

Station	Loss	Q (10^6 m^3)	SSC (mg/l)	Plant available N and P (kg)	
				N	P$_2$O$_5$
MZ0	Total	18.34		5967	3,635
	Mean	1.83	510	597	363
	Loss/ha		4	2.3	4
MZ1	Total	12.87		2590	1005
	Mean	1.29	230	259	101
	Loss/ha		2	1.6	4.1
GN0	Total	4.92		1627	551
	Mean	0.49	370	163	55
	Loss/ha		3	2.3	4.8

On-site financial costs

In this study, plant available N and P lost through runoff suspended sediment was responsible for significant economic on-site costs and this was reflected in maize grain yield reduction (Table 2) during monitoring season. Regression equations between maize grain yield and additional N and P$_2$O$_5$ application based on Tilahun Tadesse et al. (2007) data source was used as a bridge to link soil nutrient lost with grain yield loss of maize crop. Coefficient of determination in the equations shows a wide variation of yield response to the almost equivalent amount of fertilizer level. This shows that mean grain yield with no P and N fertilizers were 2691 kg/ha and 2537 kg/ha, respectively. Correspondingly, the lost net maize grain yield due to the loss of available NP were 453 kg/ha from MZ0, 421 kg/ha from MZ1 and 453 kg/ha from GN0 watersheds.

Table 2. Estimated monetary value of available N and P loss in Mizewa watersheds

Cost estimation procedure	MZ0			MZ1			GN0		
	N	P2O5	Total	N	P2O5	Total	N	P2O5	Total
Total loss (kg/ha)	2.3	4		1.6	4.1		2.3	4.8	
Potential grain yield response (t/ha)	0.267	0.301		0.263	0.302		0.267	0.307	
Grain yield with no NP fertilizers (t/ha)	0.254	0.269		0.254	0.269		0.254	0.269	
Net grain yield loss (kg/ha)	134	320	453	93	328	421	134	382	515
Price of net grain yield loss (USD/ha)	59	141	200	41	145	186	59	168	227

Price of grain maize in July 2011 (USD 0.44/kg).

According to Central Statistical Agency report of Ethiopia in 2011, average maize grain yield productivity in the study area was 2 t/ha. Therefore, the lost maize yield due to available N and P_2O_5 accounts 23, 21 and 26% of the total yield from MZ0, MZ1 and GN0 watersheds correspondingly. This effect of soil erosion on grain yield is above the reported figures of Helmecke (2009) who estimated 10, 5 and 12% for cereals pulses and root crops, respectively, at global scale. As a result, a farm enterprise having a hectare of land with maize cultivation in the study area has a profit loss of about USD 200/ha from MZ0, USD 186/ha from MZ1 and USD 227/ha from GN0 watershed in consequence of plant available N and P lost through runoff soil erosion process only in one particular rainy season.

Conclusions and recommendations

During the monitoring period 18.34×10^6 m^3, 12.87×10^6 m^3 and 4.92×10^6 m^3 of water was lost with mean SSL of 4 ton/ha, 2 ton/ha and 3 ton/ha in association with (2.3 kg available N/ha and 4 kg P_2O_5/ha), (1.6 kg available N/ha and 4.1 kg P_2O_5/ha) and (2.3 kg available N/ha and 4.8 kg P_2O_5/ha) from MZ0, MZ1 and GN0 watersheds, respectively. This study also conclude that a reduction in maize gain productivity of 23, 21 and 26% and equivalent financial cost of USD 200/ha, USD 186/ha and USD 227/ha from MZ0, MZ1 and GN0 catchments in that order was estimated. The lost runoff from each watershed has a potential to irrigate a significant hectare of land, so that one could understand the valuable benefits gained by farmers if this water was used during dry season through water saving technologies though it needs detail study for recommendations to assess runoff lost with its on-site financial cost. The sediment lost did not consider bed-load transport, which might be important in the Mizewa catchments. Hence, measuring bed load in future is important in order to obtain more realistic total sediment and nutrient load calculation. In order to obtain a better picture of erosion impacts in the area, studies on other nutrient losses like calcium and magnesium and off-site effects of erosion need to be considered. This will benefit the understanding of the problem by land users and/ or policymakers, letting them see the need to promote and/or implement soil conservation measures, as that is the language that they usually understand best. Therefore, the researchers recommend considering cost of soil erosion in national economy accounting to show significance of soil erosion to policymakers and to land users.

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Examining advance time of furrow irrigation at Koga irrigation scheme in Ethiopia

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Abstract: Koga irrigation scheme was developed to irrigate about 7004 ha. Furrow irrigation is the recommended method for the distribution of water. However, furrow irrigation has inherent inefficiencies due to deep percolation on the upper end and runoff at the lower end of the furrow. These losses depend on furrow length, furrow gradient, surface roughness, stream size and cutoff time. These factors play significant role to influence the advance time of irrigation and the operation rule of the scheme. This paper examines the advance time of furrow irrigation at Koga. The experiment was conducted during 2012 irrigation season in two periods (February and April). The advance time of irrigation was monitored at three discharge rates and four furrow gradients at 90–110 m furrow length. The required discharge was measured using RBC flume. The average advance time at respective discharge rates of 0.3, 0.6 and 0.8 litre/sec range from 290–460 min, 150–437 min and 100–294 min during 1st irrigation; and 115–370 min, 78–189 min and 43–217 min during 2nd irrigation. The advance time vary greatly among the discharge rates when the furrow length increases. The advance time of water at 0.5, 1.0, 2.0 and 2.5 % gradients was 236, 181, 197 and 398 min at 1st irrigation and 163, 175, 220 and 88 min at 2nd irrigation respectively. Furrow gradients and surface irregularities result in great variation of advance time. The advance time becomes shorter when the field gets smoother during 2nd irrigation. Under non-levelled and irregular field conditions, 0.6–0.8 litre/sec application rate can be suggested to irrigate 30–40 m furrow lengths in order to improve application efficiency above 60% and to optimize the daily operation rule of the overall scheme. The result of this study indicates the relevance of examining the furrow length, discharge and application time recommended in the feasibility study of irrigation schemes.

Key words: Koga, furrow length, advance time, discharge rate, furrow gradient

Media grab: Efficient operation and management of irrigation schemes can be enhanced when there is field testing and reexamining the irrigation design characteristics recommended during the feasibility study.

Introduction

Koga irrigation scheme was developed to irrigate about 7004 ha land. Given the wide range of slopes and the low degree of using advanced techniques in the area, furrow irrigation is the preferred method and recommended for the distribution of water to the fields. However, most surface irrigation systems have inherent inefficiencies due to deep percolation on the upper end and runoff at the lower end of the field. A well-designed and properly managed surface system can attain efficiencies of 60% or better (Waskom 1994). In a study conducted by Kassa (2003) at Melka Werer, Middle Awash Valley, with a furrow length of 200 m and different water inflow rates, the maximum attainable application efficiency of furrow irrigation is 62 to 64%.

The strategies to improve furrow irrigation efficiencies revolve around reducing runoff and deep percolation losses. These losses depend on furrow length, furrow gradient, discharge and cutoff time which in turn need to be optimized by irrigators to improve efficiency. These furrow design parameters should be chosen with analysis of local field conditions. Therefore, this paper presents the advance time of furrow irrigation based on field data from Koga under different discharge rates and slope gradients.

Methods

The advance time of irrigation was recorded at different furrow gradients and discharge rates. The Koga dam and irrigation project feasibility study was taken as the base to set up the experimental factors. Since levelling was not done for the whole scheme, the average slopes of the study sites were taken as furrow gradients. Accordingly, four furrow gradients (0.5, 1, 2 and 2.5 %) were chosen at different sites. The tested furrow discharges were purposively selected out of the recommended discharge sizes in the feasibility study. Three discharges (0.3 litre/sec, 0.6 litre/sec and 0.8 litre/sec) were considered. Three adjacent furrows of length 90–110 m are prepared.

The central furrow was used as an experimental furrow while the two adjacent furrows receiving equal discharge with the centre furrow were used as buffers. Two measuring RBC flumes were placed at the beginning and end of each centre furrow. The application was terminated when the stream flow through the outlet remains at steady flow. Wooden stakes were installed along each furrow at 10 m interval where advance time was recorded. The travel time of water advancing through the furrow (advance time) was recorded at each wooden mark of 10 m length using stopwatch. The advance time was recorded in two irrigation cycles, first irrigation period (February) and second irrigation period (April).

Results and discussion

Figures 1 to 3 present the advance time recorded at different discharge rates and furrow gradients with furrow spacing of 40 cm during first and second irrigation periods. It is clearly revealed that discharge played great role in the variation of the advance time. In fact, the advance time also varied from site to site. Regardless of differences in discharge rates, on average the advance time range from 180–400 min and 88–220 min between sites at first and second irrigation, respectively. This was attributed to differences in surface roughness, slope and field levelling or depressions. In the first irrigation, due to the confounding effect of high surface roughness, the effect of furrow gradient was not clearly observed.
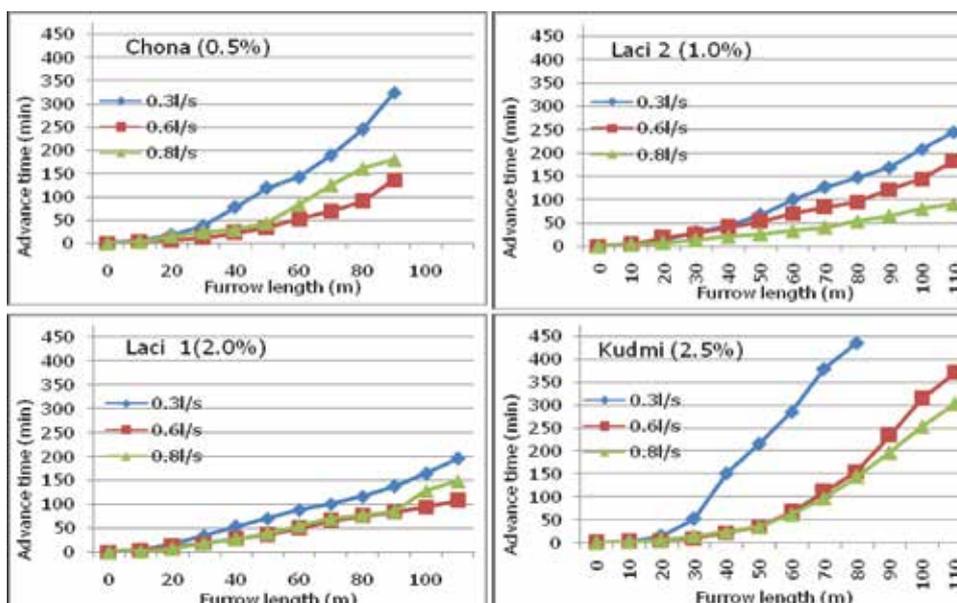

