PROCEEDINGS

Flood-based Farming for Food Security and Adaption to Climate Change in Ethiopia: Potential and Challenges

Proceedings of the Workshop held in Adama, Ethiopia, October 30-31, 2013

Convened by

International Water Management Institute (IWMI) in collaboration with Adama Science and Technology University

Teklu Erkossa, Fitsum Hagos and Nicole Lefore, editors

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Teklu Erkossa, Fitsum Hagos and Nicole Lefore

International Water Management Institute (IWMI)
P. O. Box 2075, Colombo, Sri Lanka

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Acknowledgments

The workshop was jointly organized by the East Africa and Nile Basin Office of the International Water Management Institute (IWMI) and Adama Science and Technology University, Ethiopia. We wish to express our gratitude to H.E. Ato Adugna Jabessa, Deputy General Manager, Oromia Irrigation Development Authority, for officially opening the workshop. We thank the Improved Management of Agricultural Water in Eastern and Southern Africa (IMAWESA) network for sponsoring the workshop. We are grateful to Daba Dendena and Mrs. Bruktawit Hailu of IWMI for their logistical support, and also to the Ethiopian and Oromia radio and television organizations for covering and broadcasting the event.

Introduction

Development planners are now beginning to view spate irrigation as a potential method to adapt to climate change, address groundwater recharge and provide water for agriculture in otherwise rain-fed-dependent areas. However, spate irrigation has been a neglected area of research. These gaps in knowledge about spate irrigation prevent the further development of spate systems to support increased food security, reduce poverty and improve livelihoods. The lack of adequate information on spate systems also hinders effective interventions in spate infrastructure and has resulted in ‘modern’ infrastructure that is ill-suited and unsustainable.

It is clear that much more needs to be known about complex spate systems to effectively manage the floods. We need to determine how much knowledge has been captured already, where the gaps in knowledge remain, and what areas of spate research should be prioritized to meet development goals in Ethiopia and the subregion. In addition, decision makers, project implementers and end users need to strengthen their capacity, and collaboration with research institutions is needed to ensure that interventions in spate systems are appropriate, and that they are sustainable and support equitable benefits.

As such, the International Water Management Institute in East Africa and Nile Basin, with support from the IWMI-hosted and IFAD-funded network for Improved Management of Agricultural Water in East and southern Africa, convened a learning workshop in Adama, Ethiopia, on 30-31 October 2013. The workshop was attended by 37 participants representing international, national and academic research institutions, as well as donor-supported projects and government departments involved in spate irrigation. The objectives of the learning event were as follows:

1. Enable knowledge-sharing based on evidence from spate irrigation research.
2. Share factual case studies on interventions by project implementers.
3. Support evidence-based planning and cooperation for spate use and management.
4. Build capacity of regional and national stakeholders to improve spate system development and management.
5. Provide a forum to identify synergies in current and planned research.
6. Support the alignment of spate system knowledge needs of decision makers with planned research.

This documentation of the workshop proceedings was supported by IMAWESA, through a grant to IWMI from IFAD, towards ensuring that spate irrigation research responds to needs of spate project designers and implementers. It contributes to ongoing collaboration between IWMI, IMAWESA and the Spate Irrigation Network in the region to promote knowledge-sharing and the increased use of research-based evidence in the design and implementation of spate irrigation systems.

Nicole Lefore, Coordinator, IMAWESA

Opening Address

Ladies and Gentlemen,

It gives me great pleasure to give the opening speech on this important workshop. Irrigation is considered as one of the policy tools to ensure food security and market-oriented production in Ethiopia. The Government of Ethiopia has been striving to promote irrigation development since the 1990s. The Growth and Transformation Plan (GTP) stipulates that the expansion of small- medium- and large-scale irrigation will receive greater attention in order to overcome crop failures due to delayed entrance of rainy seasons, early withdrawal and mal-distribution. Much evidence has been accumulating on spate irrigation with its impact on livelihoods of different types of permanent water harvesting, thanks to the research works of national and international organizations.

In areas where permanent water resources are not available to enable conventional irrigation, and building of water storage structures is beyond the current financial and technical capacity of the country, flood irrigation - also called spate irrigation – is believed to be another viable option to improve people's livelihoods at least in the short term. Spate irrigation is common in dry and lowland areas where floods originating from the neighboring highlands are diverted to do supplementary irrigation on predominantly cereal crops grown in the areas. While the practice of flood-based farming has existed in different parts of the country may be since antiquity, modernization of the traditional system, especially by the regional governments and nongovernmental organizations has been underway only since over a decade now. Now-a-days flood irrigation is being complemented by water-harvesting structures like ponds that make complementary irrigation and growing high-value crops possible. This can be witnessed in Boru Dadota scheme which I believe you will have a chance to visit during the course of the workshop and other areas in Ethiopia. Although the system of flood-based farming is faced with hosts of challenges, the potential area in the country that can be developed through such systems is tremendous. Therefore, documenting and making available the analysis of the existing potential, exchange of experiences in developing the system, lessons learnt by the different development organizations, research institutes, and higher learning institutes are essential for the proper tapping of the potential.

The workshop involves presentation of papers on characterizing spate irrigation, exploring its drivers, and its impact on crop productivity, poverty and nutritional outcomes, among others. Discussions will also be held not only to drive a set of recommendations regarding capacity-building, but making it necessary to have a research and technology transfer strategy to optimize the benefits from the flood-based irrigation. I believe the workshop will be enlightening as it brings together many resource persons who have worked on spate irrigation and who will highlight new evidence. The output of the workshop will not only be to advance the science of spate irrigation but to have important inputs to policy and practices.

I declare the workshop open.

H.E. Ato Adugna Jabessa, Deputy General Manager, Oromia Irrigation Development Authority

Section 1
Background Papers

Constraints to the Development, Operation and Maintenance of Spate Irrigation Schemes in Ethiopia

T. Erkossa, S.J. Langan and F. Hagos

International Water Management Institute, Subregional Office for East Africa and Nile Basin, P.O. Box 5689, Addis Ababa, Ethiopia

Abstract

Flood-based farming is among the potential options in ensuring access to water for crop and livestock production for small-scale farmers in the arid and semiarid lowlands of sub-Saharan Africa, and Ethiopia in particular. Flood-based irrigation while inexpensive is rooted in tradition in many rural communities which is in contrast to many other irrigation types which are unavailable (in terms of water source, technology or capacity) or are costly to develop. Spate irrigation has been practiced in different parts of Ethiopia for many decades, but it was only recently that it gained the government's attention. This study was conducted through a review and informal discussion with the objectives of documenting the current status, trends and prospects of spate irrigation in the country and the associated challenges, taking cases of selected schemes in different regional states. The study revealed that spate irrigation is expanding either through improvement of traditional schemes or by developing new ones. Neither the traditional nor modern schemes are free of challenges. The traditional schemes suffer from floods that damage their diversion structures, while poor design and construction of diversion structures have led to the failure of new ones. A range of socio-technical improvements in the planning, implementation and operation of schemes is proposed, including the design of headworks and canals consistent with the size and nature of expected flows, structures to minimize sedimentation, building capacity of farmers and district officers, and monitoring and improving the management that currently adversely impacts the performance of the schemes. Consulting farmers at every stage of the development, and building the capacity of engineers to deal with the unique nature of spate flows are the most likely interventions to ensure successful agricultural production using spate irrigation.

Key words: *Arid, semiarid, traditional irrigation, community involvement, floodwater, modern, siltation*

[1] Corresponding author: t.erkossa@cgiar.org

Introduction

Agriculture is the dominant factor in livelihoods and landscapes of sub-Saharan Africa. Inability to access water is a major constraint to reducing poverty and increasing livelihoods for the majority of communities and countries of the region. This is particularly true in Ethiopia where agriculture provides 80% of employment. In Ethiopia, most cultivated land is under the rain-fed system characterized by one growing season and high vulnerability to interannual variations and longer-term changes in rainfall patterns. Frequent long dry spells lead to crop failure and cause chronic food shortages and poverty (Awulachew et al. 2010), whose severity increases with decreasing elevation, in response to which the Government of Ethiopia (GoE) has recently introduced and begun implementation of policies to minimize risk through full or supplementary irrigation (MoFED 2010). Given the high initial investment required for development of 'conventional' irrigation schemes and the lack of permanent water sources in some areas, flood-based farming, including spate irrigation is considered an option applicable across large areas of the country.

Spate irrigation (SI) is an ancient form of water management involving the diversion of flash floods running off from mountainous landscapes (Lawrence and Steenbergen 2005). It is practiced in arid and semiarid lowlands that border mountains with substantial runoff (FAO 2010; Van Steenbergen et al. 2011). Oweis et al. (2005) distinguished two systems of spate irrigation: *wadi*-bed and off-wadi systems. In the former, the bed of the wadi is used to store water either on the surface by blocking its flow or in the soil profile by slowing the speed to allow water infiltration so that the crops grow on the wadi floor itself. In the latter, the flood is forced out of its natural course to nearby areas suitable for agriculture.

Globally, SI is predominantly practiced in the Middle East, North Africa, West Asia, East Africa and parts of Latin America. In Ethiopia, vernacular terms for SI imply that it has been long rooted in the water management culture of the communities; it is called *'Gelcha'* or *'Lolaa Debesuu'* in southeast lowlands and *'Telefa'* in the northern areas (Alemayehu 2008). Popularity of SI in the country is increasing, although there is no reliable record to show the rate of expansion. In 2008, an estimated 140,000 ha of land was under SI schemes (Alemayehu 2008) and more schemes were either under construction or at study and design phases. The expansion of SI in the country is attributed to both biophysical and socioeconomic factors. Ethiopia has favorable conditions for spate irrigation; flat, fertile and moisture-stressed lowlands bordered by mountainous highlands with high rainfall. In addition, continual expansion of rain-fed agriculture that uses traditional land management practices suitable for the plains in upland areas has led to loss of forest cover and extensive land degradation. This land degradation has decreased the water storage capacity of the uplands, which in turn increased flooding during the rainy season and water shortages during the dry seasons. This has occurred amidst rising water demand for livestock and crop production in the lowlands; lowland populations have grown from an influx of people from the highlands related to the increased frequency of droughts.

Against this background of increasing interest in promoting irrigation to improve livelihoods, the objective of this study was to document the driving forces behind the expansion of SI, the potentials and challenges related to the different typology of SI schemes and lessons to be learned by other countries in the region.

Methodology of the Study

This study covered four regional states of Ethiopia (Amhara, Oromia, SNNP [Southern Nations, Nationalities and Peoples] and Tigray, Figure 1.1). Both deskwork and field assessments were carried out. The available published and gray literature, design documents and reports were reviewed; some unpublished data from the research team and the projects were also used. Two schemes from Oromia (Boru Dodota and Awadi) and three from Tigray (Maekhoni, Hara 2, Fokisa) were selected for this review as representative of different geographic locations, typology (traditional, modern), scheme size (small, medium, large) and status (functioning or not functioning) (Table 1.1). The field investigation of each of these schemes involved a series of structured discussions with various stakeholders including experts who implemented or evaluated the projects, government officials and 15-20 farmers using a standard template, approach and checklist. This was followed up by a structured interview of 50 spate users (25 each from the traditional and modern schemes) and corresponding nonusers from Oromia and Tigray regions in order to understand the drivers of the expansion of spate irrigation schemes and the livelihood impact of SI use. The results of the latter provided the basis for a separate paper.

Figure 1.1. Distribution of the spate irrigation schemes and schemes visited for this study.

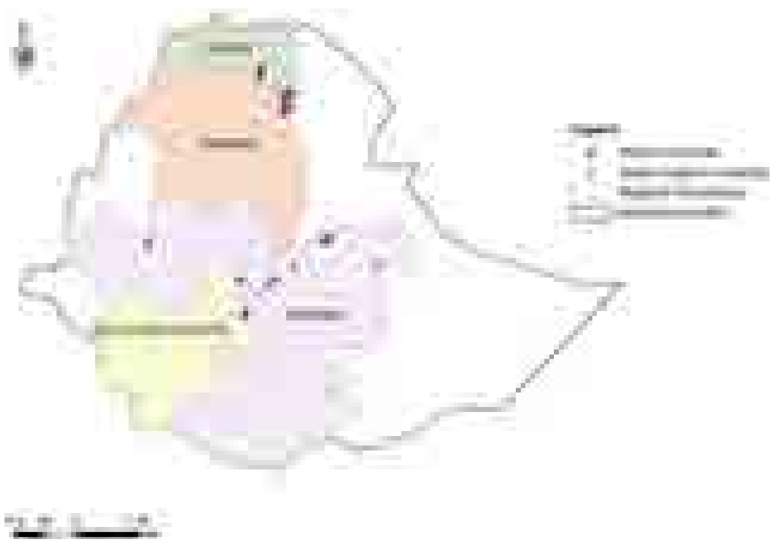


Table 1.1. Details of spate irrigation schemes reviewed in Oromia and Tigray regions.

Region	Scheme type	Name of scheme	Year of establishment	Command area (ha)	Status
Oromia	Traditional	Awadi		85	Functioning
	Modern	Boru Dodota	2007	5,000	Functioning below capacity
		Bura	2011	200	Functioning, new
Tigray	Improved-Traditional	Maekhoni		400	Functioning
	Modern	Hara 2	2010	200	Not functioning
		Fokisa		500	Functioning below capacity

Results and Discussion

Results

Spate irrigation systems have been used in different parts of Ethiopia since antiquity, and SI systems around Kobo in Amhara and Konso in SNNP administrative regions have been used for generations (Alemayehu 2008). However, over the last two to three decades, there has been a remarkable increase in development of SI schemes by farmers and development partners, although there is no comprehensive data to show the extent of the increase. In the four regions studied, both traditional and improved SI schemes are now prevalent although most of the modern schemes are not fully functional. The extent of commitment by the regional governments to the system varies, which may depend on the availability of other alternative water sources, awareness about SI and the potential area suitable for spate irrigation. Clearly, Oromia and Tigray regions have invested in large- and medium-scale schemes and upgraded the existing traditional schemes and constructed new ones.

Status and Potential of Spate Irrigation in Ethiopia

To aid the understanding of the current development and the future potential for spate irrigation, we reviewed the available literature on the subject, which is described below.

A. Incomplete inventory and supporting data: Despite the widespread use of SI in the country, information is inconsistent on the actual area under these systems and the estimate of the potential areas that can be developed. According to Alemehayu (2008), area under spate irrigation was estimated at 140,000 ha in 2008 (Figure 1.2), while the traditional schemes alone were estimated to exceed 100,000 ha as indicated in the National Investment Brief of Ethiopia. The potential for direct use of flood for irrigation or in conjunction with surface and subsurface storages is high since SI and flood recession cropping can be practiced in most of the wadis surrounded by hills receiving high rainfall; moisture-stressed lowlands cover approximately 60% of the country's total landmass (Alemayehu 2008). In an effort to utilize this potential, several regional states have embarked on development of new SI schemes or improvement of indigenous schemes so that their command area increases and the structures function permanently. For instance, Oromia regional state planned to develop spate irrigation with a command area of about 318,000 ha over 5 years (2005/06 to 2009/10) in different development corridors (Alemayehu 2008) out of which schemes irrigating over 7,000 ha were operational during the time of the study (Tables 1.2 and 1.3). In addition, final feasibility and design reports have been completed for 18 schemes with a command area of 34,000 ha (Table 1.4) while the remaining area was reported to be at different stages of study.

Figure 1.2. Status of spate irrigation in Ethiopia as adapted from Alemehayu T. (2008)

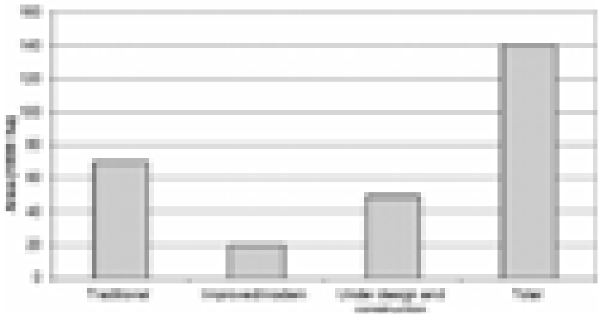


Table 1.2. Details of spate irrigation schemes reviewed in Oromia and Tigray regions.