*Figure 1. Illustration of advance time against furrow length, 1st irrigation.*
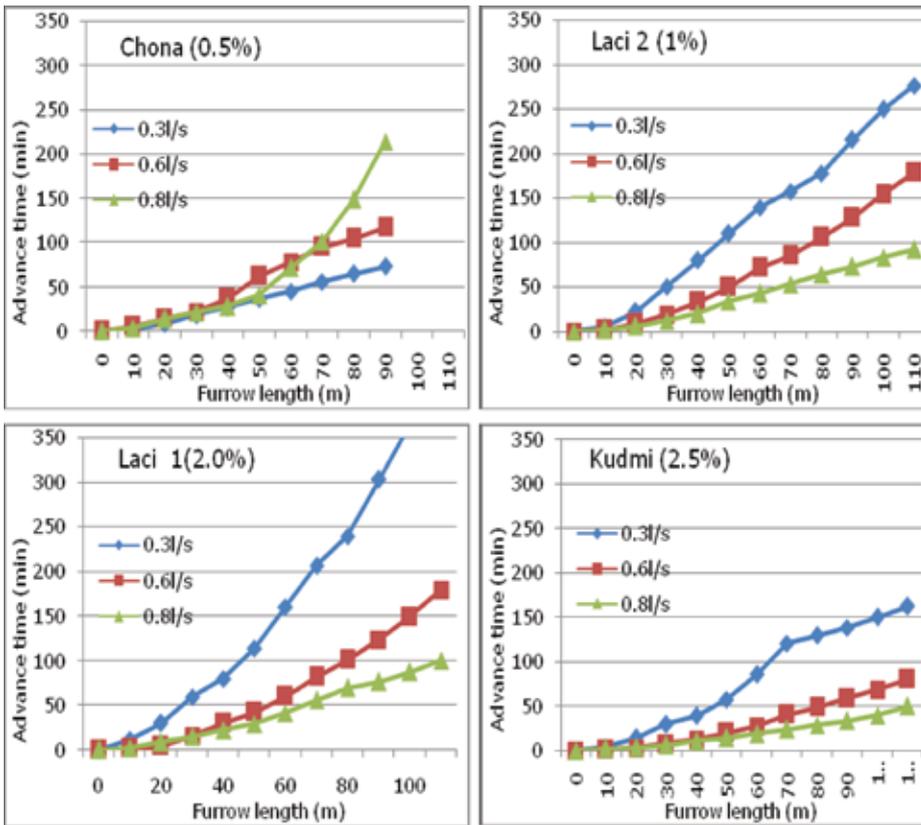
Figure 2. Illustration of advance time against furrow length, 2nd irrigation
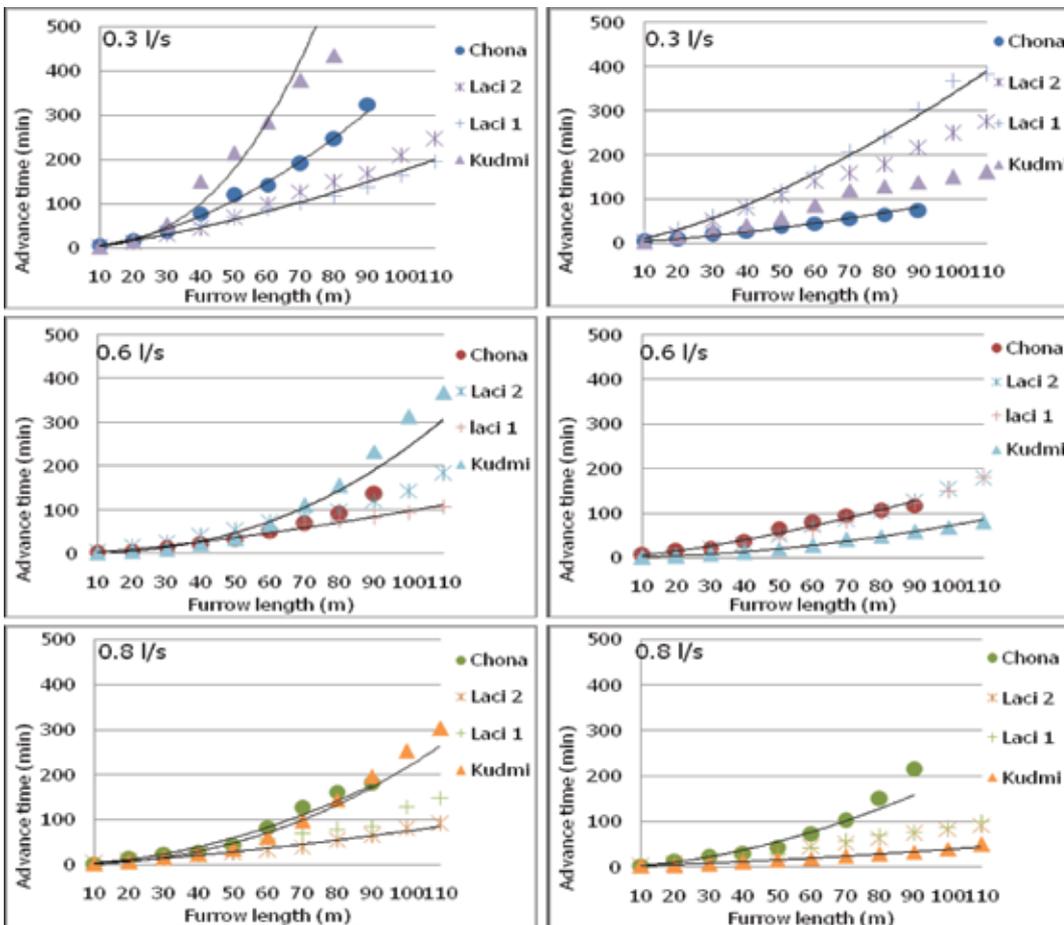

Figure 3. Illustration of advance time against length of irrigation at different slope conditions: 1st irrigation (left) and 2nd irrigation (right)

In the first irrigation, the average advance time to cover 110 m furrow length range from 195–435 min, 107–370 min and 90–300 min at 0.3, 0.6 and 0.8 litre/sec discharge rates, respectively (Table 1). However, in the second irrigation, the advance time was faster than the first irrigation most likely due to the relatively smoother surface and reduction of larger depressions. Results indicate that the advance time was approximately reduced by half compared to first irrigation. In the second irrigation cycle, the average time of advance to cover 110 m range from 70–380 min, 80–180 min and 50–213 min at discharge rates of 0.3, 0.6 and 0.8 litre/sec respectively (Table 1).

Table 1. Advance time (min) during first and second irrigations at 90–110 m furrow length

Site (gradient)	Qi (litre/sec)	First irrigation	Second irrigation
Chona (0.5%)	0.3	324.0	72.7
	0.6	136.4	116.8
	0.8	179.8	213.8
Laci 2 (1.0%)	0.3	244.8	276.0
	0.6	183.0	178.0
	0.8	90.5	92.0
Laci 1 (2.0%)	0.3	195.0	381.9
	0.6	107.0	179.8
	0.8	148.4	100.6
Kudmi (2.5%)	0.3	435.0	162.0
	0.6	369.0	80.4
	0.8	302.0	49.8

Even though the discharge at 0.3 litre/sec is non-erosive for all sites (slopes up to 2.3%), the application was very slow and become difficult to establish appropriate irrigation operation rule for the whole scheme. Discharge rates at 0.8 litre/sec and 0.6 litre/sec are erosive for slopes above 0.83 and 1.1%, respectively, but it is necessary to decide on the application rate and its advance time in relation to the operation rule. It is thus suggested to exclude very low discharge rates below 0.6 litre/sec as the application time is too long.

In the first irrigation, the advance time became very slow beyond 30–40 m furrow length (Figure 1). At 0.6 litre/sec discharge rate, the range of advance time to cover 30 and 40 m length was on average 17–28 min and 28–56 min per furrow, respectively. Similarly, at 0.8 litre/sec discharge rate, time needed to advance 30 and 40 m furrow length was on average 16–18 min and 25–30 min, respectively. Beyond 30 m the advance time for 0.6 litre/sec discharge became longer than 0.8 litre/sec. In the second irrigation (Figure 2), at 0.6 litre/sec discharge rate the advance time became short ranging from 14–18 min and 24–32 min for 30 and 40 m, respectively, whereas, at 0.8 litre/sec advance time ranges from 14–18 min and 20–28 min per furrow for 30 and 40 m length, respectively. Therefore the discharge rate that requires shorter application time is preferable as far as its erosive capacity is low. It is thus feasible to suggest 0.6–0.8 litre/sec application rate for slopes up to 2–2.5%.

The advance time of water at 0.5, 1.0, 2.0 and 2.5 % furrow gradients was 213, 173, 150 and 369 min at 1st irrigation and 134, 182, 221 and 97 min at 2nd irrigation respectively. Furrow gradients and surface irregularities result in such great variation of advance time. The effect of furrow gradient (Figure 3) shows that advance time increased when the slope decreases. Exceptional trends at first irrigation period was observed at Kudmi site this is most likely due to features of field irregularity and large size of surface roughness created at first tillage. In general, the inconsistency observed on the advance time is attributed to the non-uniformity or unlevelled fields.

Conclusion and recommendations

The existing operational furrow length at Koga is extremely long which lead to very low application efficiency. With the test furrow length of 90 to 110 m, it can be concluded that the irrigation application time per furrow was extremely long and difficult to establish appropriate irrigation operation rules among users for the whole scheme. The illustration of advance time by length graphs revealed that optimum furrow length at different sites can only be possible at short application time. In order to maximize application efficiency and minimize the losses, examining and determining an optimum furrow length before the operation of the whole scheme is essential by doing performance evaluation at different furrow lengths and application time. Moreover, the variable slopes and irregular surface shapes significantly affect the furrow length, optimum discharge, the application time and application efficiency. It implies that land levelling work needs due attention so as to improve the overall efficiency of the existing system.

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Runoff estimation and water management for the Holetta river in Ethiopia

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Abstract: The hydrology of Holetta River and its seasonal variability is not fully studied. In addition to this, due to scarcity of the available surface water and increase in water demand for irrigation, the major users of the river are facing a challenge to allocate the available water. Therefore, the aim of this research was to investigate the water availability of Holetta River and to study the water management in the catchment. Soil and Water Assessment Tool (SWAT) modelled the rainfall runoff process of the catchment. Statistical (coefficient of determination [R2], Nash-Sutcliffe Efficiency Coefficient [NSE] and Index of Volumetric Fit [IVF]) and graphical methods used to evaluate the performance of SWAT model. The result showed that R^2, NSE and IVF were 0.85, 0.84 and 102.8, respectively for monthly calibration and 0.73, 0.67 and 108.9, respectively, for monthly validation. These indicated that SWAT model performed well for simulation of the hydrology of the watershed. After modelling the rainfall runoff relation and studying the availability of water at the Holetta River, the water demand of the area assessed. CropWat model and the survey analysis performed to calculate the water demand in the area. The total water demand of all three major users was 0.313, 0.583, 1.004, 0.873 and 0.341 MCM from January to May, respectively. The available river flow from January to May obtained from the result of SWAT simulation. The average flow was 0.749, 0.419, 0.829, 0.623 and 0.471 MCM from January to May respectively. From the five months, the demand and the supply showed a gap during February, March and April with 0.59 MCM. Therefore, in order to solve this problem alternative source of water supply should be studied and integrated water management system should be implemented.

Media grab: Identification of available water and demand is essential to implement water management system. SWAT model can estimate the available river water; and CropWat model and survey can be used to calculated water demand.

Introduction

Ethiopia is endowed with a huge surface and ground water resources. Many perennial and annual rivers exist in the country. Ethiopia has 12 river basins and Awash basin is one of the 12 basins in Ethiopia. Holetta River is one of the rivers found in the upper part of Awash basin and facing challenges of runoff variability and scarcity of water availability during the dry season. Holetta River is main source of surface water in the study area; it is a perennial river having three major users and these are Holetta Agricultural Research Center (HARC), Tsedey Farm and Village Farmers. In addition to increasing water demand in the area, there is no facility to store the water in the rainy season for future use in the dry season. Therefore, the competition for water is increasing due to scarcity of water and increasing pressure by expanding populations and increasing irrigation. In order to alleviate this challenge, integrated water

resources management and effective water allocation system is essential. Therefore, the objective of this research was to study the hydrology of the Holetta River and to assess the water management in the catchment using GIS tool, statistical methods and hydrological model.

Methods

The study was conducted at Holetta catchment, which is located in the upper part of Awash River basin, Ethiopia. The study area lies at an altitude of 2069–3378 meters above sea level and located at a latitude range of 8°56'N to 9°13'N and longitude range of 38°24'E to 8°36' E. It is a catchment with drainage area of 403.47 km². The annual rainfall of the study area ranges between 818–1226 mm. The climate of the study area is described with the air temperature ranging from 6°C to 23°C with the mean of 14°C.

Figure 1. Location of Holetta catchment

All meteorological data (rainfall, temperature, relative humidity, wind speed and sunshine hour) collected from National Meteorology Agency and Holetta Research Center. Flow data and GIS data (topographic, land use/cover data and map, soil map) collected from Ministry of Water and Energy. Primary data of crop type and area coverage collected from major water users of Holetta River (Holetta Agricultural Research Center, Tsedey Farm and Farmers). The method of data collection was documents, field survey and questionnaire.

Based on the collected data (1994–2004), SWAT model, CropWat model and survey analysis are performed. The SWAT model used to estimate runoff for unguaged catchments, CropWat model used to estimate the irrigation water demand in the area and the survey analysis used to investigate the major crops grown in the area, area coverage and number of consumers.

Sensitivity analysis, model calibration and validation for SWAT model performed. The most sensitive parameters identified from sensitivity analysis and used for calibration of the model. For this study, the calibration carried out for six years (1994–1999) with one-year warm up period. Then, validation of SWAT model performed for the next five years (2000–2004). Statistical and graphical methods of comparing simulated with observed data used to evaluate the performance of SWAT model. The three statistical evaluation methods used were Coefficient of Determination (R²), the Nash-Sutcliffe Efficiency Coefficient (NSE) and Index of Volumetric Fit (IVF).

Results and discussions

Hydrological analysis

Watershed delineation and determination of HRUs were the first step in SWAT model. Holetta River catchment delineated by SWAT model has six subbasins. Then, the subbasins divided into 33 HRUs. Out of the six subbabsins of Holetta catchment, only subbasin one is gauged. The calibration and validation of SWAT model was performed at subbasin one. Then, runoff for the ungauged subbasins of the catchment is estimated by regionalization approach.