Development corridor	Planned area (ha)					
	2005/06	2006/07	2007/08	2008/09	2009/10	Total
Borana			650	1,200	1,600	3,450
Southeastern Oromia	4,216	27,550	74,264	49,509	41,258	196,797
South Bale and Guji		8,050	9,400	11,000	9,500	37,950
North Shewa		100	100	100	100	400
Rift Valley	5,000	24,000	19,000	19,500	11,500	79,000
Subtotal	9,216	59,700	103,414	81,309	63,958	317,597

Source: Five-year strategic plan for development corridors in Oromia.

Table 1.3. Area (ha) under spate irrigation in Oromia regional state in 2011.

Name of scheme	Traditional	Improved/modern	Total
Boru Dodota		5,000	5,000
Hargetti		500	500
Bililo		500	500
Ija Galma Waqo		350	350
Ija Malabe		480	480
Awadi	85		85
Bura		200	200
Total	85		7,115

Source: Oromia Water Works Design and Supervision Enterprise (OWWDSE).

It is notable that the command areas of the newly studied schemes are related neither to the amount of rainfall nor to the altitude. The new SI schemes in the region are not limited to the dry lowland areas, but appear to be expanding also to the highland areas that receive relatively high annual rainfall. As shown in Table 1.4, the target areas for these schemes receive a rainfall of 700-1,000 $mmyear^{-1}$. This may be related to the increased variability in rainfall distribution, including in the highlands that typically receive high rainfall; increased variability and periods of lower rainfall or drought have been accompanied by yield reduction or complete crop failure. The schemes are also distributed over ranges of altitude: from lowlands (1,136 masl) to the highlands (1,914 masl); they average around 2,000 ha and range between 200 and 5,000 ha.

Table 1.4. Planned modern spate irrigation schemes in Oromia for which study and design are completed.

Name of scheme	District	Command area (ha)	Mean annual rainfall in area (mm)	Average altitude (masl)
Agemsa	Mieso	1,000	700	1,455
Adami Hara	Mieso	760	750	1,303
Gagawisa	Mieso	1,000	900	1,468
Oda bela	Mieso	3,200	900	1,447
Chelchel	Raytu	5,000	1,000	1,136
Gungum/Egole	Dellomena	2,000	900	1,155
Dhadhaba gudda	Shashemene	4,000	900	1,852
Burraa	Shashemene	200	900	1,730
Hregolemeno	Shalla	1,000	950	1,835
Kobo borera	Ziway Dugda	4,000	725	1,914
Efadin	Fedis	1,000	190	1,381
Ija Guhe	Fedis	1,500	700	1,550
Arer	Babile	900	775	1,504
Efadin	Babile	1,000	700	1,381
Ija Denu	Meyu Muluke	105	750	1,337
Ija Medalu	Meyu Muluke	337	750	1,341
Tabo	Boset	5,000	700	1,200
Katar	Zwai-Dugda	2,000	800	1,699
Total		34,002		

Source: Oromia Water, Minerals and Energy Bureau (2012).

Tigray is another focus region for spate irrigation development. In addition to upgrading the traditional SI schemes that were concentrated in the southern part of the Tigray Region, the system has been introduced to the drought-prone districts in the central zone where it was not well known, such as Tanqua-Abergelle. In neighboring Amhara Regional State, traditional spate irrigation is practiced in Kobo District, which is adjacent to the Raya-Alamata in Tigray where spate is widely used. According to the district offices responsible for agriculture and rural development in the two regions, about 42,000 ha Raya-Azebo (Tigray) and 427 ha in Kobo (Amhara) districts are under SI schemes.

There is a general lack of comprehensive data on SI schemes in the SNNP Regional State. According to Van Steenbergen et al. (2011) the estimated command area of the traditional SI scheme at Yandefero was about 4,000 ha. Although not widespread as in Oromia and Tigray, local and international development actors have recently initiated new SI schemes in the region. According to the regional Irrigation Development and Scheme Administration Agency, a 300 ha scheme was under construction at Weyito in 2012 (Table 1.5). In addition, the Ethiopian Evangelical Church Mekaneyesus has constructed and handed over a modern SI scheme at Konso, but information on the command area is not available. Also, the International Fund for Agricultural Development (IFAD) is supporting the study of four new schemes in the region covering a command area of 1,250 ha.

Table 1.5. Spate irrigated areas (ha) in SSNP regional state.

Name of scheme	Traditional	Improved	Total	Under design and construction
Weiyto		300	300	
Konso/Yandefero	4,000		4,000	
Birbirsa				250
Galge				300
Mega				300
Mareqo				400
Total	4,000	300	4,300	1,250

Source: SNNP Irrigation Development and Scheme Administration Agency.

B. Drivers of expansion of spate irrigation: Expansion of spate irrigation in Ethiopia may be attributed to the increased demand from farmers for full or supplementary irrigation to overcome the increased climate-related crop failures and the shift in the policy of the government and other agencies from food aid which is believed to create a dependency syndrome (Lind and Jalleta 2005) to local food production and development to sustainably ensure food security in the drought-prone areas of the country.

Regardless of the location, farmers attributed the expansion of spate irrigation in their areas to climate-related factors such as reduced rainfall, increased dry spells and increased temperature, which reduced the length of the effective growing period and increased crop failures. About 63 and 85% of 191 farmers interviewed believed that the rainfall and the length of growing period (LGP) decreased during the last decades. Similarly, about 73 and 64% believed temperature and frequency of dry spells increased over the recent years. To overcome the shortage of water due to reduced rainfall and other factors, the farmers turned to spate flows that supplement the erratic rainfall. However, the majority (over 90%) of the farmers interviewed believe that the volume, frequency and duration of spate flows are also decreasing in response to the reduced rainfall.

On the other hand, the Government of Ethiopia has identified irrigation (especially small-scale) as an important component of adaptation to climate change (GoE 2007) and ensuring rural food security in its economic development programs (MoFED 2006). The current food security policy of the country aims at increasing production and farmers' income using locally available resources and affordable inputs, a policy supported by big donors like the World Bank (2011). In an attempt to translate the policy into action, both the federal and regional governments, supported by bilaterally and multilaterally funded projects are developing water resources for agriculture, and in areas where it is found feasible, spate irrigation is also considered as an option.

Typology and Management of Spate Irrigation Systems

Typology of spate irrigation systems: Traditional systems

The following examples and points about traditional schemes are based on our field observations. Traditional spate irrigation schemes refer to schemes that are planned, constructed and managed by farmers themselves with no or limited external interventions. The design and construction approach and size of the scheme vary depending on the amount of floodwater available to divert, experience of farmers and availability of materials for construction. The structures often have diversions and can sometimes have canal systems, such as primary, secondary and tertiary canals, as components (Van den and John 2008). Among the limitations of the traditional schemes is that the diversion structures are simple deflectors constructed using brushwood, stones and sand that can be easily washed away by heavy floods, which in turn necessitate frequent reconstruction (Daniel et al. 2005). In addition, as they can divert only a limited part of the flood, the command area per diversion is also limited, requiring a series of diversions over a wadi to irrigate large areas. However, the systems allow equitable distribution of water between upstream and downstream users (Daniel et al. 2005). As the number of users per diversion is limited, the management of water is simple. The canals are often very wide (up to 3 meters) and sometimes stabilize and become permanent when used over extended periods of time, as witnessed in Raya Valley.

Most traditional schemes in Ethiopia are small in size (less than 200 ha) and often constructed and managed by an individual or group of farmers. A wadi scheme that is located in Arsi Negele District, Oromia Region was constructed 20 years ago by an innovative farmer and it has been continuously improved by the community. In this scheme, the flood emerging from Aga Mountain is diverted from Awadi Ephemeral Riverbed by a stone bund (Figure 1.3) to irrigate 85 ha of land. Recently, the Japan International Cooperation Agency (JICA) assisted the community to replace a wooden flume constructed across a gully with steel believed to last longer (Figure 1.4). Similarly, the traditional diversion structures locally known as 'maegel' (in Raya Valley) (Kidane 2009) and 'melee' in Kobo Valley (Alamrew et al. [unpublished]) are used in Tigray and Amhara regions, respectively. Unlike many spate irrigation schemes in which cereals such as maize and sorghum are grown, onion and potato are crops commonly grown in the scheme.

Figure 1.3. Stone bund diversion in Awadi traditional SI scheme.

Figure 1.4. Improved metal flume in Awadi traditional SI scheme.

Typology of spate irrigation systems: Modern systems

Development of the modern schemes in Ethiopia is a recent phenomenon as part of the effort to enhance agricultural productivity to meet the increased demand for food and to spur overall economic growth. Efforts have been made to 'modernize' the traditional schemes or develop new ones during the last two decades. The modernization of the traditional SI schemes is often aimed at reducing the labor required to maintain diversions, improving the control of water within the distribution systems and increasing the capacity of structures to tolerate the damage due to large floods. In the modern SI systems, the structures are expected to guide and split floods while avoiding excessive sedimentation and promoting the deposition of suspended sediments in the cultivated lands instead of filling up the canals. Consequently, the design for improvement must ensure that the structures cope with frequent and sometimes large changes in wadi bed conditions (FAO 2010). In addition, FAO (2010) suggests that the design has to respect the established systems of water allocation arrangements, priorities and amounts in order to avoid conflicts. Several modern SI schemes in Raya Valley are the result of improvement of the traditional schemes through the Raya Valley Development Project (Michael 2000).

Set with its features such as a diversion headwork, rejection spillway, main canal, branch canals, secondary canals, tertiary canals, drop structures, division boxes, storage reservoirs and drainage culverts, and with a potential command area of 5,000 ha, Boru Dodota modern SI scheme was newly developed by the Oromia regional government. Apparently, the scheme was designed and constructed based on the experience from conventional river diversions with a narrow weir (Van den and John 2008) resulting in constrained flood flow leading to huge silt deposition. Due to the sedimentation problem, the scheme is running far below its design capacity. In addition, currently, a number of modern SI schemes are either under study and design or being constructed in different parts of the country.

Another example of a modern SI system is Bura Scheme, constructed in Arsi Negele District of Oromia Region by JICA, based on the lessons learnt from Boru Dodota. The scheme components include diversion headwork, rejection spillways, main, secondary and tertiary canals, drop structures, division boxes and drainage culverts designed and constructed to reduce the problems of headwork and main canal siltation. With an investment cost of about USD 1,268 ha^{-1}, the key improvement includes a wider diversion weir (10 m) that splits flood flows efficiently and avoids excessive sediment load, and a relatively higher weir crest so that silt-free water enters the main canal. In addition, it has two rejection spillways along the main canal as a consequence of which the lined main canal is almost free of silt. As this scheme was not fully functional during the time of the study, it is too early to assess its performance, but the improvements in the design and construction would be expected to curb the siltation of the structures, a main problem in spate irrigation systems. According to the development agents in the area, farmers have positive expectations expressed through allowing construction of canals through their fields and some have already started using the water.

Management of Spate Irrigation Schemes

According to FAO (2010), the life expectancy and sustainability of SI schemes is often dependent on the appropriateness of design and construction, but equally important is the effectiveness of operation and maintenance (O&M). This requires a well-tailored management plan. FAO (2010) has identified three types of management arrangements: 1) predominantly farmer-managed, 2) jointly managed by local government and farmers, and 3) jointly managed by a specialized agency and farmers. These systems of management are applied often to schemes based on command area size, being less than 1,000 ha, 1,000 ha to 5,000 ha, and more than 5,000 ha, respectively.

Management of Traditional schemes

The O&M of traditional schemes in Ethiopia are purely the responsibility of farmers. For example, the users of the Awadi traditional scheme in Oromia Region independently manage the scheme through their water user association (WUA) led by a committee. The committee organizes maintenance works such that whoever has a plot in the scheme should provide free labor on specified dates or pay a fine. The penalty due to failure to participate in maintenance work or other offences is determined by the water user committee. The committee is also responsible for water allocation and manages the financial resources of the association, including income from regular contributions from members and fines.

In the Raya Valley, farmers elect *Abo-gereb* (literally father of river) and *Abo-mai* (literally father of water). The *Abo-gereb* organizes the farmers to construct and maintain the diversion structure and main canal, and he allocates floodwater to the *Abo-mais*. The *Abo-mai* is responsible for construction and maintenance of the secondary canals and for regulating the distribution of floods to the farmers having plots within the secondary canal areas. Flood distribution is based on a predetermined sequence by casting lots (Kidane 2009). In case of any offense, the *Abo-mai* is responsible for reporting to the *Abo-gereb* who is authorized to institute penalties. According to Alamerew (unpublished), a similar system of management is applied in schemes located in Kobo Valley of the Amhara Regional State. In this case, a committee of three individuals elected by the users locally known as *Aba-haga* (literally father of water) is responsible for scheduling the construction and maintenance of structures, distribution of the flood among the users and fining offenders.

Management of Modern Schemes

There is no standard management system, but WUAs or committees were formed in all the modern SI schemes considered in this study. The difference between the modern and traditional schemes is that external agents, such as the district offices of agriculture, facilitate the formation of the WUAs on the modern schemes. In some of these schemes the government is directly involved in O&M of the schemes.

Apparently, management of the modern schemes is considered beyond the capacity of the farming communities, especially those over 5,000 ha. For example, Boru Dodota was intensively managed by the regional Water, Mineral and Energy (WME) and Agricultural and Rural Development (ARD) bureaus for the first 2 years after construction. Joint management by a specialized government agency from WME or ARD and farmers was supposed to take over. A WUA was established for the scheme. However, the WUA is not functioning properly, and the joint management arrangement was not implemented; the scheme has experienced difficulties in O&M. Scheme size, severity of the headwork, and design and construction shortcomings added up to problems with siltation. Farmers alone could handle the maintenance needs of the scheme with their hand tools. Therefore, the success of such schemes is contingent on the quality and sustainability of O&M support provided by qualified external agencies, including government and other development partners. It also implies the need for strengthening WUA capacity and legal recognition to discharge responsibilities, including facilitation of the regular O&M in conjunction with a responsible government agency.

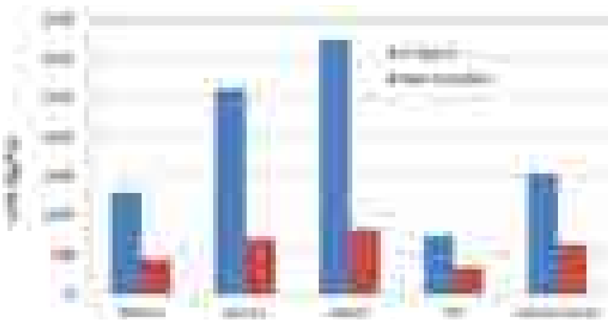
In Raya and Kobo valleys, similar to the case with the traditional schemes, farmers often elect a committee of five individuals after the construction. The committee is responsible for mobilizing farmers to carry out minor maintenance works, including desilting structures, while major maintenance is carried out by government. In addition, the committee distributes the floodwater among the Abo-mais. This is slightly different to Boru Dodota. There are two steps in the management system (the committee and the Abo-mais) and there is committed support from government for major maintenance works, which is currently lacking in the case of Boru Dodota.

Contribution of Spate Irrigation to Crop and Livestock Production

Contribution to crop production

Generally, spate irrigation supports low-input, risk-averse farming, but there are still uncertainties in the timing, frequency and size of floods. Floods can provide too little water that results in water shortages or too much water that results in damage to crops and irrigation infrastructure. Such uncertainties make cropping of high-value moisture-sensitive crops and use of inputs like fertilizers precarious. Consequently, drought-resistant crops such as sorghum *(Sorghum bicolor),* maize *(Zea mays),* millet *(Eleusinecoracana Gaertn),* cowpea *(Vigna unguiculata)* and horse bean *(Vicia faba)* are widely grown *(Michael 2000).* Most farmers in Boru Dodota scheme grow local varieties of wheat, barley, maize, tef and haricot bean that are not necessarily high yielders (Birhanu and Mengistu 2007). However, data from the year 2007 indicated that supplementary irrigation using spate increased yield of the crops as compared to both a good year (2006) and a normal year (2007) as seen in Figure 1.5. The yield increase over the good year's average for maize and haricot bean was 167 and 275%, respectively (Van Steenbergen et al. 2011). Similarly, due to uncertainties in water availability, farmers in Raya and Kobo valleys grow sorghum and tef with limited use of fertilizers similar to the case with rain-fed systems, instead of opting for crops of their choice and use of higher inputs. In good years, when rainfall and floods are sufficient, the sorghum yield can be as high as 7 tons ha^{-1}; in bad years it may completely fail. Therefore, ensuring water availability through spate or other means increases crop productivity in the areas, but the advantage can be augmented if other complementary technologies including improved varieties of high-value crops are used.

Figure 1.5. Effect of supplementary irrigation on crop yield in Boru Dodota scheme in 2007.



Source: Adapted from Birhanu and Mengistu (2007).

Contribution to livestock production

Livestock is an integral and important component of household livelihoods in most arid and semiarid lowlands where spate irrigation can be practiced (FAO 2010). Access to feed and drinking water is a crucial challenge to livestock production. Natural grazing, crop residues and crop aftermath grazing constitute the main source of feed in the mixed crop livestock systems. However, while livestock populations are increasing, feed availability and productivity of livestock are decreasing (Tolera and Abebe 2007). Natural grazing is shrinking due to increased area closure on slopes and expansion of agricultural practices in plains (Alamerew, unpublished). The importance of crop residues and aftermath grazing is increasing, but the availability of these resources depends on the productivity of the crops that are highly dependent on water availability. Spate irrigation can be beneficial for livestock. Increased crop yield (grain and straw) means increased availability of livestock feed. According to FAO (2010), spate irrigation has boosted the availability of animal feed by increasing the biomass production in Amhara Regional State of Ethiopia. In addition, the non-crop biomass (weeds) that grows within and outside the crop fields is often an important feed resource. According to development agents and farmers, spate irrigation has improved the availability of feed and, therefore, increased the household income from livestock products in Raya and Kobo valleys, which accommodate large populations of cattle, goat, sheep, etc. Floods are also an important source of drinking water, especially when stored for the dry seasons. The floods feed small ponds, known locally as “horeye” in Raya and “kure” around Kobo.

The Challenges of Spate Irrigation Systems

Spate irrigation systems are risk-prone and categorically different from perennial systems. The floods may be abundant or minimal, and production responds to the change in the frequency and amount of floods. The fluctuation of flood volume may be a source of inequity since some lands get better access to water than others (Van Steenberger et al. 2005). On the other hand, occasional high floods can cause damage to wadi beds and command areas unless design, construction, and O&M are tuned to deal with them. The high sediment load of the water, especially of the coarse materials can shorten the life span of the spate irrigation structures that are not designed to handle the sediment gush. Fine sediments can improve the fertility and physical conditions of the soil if delivered to the field, but care must be taken to avoid the rise of the command area against furrows and canals. Sedimentation of the canals can be detrimental to the functioning of the system regardless of the size of the materials deposited. New weed and soil-borne plant disease agents can be delivered to the field with floodwater and sediment, a risk not be easily managed (Ibrahim 2010; Ogba-Michael n.d.) (www.eritrean-embassy.se/.../AgronomyinSpateIrrigatedAreasofEritrea.pd) (accessed December 2013). Farmers in Boru Dodota blame the spate water for the invasion of new weed species, but they consider the problem tolerable in view of the benefits of increased crop and livestock productivity and enhanced soil health.

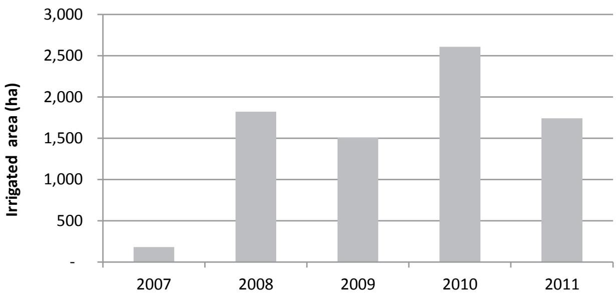
The predicaments of spate scheme modernization

Improvement efforts and construction of new spate schemes have often had depressing results, probably the result of deficient information for design and poor understanding of the flow regimes. The predicament of modernizing spate irrigation in Oromia and Tigray regions of Ethiopia, either upgrading traditional systems or developing new ones, are illustrated here.

The Boru Dodota scheme was newly constructed (started in 2007) by Oromia Water Works Construction Enterprise (OWWCE) to irrigate about 5,000 ha in the great East African Rift Valley. According to Dodota District WME Office, this was one of the cheapest spate schemes in the region, with investment costs of about USD 450 ha^{-1}. Apparently, the headwork design and construction followed conventional river diversion approaches without taking the heavy silt load of the flood into account. The narrow weir (5 m crest width) constrained the flow and led to huge silt deposition; the capacity of the system to divert the flood has been reduced (Van den and John 2008). In addition, the upper part of its lined main canal is filled with sediment up to the crest level of the first rejection spillway. In addition to the structural defects, sand miners built a silt barrier across the main canal and aggravated the siltation problem.

Stimulated by improved crop yield under spate irrigation, the demand for SI has increased over time (from 182 ha in 2007 to 2,607 ha in 2010). But in 2009, a bad year meant inadequate water to meet the demand (Figure 1.6). According to the district office of agriculture more land had been prepared in 2011 than that irrigated in 2010, but the flood that reached the area was too little due to the sediment deposited at the diversion headwork. Therefore, maintaining the conveyance system to ensure water delivery, storing water during the good years either on the surface as ponds or recharging the groundwater can help in narrowing the demand and supply gap.

Figure 1.6. Trend of irrigated land area in Boru Dodota spate irrigation scheme.



Although nine reservoirs have been built within the scheme to harvest the peak flow, they were empty because the gates do not close properly. On the other hand, several farmers have built ponds in their own fields. JICA supported some of the farmers' efforts and provided geo-membrane to line ponds. One farmer explained his life has changed for good because of the three interconnected ponds around his house (Figure 1.7). Stimulated by the improved livelihood of those using the flood, many farmers are constructing their own ponds, even without external support. Therefore, although not functioning as planned, the introduction of the modern SI in the area has stimulated floodwater harvesting initiatives by farmers, which may have a lasting effect.

Figure 1.7. Interconnected ponds developed by a farmer.

Upgrading or development of modern schemes has been underway in both Tigray and Amhara regions. In Tigray, while many traditional schemes were improved, more than 20 modern schemes were newly constructed in Raya Valley and another four in Tanqua-Abergelle *(Afera, shiwata, Durko and Agbe).* Two schemes from the region are briefly presented below as examples of the issues faced.

Fokisa: This is a modern scheme that operates far lower than the designed capacity because of siltation. Siltation of the diversion weir and canal is related to a design problem aggravated by the dominantly degrading and steep topographic feature of the catchment. The major part of the catchment area is steeper than 50% and is devoid of vegetation cover or soil and water conservation practices. According to Raya Valley Agricultural Development (RVDP 1997), the sediment yield in the catchment ranges from 1,550 to 1,740 $m^3km^{-2}year^{-1}$. The success of the modernization effort would be enhanced by revisiting the design and construction approaches, as well as understanding the status of the water source (catchment) areas and incorporating complementary watershed management activities in the plan.

Hara 2: This scheme was constructed in 2010, only to fail in the same year before it was handed over to the users. The weir was toppled over and washed away, perhaps because the runoff was underestimated in the design. According to development workers in the area, at least three other schemes constructed in the same year failed in the same manner. Although there is no definite explanation for the failures, design problems may be related to the paucity of reliable data and lack of qualified engineers. Construction problems may also be a factor, as poor workmanship and lack of effective supervision were suggested to be possible reasons. Such information gaps may be partially bridged through effective participation of the local community.

Tigray is similar to the case in Oromia. After assessing the performance of the schemes developed earlier, modifications were made on the design of those constructed more recently. Improvements included changing the orientation of the offtake, omission of the under-sluice and limiting the command area under one scheme to 200 ha as with the traditional schemes. The advantage of keeping the size of the schemes smaller is threefold: it reduces the technical predicaments related to siltation and failure of the structures; it eases O&M challenges for the users; and it reduces upstream-downstream conflicts.

Discussion

To overcome the recurring chronic food insecurity that affects large parts of the population and to feed an increasing population, Ethiopia needs to significantly increase agricultural production (FAO 2006). According to Awulachew et al. (2010), agriculture in Ethiopia is largely rain-fed with only 4-5% of cultivated land estimated to be under irrigation. Even export crops, such as coffee, oilseed and pulses that contribute the major share of foreign currency are grown largely under rain-fed systems. Rain-fed systems however are increasingly vulnerable to weather-related crop failure. At the same time, deforestation and inappropriate land management practices are widespread, particularly given the expansion of farmlands into marginal areas such as steep slopes and in the highlands (Lemma et al. 2011). Land degradation has led to reduced storage capacity of the catchments and has increased peak flow during the rainy seasons and diminished baseflows during the dry seasons. In the meantime, reduced agricultural productivity and shortage of land in the highlands have accelerated migration of people to lowlands. Agriculture became more important in the traditionally agro-pastoral areas. These factors have raised the demand for irrigation as rainfall in the lowlands is hardly adequate for crop production. However, conventional irrigation development is limited by the availability of perennial water resources and is also costly.

Traditionally, some farmers in the mid-altitude and lowland areas have been using spate irrigation to supplement the unreliable rainfall, both for crops and growth of pasture. However, the structures used are often primitive and can easily get washed away. The government and other development partners seem to be convinced that spate irrigation systems hold potential at least in the short term to overcome the problem of crop failure. In different parts of the country, modern spate irrigation systems are expanding through the upgrading of the traditional schemes or development of new ones. As demonstrated in this study, the results of the modernization effort are often not satisfactory because of technical, socioeconomic and institutional shortcomings.

The design of improved water diversion structures, canals in spate schemes and estimation of the area that can be potentially developed using the spate water require data on hydrology and sediment transport (FAO 2010). Since such information is limited in the least settled parts of developing countries that are often targeted for spate irrigation, empirical models need to be used in conjunction with local knowledge that can be extracted from the local community. This requires development of local capacity in design and construction of spate systems combined with research to refine the socio-technical approaches in design, construction, and O&M of spate irrigation systems.

Conclusions

Traditional small-scale spate irrigation has existed in Ethiopia perhaps for millennia, but it is only recently that it has attracted the attention of government and other stakeholders. It is increasingly recognized as an essential input, especially in the lowlands, to increase crop and livestock productivity and enhance food security. This study revealed that the traditional spate irrigation systems are suitable for farmers to manage independently because of their size and limited number of users that can be easily mobilized due to the proximity of their settlements. However, the frequent failure of the structures necessitates frequent reconstruction, which challenges labor productivity. Currently, efforts to improve the schemes to overcome the problems and to maximize the quantity of flood diverted as well as the development of new schemes are widespread in the country. In these efforts, conventional approaches of river diversion design are often used without attention to the unique nature of the spate flows and farmers' opinion. Consequently, most modern spate irrigation schemes are not optimally operating, particularly due to siltation. Unlike the traditional schemes, because of the expansiveness in size and immensity in their silt deposit, management of modern spate schemes is beyond the capacity of the farmers and development agents at district offices.

Recommendations

Improvements of traditional schemes should reduce the labor required for maintenance and minimize damage to canals and fields by floods. However, modernization of traditional schemes should be preceded by understanding of the system when consulting with farmers. Reduction of siltation at the headwork and canals should be a major design criterion in large and modern schemes. Farmers need external support including provision of earth-moving machines in managing large-scale spate irrigation schemes that do not desilt automatically. Small-scale schemes that are easier for farmers to manage with minimum support from local experts may be more sustainable than the large schemes. Introduction of spate irrigation to new areas requires sufficient awareness creation and demonstration through piloting and performance evaluation. Integrating spate irrigation with watershed management may ensure sustainable water supply while reducing siltation of structures.

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Spate Irrigation in Ethiopia: Potential, Development Status and Challenges

Taye Alemayehu
Metameta Research and Ethiopian Institute of Water Resources (AAU)
e-mail: taye@metameta.nl

Abstract

The paper highlights the current development status of spate irrigation in Ethiopia and its challenges. It discusses the huge potential of spate irrigation in Ethiopia and highlights the possibility of transforming this high spate potential to drought-prone lowland parts of the country and to growth centers. It also addresses the development attempts so far and the challenges faced, including traditional and modern practices. This article raises critical issues like land tenure systems and water and land use rights in areas where spate irrigation is practiced and where there are potential users of spate irrigation. Finally, it forwards its recommendations.

Old, improved and combined spate irrigation practices are prevalent in Ethiopia. Most spate farms in the southeastern parts of the country are traditional. Improved spate irrigation is being implemented almost in all areas where there is traditional practice. Population pressure, natural calamities, and loss of the bulk of grazing lands in pastoral areas of the country have led to increased use of spate water. The recent, problem-driven, water-centered growth approach has given due emphasis to this potential, resulting in preparation of integrated land use plans and implementation of water-related projects in the lowlands.

Lack of basic services like roads, potable water, power supply, and education coupled with harsh health issues like malaria, are hampering development in most spate irrigation areas. Sedimentation, change in stream/river morphology, and failure of structures are also some of the technical challenges. As spate water use increases, the problems of land tenure and water use rights grow. Modern land and water administration laws and regulations in spate irrigation areas have failed to address water rights; water allocation of perennial flows is different from spate irrigation water. Increased inequity and use conflict are seen in some areas.

Defining the most beneficial agronomic practice of spate farms, introduction of market-oriented agriculture, conjunctive use of shallow groundwater and surface water, respecting the traditional rights of the pastoral communities and involving farmers in planning, designing and decision making are priority actions.

Key words: *Land and water rights, pastoralists, conjunctive use*

Introduction

Ethiopia is located between 3^0N and 15^0N latitude and 33^0E and 48^0E longitude. It has a total area of about 1.13 million km^2. It is the second most populous country in Africa with a population of about 80 million. Ethiopia is an ancient country with a rich diversity of people and cultures and a unique alphabet that has existed for more than 3,000 years. About 85% of the country's populations are rural. Since 1991 Ethiopia has had a federal administrative structure, which constitutes the federal government and nine regional governments. The National Regional States are further divided into 580 districts *(woredas)* and about 15,000 lower administrative units *(kebeles)*.

Topographically, Ethiopia is divided into a huge central plateau surrounded by lowland plains creating good potential for spate irrigation. The Ethiopian plateaus include elevations as high as 4,620 m while the lowlands descend to 125 m below sea level at Dalol, Afar. It also has numerous active volcanoes. Ethiopia lies within the tropics, wherein every place has overhead sun twice a year. In Ethiopia, temperatures are greatly influenced by changing altitude. Extremes in temperature range from the mean annual temperature of 34.5 °C in the Danakil depression at 120 m below sea level to a minimum temperature below zero on mountain slopes of over 4,000 m above mean sea level.

In Ethiopia, the major factors influencing rainfall are the intertropical convergence zone, the northern trade winds and the southern monsoons. The country has both bimodal and unimodal rainfall profiles. Annual rainfall in the country ranges between 2,700 mm in the southwestern highlands and less than 200 mm in some parts of the northern and southeastern lowlands with a further decrease to 100 mm in the northeastern lowlands.

Available information indicates that nearly 70% of the total arable land in Ethiopia receives an annual rainfall of less than 750 mm. The areas with annual rainfall of 500-750 mm are believed to support optimum level of agricultural activities, if the annual rainfall distribution is undisturbed and proper land management is applied. However, the annual rainfall distribution of most parts of Ethiopia, including the highlands, not only lacks uniformity but is also highly unpredictable in its interannual variations (MoA 2001; Ephraim et al. 2003). The overall coefficient of rainfall variability ranges from 10 to 50%.

Altitude is the single most important factor influencing climatic control of the country. The main climatic regions of Ethiopia are dry, tropical rainy and temperate rainy. About 66% of the total area of the country is considered as arable land. About 10.3% and 12.5% of the total land area are intensively and moderately cultivated, respectively. Only 1.6% of the country is covered under perennial crops. The country is largely dependent on the agriculture sector, which provides 86% of employment and 57% of GDP. Income in Ethiopia is highly variable from year to year, partly due to frequent and severe droughts (MoWR 2002).