About 270 iterations done by SWAT sensitivity analysis and 26 parameters reported as sensitive in different degree of sensitivity for flow. Among these 26 parameters, eight of them have more effect on the simulated result. After sensitivity analysis carried out, the calibration of SWAT model was done manually. The analysis of simulated result and observed flow data comparison considered daily and monthly. The calibration performed until the best-fit curve between simulated and observed flow obtained. The validation performed by simply executing the model for the different period using the previously calibrated input parameters. Statistical and graphical methods used to evaluate the performance of SWAT model. Figures 2 and 3 showed the graphical performance evaluation of SWAT model.
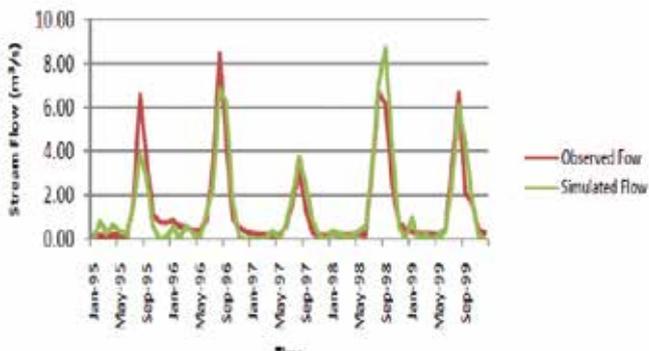
Figure 2. Observed and simulate hydrograph after monthly calibration
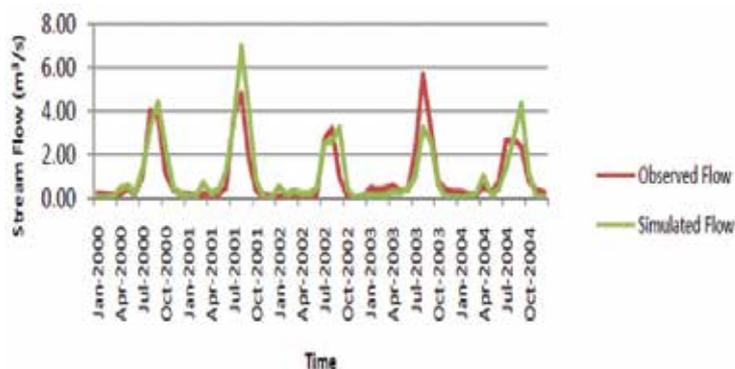
Figure 3. Observed and simulated hydrograph after monthly validation

Based on monthly calibration, the result showed that the regression coefficient (R^2) was 0.85; Nash-Sutcliffe Efficiency Coefficient was 0.84 and Index of Volumetric Fit was 102.8%. Based on the result of monthly validation, the regression coefficient was 0.73; Nash-Sutcliffe Efficiency Coefficient was 0.67 and Index of Volumetric fit was 108.9%. These indicated that the model performance was very good and highly acceptable during calibration and good in the acceptable limit during validation.

Questionnaire analysis

Survey was used to identify the number of Holetta River consumers, major crops grown by irrigation, the total area coverage and conflict between users. Major crops identified from the survey was potato with 96.67%, cabbage with 91.67% and tomato with 56.67% for farmers; potato, cabbage, barely and apple for HARC; and Potato, tomato and cabbage for Tsedey farm. Based on the analysis, 371 households use the river for irrigation purpose, 300 households use for human consumption.

CropWat model analyses

The major crops identified from the survey analysis used in the calculation of crop water requirement. In order to estimate the irrigation water demand for each crop, evapotranspiration, effective rainfall, crop type data, area coverage and soil data fitted in CropWat model. Then, CropWat model calculated the irrigation water requirement

(mm/month) for each crop. Based on the result, the total irrigation water demand of all three users was 0.305, 0.575, 0.995, 0.865 and 0.332 MCM for January, February, March, April and May, respectively.

Water demand analysis

The result of CropWat model and survey analysis was used as an input for the calculation of water demand. The period taken was only for the dry seasons, from January to May. Based on the analysis, the total irrigation water demand of all three users was 0.305, 0.575, 0.995, 0.865 and 0.332 MCM for January, February, March, April and May, respectively. The farmers also use the river for human consumption and livestock. Therefore, the water demand for human consumption and livestock is calculated for the farmers. The total human consumptive requirement was 0.00279, 0.0025, 0.00279, 0.0027 and 0.0279 MCM for January, February, March, April and May, respectively. According to the result, total livestock consumptive requirement was 0.0059, 0.0053, 0.0059, 0.0057 and 0.0059 MCM for January, February, March, April and May, respectively. The overall water demand of all three major users was 0.313, 0.583, 1.004, 0.873 and 0.341 MCM for January, February, March, April and May, respectively. The available river flow from January to May obtained from the result of SWAT simulation at subbasins 2, 3, 4 and 5. The average flow was 0.749, 0.419, 0.829, 0.623 and 0.471 MCM for January, February, March, April and May, respectively. From the five months, the demand and the supply showed a gap during February, March and April. This indicated that there is shortage of supply during these months with 0.59 MCM.

Conclusions

The study was conducted to estimate runoff at Holetta catchment and to model rainfall runoff in the area. The study also analysed the water demand in the area and the gap between the water supply and demand. The catchment has 6 subbasins and 33 hydrological response units (HRUs). Only subbasin one is gauged; therefore, sensitivity analysis, calibration and validation of the model performed at subbasin one and then the calibrated model was used to estimate runoff for the ungauged part of the catchment. Statistical and graphical methods were used to evaluate the performance of the model. The statistical methods used were R^2, NSE and IVF. The result showed, R^2, NSE and IVF were 0.85, 0.84 and 102.8, respectively for monthly calibration and 0.73, 0.67 and 108.9, respectively, for monthly validation. Therefore, this indicated that SWAT model performed well for simulation of the hydrology of the catchment.

CropWat model was used to calculate the irrigation water requirement for major crops and the area coverage determined from questionnaire. The overall water demand in the area was 0.313, 0.583, 1.004, 0.873 and 0.341 MCM for January, February, March, April and May, respectively. The available flow was 0.749, 0.419, 0.829, 0.623 and 0.471 MCM for January, February, March, April and May, respectively. Comparing the available flow and water demand in each month, it showed a gap during February, March and April. Therefore, there is shortage of supply during these months with 0.59 MCM.

Recommendations

Even though the SWAT model performs well in the study area, the accuracy was highly dependent on quality of data. The Holetta catchment has only one gauging station. In order to improve data quality, it is better to have at least two gauging stations in the catchment. In addition to this, in poorly gauged areas, use of satellite data is very advantageous. For future studies, SWAT model can apply to estimate sediment yield in the area and to evaluate the effect of different catchment changes on the river.

The water demand analysis showed that there was shortage of river water supply during February, March and April. The analysis also showed that there is conflict between users. In order to solve water shortage, alternative source of water supply should be studied and integrated water management system should be implemented. In order to minimize the conflict, well-established irrigation committees including all the users with a clear guide and management rules is required and establishing water allocation system is essential.

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Visualizing clogging up of soil pores in tropical degraded soils and their impact on green water productivity

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Abstract: Restrictive soil layers commonly known as hardpans restrict water and airflow in the soil profile and impede plant root growth below the plough depth. Preventing hardpans to form or ameliorate existing hardpans will allow plants root more deeply, increase water infiltration and reduce runoff, all resulting in greater amounts of water available for the crop (i.e. green water). However, there has been a lack of research on understanding the influence of transported disturbed soil particles (colloids) from the surface to the subsurface to form restrictive soil layers, which is a common occurrence in degraded soils. In this study, we investigated the effect of disturbed soil particles on clogging up of soil pores to form hardpans. Unsaturated sand column experiments were performed by applying 0.04 g/ml soil water solution in two sand textures. For each experiment, soil water solution infiltration process was visualized using a bright field microscope and soil particles remained in the sand column was quantified collecting and measuring leachate at the end of the experiment in the soil and water lab of Cornell University. Preliminary results show that accumulation of significant amount of soil particles occur in between sand particles and at air water interfaces, indicating the clogging of soil pores occurs as a result of disturbed fine soil particles transported from the soil surface to the subsurface.

Key words: Soil pore clogging; hardpans; green water productivity

Introduction

The Ethiopian highlands receive a high amount of rainfall ranging between 1200 to 2200 mm per year. However, 50% of this rainwater is lost as surface runoff FAO (2003) resulting in moisture stress in crop production causing a decrease in crop yields. The presence of restrictive soil layers commonly known as hardpans in the soil profile is one of the known causes of saturation excess runoff production. Hardpan soils are located 10 to 60 cm below the soil surface and restrict water and airflow in the soil profile. These layers impede root growth below the plough depth, thereby reducing plant's capacity to obtain water and nutrients when soil moisture and nutrient reserves in the lower profile are critically needed for crop production Busscher and Bauer (2003); Tekeste (2006), which thereby reduce crop yields. This issue is of a particular concern in the Ethiopian highlands where soils have become eroded and degraded due to increased land use arising from increasing population pressure, leading to clogging of soil pores resulting in formation of restrictive soil layers.
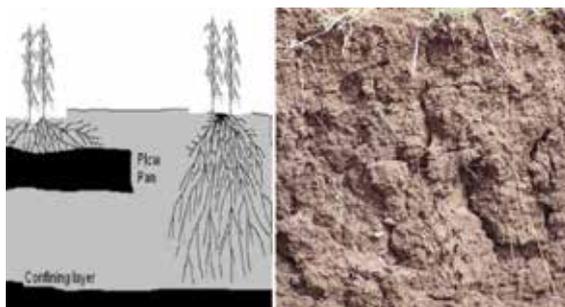
Figure 1 a). Plant root deformed by a hardpan (left) and plant root growth in a ripped hardpan (right) (FAO 2005), b) Compacted soils in the upper 60 cm above the macro pore networks in a soil profile in the Ethiopian highlands.

Preventing hardpans to form or ameliorate existing hardpans will allow plant root more deeply, increase water infiltration and reduce runoff, all resulting in greater amounts of water available for the crop (i.e. green water). However, there has been a lack of research on understanding the influence of transported disturbed soil particles (colloids) from the surface to the subsurface to form restrictive soil layers, which is a common occurrence in degraded soils. Thus, in this study we investigated the effect of disturbed soil particles on clogging up of soil pores to form hardpans.

Methods

To elucidate hardpan formation processes, unsaturated sand column infiltration measurements were performed in the soil and water laboratory of Cornell University. Acrylic columns made up of glass with dimensions of $2 \times 2 \times 20$ cm were used to facilitate visualization of the infiltration processes. The columns were packed with 30 g of two sand textures collected from (Unimin Corporation, Le Sueur, MN, USA). The finer sand texture was with a diameter of 0.00025–0.000425 mm and the relatively coarser sand texture was with a diameter of 0.000425–0.000625 mm. The experimental set up is shown in Figure 2 below. The sand columns were exposed to constant influent (soil-DI water solution considered as rainfall) rate of 0.5 ml/min for an hour and half controlling the inflow rate by a peristaltic pump. Air dried soil samples that were collected in the Debre Mewi watershed, located 30 km in the south of Lake Tana, Ethiopia, were used to prepare the soil solution. The characteristics of infiltration measurements are shown in Table 1.
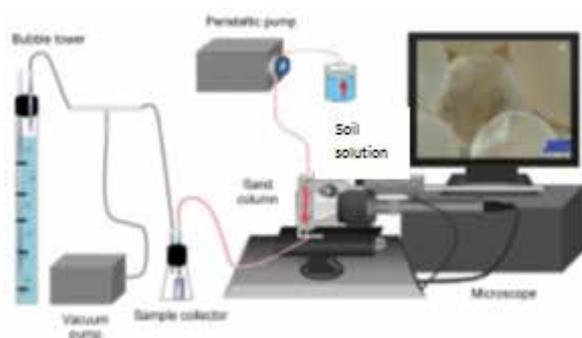

Figure 2 Illustration of infiltration measurement showing the microscope connected to the camera capturing the vertical movement of soil solution in the column. The peristaltic pump is used to regulate the flow rate into the column and the suction by bubble tower is used to regulate regular leachate collection in the sample collector. Image adapted from Sang (2012).

The leachates, draining from the sand column, were collected in cuvettes at five minute intervals at a five cm suction that was controlled by the bubble tower. Concurrently, transportation, circulation and deposition of clay particles (soil colloids) were visualized using a bright field microscope (KH-7700, Hirox-USA, River Edge, NJ, USA). The microscope used the MXG-5040RZ lens with a variable angle lighting adapter (AD-5040SS). Time series images were taken at three different depths and short videos were captured to see the lateral view of the soil-sand interface, the vertical movement of soil solution and clogging up of pores. After finishing the experiments 1 cm soil layers were taken from the columns and washed with 5 ml of water. Sediment concentration in the leachate and the wash water was measured by determining the absorbance of radiation at a wave length of 590 nm with a spectrophotometer.

Table 1. Characteristics of infiltration measurements in columns with relatively fine and coarse sand

	Fine sand texture sand column	Relatively coarse sand texture sand column
Sand size (mm)	0.00025–0.000425	0.000425–0.000625
Mass of clay soil added (g)	2	2
Volume of water added (ml)	50	50
Mass of sand in the column (g)	30	30
Inflow rate (ml/min)	0.5	0.5
Time to collect the first leachate (minutes)	17	21

Results and discussion

Time series microscope images showed that accumulation of significant amount of soil particles occur in between sand particles and at air water interfaces, indicating the clogging of soil pores as a result of disturbed fine soil particles transported from the soil surface to the subsurface. Time series images for infiltration measurements on columns packed with sand texture of 0.000425–0.000625 mm diameter are shown in Figure 3. The first three consecutive pictures were taken at the start of soil solution (0.04 g/ml) application, 30 minutes of soil solution application and 1 hour application, respectively. The fourth picture at the right end was taken 2 hours after the second soil solution infiltration on the previous sand column. Note that in the third pictures soil colloids are retained in the sand particles while in the fourth picture accumulation of soil particles occurred in the air water interfaces. Repeated rainfall applications have shown an increased accumulation of clay particles with time.


Figure 3. Microscope image of infiltration measurement showing the sand column at the start of the measurement, 30 minutes of soil solution application, 1 hr application and 2 hours after the second soil solution infiltration on the previous sand column, respectively.

Spectrophotometer measurements of the drainage water of the columns (Figure 4) indicated that higher light absorbance was observed in the beginning of infiltration measurements than at the end of the infiltration, indicating higher amount of clay particles were drained and lower amount of clay particles were retained at the beginning. A decreased trend in the light absorbance graph in Figure 4 suggests a decrease in leachate sediment concentration with time and less light absorbance indicating the occurrence of clogging up of pores in between sand particles. In the finer texture sand column, ponding was observed in repeated infiltration measurements of a column and less clay was being eluted and deposited in the sand.
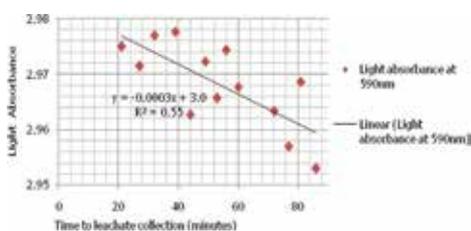

Figure 4. Light absorbance plotted against leachates collection time. The first leachate was collected at the 21st minutes from the beginning of the infiltration measurement.

Our experiments show that forming of the hardpan in the Ethiopian soils can be related to the infiltration of sediment rich water after the soils are tilled and the soil cover is removed by ploughing. In addition, these experiments show that clay attachment can occur by reclogging but also at the air soil interface or the point where the meniscus attaches to the grain. These particles can be attached firmly against the clay particles by the capillary forces associated with the meniscus. The visualization studies confirm hypothesis of Goldberg (1990), Frenkel et al. (1992) and Lieffering and McLay (1996) that clay soils contribute to blocking of soil pores by deflocculation and movement of clay particles into the conducting pores as discussed above. When such processes repeat year after year, this pore clogging by clay particles inhibits water flow in the soil profile resulting in rainwater loss as surface runoff. Further infiltration measurements are in progress considering variables, such as the role of clay mineralogy, moisture condition, sand diameter size and infiltration rate on clogging up of soil pores.

Conclusions and recommendations

Clogging up of soil pores as a result of disturbed fine soil particles transported from the soil surface to the subsurface can significantly reduce water flow in the soil profile resulting in rainwater loss as surface runoff. Improving the productivity of rain fed agriculture system in Ethiopia requires either ameliorating of these pores clogging or preventing them to form. Ameliorating measures include biological and mechanical practices such as planting deep rooted and bio fuel crops and deep tillage practices while preventing measures includes a decrease in intensity of tillage that results in destabilization of soil aggregates and disruption of pore spaces within or between soil aggregates.

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Arresting gully formation in the Ethiopian highlands

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Abstract: Over the past five decades, gullying has been widespread and has become more severe in the Ethiopian highlands. Only in very few cases, rehabilitation of gullies has been successful in Ethiopia due to the high costs. The objective of this paper is to introduce cost effective measures to arrest gully formation. The research was conducted in the Debre-Mewi watershed located at 30 km south of Bahir Dar, Ethiopia. Gullying started in the 1980s following the clearance of indigenous vegetation and intensive agricultural cultivation, leading to an increase of surface and subsurface runoff from the hillside to the valley bottoms. Gully erosion rates were 10–20 times the measured upland soil losses. Water levels, measured with piezometers, showed that in the actively eroding sections, the water table was in general above the gully bottom and below it in the stabilized sections. In order to develop effective gully stabilizing measures, we tested and then applied the BSTEM and CONCEPT models for their applicability for Ethiopian conditions where active gully formation has been occurring. We found that the model predicted the location of slips and slumps well with the observed groundwater depth and vegetation characteristics. The validated models indicated that any gully rehabilitation project should first stabilize the head cuts. This can be achieved by regrading these head cuts to slope of 40 degrees and armoring it with rock. Head cuts will otherwise move uphill in time and destroy any improvements. To stabilize side walls in areas with seeps, grass will be effective in shallow gullies, while deeper gullies require reshaping of the gullies walls, then planting the gully with grasses, eucalyptus or fruit trees that can be used for income generation. Only then there is an incentive for local farmers to maintain the structures.

Introduction

The northern parts of Ethiopian highlands suffer from severe land degradation by widespread gully and channel erosion and network development. Studies have shown that over the past five decades, gullying in this region has been widespread and has become more severe (Nyssen et al. 2006; Tebebu 2009; Tebebu et al. 2010). The deepest and the most spectacular gullies occur in the bottom of the watershed where in semi humid monsoonal and wetter climates the soil becomes saturated starting around the middle of the rainy phase and then remain saturated till the rain stops. The most severe gully areas have black soils. These soils shrink in dry seasons resulting cracks and causing very little strength when saturated.

Gully formation is a natural phenomenon that carries excess water from the watershed to the outlet. It occurs after the watershed is altered for example by cutting down the forest and replacing it by agricultural land. This results in additional interflow and runoff that the existing drainage network cannot handle. A new equilibrium is established to carry of this water. It has been argued that gullies are the most efficient way of carrying of the excess water (Kleidon et al. 2013).

Gullies start with a disturbance at a sharp drop in elevation of the soil. This drop (also called headcut when it occurs within a channel) can occur suddenly due to road construction or gradually in location of springs where soil is soft and erodes such as was the case in the Debra Mewi watershed. In some cases, gully formation starts at an old gully when due to change in drainage pattern, the soil becomes saturated. The sharp drops in the channel are called head cuts.

Once there is a drop in elevation, the head cut proceeds backwards resulting in incised gullies with vertical walls (Figure 1). Especially under saturated conditions, these walls are unstable and resulting in bank failure and dumps lose unconsolidated soil at the bottom of the gully. This soil is then picked up by the flowing water. Gullies carry much more sediment than existing and stable rivers, mainly because the sediment concentration in existing rivers is limited by the amount of sediment that can be picked up from the consolidated banks and bottom by the flowing water (Simon et al. 2007). In gullies with actively failing banks the flowing water carries sediment at its maximum (or transport capacity) because the unconsolidated soil can be picked up easily. This is observed in the landscape because gullies are being filled up when the slope decreases or the channel becomes wider.

Figure 1. Unstable steep bank of a gully in the Debre Mewi watershed.

Since gully formation is a natural process of erosion (or similarly expressed local farmers that consider the rapid formation of gullies 'an act of god'), it is difficult to halt the formation before the head cuts reach the uplands where the soil does not saturate. Many unsuccessful attempts in the course of the years are the witness. However it is not impossible to stop gully erosion as is shown in the more developed countries but it is usually at great expense. The cost of the methods used in the US or Europe cannot be afforded by local farmers in Ethiopia. However, the same principles used in gully stabilization in the developing world can also be applied to gullies in Ethiopia and instead of using western and costly structures, it should be possible to use local materials and obtain the same results of stabilizing a gully at a much lower cost.

In this paper, we will start the process of devising 'appropriate' solutions stabilizing the gully formation under Ethiopian conditions. To develop these solutions, we will use a combination of the Bank Stability and Toe Erosion Model (BSTEM) and the CONservational Channel Evolution and Pollutant Transport System (CONCEPTS) computer models, developed by the US Department of Agriculture, Agricultural Research Service (ARS). These models consist of fundamental equations that describe bank stability.

BSTEM is a spreadsheet tool used to simulate stream bank erosion mechanistically of a single bank profile (Simon et al. 2011). It has been used to evaluate bank stability conditions and to design stream bank stabilization measures. CONCEPTS is a process-based, dynamic computer model that simulates open-channel hydraulics, sediment transport, channel morphology and the impact of in-channel protection measures on channel morphology (Langendoen and Alonso 2008; Langendoen and Simon 2008). CONCEPTS have been used throughout the mid-continental US to site grade control and to evaluate the impact of bank protection works at the reach and watershed scale. These two models are, therefore, effective tools that can be used by governmental and non-governmental agencies, academia and watershed managers to evaluate the control measures that are increasingly installed in the Lake Tana watershed.

These control measures consist either of structures such as gabions and check dams, or biological bank stabilization plantings. In this paper, we demonstrate the capabilities of BSTEM and CONCEPT for use in the Debre Mewi watershed where active gully formation is occurring as documented by Tebebu et al. (2010), Tebebu (2009) and Tilahun (2012). The paper is partly based on Langendoen et al. (2013) that was presented at the workshop in Bahir Dar in May 2013 and can be downloaded at http://soilandwater.bee.cornell.edu/research/international/eth_pubs.htm.

Methods

Study area

The Debre-Mewi watershed is located at 30 km south of Lake Tana, Bahir Dar, Ethiopia. Gullying started in the 1980s following the clearance of indigenous vegetation and intensive agricultural cultivation, leading to an increase of surface and subsurface runoff from the hillside to the valley bottoms. Several gullies were studied in this watershed by Tebebu et al. (2010) and Tilahun (2012). In this study, we will concentrate the gully complex (locally known as the 'Tigist Gully') that consists of two branches that join at the mid-slope position of the hillslope forming one larger, wider and deeper gully (Figure 2). The contributing area to the gully is 17.4 ha, elevation ranges from 2184 to 2300 m above sea level and average rainfall, falling mainly from June to September, is 1240 mm. Land use consists of rain fed agriculture in a mixed farming system with scattered indigenous tree species. The soils in the landscape are dominated by Vertisols.
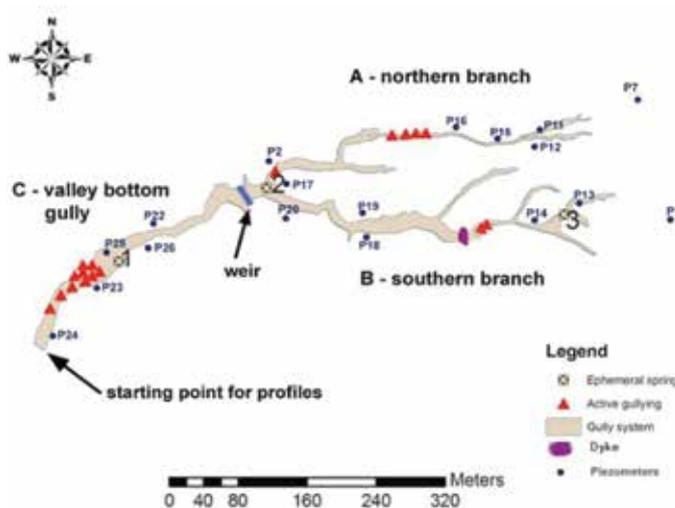

Figure 2. Gully complex in the Debre-Mewi watershed, Ethiopia. Triangles indicate active gully erosion.

The depths and the corresponding widths of the valley bottom gully were estimated before the rainy season (2007) and after (2008) as a function of the distance from the valley bottom (Figure 3, a cross section gives the expansion of the gully). The gully was eroding in all locations where the water table was above the bottom of the gully indicated by triangles in Figure 2. The downstream end of the gully (called Valley Bottom Gully, VBG) had a very effective head cut. During the 2008 rainy season, the gully was actively increasing and it widened up to 20 m in top width where the water table was near the surface (approximately 4 m above the gully bottom). The annual soil loss from the gully complex in 2008 amounted to about 7000 ton/year or 440 ton/ha/year which was 10–20 times the measured upland soil losses. Water levels were measured with piezometers and showed that in the actively eroding sections of the water table was in general above the gully bottom and below it in stabilized sections.

Simulating gully stability

In this section we will first analyse the measures that would have been required to stabilize the gully walls in 2007 and 2008 for the bottom section (VGB) of the Tigist Gully assuming that the bottom of the gully is each year is at a fixed depth. Since there is an active head cut nearby effectively deepening the gully, these improvements would therefore only be temporary. Thus, stabilizing head cuts is a necessary improvement in gully stabilization. In the last section, 'appropriate' measures to stabilize head cuts are devised using CONCEPTS.
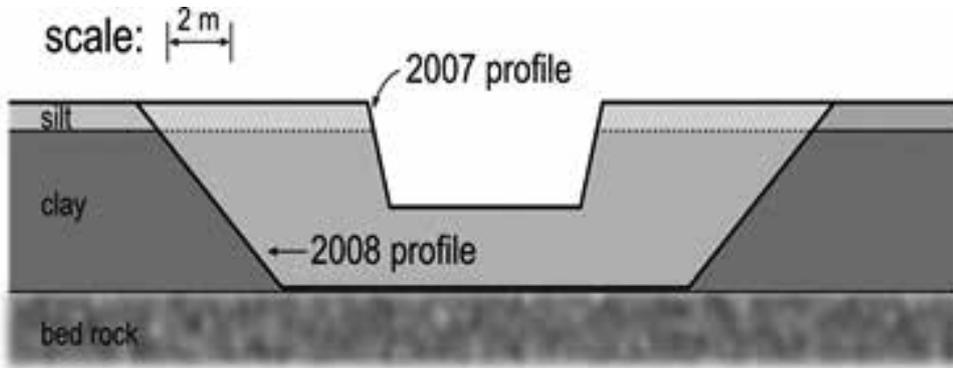
Figure 3. Schematic drawing of the 2007 and 2008 gully geometry and vertical soil profile used in the BSTEM and CONCEPT analysis of bank stability.