Materials and methods

Modern spate irrigation has not been given due attention by researchers and scholars in agricultural fields. It is less than a decade since a systematic intervention has been made by the government and NGOs. As a result, there are no well-documented references to be cited. The main sources of information to compile this profile included observation in the field, annual performance review reports by implementing agencies and some publications that indirectly document spate issues. A review of previous reports and articles provided the major source of information to prepare this paper.

Site visits in some of the spate irrigation potential and practicing areas in Hararge, Borena, Afar, Omo Valley and Tigray were used to assess and characterize the different practices and validate foreseen scenarios. Informal interviews were done with the user communities to learn about the indigenous knowledge, and the pros and cons of improved spate irrigation systems, land tenure, existing water use practices, and gender and other issues. Development agencies, such as the water bureaus, were approached for data on spate irrigation projects and productivity.

Findings

Attempts have been made to evaluate the spate potential of Ethiopia. This paper highlights the possibility of transforming the high spate potential into the actual development and growth center. It also addresses the development attempts made so far and the challenges faced, including traditional and modern practices. In addition, this paper raises critical issues like land tenure and water and land use rights in areas where spate irrigation is practiced amongst potential users.

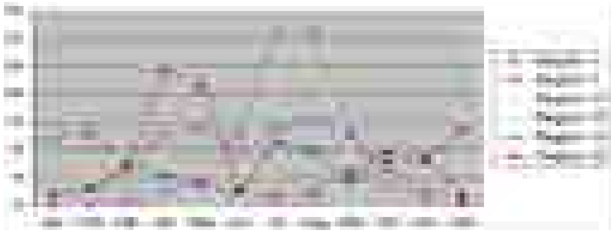
Discussion

Water Resources Potentials of Ethiopia

The mean annual specific runoff varies from zero to 35 $ls^{-1}km^{-2}$. Minimum flows occur from December to March. Apart from the big rivers and their tributaries, there is hardly any perennial flow in areas below 1,500 m. In general, perennial streams and springs exist only in the vicinity of mountains with an annual rainfall of more than 1,000 mm.

The country's annual renewable freshwater resources amount to some 122 billion m^3yr^{-1} (Bm^3yr^{-1}) contained in 12 river basins, which is only 1,525 $m^3yr^{-1}capita^{-1}$ share. However, only 3% remains in the country. At this stage, the country withdraws less than 5% of its freshwater resources for consumptive uses. The western portion of the country, with only 40% of the total land area, generates 83% of the surface water potential. It is estimated that 54.4 Bm^3yr^{-1} of surface runoff and 2.6 Bm^3yr^{-1} of groundwater could be technically developed for consumptive use. It is also estimated that in addition to clean water supply to its entire population, up to 3.7 Mha of land and 30,000 MW of power can be developed using the available water resources potential. However, only less than 300,000 ha of the irrigation and 854 MW hydropower potentials, respectively, have been developed so far. The current level of irrigation development is lower than 50% of the over 600,000 ha of irrigable land that should have been developed to meet the food demand of the present population in addition to what is being cultivated under rain-fed agriculture. The clean water supply coverage is only about 50% (DHV 2002; UNESCO 2004). See Figure 2.1 for rainfall pattern as a percentage of mean annual rainfall for six selected representative regions.

Figure 2.1. Rainfall pattern as a percentage of mean annual rainfall for six selected representative regions.



1.1 Drought and Famine in Ethiopia

Droughts are major social, environmental and economic disruptive forces in Ethiopia. They have caused heavy loss of human and livestock populations, mass starvation and mass drift to relief centers and nearby towns and cities. Five major droughts in two decades have left most Ethiopian households reeling, and hundreds of thousands of people still live on the brink of survival (UN 2008).

About 30 major drought episodes have been recorded over the last nine centuries (Workneh 1987). Thirteen of these droughts covered the whole country and were reported to have been severe. A dozen of the recorded droughts and famines took place in the 20th century out of which five occurred during the period 1972-1991. The last two decades have been marked by catastrophic and widespread droughts and famines occurring 2-3 years on average as compared to every 7-10 years over the previous decades.

The climatic conditions of the drought years were characterized by either failure, late or early onset of, or inadequate, rainfall during the small and/or main rainy seasons (Workneh 1987; UNESCO 2004). Apart from the oceanic factors that cause climate-induced droughts, terrestrial factors such as changes in ecological and demographic conditions resulting mainly from rapid population growth and anthropogenic activities such as extensive cultivation and overgrazing are major causes of drought.

1.1 Spate Irrigation in Ethiopia

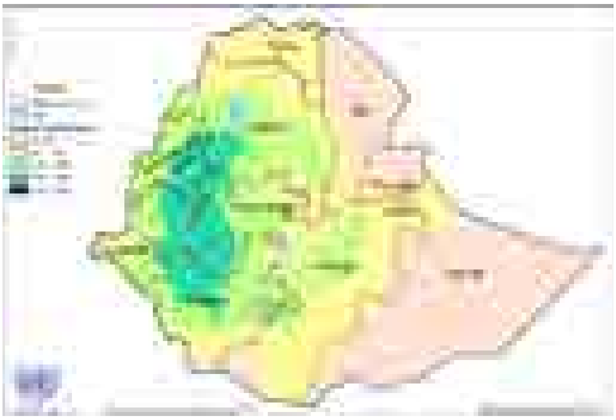
Definition of spate irrigation in Ethiopia

The definition of spate irrigation in Ethiopia differs from place to place. Generally, the meaning of the word spate is using seasonal floods to compensate for rainfall shortages and erratic rainfalls that could have affected seasonal harvests. In areas of traditional spate irrigation practices they have local names for spate irrigation. In southeast Ethiopia *'Gelcha'* is used for spate irrigation with a literal meaning of 'divert the flood into the farm.' *'Telefa'* is used in the northern parts of Ethiopia with the literal meaning of 'diversion.'

Potential and cultivated areas in spate irrigation

Ethiopia is known as a water tower of Africa for its peculiar geomorphologic and climatic setting. No drainage is coming in but flows out radiating in all directions. Arid and semiarid regions constitute 60% of the country's surface area with a rainfall variable coefficient of 50% (Figure 2.2). The remaining 40% is a recharge area with surplus rainfall with most of it flowing untouched through the surroundings.

Figure 2.2.Annual rainfall map of Ethiopia (OCHA 2006).



Lowlands with thick and fertile alluvial covered plains and availability of runoff flowing across these plains of millions of hectares of land are suitable for spate irrigation in Ethiopia. See slope gradient below (Figures 2.3, 2.4 and 2.5).

Figure 2.3. Slope gradient.

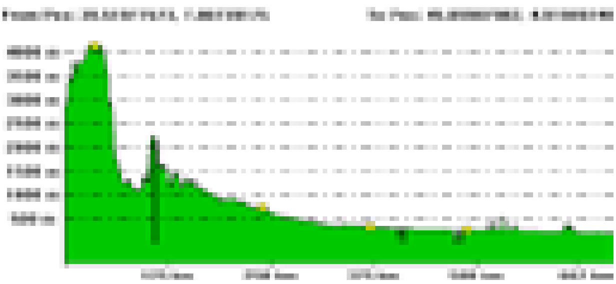
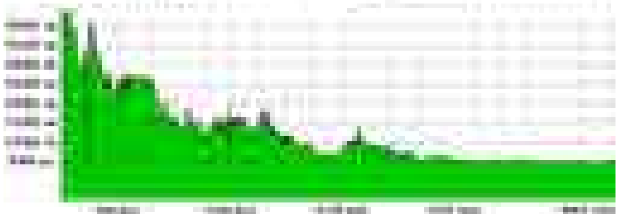


Figure 2.4. Slope gradient from northern highlands to southwestern lowlands.



As mentioned above, Ethiopia is suffering from repeated drought and most of its lowland areas are food-insecure. With increasing population and land degradation the food-insecurity problem is affecting even the highland areas. The main reason for the occurrence of drought is the erratic nature of rainfall and a moisture deficit for full crop growth (Figure 2.5). Various attempts have been made to harvest rainwater, floodwater, and groundwater to tackle the food security problem. Hundreds of thousands of ponds and hand-dug wells were constructed throughout the country in 2004/05 but the effort was not as successful as expected. Figure 2.6 shows a comparison of effective rainfall and evapotranspiration, in the eastern Ethiopian lowlands.

Figure 2.5. The densely populated recharge zone (highland) and the underutilized moisture-stressed lowlands.

Figure 2.6. Comparison of effective rainfall and evapotranspiration, in the eastern Ethiopian lowlands.

The radial flow from every side of the middle part of the country is considerable and can be captured before entering the deep-cut gorges. It is possible to cultivate the most food-insecure arid parts of the country by making diversion canals of various scales.

Development status

Despite the burning need and the prevailing problem little is done in Ethiopia to use spate water for irrigation. The history of water harvesting in Ethiopia dates back to the pre-Axumit period (560 BC) (Getachew 1999). It is a common and growing practice, particularly in arid parts of the country.

In East Ethiopia farm runoff is collected in small embankment gullies, and the ponded water is used for irrigating valuable (perennial) crops, such as chat (Chat cadulis), coffee and fruit trees. Use of seasonal floods originating from eastern highlands and ending up in the lowlands has been practiced in Dire Dawa area since the 1980s. Many farmers along these riverbanks are practicing flash flood spreading for crop production. Farmers in these areas were able to establish simple diversion (using wooden trash and soil materials) canals to convey the floodwater into their farms.

Similar activities are found in the northern parts of the country, Tigray, Amhara and southern regions. Runoff irrigation is widely practiced in the Chercher Plains around Mahoni and Waja near Alamata in Tigray, the Gato Valley in North Omo, parts of eastern and western Hararghe, and many other places. The practice in the Gato Valley also includes the use of ridge ties to retain the moisture around the plants. Similarly, the people in Konso, Gidole and many other parts of the southern region have been exercising the art of conserving soil and water. These traditional rainwater harvesting techniques use the soils as a media, particularly using bench terraces and trash lines on their cultivated lands (Habtamu 1999). Figure 2.7 shows spate irrigation practicing areas in Ethiopia.

Figure 2.7. Spate irrigation practicing areas in Ethiopia.

According to various recent estimates, the area of traditional spate irrigation farms in north, south and southeastern parts of the country exceeds 100, 000 ha. But areas under improved and modern operational spate irrigation do not exceed 20,000 ha. Figure 2.8 shows traditional and modern spate canals, southeastern Ethiopia. Spate projects under design and construction exceed 50,000 ha and each year numbers of new projects are added, especially in the southeastern parts of Ethiopia. From a very recent report (Annual Report, January, 2008) by the Ministry of Federal Affairs of Ethiopia it is learned that the total area covered by spate irrigation in the lowland parts of the country is 140,000 ha (see Figure 2.7 for major spate areas).

Figure 2.8. Traditional and modern spate canals, southeastern Ethiopia.

Administration of spate irrigation

Administratively, farm structures and farms are mostly private. But irrigation schemes are mostly public. O&M of spate structures are administered by both public and private parties.

Size of spate irrigation systems

There are three scales of perennial irrigation systems in Ethiopia. Schemes larger than 3,000 ha of irrigable land are categorized as large scale, those from 200 to 3,000 ha as medium scale and any scheme below 200 ha as small scale. As improved spate irrigation is new and its coverage is limited to a few localities no agreed scale is assigned. Oromia is using its own range of <500 ha as small, 500 to 2,000 ha as medium and >2,000 ha as large comparing the level of complexity and manageability with perennial irrigation schemes.

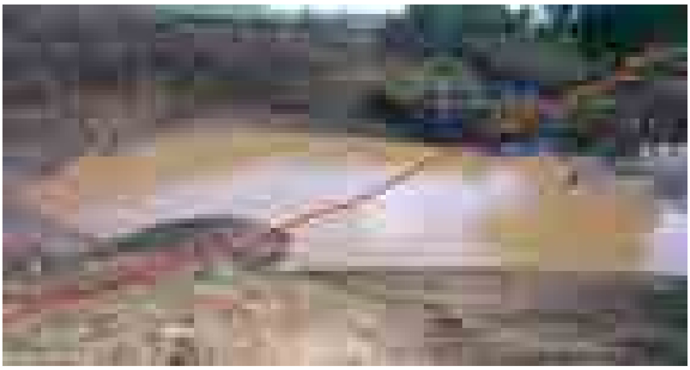
Characteristics of spate irrigation systems

Almost all traditional systems are managed by farmers and are small scale in size. Infrastructural upgrading of traditional systems is done by local governments and in very limited cases by NGOs with labor and material contribution from the user community. O&M of these improved systems are totally handled by the community; local government and NGOs offer occasional support when costs and damages to the structures are beyond the capacity of the users. Construction of medium- and large-scale spate irrigation schemes is done mostly by government and seldom by NGOs. In one of the regional governments, Oromia, an enterprise has been given a mandate to own/administer large perennial and spate irrigation schemes. It covers all the investment costs and distributes water to the users on cost recovery principles. It is planned that water use fees will compensate for O&M of main, secondary and tertiary canals and the weir site. Permanent staff and all necessary equipment for maintenance of the scheme will be assigned for each scheme.

Sources of water for spate irrigation

The main source of water for spate irrigation is seasonal flows in the dry streams. Using water harvesting and groundwater recharging techniques, farmers in some areas use water from ponds and shallow groundwater reserves to irrigate their farms (Figure 2.9). Such practice is growing fast, and the need for centrifugal pumps is increasing at higher rates.

Figure 2.9. Pumping water for supplementary irrigation from remnant ponds along traditional spate flow canals.



Water distribution methods

The more commonly used water distribution method is spreading flood in individual fields followed by field to field supplies where users are organized in WUAs. Extensive distributions are not common as most spate irrigation systems are limited in size.

Water diversion structures

Most diversion structures in traditional spate irrigation areas are spurs. They are constructed from earth, brushwood, sorghum roots, sand-filled bags and the like. Modern systems are constructed from masonry, concrete and gabions or combinations of the above with metal control gates. In some cases, sheet metal canals are used to convey water in places of valley crossings as shown in Figure 2.10.

Figure 2.10. Use of sand-filled bags and sheet metal to distribute water.

Use of stone, brushwood and trunks and making trenches to guide the water flow are common traditional techniques to protect bank and train wadis. In improved and modern spate irrigation systems, masonry walls and gabions are commonly used for this purpose.

Water distribution rules and rights

Although there are federal water policies, laws and regulations, these are not well-enforced. Therefore, there are no well-defined and common water distribution rules and rights in Ethiopia. Traditional rules and norms are more potent than the less-enforced government water policy and regulations. The followings are the most common prevailing practices.

a) Plot demarcation: Soil bunds are used as plot boundaries and rarely exceed 50 cm in height.

b) Breaking diversion bunds: WUAs set schedules for each farmer to break diversion bunds. The amount of water to be abstracted depends on the amount of flood. The dimensions of diversion bunds are judged by the WUAs.

c) Flow division: The same approach applies as above.

d) Sequence in which fields along channels are irrigated: Normally irrigation starts from upstream users and is fairly distributed to downstream lowland users. In most spate irrigation areas, the practice is started by the most moisture-stressed downstream users and as spate expands upstream the use right of those downstream beneficiaries is protected by leaders of the smallest administrative units, community elders and WUAs.

e) Depth of irrigation: Total coverage of plots is the minimum requirement; the depth varies depending on the frequency and quantity of flood. In most spate irrigation farms it does not exceed 20 cm. In high flood areas it goes as high as a meter.

f) Practices regarding second and third water turns: The same above-given principles apply.

g) Large and small floods: Areas inundated by large floods are cultivated following the retreat of the rivers. Thousands of hectares of land are cultivated using such overflows from large perennial rivers. This may/may not be categorized as spate irrigation.

Enforcement of water distribution rules

Regarding water distribution rules, the smallest administrative units intervene to enforce agreed rules and the implementing public organizations give technical assistance. In most spate areas water distribution is linked with farmer engagement in maintenance activities. To be eligible for access to water, users are forced to engage in canal clearing and maintenance.

Modalities used for maintenance of spate irrigation schemes

In terms of maintenance of spate systems in Ethiopia the most demanding one is maintenance of the main canal; this is commonly done by the community with technical assistance from local government or NGOs. Maintenance of individual fields is done by farm owners themselves. When maintenance on the individual field is beyond the capacity of a single farmer or his family he/she asks for assistance from neighbors using the traditional cooperation systems called 'debo' or 'jigi' (depending on localities). Commercial farmers farm out most of the maintenance work to local contractors. In some food-insecure areas communities are paid grains as part of the food-for-work program to maintain spate structures.

Soil-moisture conservation techniques used in spate irrigation

The common practice to conserve soil moisture is plowing before irrigation so as to create a porous media to help the water to infiltrate deeper and retain as much moisture as possible. Conservation tillage and soil bunds are also common but are mostly applied after sowing the field.

Risks of spate irrigation and adaptation of cropping strategies

In areas of longer flood flows the major risk that farmers face is the flood itself, which frequently washes away farms and breaks structures. In areas of low spate flows there is a risk of crop failure as a result of interrupted flow. Among the various cropping strategies that are practiced by farmers, growing local varieties adapted to local agro-climatic conditions is the main one followed by using improved drought-resistant seeds. Intercropping and adopting short-seasoned crop types (after confirming the failure of the first one) is also common. Even without anticipating risk, farmers in eastern Ethiopia practice intercropping to satisfy their various requirements and to enrich the soil nutrients. Haricot bean, rape seed and chat (Catha Endulis) are main secondary crops to be cultivated during the main rainy season.

Crops and productivity of spate farming

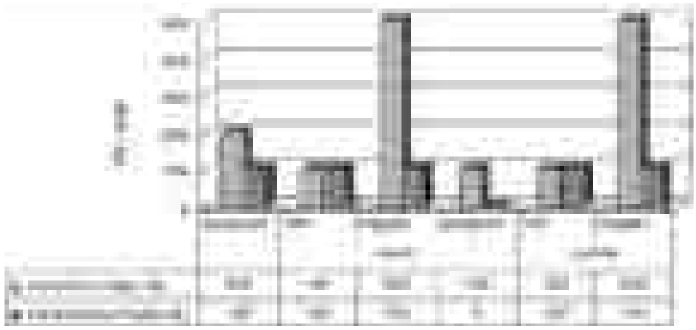
Types of cultivated crops depend on preference of the community. Although sorghum is the main crop to be cultivated in spate irrigation areas some communities do not like sorghum as a food crop. In such areas, maize replaces sorghum. Cereals, mainly wheat, are also cultivated as a food crop. Productivity of spate irrigated farms has recorded a tenfold increase with the same farm management and input at a recently completed spate scheme. Wheat production in one of the spate irrigation farms in central Ethiopia has risen to 3.2 tons on an irrigated field against 0.3 ton on an adjacent nonirrigated plot. The main income-generating practice in spate areas is cultivation of vegetables. In eastern parts of the country cultivation of khat is also the main income-generating practice. Sesame is also common in some localities.

In 1998, one farmer on a spate irrigation farm in Lage Oda Merga PA in eastern Ethiopia was able to raise his sorghum yield from 3 to 8 quintal (1 quintal=100 kg) in 1.2 ha of land. Another farmer raised his farm productivity from 8 quintals to 20 of sorghum, again from the same size of land. The low yield of the farmers was due to the use of local variety, red sorghum, Jildi (Getachew 1999). Figure 2.11 shows sorghum and wheat under spate irrigation, eastern Ethiopia.

Figure 2.11. Sorghum and wheat under spate irrigation, eastern Ethiopia.

As mentioned in a survey done by Ephraim et al. (2003) in northern Ethiopia, farmers described the difference in productivity of certain crops by giving examples. Accordingly, sorghum production in one of the spate farms showed a change of about 100% because of runoff diversion, while in another farm absence of runoff may have caused a total loss. Chili pepper production showed a tremendous increment under spate irrigation, i.e., under rain-fed (dry) condition the yield is a mere 1,000-1,200 $kgha^{-1}$ but runoff diversion increases chili pepper yield up to 5,000 $kgha^{-1}$ (Figure 2.12). On the other hand, the production of Tef has no significant change in volume of production due to flood irrigation. However, availability (application) of the flood irrigation has an effect on improving the quality of Tef grains, which enhances the market prices due to the higher consumer preferences for the latter. Therefore, use of the flood irrigation for Tef still has a benefit to farmers as it ultimately increases the price of Tef at the market (ibid.).

Figure 2.12. Yield differences due to flood diversion.



Source: PRA report, December 2001

Cost of development of spate irrigation system

Incurred costs for development of spate irrigation projects vary spatiotemporally. In remote parts of the country although labor cost is cheap or free and locally available material is free or cheap, the cost of mobilization and demobilization of machinery makes it expensive. The scale of projects also affects the cost. In modern structures the local community input is minimum (not more than 10%) and as a result the project cost is high, whereas the contribution of the community in improved spate irrigation systems is so high that this makes it cheaper. As estimated from ongoing spate projects, the current construction cost of spate projects ranges from USD 170 to 220 ha^{-1} for non-permanent headworks, including soil bunds, gabion structures and diversion canals and up to USD 450 for permanent headworks for small systems including diversion weirs and bunds. The cost of permanent headworks for large systems including diversion weirs, breaching bunds and siphons as estimated from the ongoing project (Koloba Spate Project) ranges from USD 330 to 450 ha^{-1} (OIDA Annual report 2007).

Gender and spate irrigation

Spate irrigation is a labor-intensive task and involves almost all segments of the community, except small children (Figure 2.13). Involvement of men, women and children depends on the degree of complexity of the task and cultural issues. The main responsibilities of men and women in spate are summarized in Table 2.1 below.

Table 2.1. Roles in spate irrigation schemes by gender.

Activity	Men	Women
Infrastructure-related	✓	
Operation (water distribution)	✓	
Maintenance	✓	
Agricultural practices	✓	✓
Harvesting	✓	✓
Marketing	✓	✓✓

Figure 2.13.Women and children participating in the development of a traditional spate irrigation system.

Constraints of spate irrigation

Constraints of spate irrigation are multidimensional. The limited experience combined with the lack of due attention by researchers, government, NGOs and donors makes it more difficult to overcome the problems. The following are the major constraints pointed out by different authors and clearly seen in the fields.

1. Rapid deterioration of physical conditions of systems

This problem is prominent in traditional irrigation areas where farmers are forced to maintain the main canal and others whenever there is high flood. The loose structures made of bush or soil is washed away by flood and they frequently lose a portion of the soil in such events. Erosion of riverbanks and loss of a portion of farm lands is also common in some areas. Although they are not as destructive as on the traditional systems these problems also affect improved and modern systems. Frequent silting up of diversion canals is also one of the prominent problems facing spate systems in Ethiopia (Figure 2.14).

Figure 2.14. Damaged flume structure and silt-filled canal.

2. Rainfall variability

Availability and quantity of floodwater that may reach farm plots of households depend on the overall rainfall received in the upstream. However, the floodwater only complements the actual rainfall directly received on the farm plots, which primarily influences the different aspects of the microclimate to favor plant growth. In most arid parts of the country the contribution of the floodwater of whatever magnitude is, therefore, minimal in the absence of direct rainfall on the area. Therefore, despite the existence of the traditional spate irrigation systems that provide lifesaving irrigation water, the production system remains as rain-fed agriculture that makes farmers vulnerable to intermittent shocks unavoidable in the event of failure/shortage of seasonal rainfall.

3. Equity

There are cases where equity is a problem on spate schemes. The case in northern Ethiopia is one example. According to a PRA survey done by Ephrem et al. (2003), there are certain aspects of the traditional spate irrigation system that limit its equitability aspect. Individual users are given a date by leaders of their water user association for their turns to use floodwater. However, no flood may occur on that predetermined date, and if there is no rainfall in the upstream on that date the person's turn will be cancelled. Under such institutional arrangements, particularly with an unreliable rainfall pattern, individual households might miss an entire seasonal flood.

4. Lack of government financial support and extension services

The above-mentioned survey also identified lack of support in spate areas as a very limiting factor. There are no significant efforts made by development and research institutions to address the rigorous demands of risk minimization in the spate irrigation areas. Although farming communities have managed to deal with their environmental constraints through different locally innovated technologies and adoptive sociocultural setups, obvious gaps exist in terms of providing research and development support to improve promising traditional practices. This would mean opportunities for communities to share knowledge across areas and the capacity to upgrade local technologies.

On the other hand, lack of visible external interventions towards long-term enhancement of the risk management capacity of poor farmers (e.g., improving existing traditional practices) will limit the contribution of the traditional spate irrigation systems to sustainable food security in the study area and other areas with a comparable setting. Moreover, in the absence of a focus on the creation of alternative livelihood opportunities and improvement of the institutional and structural status of the area (extension, markets, credit and infrastructures, etc.) the sustainability of the existing farming systems and production practices seems unreliable (ibid.).

5. Lack of market opportunities

Production of high-value vegetables in remote parts of the country is hindered by the lack of access to markets. In eastern Ethiopia, farmers with adequate water and suitable land for vegetable growth are forced to cultivate maize or plant sugarcane and other nonperishable crops. Most farm produce is not market-oriented, but is mainly for home consumption. Absence of clustering of small and fragmented smallholder plots, infrastructure and communication is also a problem that hinders market-oriented farming practices.

6. Land tenure

Land is public property in Ethiopia. Fragmentation of land in smallholdings and the increasing trend of shrinking landholding across time influence the ability of land users to cope with their problems, as well as investment on improved technologies. Another constraint for investment on sustainable spate systems noticed during the PRA study mentioned above was the absence of landownership. Due to absence of clear landownership, farmers cultivate the land under temporary arrangements and expect the land to be taken away from them during the next land redistribution. Under these conditions, farmers may perceive investment in long-term land improvement (construction of high labor input structures, conserving riverbank erosion, etc.) as inappropriate because they are unlikely to reap the benefit of their work. Therefore, farmers prefer low or no investment in technologies, which may lower opportunities to improve productivity.

Conclusions

There are millions of hectares of land, which can be spate irrigated, are food-insecure and currently receive relief aid. These areas can be transformed to have a food surplus and become development centers by using the available spate potential and the suitable fertile arable land. Therefore, systematic assessment of spate potential in the lowlands of Ethiopia and implementing feasible spate irrigation projects are essential to change the existing food-insecurity scenario in the lowlands of Ethiopia.

Conjunctive use of spate systems as a means of soil and water conservation adds more value to spate irrigation practices. Water stored in the subsurface will be utilized in the absence of floods, and the alluvial deposit helps minimize the cost of fertilizer inputs.

The agronomy of spate irrigation systems should be given greater attention. Production of high-value crops, such as sesame and groundnut, supported by research and proper land use plans should be implemented. Parallel with this the market conditions must also be improved. Donors, NGOs and all stakeholders should learn from existing successful spate practices and assist farmers to combat poverty.

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UN Integrated Regional Information Networks(Various unpublished reports and plans)

Section 2
Impacts of Spate Irrigation

Spate Irrigation and Poverty in Ethiopia

Fitsum Hagos,[1] Teklu Erkossa,[1] Nicole Lefore[2] and Simon Langan[1]
[1]*International Water Management Institute, Nile Basin and East Africa Office, Addis Ababa*
[2]*International Water Management Institute, Southern Africa office, South Africa*

Abstract

The study examined whether the use of spate irrigation in drought-prone areas of Ethiopia reduced poverty. Each of about 25 users of indigenous and modern spate irrigation schemes and an equal number of corresponding nonusers from the same peasant associations in Oromia and Tigray regional states were interviewed. The survey found that the poverty level of the spate irrigation users was significantly lower than that of the nonusers in terms incidence, depth and severity. Access to improved spate irrigation has led to reduced poverty, measured by all poverty indices, compared to traditional spate. Finally, the dominance test showed that the poverty comparison between users and nonusers was robust. From the study, it can be concluded that the use of spate irrigation in areas where access to other alternative water sources is limited, either by physical availability or by economic constraints, can significantly contribute to poverty reduction, and that modernizing the spate system strengthens the impact.

Key words: *Headcount ratio, poverty gap, severity of poverty, stochastic dominance test, Ethiopia, Africa*

Introduction

Most farmers in drought-prone lowlands of Ethiopia produce only once a year. A long dry spell or drought can lead to crop failure that exacerbates food shortage and poverty. The severity of such climate-related crop failures increases with decreasing altitude. The Ethiopian government is convinced that full or supplementary irrigation is required to minimize the risk of crop failure (FDRE 2010), depending on the availability of the water resources.

Flood-based farming including spate irrigation (SI) is among the potential options in ensuring water availability for crop and livestock production in the arid and semiarid lowlands as access to other sources of water is limited either by physical availability or high costs. SI is a unique form of water resources management that has been practiced in arid and semiarid regions where evapotranspiration greatly exceeds rainfall (FAO 2010). It is a form of water management involving the diversion of flashy floods running off from mountainous catchments, using simple deflectors of bunds constructed from sand, stones and brushwood on the beds of normally dry wadis (Lawrence and Steenbergen 2005).

Spate irrigation (SI) has been practiced by farmers in different parts of Ethiopia for many decades as a relatively low-cost and technically simple alternative. It was only recently that the government and other development partners began to pay attention to spate. According to Alemayehu (2008), SI is practiced in Tigray, Amhara and Oromia regional states. Since antiquity it has also been practiced at Konso in Southern Nations, Nationalities and People's Region (SNNPR) and in places like Aba'ala in Afar Region (Spate Project Technical Report 2012). SI is very common in Raya Azebo (Tigray), Kobo (in Amhara), Dedota and Arsi Negelle (Oromia) and Omorate (SNNPR). Recent estimates for the area under SI in Ethiopia are not available, but Alemayehu (2008) reported about 140,000 ha of land under SI system in 2008 with a very high annual increase anticipated. Over the last two to three decades, there has been an increased investment in improving the traditional schemes or development of new SI schemes in different parts of the country with the objectives of ensuring food security and poverty reduction.

SI schemes can be classified as traditional and modern diversions (for details see Erkossa et al. 2013). Traditional diversions consisting of deflecting spurs or, in flatter plains areas, bunds that are constructed across the flood channel and canals, are usually short and rarely include a secondary distribution system. Improved traditional systems are farmer-implemented, improved diversion structures and rejection spillways near canal heads, drop structures and flow diversion structures in main canals. In modernized and new systems, numerous traditional intakes are replaced with concrete diversion weirs with sediment sluices as well as steep canals and sediment management structures to minimize sedimentation (Erkossa et al. 2013). This study used only two typologies, traditional and improved, without modern improved SI systems.

Various studies indicated the positive impacts of permanent irrigation on productivity and people's livelihood as measured in marginal factor productivity, poverty (income and expenditure) and food security (Hanjra and Gichuki 2008; Hanjra et al. 2009; Namara et al. 2010; Hagos et al. 2012, 2013). As far as we could tell, however, there is no empirical evidence on the impact of SI on household poverty.

The study aims, therefore, to explore if SI has a significant impact at household level in improving livelihoods of smallholder farmers. It seeks to address the following research question: Does SI lead to significant reduction in household poverty? The study provides evidence on whether investing in SI has important implications on livelihoods (measured in terms of household poverty), which is important for the policy decision to promote this particular intervention.

Methodology

We estimated poverty following the money metric approach. Income or consumption could be used as the indicator of well-being. Most analysts argue that, provided the information on consumption obtained from a household survey is detailed enough, consumption is a better indicator than income for poverty measurement for many reasons (Coudouel et al. 2002). Hence, in this paper we estimated poverty profiles using expenditure adjusted for differences in household characteristics. The food and absolute poverty lines for 2010/11 were determined to be Birr 1,985 and 3,781, respectively (FDRE 2012). These values were used to calculate poverty indices.

We used the Foster-Greer-Thorbecke (FGT) class of poverty measures to calculate poverty indices (Foster et al. 1984). The FGT class of poverty measure is given as follows:

$$P_{\alpha} = \frac{1}{N}\sum_{1}^{N}\left(\frac{G_i}{z_i}\right)^{\alpha}, (\alpha \geq 0) \tag{1}$$

where, z denotes the poverty line, G_i Difference between expenditure per adult equivalent and poverty line for household *i* N = Total population (of the sample), and α is a nonnegative parameter indicating the degree of sensitivity of the poverty. It is usually referred to as the poverty aversion parameter. Higher values of the parameter indicate greater sensitivity of the poverty measure to inequality among the poor. The relevant values of α are 0, 1 and 2.