Results and discussion

Gully bank stabilization

The 2007 valley gully bottom had average top width of 7.3 m, an average bottom width of 5.9 m and an average depth of 2.6 m (Figure 3), resulting a bank slope of 75 degrees that was used to represent this bank. The profile consists of a 0.7 m thick silt layer overlying a 4 m thick red clay layer, which overlies more resistant bed rock (Figure 3). The stability of the bank was simulated with BSTEM when there were no tension crack and with CONCEPTS with tension cracks for typical values of parameters for a Vertisol, with varying groundwater table depths (0, 0.5, 1, 2 and 2.6 m below the floodplain elevation and with the enhanced stability by reducing bank slope or adding vegetation to the bank top Langendoen et al. (2013) in Figure 4.
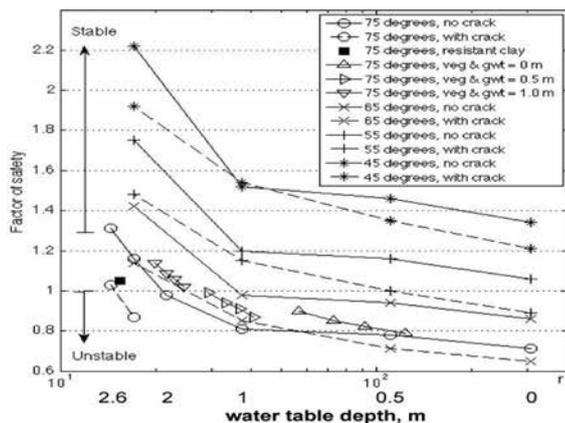

Figure 4. Effects of groundwater table, tension cracks, soil matrix shear strength and bank slope on the stability of the 2007 Valley Bottom Gully bank. The cohesion, $c' = 3 kPa$, friction angle, $f' = 28°$ and saturated unit weight $g = 18 kN/m^3$ for the two soils was selected as: silt and for the red clay, $c' = 5 kPa$, $f' = 25°$ and $g = 18 kN/m^3$.

On the Y axis a safety factor, F_s, is plotted. A value of $F_s \leq 1.0$ indicates an imminent failure; Values $F_s > 1.0$ are viewed as stable. However, the uncertainty and variability of soil properties and failure geometries results are such that we consider values between 1.0 and 1.3 conditionally stable.

The bottom axis is a dimensional variable defined as: $r = \dfrac{\gamma H}{\bar{c}_a \tan \phi'}$

Where $\bar{\gamma}$ is average unit weight of the soil composing the failure block (18 kN/m³), H is the gully depth, $\bar{c}_a$ is average apparent cohesion along the slip surface and $\overline{\tan \phi'}$ is average of the tangent of the friction angle along the slip surface. Depth to groundwater is indicates as well.

Figure 4 shows that the factor of safety of the 2007 VBG of 75 degrees without tension cracks is always smaller than 1.3 (conditionally stable) and only exceeds unity for groundwater tables near the gully bottom (r = 14.4 and r = 17.0). However, Vertisols have crack. In that case, only when the groundwater table at the bottom of the gully it provides a factor of safety greater than one (Fs = 1.03). In order to make the bank stable the bank slope should be reduced and calculations with bank angles of 65, 55 and 45 degrees were evaluated. Figure 4 indicates that the bank angle needed to be reduced to 45 degrees in order for the factor of safety to exceed one under fully saturated conditions (groundwater table at the top of the bank, r ≈ 300). Planting vegetation around the gully will increase the cohesion values in the top 1.7 m of the profile. However as can be observed in Figure 4, it had only a minor effect on the stability of the gully. Figure 5 confirms the model results for the Warke gully on the road from Bahir Dar to Addis where the trees that now grow in the gully were initially planted on the sites of the gully.
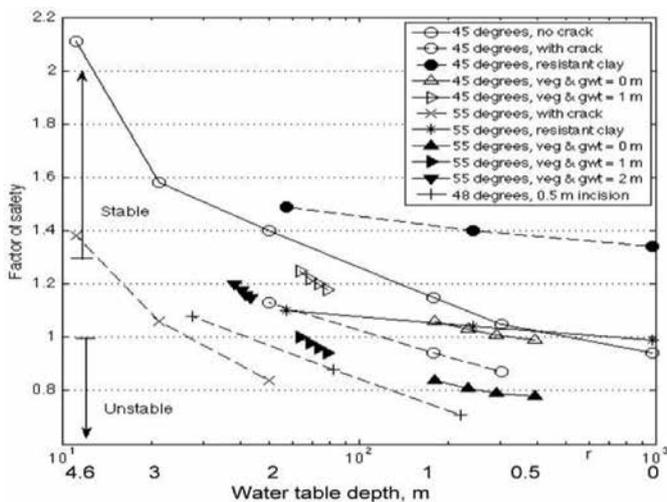

Figure 5. Trees originally planted on the gully banks slipped with the soil in the gully bottom in the Warke watershed.

For the 2008 Valley Bottom Gully (VBG), the average top width of 22.1 m, an average bottom width of 12.1 m and an average depth of 4.6 m, a bank slope of 45 degrees was used to represent this geometry (Figure 3). A similar analysis was carried out as for 2007 VGB (Figure 6). Figure 5 shows that the 2008 VBG gully banks exhibit limited stability for the 45 degrees case. This is confirmed by our observations during the dry season when the water table is below the gully bottom and the gully walls are stable. If the groundwater table exceeds an elevation 2 m below the bank top as is the case during the wet season (r ≈ 50), pore water pressure will reduce soil shear strength such that Fs< 1. In case that the bottom decreases by 0.5 m and the bank height the gully sidewall would become unstable for all groundwater table depths smaller than 3 m (r> 30). Increasing bank slope by 10 degrees from 45 to 55 degrees will similarly destabilize the gully bank for all groundwater tables exceeding 1.5 m above the gully bottom (depths smaller than 3 m). In this case as well, plantings will only minimally aid in stabilizing the gully walls. Preventing ongoing mass wasting of the 2008 VBG requires a combination of: 1) gully bottom grade control, e.g. check dams 2) toe protection; and 3) drainage to control pore-water pressures in the upper portion of the soil profile, which could also be accomplished by vegetation.

Figure 6. Effects of groundwater table, tension cracks, soil matrix shear strength and bank slope on the stability of the 2008 Valley Bottom Gully bank.

Stabilizing head cuts

In the USA, headcuts are stabilized by using concrete structures at the gully head and then dissipating the energy in the drop. These structures are too expensive for Ethiopia and therefore we will test gully stabilizing structures in which we decrease the slope of the head cut and then place locally available stones on the regarded gully.

In CONCEPTS a gully is simulated with a headcut of 1 m that is regraded to a slope of 40 degrees with a channel bottom width of 2 m and a channel depth of 2 m below head cut; channel side slope = 60 degrees and a channel slope = 0.01 In Figure 7, the initial profile is given. We will assume again typical values for the Vertisol (listed in the caption of Figure 4) and a steady state flow of 2 m³/sec which is approximately expected for a thunderstorm in the 17 ha watershed. Other parameters assumed in CONCEPTS are a valley width = 200 m, valley side slope = 0.05, Manning downstream of gully = 0.05, Manning upstream of gully = 0.04, critical shear stress = 4 Pa, soil detachment coefficient = 2E-7 m s-1 Pa-1.
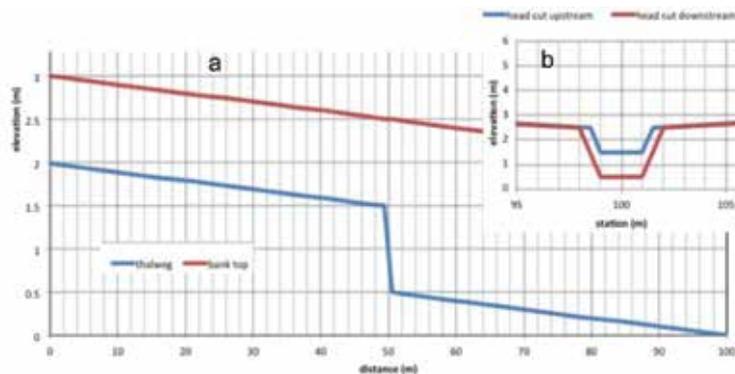

Figure 7. The initial gully configuration before any water was applied. a) Longitudinal section; the 1 m high head cut was regraded to 40 degrees. Top line is the soil surface and the line below is the shape of the gully bottom; b) Cross section of the channel above and below the head cut.

Two scenarios for the regraded gully are tested with CONCEPTS: (1) bare soil and (2) rock cover stable under a 2 m³/sec flow where the rock cover was extended about 8 m upstream to protect against the accelerating flow upstream.

For the bare soil, the head cut slope was reduced from about 0.83 to 0.12 (Figure 8a) where the shape of the bottom profile is shown in 2 to 4 day intervals with the 2.0 m³/sec flow. The surface erosion extended over a length of about 12 m. The erosion of the regraded head cut produced mass failures only at the brink of the regraded head cut at 49 m and the next cross section upstream and at 47 m (Figure 8b). The failure at station 49 m occurred 18 days into the simulation, whereas the failure at station 47 m occurred 25 days into the simulation.
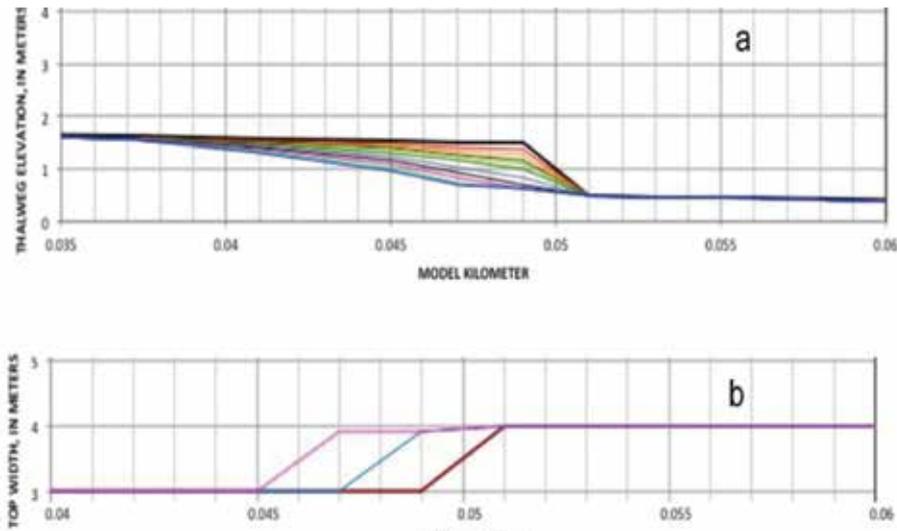
Figure 8. Evolution of gully bottom (a) gully width (b) for unprotected gully bottom where a head cut of 1 m was regraded to a slope of 40 degrees. Profiles in (a) are given for each 2 days initially and 4 days at the end. The discharge was 2 m³/sec.

With a protective rock cover, no erosion occurred, though of the regraded headcut. Thus the gully bottom remains the same as shown in Figure 7a. Only some toe erosion occurred. This could be prevented by putting some stones also on the toe.

Conclusions and recommendations

Gully erosion is contributing significant sediment load to the downstream river network. In order to prevent siltation of the newly constructed reservoirs in Ethiopia, stopping gully erosion is important. In this paper, we used BSTEM and CONCEPTS computer models to devise cost effective gully stabilizing methods. One of the important findings was that head cuts in gullies should be stabilized first, otherwise any upstream improvements will be swallowed by the head cuts moving up the gully. A promising and appropriate technique for stopping headcuts according to the CONCEPT model is regrading the headcut to slope of 40 degrees or less and armoring the graded section and the upstream and downstream for some distance with rock. Research should be performed on the best way to accomplish the regrading and armoring of the head cut.