The FGT class of poverty measures have some desirable properties (such as additive decomposability), and they include some widely used poverty indices (such as the head-count ratio, poverty gap and severity of poverty measures). Following Duclos et al. (2006), the relevant values of *a* are 0, 1 and 2 where at *a* = 0 the equation measures poverty incidence or the headcount ratio, at *a* =1 the equation measures depth of poverty (poverty gap) and at the equation measures poverty severity index or squared poverty gap. This takes into account not only the distance separating the poor from the poverty line (the poverty gap), but also the inequality among the poor.

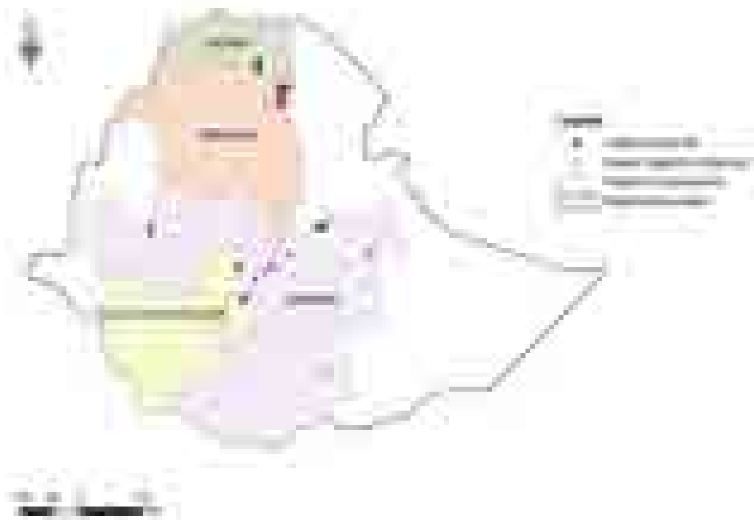
We calculated these indices using STATA 11.0 and tested for differences in poverty profiles between groups following approaches suggested by Kakwani (1993) and Davidson and Duclos (2000).

Poverty comparisons can, however, be sensitive to the choice of the poverty line. The important issue in poverty analysis is that the poverty line yields consistent comparisons (Ravallion 1994). Stochastic tests used to check the robustness of ordinal poverty comparisons prove to be useful in poverty analysis (Atkinson 1987). The idea of standard welfare dominance is to compare distributions of welfare indicators in order to make ordinal judgment on how poverty changes (between groups in this paper) for a class of poverty measures over a range of poverty lines (Ravallion 1994; Davidson and Duclos 2000). Hence, we conducted ordinal poverty comparisons using stochastic dominance tests and checked the robustness of the poverty orderings. This is to make ordinal judgments on how poverty changes for a wide class of poverty measures over a range of poverty lines.

Study sites and data sources

Two sites each in Tigray and Oromia were chosen for this study, with one traditional and one improved traditional. In Tigray, the sites included Fokisa (improved) and Gereb Heshewa (traditional). In Oromia, the sites were Dodota (improved) and Awadi (traditional). These sites were a subsample of samples (see Figure 3.1) used earlier in characterizing spate irrigation in Ethiopia (Erkosssa et al. 2013). From each site, 50 households were systematically selected for the purpose of this study, 25 users and 25 nonusers of spate irrigation. Each selected household was interviewed, using a pretested questionnaire, on access to services and infrastructure, demographic characteristics, access and use of spate irrigation, crop, livestock credit and off-farm income, food and nonfood expenditure, food security, and nutrition and health outcomes. Food and nonfood expenditures were used to assess the poverty impact of access to SI.

Figure 3.1. Location of the spate irrigation schemes and sites visited for this study.



Results and Discussion

Section 4 provides the results of summary statistics, poverty profiles and stochastic dominance tests, reported below.

Descriptive summary

The mean comparison tests indicate that users are better-off than nonusers, on average, in terms of several livelihood indicators (see Table 3.1), such as food expenditure, nonfood expenditure, completed primary education, etc. SI users have also a statistically higher livestock holding, family size (although insignificant in terms of female adults) compared to nonusers. This may imply that SI users are better-off compared to nonusers. But a mean comparison test does not consider the effect of other covariates in the calculation of mean value of a given variable and assessing the difference between groups. Thus we could not reach a final conclusion before we made a systematic analysis (by controlling other covariates) on whether access to SI has led to significant effects on household poverty.

Table 3.1. Mean comparison of spate users and nonusers.

Variable name	Mean of user of spate (n= 97)	Mean of nonusers of spate (n= 97)	t-test
Age of household head (in years)	43	42.1	0.445
Family size (in number)	5.361	4.814	-1.877*
Female adults (in number)	1.271	1.302	0.409
Male adults (in number)±	1.536	1.474	-0.411
Off-farm income (in ETB)	1490.88	1197.15	-0.568
Asset holding (in TLU)	1.845	1.281	-1.720*
Livestock income (in ETB)	783.21	1453.57	1.216
Credit income (in ETB)	740.38	753.51	0.075
Food expenditure during the last month (in ETB)	1951.46	1488.74	-2.330**
Nonfood expenditure during the last month (in ETB)	434.73	216.31	-2.625***
Total expenditure during the last month (in ETB)	2386.2	1705.057	-2.873*
Members' quantity, completer primary education	2.1237	1.659	-1.905**
Members' quantity, completer secondary education	0.773	0.659	-0.629

In some cases, observations (n) are not similar in number: ┼ = one observation is missing; ±= users 84 and nonusers = 78. *, **, *** significant at 10, 5, 1%, respectively.

Poverty indices

The study indicated that overall poverty in the study sites was lower compared to the national figures released in 2012 based on household income and expenditure survey (HICE) of 2010/11. The food poverty headcount index and food poverty gap index in the country are estimated at 33.6 and 10.5%, respectively, in 2010/11 while the national food poverty severity index stood at 4.6% (FDRE 2012). The incidence of food poverty of the overall sample is 5.5%, while depth and severity of food poverty are estimated at 0.4 and 0.05%, respectively. That is 5.5% of the individuals in the population were below the poverty line while the average distance from the poverty line is estimated at 0.4% (poverty gap) of the poverty line (or 794 Birr.month^{-1}.individual^{-1} that is required to bring the poor out of poverty) and about 0.05% severely affected by inequality.

On the other hand, as regards absolute poverty, 27% of the population are poor (headcount index) while poverty gap and severity of poverty are estimated at 6.7 and 2.2%, respectively (see Table 3.2). That is, about 27% of the individuals in the population in the study site were below the absolute poverty line (absolutely poor), considering both food and nonfood expenditures. The poverty gap, which is the average distance from the poverty line, is estimated at 6.7% of the poverty line amount (or Birr 2,646 month^{-1} individual^{-1} are required to bring the poor out of poverty). Finally, inequality is very severe for 2.2% of the individuals.

Table 3.2. Poverty indices of users and nonusers.

	Poverty indices		
Categories	P0	P1	P2
Food poverty of the overall sample (n = 577)	0.055 (0.009)	0.004 (0.001)	0.0005 (0.0002)
Absolute poverty of the overall sample (n = 577)	0.272 (0.018)	0.067 (0.005)	0.022 (0.002)
Food poverty SI users (n = 194)	0.031 (0 .012)	0.002 (0.0015)	0.0004 (0.0004)
Food poverty SI nonusers (n = 394)	0.068 (0.0127)	0.0046 (0.0012)	0.00063 (0 .0003)
z-statistics*	-44.562**	-27.534**	-15.886**
Absolute poverty SI users (n = 194)	0.186 (0.0279)	0.0373 (0.0073)	0.0116 (0.003)
Absolute poverty SI nonusers (n = 394)	0.319 (0.0235)	0.0817 (0.0073)	0.0278 (0.0031)
z-statistics	-99.928**	-91.728**	-74.865**

* The z-statistic is derived using Kakwani's (1993) and Davidson and Duclos' (2000) formulae to test for equality of poverty measures. The critical value for the test statistic is 1.96 (applicable for all tests in Tables 3.2 and 3.3) at 5% level of significance.

** Significant at 5% level of significance.

Access to SI significantly reduced household poverty. The headcount ratio of food poverty with and without access to SI is 3.1 and 6.8%, respectively. Similarly, the poverty gap of food poverty with and without access to SI is 0.2 and 4.6%, respectively. The severity of poverty of food poverty with and without access to SI is 0.4 and 0.6%, respectively. The corresponding ratios of incidence of poverty for absolute poverty with and without access to SI are 18 and 32%, respectively, while those of the poverty gap of absolute poverty with and without access to SI are 3.2 and 8.2%, respectively, and the severity of poverty of absolute poverty with and without access to SI is 1.1 and 2.8%, respectively. The poverty indices could be interpreted in a similar manner, as indicated above.

The use of improved SI resulted in a significant difference in household poverty levels as compared to the use of traditional SI schemes (see Table 3.3). The headcount ratio of food poverty with improved and traditional SI is 2 and 6%, respectively. The poverty gap of food poverty with improved and traditional SI is 0.3 and 0.5%, respectively. The severity of poverty of food poverty with improved and traditional SI is 0.1 and 01.1%, respectively.

Table 3.3. Poverty indices of users and nonusers.

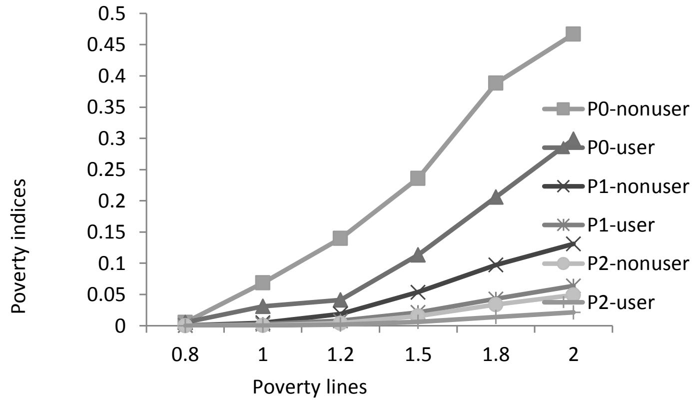
	Poverty indices					
Categories	P0		P1			P2
Food poverty of improved SI (n = 246)	0.020	(0.009)	0.003	(0.001)	0.001	(0.0003)
Food poverty of traditional SI (n = 434)	0.060	(0.0114)	0.005	(0.0012)	0.0011	(0.0002)
z-statistics	-	53.362**	-	30.889**	-	19.249**
Absolute poverty of improved SI (n = 246)	0.219	(0.026)	0.0537	(0.007)	0.016	(0.003)
Absolute poverty of traditional SI (n = 434)	0.295	(0.022)	0.080	(0.007)	0.027	(0.003)
z-statistics	-	174.729**	-	100.411**	-	83.909**

** Significant at 5% level of significance.

Robustness of the ordinal measure

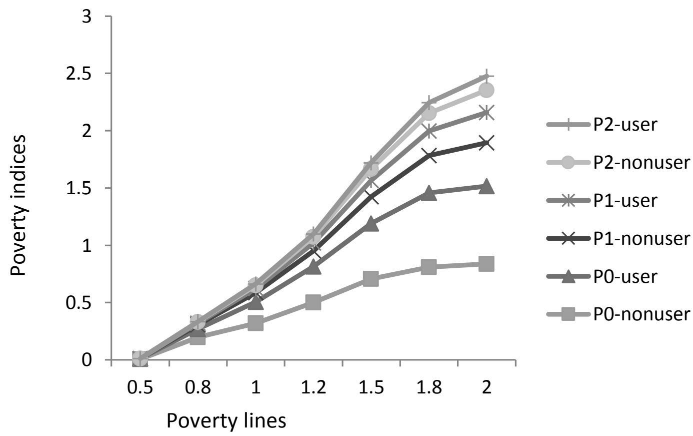
Whether poverty comparisons between the users and nonusers are robust could be examined using stochastic dominance tests. The test results indicated that the probability distributions of poverty indices (P0, P1 and P2) of users in food poverty are stochastically dominant than the distribution of poverty indices (P0, P1 and P2) of nonusers (see Figure 3.2).

Figure 3.2. Stochastic dominance test of food poverty of users and nonusers.



Likewise, the test results indicated that the probability distributions of poverty indices (P0, P1 and P2) of users in absolute poverty are stochastically dominant than the distribution of poverty indices (P0, P1 and P2) of nonusers (see Figure 3.3).

Figure 3.3. Stochastic dominance test of absolute poverty of users and nonusers.



The above result indicated that the poverty comparison between the users and nonusers is robust. In other words, regardless of changing the poverty line, the probability distribution of poverty indices of users is dominant than the probability distribution of poverty indices of nonusers, in both food and absolute poverty.

Conclusion and recommendations

The use of spate irrigation increased crop productivity, household income and reduced household poverty. Nonetheless, there was no empirical evidence so far that explores the welfare impact of spate irrigation. This paper provided evidence that may have important implications on policy decisions.

The study revealed that overall poverty in the study sites was lower compared to the national figures. The food poverty headcount index in the country was estimated at 33.6% in 2010/11, while the poverty gap index was estimated to be 10.5% and the poverty severity index stood at 4.6%. For the study area, however, the incidence of food poverty of overall sample is 5.5%, while depth of poverty is estimated at 0.4% and severity of poverty is estimated at 0.05%. Likewise, headcount is estimated at 27% while poverty gap and severity of poverty are estimated at 6.7 and 2.2%, respectively, of absolute poverty.

Regardless of the location or type of scheme (traditional or modern), access to spate irrigation significantly reduced poverty. When we compare households with and without access to spate irrigation, there is significant difference in poverty levels. Moreover, the difference in the level of household poverty was significantly affected by the type of spate irrigation scheme (improved or traditional) to which they have access to; those using the improved scheme are better off. Furthermore, the test results indicated that the probability distributions of poverty indices (P0, P1 and P2) of users in food and absolute poverty are stochastically dominant than the distribution of poverty indices (P0, P1 and P2) of nonusers.

The most important conclusion of this study is that SI has a significant impact on poverty reduction, even more so for improved schemes. Therefore, the study has an important policy implication: enhance access to SI in areas where access to other water resources is limited. In addition, improvement to the traditional SI schemes or development of new ones is also important (taking into account the design and construction factors noted in other papers here).

Acknowledgements

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Annex

Table A1. Nutrition (calorie) based equivalence scales.

Age in years	Men	Women
0 - 1	0.33	0.33
1 - 2	0.46	0.46
2 - 3	0.54	0.54
3 - 5	0.62	0.62
5 - 7	0.74	0.70
7 - 10	0.84	0.72
10 - 12	0.88	0.78
12 - 14	0.96	0.84
14 - 16	1.06	0.86
16 - 18	1.14	0.86
18 - 30	1.04	0.80
30 - 60	1.00	0.82
60 plus	0.84	0.74

Source: Dercon and Krishnan (1998).

Diversion of Flashy Floods for Agricultural Use and its Effect on Nutrition in Ethiopia

Fitsum Hagos,[1] Afework Mulugeta,[2] Teklu Erkossa,[1] Nicole Lefore[3] and Simon Langan[1]

[1] International Water Management Institute, Nile Basin and East Africa, Addis Ababa

[2] Mekelle University, College of Health Sciences

[3] International Water Management Institute, Southern Africa office, South Africa

Abstract

The study examined whether access to spate irrigation leads to better nutrition outcomes. The results showed that there is an overall improvement in the study sites compared to the 2011 DHS study. As far as households with access to spate irrigation are concerned, weight-for-height z-scores indicated that 8.2% of the children had prevalence of global acute malnutrition; 8.2% of them had moderate acute malnutrition. None of the children had severe acute malnutrition. The weight-for-age results indicated that 27.5, 17.6 and 9.8% of the children showed prevalence of underweight, moderate underweight and severe underweight, respectively. The height-for-age z-scores showed 56.5, 30.8 and 21.7% of the children had prevalence of stunting, moderate stunting and severe stunting, respectively. On the other hand, households without access to spate irrigation indicated that as far as the weight-for-height z-scores of children are concerned, there were no children (boys and girls) with prevalence of global acute malnutrition; weight-for-age z-score showed that 13.6, 10.2 and 3.4% of the children had prevalence of underweight, moderate underweight and severe underweight, respectively. The height-for-age z-scores showed that 45.5, 25.5 and 20.0% of the children had prevalence of stunting, moderate stunting and severe stunting, respectively. The anthropometric measures, thus, showed the nutritional outcomes of users were worse-off than of nonusers of spate irrigation. This happens in the face of better income and consumption expenditures, mainly nonfood, for users compared to nonusers. This underlines the importance of nutrition education alongside efforts to improve access to irrigation. Moreover, multisectoral collaborations are needed between the health, agriculture, water, social protection, education, gender and other sectors to improve the nutrition outcome of children.