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Effect of drip lateral spacing and irrigation regime on yield, irrigation water use efficiency and net return of tomato and onion production in the Kobo Girrana valley of Ethiopia

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Abstract: The irrigation system in Kobo-Girrana valley is extensively developed into modern drip irrigation using ground water sources. Tomato and onion are among the major vegetables grown under drip irrigation. However, the drip lateral spacing is fixed to 1m for all irrigated crops. This lead to low crop water productivity, loss of land, less net return income and un-optimized irrigation production. An on-station experiment was conducted to determine the effect of drip line spacing and irrigation regime on yield, irrigation water use efficiency and net return income. The experiment was carried out for two consecutive irrigation seasons in 2010/11 and 2011/12 at Kobo irrigation research station. The experimental treatments were: two lateral spacing of single row and double row corresponding to each test crop and three irrigation regime (Kp = 0.8, 1.0 and 1.2). The results revealed that an interaction effect between the lateral spacing and irrigation regime was obtained in marketable yield and water productivity of test crops. Application of 0.8 Kp with 2m lateral spacing and 1.2 Kp with 1m lateral spacing provided relatively higher marketable yield of tomato and onion, respectively. Similarly, high water productivity was recorded with same irrigation depths and spacing regimes as to the yield. This result generally revealed that one lateral design for each two plant rows gave high net income than the one lateral design for each one plant row for drip irrigated fresh marketable yield of onion and tomato. An optimized production and irrigation efficiency can be attained by applying irrigation depth adjusted by the given pan coefficients and drip lateral spacing in Kobo areas.

Key words: Drip spacing, marketable yield, water productivity, Pan Coefficient, Kobo

Introduction

Onion and Tomato are among the major vegetable crops grown in Kobo Girana valley. Recently, use of drip irrigation for these crops has increased through government assisted ground water resources. Currently significant area is under drip irrigation development. However, the drip lateral spacing is fixed to 1m for all irrigated crops. This lead to low crop water productivity, loss of land, less net return income and un-optimized irrigation production. Lateral spacing is always a compromise b/n optimal water distribution and lateral cost. So, it is imperative to investigate

whether spacing adjustment and using one lateral pipe between two plant rows is effective and economical in terms of initial investment cost and irrigation management efficiency. As a result, this study was conducted to determine the effect of drip line spacing and irrigation regime on yield, net return and irrigation water use efficiency.

Methodology

The experiment was carried out in Kobo irrigation sites for two consecutive years of 2011 and 2012 for onion and tomato. Kobo research station is situated at 12.08° N latitude and 39.28°E longitudes at an altitude of 1470 masl. The 15 years mean annual rainfall is about 630 mm and average daily reference evapotranspiration rate of 5.94 mm. The soil type in the experimental site is silty clay loam which has average infiltration rate of 8 mm/hr, pH value of 7.8, average FC and PWP of 11.5% and 3.2% on volume basis, respectively.

The drip system was gravitational type which stand 1.5 m head difference from the ground and consisted of PE laterals of 16 mm in diameter and PE manifold pipeline of 32 mm diameter. The discharge rates of the emitters were calculated as 0.9l/h and emitter spacing was chosen as 0.50 m. The experimental design was factorial RCBD with 4 replications. Six treatments were composed from two factors: lateral spacing (single and double) and three irrigation regimes (0.8, 1 and 1.2). For tomato and onion 1 m and 2 m lateral spacing and 0.5 and 1 m lateral spacing were used, respectively. The amounts of irrigation water applied (Im^3) in the irrigation treatments were determined by Class A pan evaporation using the equation given below:

$I = A*Ep* Kp*P$
where A – is the plot area (m^2)
Ep – is the cumulative pan evaporation amount for the 4-days irrigation interval
Kp – is the coefficient of pan evaporation (i.e. Kp =0.8, 1.0 and 1.2) and
P – is the percentage of wetted area (Pw) or percentage

For tomato and onion 30 and 10cm plant spacing was used respectively.
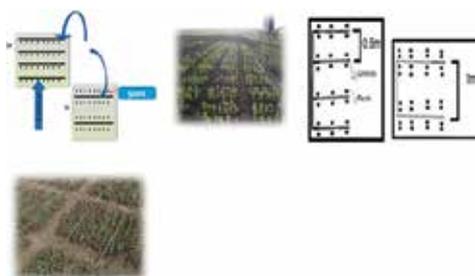

Figure 1. Schematic layout of laterals and plants in the experimental plots for tomato and onion

The percentages of wetted area were determined by methods from **Keller and Bliesner (1990)** and Yildirim (2003). The Pw was the average horizontal area wetted in the top 15–30 cm of the crop root zone as a percentage of the each lateral line area. Thus, the percentages of wetted area measured in the experimental site were 90or 45% for lateral spacing of single or double, respectively. The first irrigation for all plots was based on water deficit that would be needed to bring the 0–60 cm layer of soil to field capacity. Subsequent irrigations were applied considering the 4-day irrigation interval. Irrigation water use efficiency is generally defined as crop yield per water used to produce the yield (Viets 1962; Howell 1996). Thus, IWUE was calculated as fresh fruit weight (kg) obtained per unit volume of irrigation water applied (m3). The net income for each treatment was computed by subtracting all the production costs from gross incomes. All calculations were done based on a unit area of 1 ha (Koral and Altun 2000; Inan 2001).

Result and discussion

Effects of treatments on marketable yield of onion and tomato

As observed in Table 1, lateral spacing and different irrigation regimes had a separate significant effect on marketable yield of onion. However, there were no interaction effects between different lateral spacing and irrigation regimes (pan coefficients) on marketable yield of onion. The highest and the lowest marketable bulb yield of 23.54 and 18.21 ton/ha were obtained due to the effects of 1m lateral spacing with 120% of pan amount and 0.5 m with 100% of pan amount, respectively.

Lateral spacing highly affected marketable fruit yield but different irrigation amounts didn't show a significant effect on marketable fruit yield of tomato. A maximum of 21.53 ton/ha marketable fruit yield was obtained due to the effect of double lateral spacing. There was no an interaction effect of plant spacing and irrigation amounts on marketable yield of tomato. The amount of marketable yields was slightly decreased as the amount of irrigation water applied increased. The maximum (23.41 ton/ha) and minimum (15.88 tone/ha) marketable yield of tomato was obtained due to effects of double row spacing with 80% pan coefficient and single row spacing with 120% pan coefficient.

Table 1. Main effects of lateral spacing and irrigation amount on marketable yield and water productivity of onion and tomato

Lateral spacing	Marketable yield (ton/ha)		Water productivity (kg/m^3)		Irrigation regime	Marketable yield (ton/ha)		Water productivity (kg/m^3)	
	Onion	Tomato	Onion	Tomato		Onion	Tomato	Onion	Tomato
Single	19.01	17.21	3.48	1.997	80%	20.01	20.48	6.93	3.87
double	22.45	21.53	8.13	4.935	100%	20.14	20.03	5.5	3.81
					120%	22.04	17.60	4.99	2.72
LSD	1.24**	2.06**	0.38**	0.244**		1.515*	ns	0.46**	0.299**
CV(%)	10.2	18.1	11	12		10.2	18.1	11	12
GM	20.73	19.37	5.80	3.466		20.73	19.37	5.80	3.466

*-significant difference **-high significant difference.

Table 2. Interaction effects of lateral spacing and irrigation amount on marketable yield and water productivity of onion and tomato

Lateral spacing and Irrigation Regime	Seasonal irrigation amount (mm)		Marketable yield (tone/ha)		Water productivity (kg/m^3)	
	Onion	Tomato	Onion	Tomato	Onion	Tomato
Single row, 80% pan coefficient	461.5	449.79	18.26	17.55	4.02	1.601
Single row, 100% pan coefficient	576.9	562.24	18.21	18.21	3.36	2.293
Single row, 120% pan coefficient	692.3	674.69	20.55	15.88	3.06	2.098
Double row, 80% pan coefficient	230.8	224.9	21.76	23.41	6.91	6.130
Double row, 100% pan coefficient	288.5	281.12	22.06	21.85	9.85	5.330
Double row, 120% pan coefficient	346.1	337.35	23.54	19.33	7.63	3.343
LSD			ns	ns	0.65**	0.4230**
CV (%)			10.2	18.1	11	12
GM			20.73	19.37	5.80	3.466

*-significant difference **-high significant difference.

Irrigation water use efficiency

As indicated in Tables 2 and 3 above, lateral spacing and different irrigation regimes separately affect water productivity and had an interaction effects on water productivity of onion. Maximum 9.85 and minimum 3.06kg/m^3 water productivity existed due to the effects of double row with 100% pan coefficient and single row with 120% pan coefficient, respectively. The value of water productivity decreased as the amount of irrigation amount increased.

For tomato crops, the irrigation water use efficiencies ranges from 1.6–6.13kg/m³ depending up on treatments. The maximum irrigation water use efficiency of 6.13kg/m³ was obtained from double lateral spacing (2m) with 80% pan coefficient. Similarly, Mbarek and Boujelben (2004) showed that IWUE was greatest with double rows in the tomatoes grown in the greenhouse. Generally the highest water use efficiencies occurred in double lateral spacing with small pan coefficients. Furthermore, IWUEs differ considerable among the treatments and generally tends to increase with a decline in irrigation (Howell 2006). IWUE is an important factor when considering irrigation systems and water management and probably will become more important as access to water becomes more limited (Shdeed 2001). On the other hand, water productivity can be increased by increasing yield per unit land area. In addition, water management strategies and practices should be considered in order to produce more crops with less water.

Economical analysis and evaluation

Economical analysis and evaluation were computed by using the results of this study based on investment, operation and production costs. Based on the irrigation amount of each treatment in the growing season irrigation duration, labour cost for irrigation and pump cost were estimated. The production costs were computed by considering all production inputs (i.e. costs of seeds, ploughing of land, transplanting, hoeing, weeding, pesticide, fertilizer, harvesting etc.) for onion and tomato. The production costs were similar for each treatment and calculated as Ethiopian birr (ETB) 10,000.00/ha for onion and ETB 7000/ha for tomato in the production season. On the other hand, drip irrigation system costs can vary greatly, depending on crop (plant and therefore, emitter spacing and hose) (Solomon 1998).

Thus, based on lateral length, connections, tapes and drippers for the treatment in which the lateral spacing was 1 m and the investment costs were 26% less than in the treatment in which the lateral spacing was 0.5 m for onion. And for tomato, 2 m lateral spacing had 20.64% less investment cost than 1 m lateral spacing. The investment cost of drip system was calculated with 7 years life period (Enciso et al. 2005). According to the calculation for onion 1m lateral spacing with 120% irrigation amount gave the maximum yearly net income of ETB 81,415.93. On the other hand, less net income of ETB 58,957.35 was obtained in 0.5 m lateral spacing with 80% irrigation amount. And for tomato, the lowest ETB 28,761.00 and highest ETB 49,175.00 yearly net income were obtained due treatments of single row spacing (1 m) with 120% irrigation amount and double row spacing (2 m) with 80% irrigation amount, respectively. This result generally revealed that one lateral design for each two plant rows gave high net income than the one lateral design for each one plant row for drip irrigated fresh marketable yield of onion and tomato.

Conclusion

In the experimental study of onion, 692 mm irrigation water amount in 0.5 m lateral spacing with 120% pan coefficient gave a marketable yield of 20.55 ton/ha. However the highest fresh marketable yield of onion (23.54 ton/ha) was obtained by the effect of 1 m lateral spacing with 120% pan coefficient which requires a total seasonal irrigation requirement of 346mm.

A maximum water use efficient of 9.85 kg/m³ was recorded by 1 m lateral spacing with 100% pan coefficient followed by 7.1 kg/m³ water use efficiency of 1 m lateral spacing with 120% pan coefficient.

Investment costs in the design of one lateral for two crop rows were 27% less because the length of laterals, dripper numbers and connections were fewer than the design of one lateral for each crop row. Also the yield obtained was high compared to the treatment with one lateral for each row. Consequently, economic analysis based on investment and production costs, yields obtained, amounts of irrigation water applied per ha, was done to compare these two treatments. As a result, 1 m lateral spacing with 120% irrigation amount was given the highest as ETB 81,415.93 yearly net income return.

For tomato drip lateral spacing determination study the maximum marketable yield of 23.41 t/ha was obtained by treatment effects of 2 m lateral spacing with 80% pan coefficient to which total seasonal irrigation water amount of 225 mm.

Similarly 2 m lateral spacing with 80% pan coefficient gave the maximum water use efficiency of 6.13 kg/m³. Fresh marketable yield slightly decreases as the irrigation regime increases. To get optimum tomato production using one lateral pipe for two plant rows and 80% pan coefficient of irrigation regime is recommendable.

Drip irrigation cost of double row lateral spacing was 20.64% less than a single lateral spacing for each crop rows. A maximum marketable yield obtained in treatment of 2 m lateral spacing by 80% pan coefficient contribute for a high economical yearly net return income of ETB 49,175.

An optimized production and irrigation efficiency can be attained by applying irrigation depth adjusted by the given pan coefficients and drip lateral spacing in Kobo areas.

Generally in Kobo Girana area double lateral spacing is more economical than a single lateral spacing design for onion and tomato vegetables.

Acknowledgements

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Hydrological modelling of a catchment using the SWAT model in the upper Blue Nile basin of Ethiopia

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Abstract: Sustaining upland agriculture and food security is very much constrained by continuing land degradation brought by soil erosion due to lack of effective rainwater management strategies. Recently a large body of research evidence has established that significant potential exists to increase agricultural productivity through sustainable rainwater management interventions. Hydrological models are essential to understand the hydrological response of a catchment. The current paper focuses on hydrological modelling of catchment with SWAT model using its two versions, SWAT-CN and SWAT-WB. It is also aimed to verify the impact of existing land and water management practices on runoff yield and the applicability of the model for water resource assessment in the watershed. The model was applied on two watersheds, Mizewa (27 km^2) and Gumara (1278 km^2) that are located in the upper Blue Nile basin of Ethiopia in Fogera district. Data needed for modelling work was collected from available nearby stations and from the recently installed hydrological-meteorological stations. Model performances were compared prior to parameter optimization . After these initial findings, the SWAT-CN model was calibrated and validated and hence reasonable results were obtained. The results indicate that the model performance was in acceptable range and there are no many changes to predict the flow by the two versions of SWAT model. The concept of rainwater management is at an infant stage, though water scarcity and catchment degradation are serious threats in Mizewa watershed. HRU analysis indicates that agricultural land is the most runoff generating areas. Soil evaporation compensation factor (ESCO) and initial SCS curve number II value (CN2) are the two most sensitive parameters indicating that effective rainwater management interventions has a great impact in reducing soil erosion and land degradation. Some future management interventions were proposed such as discussing with local farmers and stakeholders.

Key words: SWAT-CN; SWAT-WB; HRU; Mizewa catchment; Gumara catchment; Blue Nile Basin; Ethiopia

Media grab: Community based and effective rainwater management strategies result in reduced soil erosion and increased agricultural productivity. Hydrological models are essential to achieve this goal.

Introduction

The highlands of Ethiopia are characterized by relatively high rainfall. However, this could not be retained in the form of surface and ground water. Instead, the intense precipitation is lost in the form of runoff resulting in soil erosion and degraded environment. Recently, the Ethiopian Strategic Investment Framework for Sustainable Land Management (ESIF-SLM 2010) reported that lack of land and rainwater management strategies resulted in improper land use and severs consequent livelihood though the highlands of Ethiopia. A large body of research evidence has established that significant potential exists to increase agricultural productivity that are producing far below potential through sustainable rainwater management strategies (Bossio et al. 2007; Molden et al. 2007). Sustainable rainwater management (RWM) is achieved if only there is a focus on the entire watershed and community-based approaches are adopted. Understanding the hydrological processes within the watershed is crucial to make decisions on better RWM. The current study focused on hydrological modelling of catchments using SWAT model to estimate key hydrological fluxes and to analyse the impact of existing land use on runoff and erosion yield. It also focuses on reviewing existing RWM practices, water use and proposing future RWM interventions.

Methods

The source of water in Mizewa watershed was identified through field observation and found to be ground water and river flow. The ground water was used for drinking water supply through hand-dug-wells. In the lowland areas, farmers use the river for irrigation of Khat plot along its bank which has been a common practice recently. The practice endangered the existence of the already scare water in the area. The river was also used for drinking water, fishing and livestock. The farmers in the middle land area of the watershed, beside the rain-fed crop, also used Mizewa River and Ginde Newr in small amounts for their production of onion, potato, tomato, Khat and vegetable. Irrigating the fields was accomplished through gravity by diverting water and also pumping from Mizewa and Gindenewr Rivers. Figure 1 below shows multi-use of Mizewa River.
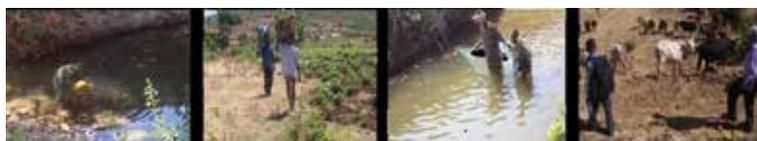
Figure.1 Multi-use of Mizewa River (i.e. for drinking, irrigation, fishing and livestock, respectively)

A detail review of existing RWM practices (watershed characterization) including mapping of locations were performed in Mizewa watershed through surveying and field observation. Discussions were also performed with stakeholders and local farmers on the efficiency of existing RWM practices. The farming practice in the midland and highland watershed is on sloppy and stony ground. The local farmers protected their farmland using stone bunds and contour ploughing which probably reduces upland erosion. The bund also acts as farm boundary to protect the entrance of livestock. It seems that in the entire watershed, the concept of rainwater harvesting is at an infant stage, though water scarcity and catchment degradation are serious threats. The efficiency of the pond was also poor in which water may not be properly stored. Lack of proper maintenance to the pond resulted in leakage and accumulation of debris at the bottom.

Figure 2. Existing RWM practices and location of stone bunds greater than 100 m length

The potential RWM interventions were identified by consulting local farmers and other stakeholders who might think what is needed and feasible in the future. Various sources were also consulted; this includes Agricultural Bureau of the *Woreda* and reports of different workshops organized by NBDC program. As a result, level fanya juu, grass strip

along contour, check dam, hand-dug-wells with treadle pump, diesel pump with rivers, roof water harvesting together with ponds, diversification of crops, fallowing, well designed stone bund, planting scattered tree on farm land, hill side terrace (with or without trench), forestation and planting high yielding crops like citreous fruit were also proposed. Some practices were suitable for all landscapes and some others were specific. The watershed was divided into 3 landscapes and 10 farmers were asked to select RWM intervention from the potential for their land and discussed under result section.

SWAT is physically based on conceptual and computationally efficient model that operates on a daily time step at basin scale (Arnold et al. 1998, 2000; Neitsch et al. 2001). It was designed to predict the impact of watershed management practices on hydrology with varying soils, land use and management conditions (Neitsch, et al. 2005). SWAT-CN assumes the runoff occurs whenever the rainfall intensity is greater than the rate of infiltration. In SWAT-WB Method, once the soil in the area saturate to the surface, any additional rainfall that falls irrespective of intensity becomes overland flow. Digital Elevation Model (DEM) was obtained from United States Geographic Survey (USGS) with 90 × 90 resolutions. It is one of essential spatial input for SWAT model which defines well the topography of the area. Soil map prepared by Food and Agricultural Organization (FAO) was used for the watershed while land use map were surveyed using high resolution hand-held Geographic Positioning System (GPS) for Mizewa watershed. As a result, 11 land uses and single soil group was identified for Mizewa watershed while 6 land use and 4 soil groups were identified for Gumara watershed. Figure 3 below presents the result of land use and soil map. The land use map, soil map and slope were overlaid to create Hydrologic Response Units (HRUs).
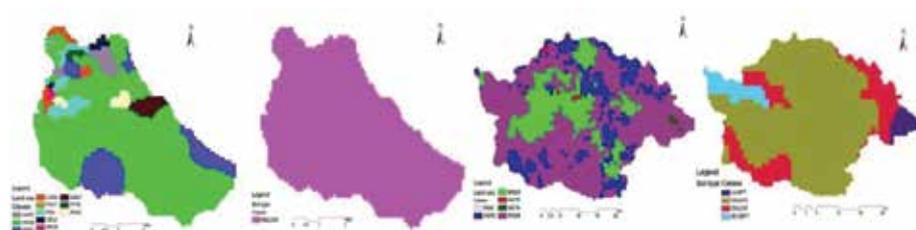

Figure 3. Land use and soil map of Mizewa and Gumara watershed respectively

Hydro-meteorological data were obtained from nearby and recently installed stations (1-year) in Mizewa watershed. Rating curve were developed for Mizewa river at upstream and outlet of the catchment.
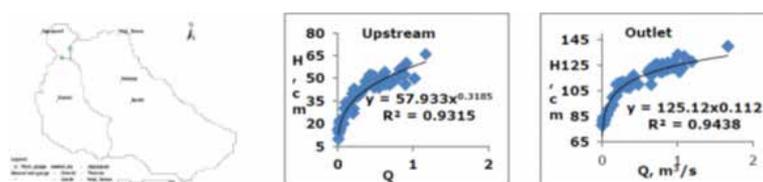

Figure 4. Locations of recently installed stations and rating curve for Mizewa watershed

The model were developed using spatial data (DEM, land use, soil) and hydro-meteorological data. Model comparison was done prior to parameter optimization and the result presented in Table 1 below.

Table 1. Model efficiency before calibration

	SAWT_CN		SWAT_WB	
Objective Function	Gumara	Mizewa	Gumara	Mizewa
Nash-Sutcliffe efficiency (Ens)	0.295	0.25	0.294	0.19
Coefficient of Determination (R2)	0.427	0.42	0.409	0.40

After these initial findings, parameter sensitivity analysis, model calibration and validation were done for Gumara and Mizewa watershed using SWAT_CN method. For the case of Mizewa watershed, the model was calibrated at the upstream gauging station and validated at the outlet of the catchment while for the case of Gumara watershed, 1995 to 2004 data was used for calibration, 2005 to 2009 data was used for validation and 192 to 1994 was data used to warm-up the model. And hence reasonable results were obtained.
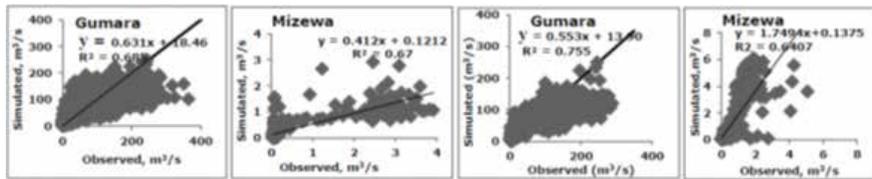
Figure 5. Simulated vs. observed flow for calibration and validation period respectively
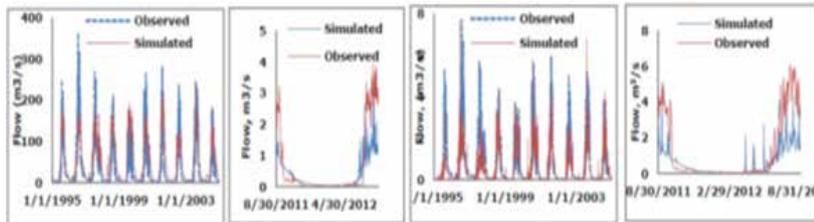

Figure 6. Flow simulation for calibration and validation periods of Gumara and Mizewa, respectively

Table 2. Model efficiency for calibration and validation periods of Gumara and Mizewa, respectively

Objective function	Gumara	Mizewa	Gumara	Mizewa
Nash-Sutcliffe efficiency (Ens)	0.67	0.50	0.66	0.62
Coefficient of Determination (R2)	0.68	0.54	0.76	0.66

Result

The farmers select RWM what they think might work in the future for their land based on the landscape. In lowland, 50% of the farmers selected diesel pump with river and 20% of them selected well-designed stone bunds due to irrigation of Khat plots in the area and stones were available intensively. In middle land, 60% of the farmers select roof water harvesting together with ponds while 20% select diesel pump with river due to Awramba community that have metallic roof houses. Furthermore, farmers have Khat plots to some extent. At the highland of the watershed, 50% of the framers select hill side terrace and 30% of them selected forestation since the land was much degraded at this landscape and they think hill side terrace and forestation as feasible interventions to regenerate the land.

Predicted flow was found to be most sensitive for soil, land use properties indicating RWM interventions has a significant impact on reducing soil erosion and degradation. The most sensitive parameters include: soil compensation factor (ESCO), initial SCS curve number II (CN2) and ground water parameters: like threshold depth of water in shallow aquifer for 'revap' or percolation to deep aquifer to occur (REVAPmin) and groundwater 'revap' coefficient (GW_REVAP). The comparison of observed and calibrated flow indicated that there was a good agreement between observed and calibrated flow yielding higher model efficiency. The result of the two models was compared for Gumara and Mizewa watershed with short-term and long-term records there are no many changes to predict the flow.

The surface runoff prediction for each HRU was analysed for Gumara watershed. Areas with Halpic Luvisols contributed the least surface runoff to the reach. Halpic Luvisols has the highest sand content, the lowest clay content and high hydraulic conductivity of all soil in Gumara watershed. Areas with Chromic Luvisols contributed large amount of surface runoff. Chromic Luvisols has low hydraulic conductivity and high clay content of all soil within the watershed. Halpic Luvisols was the only soil group in the case of Mizewa watershed. Areas covered with agricultural land produced large amount of surface runoff of all land uses in Mizewa and Gumara watershed while areas covered with Meadow Brome grass (BROM) and rang-brush (RNGB) contributed small amount of runoff within the watersheds.

Conclusions and recommendations

In this research, emphasis has been given to hydrological modelling of a catchment using SWAT model. The model performance criteria indicated that the model was good and has acceptable performance. Hence, the model can be applied to the watersheds. The result of sensitivity analysis indicated that ESCO and CN2 were the most sensitive parameters. Thus, further detail study on soil and land use could possibly improve model performance and accuracy. HRU analysis result indicated that agricultural lands were the most runoff generating areas. Hence, training farmers through innovation platform in order to adopt selected RWM interventions will result in better agricultural productivity. Further study is recommended on erosion hotspot areas, since it is not possible to implement RWM interventions for the entire watersheds.