Key words: *Weight-for-age, height-for-age and weight-for-height z-scores, Ethiopia, Africa*

1. Background

Various studies indicated the positive impact of perennial irrigation systems on productivity and people's livelihood, measured in marginal factor productivity, poverty (income and expenditure) and food security in sub-Saharan Africa, particularly in Ethiopia (Hanjra and Gichuki 2008;

Hanjra et al. 2009; Namara et al. 2010; Hagos et al. 2012, 2013). As far as we could tell, however, there is no empirical evidence related to household's livelihood impact of diverting floods for crop production also known as spate irrigation (SI).

SI is a unique form of water resources management that has been practiced in arid and semiarid regions where evapotranspiration greatly exceeds rainfall (FAO 2010). It is a form of water management involving the diversion of flashy floods running off from mountainous catchments, using simple deflectors of bunds constructed from sand, stones and brushwood on the beds of normally dry wadis (Lawrence and Steenbergen 2005). Short-duration floods are diverted from riverbeds and spread over land – to cultivate crops, feed drinking water ponds, or irrigate pasture areas or forestlands (Van Steenbergen et al. 2011).

SI schemes can be classified as small, medium and large, depending on the area they irrigate and could be categorized into traditional and modern diversions (for details see Erkossa et al. 2013). Traditional diversions consist of deflecting spurs or, in flatter plains areas, bunds that are constructed across the flood channel and canals, which are usually short and rarely include a secondary distribution system. In improved traditional systems there are farmer-implemented (although government- or NGO-supported) improved diversion structures and rejection spillways near canal heads and drop structures and flow diversion structures in main canals. In modernized and new systems, numerous traditional intakes are replaced with concrete diversion weirs with sediment sluices as well as steep canals, and sediment management structures are provided to minimize sedimentation (Erkossa et al. 2013).

SI promotes higher productivity of farming systems by supplementing the low and erratic rainfall (Van Steenbergen et al. 2011). Since most farmers produce only once a year, a long dry spell or drought can lead to a chronic food shortage and poverty. The severity of such climate-related crop failures increases with decreasing altitude. Therefore, the Ethiopian government is convinced that full or supplementary irrigation is required to minimize the risk of crop failure. Since it is considered as an existing opportunity and perceived to have low investment cost, SI systems are considered as the option in vast areas of the lowlands to support the unreliable rain-fed cropping system. As a result, in Ethiopia spate irrigation is – as elsewhere in sub-Saharan Africa – on the increase (Van Steenbergen et al. 2011).

This form of water management system is practiced in Tigray, Amhara and Oromia regional states. It has also been practiced at Konso in Southern Nations, Nationalities and People's Region (SNNPR) since antiquity and in some places in the Afar Region (Alemayehu 2008). Alemayehu (2008) reported an estimated area under SI in year 2008 to be about 140,000 ha, with a very high annual increase.

SI is very common in the districts of Raya Azebo (Tigray), Kobo (in Amhara), Dedota and Arsi Negelle (in Oromia) and Omorita (in SNNPR). This study focused on two traditional and two modern SI schemes in Tigray and Oromia regions. The study covered 200 households from both sites, half of them with access to SI (intervention) and half of them without access (control).

The study aims, therefore, to explore if SI has a significant impact on improved growth and nutrition of children of smallholder farmers. A pertinent research question to examine is whether there are differences in nutritional outcomes of children under the age of 5 years between SI users' and nonusers' households. The study provides evidence that has an important policy implication.

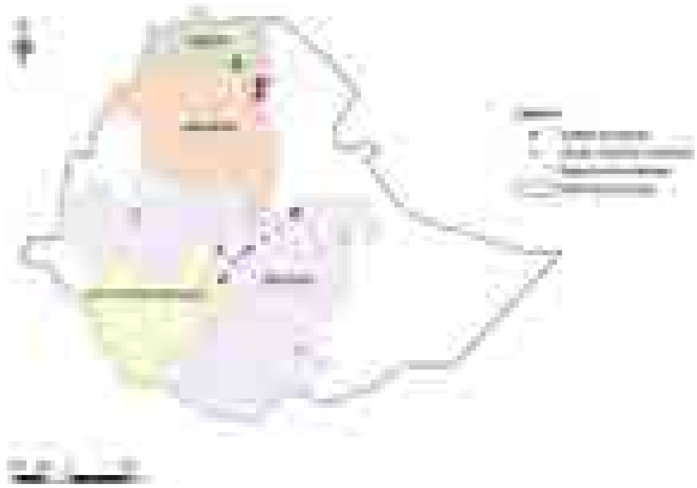
2. Methodology

Evaluation of nutritional status in this study is based on a comparison of height and weight for the children with data for child growth standards reference population of well-nourished children (WHO 2007). Height-for-age (HAZ) is the measure of linear growth. Children with HAZ below -2Z scores below the 5th percentile of the 2007 WHO standard population were classified as stunted. That is a child who is below -2Z from the reference mean for height-for-age is considered short for his/her age. Weight-for-height (WHZ) describes current nutritional status. A child who is below -2Z from the reference mean for WHZ is considered too thin for his/her height, or wasted, a condition reflecting acute or recent nutritional deficit. Weight-for-age (WAZ) is a composite index of WHZ and HAZ, and thus does not distinguish between acute malnutrition (wasting) and chronic malnutrition (stunting). A child can be underweight for his/her age because he or she is stunted, wasted, or both. WAZ, thus, is an overall indicator of a population's nutritional health. Children with HAZ and WAZ between <-2 z-score and >=-3 z-score were classified as moderately stunted and underweight, respectively. Children with HAZ and WAZ below < -3 z-scores were classified as severely stunted and underweight, respectively (Wang and Chen 2012). HAZ, WAZ and WHZ values below < -6 or > 6 were considered outliers. But none of the z-scores were out of range. In our data set for 12 cases, z-scores were not available (missing) and when we did range a plausibility check the observations were reduced by two or three units in the total sample. WHZ, WAZ and HAZ z-scores of children of households with access and with no access were reported to see the impact of access to spate irrigation. Gender disaggregated values for WHZ, WAZ and HAZ z-scores were reported to see if there were gender differences in nutritional outcomes. The z-scores were calculated using ENA (Emergency Nutrition Assessment) SMART. For similar approaches (see Mulugeta et al. 2009, 2010). But access to SI may not be the direct cause of malnutrition.

3. Study site and data sources

Two sites each in Tigray and Oromia, Fokisa, improved and Gereb Heshewa, traditional (both in Mehoni) and Dodota, improved (western Arsi) and Awadi (Arsi Negele) traditional, respectively, were purposively selected for the study. These sites were a subsample of samples (see Figure 4.1) used earlier in characterizing SI in Ethiopia (Erkosssa, et al. 2013). Fifty (50) households from each site, 25 with access and 25 without access, were selected using systematic sampling for the purpose of this study. Each selected household was interviewed, using a pretested questionnaire on access to services and infrastructure, demographic characteristics, access and use of spate irrigation, crop, livestock credit and off-farm income, food and nonfood expenditure, food security, and nutrition and health outcomes.

Figure 4.1. Location of the spate irrigation schemes and sites visited for this study.



4. Data management and statistical analysis

For this study, age, sex, weight and height of children under 5 years of age (122 children in total) were measured and recorded using locally made stadiometer with a sliding headpiece, and portable mechanical analogue-hanging scales, respectively. Height was measured to the nearest 0.1 cm and weight to the nearest 0.1 kg. Each subject was weighed with minimum clothing and no foot wear. The scales were carefully handled and periodically calibrated to ascertain accuracy. To avoid variability among the data collectors, the same measurers were employed for a given anthropometric measurement. Anthropometric measurements were converted to height for-age, weight-for-age and weight-for-height z-scores.

5. Results and discussion

5.1 Descriptive summary

The mean comparison test indicates that users are better off in terms of several livelihood indicators (see Table 4.1), like food expenditure, nonfood expenditure, primary education (complete), etc. SI users have a statistically higher livestock holding and family size (although insignificant in terms of female and male adults) compared to nonusers. This may imply that SI users are better-off in terms of major livelihood indicators compared to nonusers. But mean comparison test does not consider the effect of other covariates in the calculation of the mean and assessing the differences in livelihoods between groups. Thus we could not reach a final conclusion before we systematically analyze if access to SI has led to significant effects on nutrition outcomes.

Table 4.1. Mean comparison of spate users and nonusers.

Variable name	Mean of user of spate (n = 97)	Mean of nonusers of spate (n = 97)	t-test
Age of household head (in years)	43	42.1	0.445
Family size (in number)	5.361	4.814	-1.877*
Female adults (in number)	1.271	1.302	0.409
Male adults (in number)±	1.536	1.474	-0.411
Off-farm income (in ETB)	1490.88	1197.15	-0.568
Asset holding (in TLU)	1.845	1.281	-1.720*
Livestock income (in ETB)	783.21	1453.57	1.216
Credit income (in ETB)	740.38	753.51	0.075
Food expenditure during the last month (in ETB)	1951.46	1488.74	-2.330**
Nonfood expenditure during the last month (in ETB)	434.73	216.31	-2.625***
Total expenditure during the last month (in ETB)	2386.2	1705.057	-2.873*
Members' quantity completer primary education	2.1237	1.659	-1.905**
Members' quantity completer secondary education	0.773	0.659	-0.629

In some cases observations (n) are not similar in number: ┼= one obs. is missing; ±= users 84 and nonusers= 78. *, **, *** significant at 10, 5, 1%, respectively

Correlation coefficients indicate, however, that access to SI does not have significant impact on food shortage, food serving and effect and adaptation to food shortage.

5.2 Anthropometric results

As far as WAZ z-scores are concerned, the study showed that prevalence of underweight (<-2 z-score) was 19.1%, where about 21.1% of the boys and 17.0% girls were underweight. The study also showed a prevalence of moderate underweight (<-2 z-score and >=-3 z-score) 13.6% of the children, disaggregated into 12.3% boys and 15.1% girls. The study also shows a prevalence of severe underweight (<-3 z-score), where 5.5% of the children, disaggregated into 8.8% boys and 1.9% girls, had severe underweight implying the occurrence of both acute and chronic malnutrition in the study communities.

Looking into the results for HAZ z-scores, it shows the prevalence of stunting (<-2 z-score) where 50.0% of the children, i.e., 51.1% boys and 49.0% girls were stunted. About 30.0% of the children had moderate stunting (<-2 z-score and >=-3 z-score), with 32.7% of the boys and 27.5% of the girls. Of these 20.0% of the children, 18.4% of the boys and 21.6% of the girls had a prevalence of severe stunting (<-3 z-score). This implies that there is chronic malnutrition.

The WHZ results show that overall in the study sites 3.7% of all children have acute malnutrition (<-2 z-score) (see Table 4.2). When disaggregated, it was found that 5.4% of boys and 2.0% of girls have acute malnutrition. The study also shows 3.7% had moderate acute malnutrition (<-2 z-score and >=-3 z-score), disaggregated as 5.4% boys and 1.9% girls. None of the children had severe acute malnutrition (<-3 z-score). This implies that there was moderate but not severe acute malnutrition. The WAZ, WHZ and HAZ values for gender disaggregation are presented in the Appendix.

The 2011 DHS results indicated that overall, 29% of all children were underweight, and 9% of children were severely underweight. In rural areas, 42% of children were stunted (CSA 2012). The WHZ and WAZ indicators in the current survey show that the nutritional status of children has improved compared to the status in 2011; whether this is the result of SI use is a thing we will see below.

When we consider only households that use SI, the survey WHZ results indicated that 8.2% of the children had a prevalence of global acute malnutrition (<-2 z-score), where 11.1 and 4.5% constituted boys and girls, respectively. Of these 8.2% of the children had a prevalence of moderate acute malnutrition (<-2 z-score and >=-3 z-score), disaggregated into 11.1% of the boys and 4.5% of the girls. Prevalence of severe acute malnutrition (<-3 z-score) seems to affect none of the children.

Table 4.2. Anthropometric measures of children of users and nonusers.

Measures±	Overall sample (n= 111)	Users (n=49)	Nonusers (n=59)	Interpretation
Weight-for-height z-score (values in %)				
Below -2Z	3.7	8.2	0.0	Acute malnutrition
<-2 z-score and >=-3 z-scores	3.7	8.2	0.0	Moderate acute malnutrition
< -3 z-scores	0.0	0.0	0.0	Severe acute malnutrition
Weight-for-age z score				
Below -2Z	19.1	27.5	13.6	Underweight
<-2 z-score and >=-3 z-scores	13.6	17.6	10.2	Moderate underweight
< -3 z-scores	5.5	9.8	3.4	Severe underweighted
Height-for-Age z-score				
Below -2Z	50.0	56.5	45.5	Stunting
<-2 z-score and >=-3 z-scores	30.0	34.8	25.5	Moderate stunting
< -3 z-scores	5.5	21.7	20.0	Severe stunting

± Figures aggregated into boys and girls are given in the Appendix.

Source: Survey 2013.

The weight-for-age (WAZ) distribution results, in contrast to WHO standards, indicated that 27.5% of the children showed a prevalence of underweight (<-2 z-score), where 22.2% were boys and 33.3% were girls. Moreover, the result showed that 17.6% of the children, 11.1% boys and 25.0% girls showed a prevalence of moderate underweight (<-2 z-score and >=-3 z-score). Finally, 9.8% of the children, 11.7% of the boys and 8.3% of the girls showed a prevalence of severe underweight (<-3 z-score).

The distribution of height-for-age (HAZ) z-scores showed a prevalence of stunting (<-2 z-score) in 56.5% of the children, 65.4% boys and 45.0% girls. Of these 30.8% of the children, 34.8% of the boys and 30.0% of the girls showed a prevalence of moderate stunting (<-2 z-score and >=-3 z-score) and 21.7% of the children, 26.9% of the boys and 15.0% of the girls, showed a prevalence of severe stunting (<-3 z-score).

There was no prevalence of global acute malnutrition (<-2 z-score) in the children from the households without access to SI (see Table 4.2). But WAZ z-score showed that 13.6% of the children from the households without access to SI showed a prevalence of underweight (<-2 z-score). This constituted 20.7% of boys and 6.7% of girls. Nearly 10.2% of the children showed a prevalence of moderate underweight (<-2 z-score and >=-3 z-score), where 13.8% and 6.7% constituted boys and girls, respectively. The study showed a prevalence of severe underweight (<-3 z-score) in 3.4% of the children, where 6.9 and 0.0% constituted boys and girls, respectively.

The HAZ z-scores of children of households without access to SI showed that 45.5% of the children showed a prevalence of stunting (<-2 z-score). This constituted 37.5% of boys and 51.6% of girls. Of the children, 25.5% showed a prevalence of moderate stunting (<-2 z-score and >=-3 z-score), 25.57% boys and 25.0% girls. Prevalence of severe stunting (<-3 z-score) affected 20.0% of the children, 12.5% boys and 25.8% girls.

Spate does seem to have no significant impact, or does not lead to improvement, on anthropometric measures compared to households that did not use spate irrigation (Table 4.3). The study shows that spate irrigation reduces the absolute number but the relative number of the malnourished, underweight and stunted increases. Girls are not worse-off than boys. No comparable or more comprehensive study like DHS was available to see the effect of irrigation or SI on nutritional outcomes. The overall small sample size (and absence of comparable data) is an impediment to draw conclusive results.

Table 4.3. Anthropometric measures of children of traditional and improved SI.