Acknowledgements

Water investment domains for sustainable agricultural development in the Blue Nile basin

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Abstract: In the Blue Nile basin, crop cultivation is predominantly rainfed and water availability is highly variable across both space and time. As a result, it often constitutes a limiting factor for reaching full agricultural potential in the region. While one third of the basin is estimated to have no soil moisture limitations, the remaining two thirds are crop water constrained in various ways. Analysis shows that across approximately 40% of the basin available soil moisture is utilized sub-optimally with smart management and crop water limitations can be alleviated. In contrast, across a further 25% of the basin, water deficits strongly limit plant growth. While rainfed agriculture is still possible in some of these areas, appropriate management is even more important. A great deal of variation also exists in terms of market access for agricultural inputs and produce. Travel time to markets in the basin can be up to 12 hours. One's distance to market centres influences the accessibility of farm inputs such as fertilizers, improved seeds and veterinary services. Inaccessibility vs. accessibility to population dense areas also determines the potential for agricultural production and the marketing of crops and livestock products, in particular for perishable produce. To capture the complexity and heterogeneity regarding both crop water limitations and agricultural market access, this study combines information on rainwater management potential and market proximity to map so-called water investment domains (WID). Context-specific recommendations for each of the domains are provided. In the short term, the results point to a need for agricultural produce strategies that are spatially differentiated and in the longer term for investment in infrastructure in order to enable full utilization of the agricultural potential across the entire basin. The results are intended to guide policymakers and other rural development actors in the identification of appropriate investment decisions and for improved planning of rural development strategies. Thus, the study aligns to the 'water-centred agricultural growth' strategy adopted by the Ethiopian Government, developed in response to the poverty and food security challenges faced in the country. The approach is widely applicable, easily replicable and can be used to inform decision-makers beyond the Blue Nile basin.

Media grab: Crop water limitations and proximity to markets vary widely across the Blue Nile basin. The combination of these two factors can be used to target investments and rainwater management interventions.

Introduction

The Blue Nile basin is one of the major agricultural areas of Ethiopia. Compared with 25% of the national population, it has over 40% of cultivated land and 39% of the cattle stock. The landscape is dominated by rainfed mixed crop–livestock farming systems.

These span across arid into humid and subhumid zones, but are mostly found in the temperate areas of the basin. Most of the dry lowlands are managed by pastoralists or agropastoralists. Overall, livestock is a vital component of the local food systems.

The major part of the crop cultivation in the basin is purely rainfed and large areas are water limited. As proposed in the Ethiopian Government's 'water-centred agricultural growth' strategy, water should be seen as the entry point to raising agricultural productivity. Investments in rainwater management (RWM) practices are thus both an answer to actual water constraints which limit the success of many farmers and to aligning interventions with current policy priorities. With wide-spread land degradation and erosion across the basin, any rainwater management (RWM) intervention to improve agricultural development must also focus on sustainable land management (Merrey and Gebreselassie 2011).

Another factor impacting strongly on the agricultural development potential of a region is market access. Proximity often enhances market participation, with increased livelihood diversification options. It also increases the accessibility of farm inputs necessary for intensifying production. Remoteness, on the other hand, commonly increases transaction costs and is therefore an incentive for bulk sale of crops or livestock and hence specialist crop or pastoral production. The agricultural options in turn depend on the agricultural potential of the area.

The Blue Nile basin demonstrates a high degree of heterogeneity in terms of both bio-physical and socio-economic aspects and the way these factors interact influences both the applicability and impact of interventions. The objective of this study was to map water investment domains (WID). These capture the complexity and heterogeneity regarding both crop water limitations and agricultural market access across the Blue Nile basin. Context-specific recommendations for each of the domains are provided.

Methods

Rainwater management potential

A new approach is derived for mapping the potential for rainwater management (RWM) which takes into account rainfall seasonality and climatic moisture requirements, i.e. potential evapotranspiration. This is an improvement compared to earlier assessments which typically rely only on annual rainfall data (e.g. Chamberlain et al. 2006).

In principle, precipitation (P) and potential evapotranspiration (PET) data of suitable temporal resolution (daily or weekly) are sufficient to characterize the moisture regime of a given location. However, water limitation for plant growth depends on a range of additional site-specific characteristics such as soil properties and slope as well as on the phenological stage of the plants. To improve the robustness of the methodology, normalized difference vegetation index (NDVI) was used as a measure of actual plant growth. NDVI is used to compare sites with comparable moisture regimes in terms of their 'greenness'. Sites that appear less green than expected for their moisture regime use the available water sub-optimally and can therefore be upgraded by appropriate RWM interventions.

The analysis is based on normalized difference vegetation index (NDVI), potential evapotranspiration (PET) and precipitation (P) for the period 2000–2011. Determination of a representative growing period was done using a fixed length of 100 days, with the period of the highest average NDVI assumed to be representative. For each identified growing period, the overall P/PET ratio was determined and assigned as the average water availability to demand ratio for that period.

Three classes of soil moisture availability determining crop growth in rainfed agriculture were defined in order to distinguish the need for RWM interventions (Table 1 and Figure 1).

Table 1. Selection criteria for the six identified water investment domains.

| Soil moisture and crop growth	RWM need	Market access	Water Investment Domain (WID)
No Moisture Limitations, full crop growth	No need	Close	NML-CMA
		Remote	NML-RMA
Sufficient Moisture Availability, optimal crop growth possible	RWM to reach optimal crop growth	Close	SMA-CMA
		Remote	SMA-RMA
Limited Moisture Availability, optimal crop growth not possible	RWM to optimize use of limited moisture	Close	LMA-CMA
		Remote	LMA-RMA
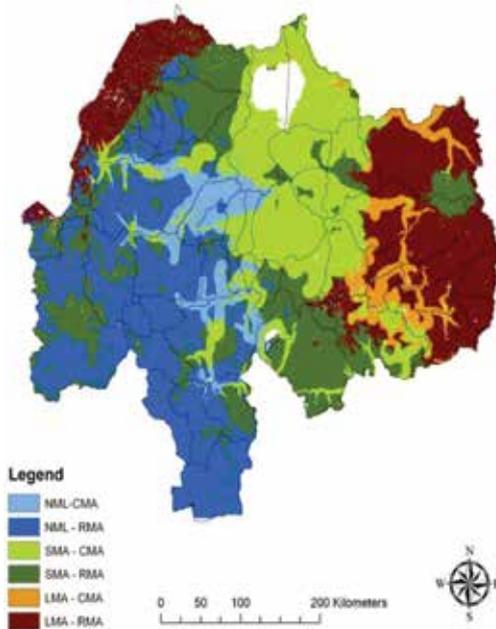
Figure 1. The Water investment domains (WDI) in the Blue Nile basin, derived from three classes of soil moisture availability and two classes of market accessibility.

Class 1. No moisture limited crop growth, no need for RWM

Two types of areas are included in this class: a) all areas with P/PET>1.4, here optimal achievable NDVI values indicate that plant growth is not moisture limited; b) some of the areas with P/PET 0.7–1.4, i.e. less soil moisture, but still showing optimal NDVI. In Class 1, there is no need for RWM

Class 2. Sufficient moisture, optimal crop growth possible, with RWM interventions

This class only includes the areas with a P/PET range of 0.7–1.4 showing sub-optimal NDVI values. Here, in contrast to areas in the same P/PET range in Class 1, available soil moisture is not utilized in the best possible way. Thus, with smart RWM practices available moisture can be sufficient for optimal plant growth.

Class 3. Limited moisture, optimal crop growth not possible, RWM to optimize sub-optimal water availability

This class comprises areas with a P/PET ratio less than 0.7. Here soil water deficits clearly limit plant growth. Rainfed agriculture is still possible, but optimal yields are not achievable. However, the results show a considerable NDVI range, indicating that by meticulously applying RWM practices crop growth can be considerably improved, i.e. to reach optimal growth within existent local soil moisture constraints.

Water investment domains

Agricultural development options are strongly influenced by market proximity. A combination of the newly created dataset on rainwater management potentials with spatially-explicit data on travel time to markets, i.e. closeness and remoteness, yields geographically defined zones where these interactions play out. These zones are named Water Investment Domains (WID) and are defined as geographical units in which similar water-related agricultural development problems or opportunities are likely to occur.

Through combination of three soil moisture categories and two accessibility classes, the differences in agricultural potential from a water resources availability perspective and access to rapidly growing urban markets is spatially shown in the six WIDs (**Table. 1**). The domains are described according to a number of bio-physical and socio-economic traits, with summary statistics given per domain. Total area covered, the human and livestock population, the share of the area under different land cover classes and erosion potential were tabulated for all WIDs (Table 2).

Table 2. Characteristics of the six water investments domains, WIDs, in the Blue Nile basin.

Water Investment Domain (WID)	Population		Livestock		Area (km²)				Agricultural system	
	People	Share total	TLU[a]	Share total	Total area	Share total	Cropland mosaic	Share WID	Only livestock	Mix livestock & crops
NML-CMA	1 045 000	6%	428 554	6%	11 505	6%	7 288	65%	12%	85%
NML-RMA	2 745 750	15%	1 078 666	15%	51 255	26%	20 152	39%	31%	68%
SMA-CMA	6 464 690	34%	2 081 371	29%	41 109	21%	27 054	66%	4%	95%
SMA-RMA	3 394 520	18%	1 522 003	21%	42 375	22%	19 570	46%	21%	79%
LMA-CMA	1 551 040	7%	478 499	7%	9 204	5%	5 081	55%	1%	98%
LMA-RMA	3 924 140	21%	1 575 552	22%	58 984	30%	12 520	52%	24%	76%
	18 206 110	100%	7 140 215	100%	124 885	100%	91 383	47%	19%	79%
[a] TLU = Tropical livestock units										

Results and discussion

The spatial distribution of the six domains is shown in Figure 1. About one-third of the basin is estimated to have no soil moisture limitations. These domains, NML-CMA and NML-RMA, are found in the southwestern part of the basin. The further we move to the west, the greater the distance to markets. The remaining two-thirds of the basin is crop water constrained in different ways. In areas with sufficient moisture availability, SMA, constitute about 40% of the basin's area and are mainly found in the central parts of the basin. Half of this domain class is relatively easily accessible; the other half, however, is more remote. In the remaining 25% of the basin, water deficits strongly limit plant growth. These areas with limited moisture availability, LMA, are found in the eastern and northwestern parts of the basin. Most of them have the added challenge of remoteness to the markets. As expected, the domains with close market access, CMA, are found in the more urban central parts of the basin and along the major roads, while the RMA domains dominate in the western, southern and eastern parts of the basin.

The six water investment domains differ in many aspects, as shown in Table 2. One of the most important characteristics in relation to soil moisture availability for crop growth is the agricultural intensity in each domain. In landscapes dominated by fragmented mixed land uses, such as the smallholder dominated Blue Nile basin, it is very difficult to use remote sensing to spatially differentiate crop and pasture lands. However, the category 'cropland mosaic' in Table 2, extracted from Globcover 2009, gives a clear indication of the spatial distribution of cropland. According to this dataset, almost half of the basin is cultivated, i.e. about 50% of the 'share WID' is cropland mosaic. Furthermore, the domains SMA–CMA and NML–CMA are the two most agriculturally intensive areas, with approximately two thirds of each of the area cultivated. Comparing accessible with remote areas, higher shares of cropland mosaic are found in the more accessible WIDs. This confirms the influence of market accessibility on agricultural intensification in the landscapes. Highest numbers and highest densities of people and livestock are found in the SMA–CMA domain. In general, a higher population density (human and animal) can be found in the accessible areas as compared to the remote areas.

The 'mixed livestock and crop' agricultural system clearly dominates the area, with an average of 79% for the entire basin. In contrast, 'only livestock' systems are practised in about one fifth of the basin only. When comparing agricultural systems for RMA and CMA across all six domains, it is clear that the highest shares of 'mixed livestock and crop' systems are found close to markets (85–98%). In contrast, 'only livestock' systems are found in higher shares in the remote areas (21–31%). In total more than 90% of the areas with only livestock systems are under the remote RMA domains.

Conclusions and recommendations

With three quarters of its area having enough soil moisture to reach full crop growth potential, the Blue Nile basin clearly has great agricultural potential. About one-third of this high potential area is already exhibiting optimal plant growth. This provides very good opportunities for high-value perishable crop and livestock products, such as horticulture and possibly dairy production. In the other one third of the high potential area, there is a need for more well-targeted RWM interventions. Most of the area with good potential under appropriate RWM is cultivated under a mixed crop–livestock system. This means that there is a high potential for using the livestock component to increase

the resilience of the overall system and optimization of both crop and livestock. Highlighting potential synergies will thus be important. In a considerable portion of the areas with no or limited soil moisture limitations, there is a need to invest in infrastructure. NML–RMA is, for example, five times the size of NML–CMA. Currently about one third of the remote NML–RMA domain is exploited in a livestock-only system. Despite the lack of investments in roads and market infrastructure, good potential for non-perishable crops exists. It would thereby be very important to look at the larger-scale impacts on the livestock production.

Only 25% of the Blue Nile basin's area is experiencing severe soil moisture limitations. In these areas it is very important to put appropriate RWM in place and by doing so to increase the resilience of the systems. Technologies such as drought-resistance crops, feed purchasing systems, water harvesting, including storage structures and soil water management and diversification in order to deal with variable circumstances should be supported by the extension services.

Acknowledgements

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