Measures	Traditional SI (n= 21)	Improved SI (n= 33)
Weight-for-Height z scores (value in %)		
below -2Z	14.3	3.0
<-2 z-score and >=-3 z-scores	14.3	3.0
< -3 z-scores	0.0	0.0
Weight-for-Age z scores		
below -2Z	29.2	18.8
<-2 z-score and >=-3 z-scores	12.5	15.6
< -3 z-scores	16.7	3.1
Height-for-Age z scores		
below -2Z	50.0	60.0
<-2 z-score and >=-3 z-scores	40.9	26.7
< -3 z-scores	9.1	33.3

Source: Survey 2013.

When we examine households using improved SI (see Table 4.3), the WHZ z-score shows that 14.6% of the children showed acute malnutrition (<-2 z-score). This comprised 20.0% of boys and 9.1% of girls. Of the children, 14.3% showed moderate acute malnutrition (<-2 z-score and >=-3 z-score), where 20.0% and 9.1% constituted boys and girls, respectively. No children (0.0%) showed prevalence of severe acute malnutrition (<-3 z-score). The WAZ z-score shows that 29.2% of the children showed a prevalence of underweight (<-2 z-score). This comprised 33.3% of boys and 25.0% of girls. Of the children, 12.5% showed prevalence of moderate underweight (<-2 z-score and >=-3 z-score), where 8.3 and 16.7% constituted boys and girls, respectively. Of the children, 16.7% showed a prevalence of severe underweight (<-3 z-score), where 25.0% and 8.3% constituted boys and girls, respectively.

The HAZ z-score shows that 50.0% of the children showed a prevalence of stunting (<-2 z-score). This comprised 63.6% of boys and 36.4% of girls. Of the children, 40.9% showed a prevalence of moderate underweight (<-2 z-score and >=-3 z-score), where 63.6 and 18.2% constituted boys and girls, respectively. Of the children, 9.1% showed a prevalence of severe underweight (<-3 z-score), where 0.0 and 18.2% constituted boys and girls, respectively.

On the other hand, in households using traditional SI, the WHZ z-score shows that 3.0% of the children showed acute malnutrition (<-2 z-score). This comprised 5.3% of boys and 0.0 % of girls. Of the children, 3.0% showed moderate acute malnutrition (<-2 z-score and >=-3 z-score), where 5.3 and 0.0% constituted boys and girls, respectively. No children (0.0%) showed a prevalence of severe acute malnutrition (<-3 z-score).

The WAZ z-score shows that 18.8% of the children showed a prevalence of underweight (<-2 z-score). This comprised 11.1% of boys and 28.6% of girls. Of the children, 15.6% showed a prevalence of moderate underweight (<-2 z-score and >=-3 z-score), where 11.1 and 28.6% constituted boys and girls, respectively. Of the children 3.1% showed a prevalence of severe underweight (<-3 z-score), where 0.0 and 7.1% constituted boys and girls, respectively.

Finally, the HAZ z-score shows that 60.0% of the children showed a prevalence of stunting (<-2 z-score). This comprised 64.7% of boys and 53.8% of girls. Of the children, 26.7% showed a prevalence of moderate underweight (<-2 z-score and >=-3 z-score), where 23.5 and 30.9% constituted boys and girls, respectively. Of the children, 33.3% showed a prevalence of severe underweight (<-3 z-score), where 41.0 and 23.3% constituted boys and girls, respectively. Improved SI, thus, has led to improvement of acute malnutrition, underweight and moderate underweight, prevalence of stunting and severe stunting. On the other hand, traditional SI has led to improvements in moderate malnutrition, underweight, and severe underweight. To save space, the values of WHZ, WAZ and HAZ z-scores are not reported here.

Overall, having SI did not lead to significant improvement of nutritional outcomes when we compare users and nonusers; when we compare traditional and improved SI, the results are mixed. This may imply that using SI may not directly lead to improvement outcomes although it leads to increase of consumption expenditures, mainly nonfood. Our field observation seems to justify this fact: farmers use SI to grow cash crops (vegetable and fruits in Dadota and *chat* in Fokissa) which may increase household income and, hence, expenditure. Farmers grow cereals using rain-fed agriculture. Growing nutritious crops, accompanying access to SI with nutritional education, is necessary.

6. Conclusion and Recommendations

Access to SI is expected to increase crop productivity that, in turn, is expected to improve household nutrition. But the evidence from this study indicates that users do not have a better condition in nutrition outcomes compared to nonusers. The WHZ z-score results, compared to WHO standards, indicated that 8.2% of the children had moderate to acute malnutrition. WAZ z-scores indicated that 27.5% of the children showed a prevalence of underweight, 17.6% of the children showed prevalence of moderate underweight and 9.8% of the children showed a prevalence of severe underweight. According to the HAZ z-scores results 56.5% of the children showed a prevalence of stunting, 30.8% of the children showed a prevalence of moderate stunting and 21.7% of the children showed a prevalence of severe stunting. This implied that acute, both current and past, and chronic malnutrition was prevalent even in the presence of SI to the household. Access to SI, thus, did not lead to a significant difference in nutritional outcomes, although the average value of expenditure, food and nonfood was significant between the two groups. Increasing production, though a necessary condition, like irrigation, is not a guarantee for improved nutrition. Nutrition is a multidimensional problem that needs multisectoral collaborations between the health, agriculture, water, social protection, education, gender and other sectors. This study also underlines the importance of nutrition education as one of the entry points alongside improving access to SI. The importance of nutrition education is emphasized because better nutrition is important for the physical and mental growth of children under 5 years. The nutritional outcomes were not different among boys and girls, probably indicating the gender difference in rural Ethiopia is not prominent.

Overall wasting, underweight and stunting are serious compared to the WHO standard population. The country has a long way to go in improving nutrition outcomes.

Spate systems are risk-prone and are categorically different from perennial systems. The floods may be abundant or minimal and production varies from year to year. The fluctuation also brings along an unavoidable degree of inequity, with some lands always better served than others. Spate systems, moreover, have to deal with occasional high floods that – unless properly controlled – can cause damage to riverbeds and command areas (Van Steenbergen et al. 2011). Access to panel data could reflect these variations and can lead to a more realistic conclusion than one-period data.

Acknowledgements

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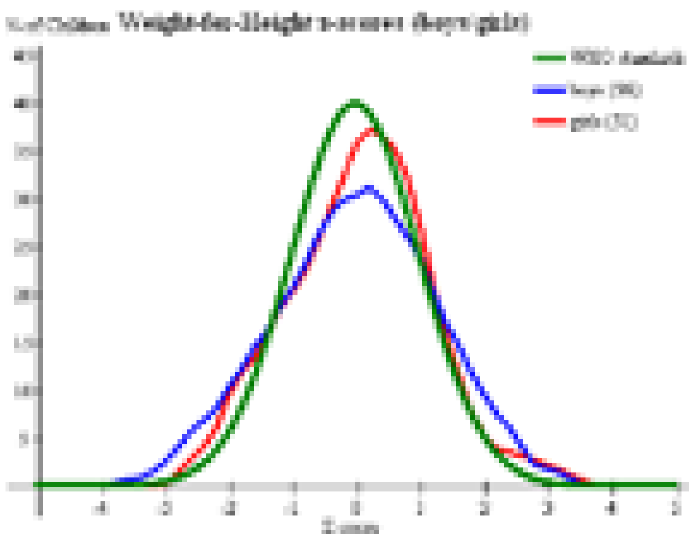
Appendix

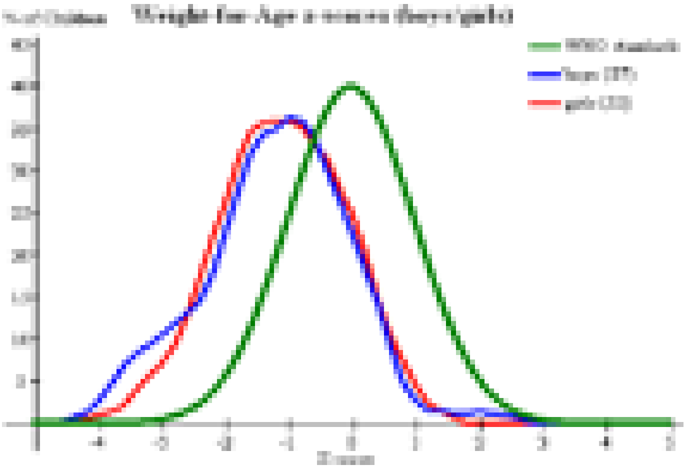
The appendix shows Figures A1 to A8.

Figure A1. WHZ z-score for the whole sample disaggregated by sex.



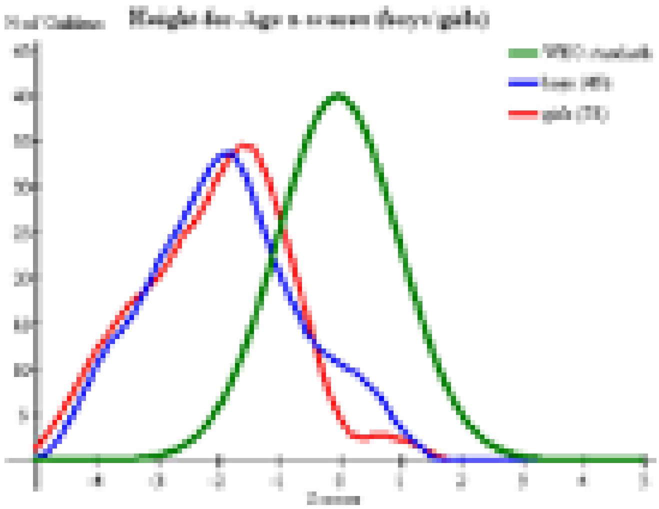
Source: Survey 2013.

Figure A2. WAZ z-score for the whole sample disaggregated by sex.



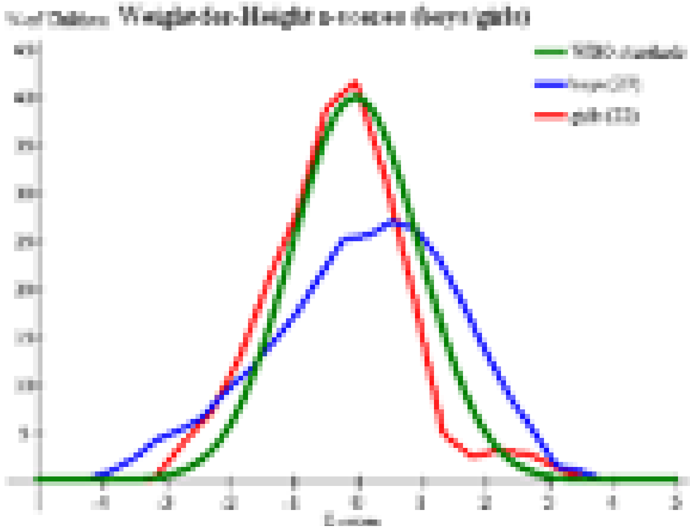
Source: Survey 2013.

Figure A3. HAZ z-score for the whole sample disaggregated by sex.



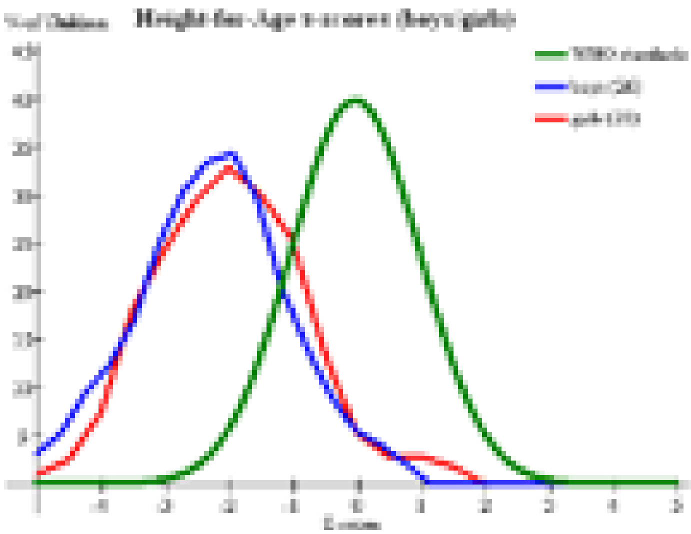
Source: Survey 2013.

Figure A4. WHZ z-scores for the sample with access to SI disaggregated by sex.



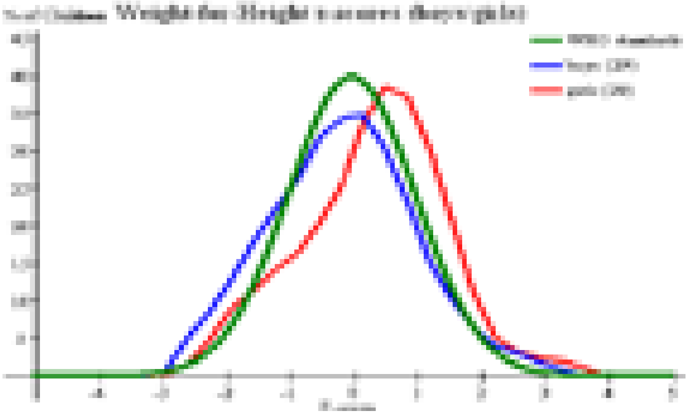
Source: Survey 2013.

Figure A5. HAZ disaggregated by sex for the sample with access to SI disaggregated by sex.



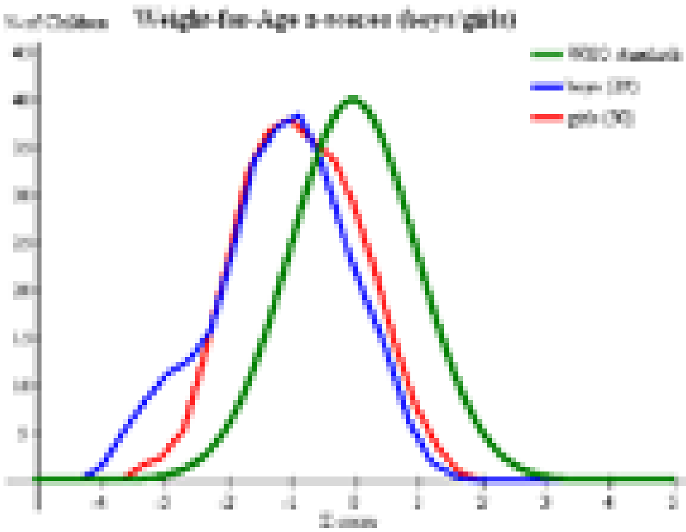
Source: Survey 2013.

Figure A6. WHZ z-scores for children of households without access to SI disaggregated by sex.



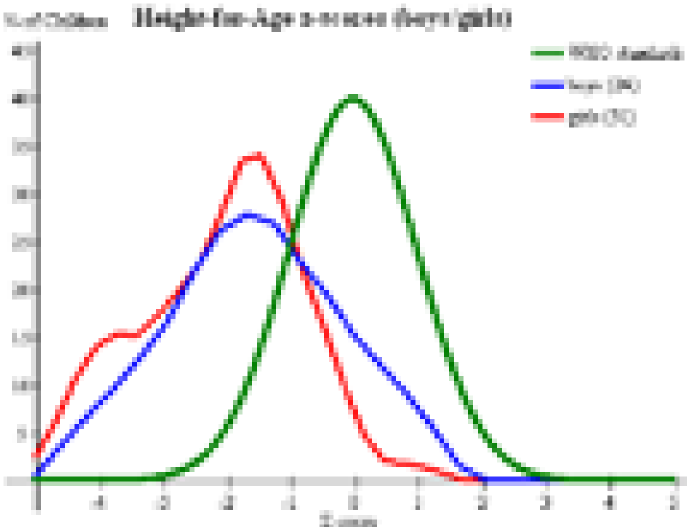
Source: Survey 2013.

Figure A7. WAZ z-scores for children of households without access to SI disaggregated by sex.



Source: Survey 2013.

Figure A8. HAZ z-scores for children of households without access to SI disaggregated by sex.



Source: Survey 2013.

Section 3
Flood and Sediment Modeling

Optimizing Flood and Sediment Management of Spate Irrigation in Aba'Ala Plains

Kbrom Ambachew and Abebe Fanta

Kbrom Ambachew (kibe0611@gmail.com) and Abebe Fanta (fantaalemitu@gmail.com)

Haramaya University, P. O. Box 138, Dire Dawa, Ethiopia

Abstract

Floodwater management and sedimentation are the key issues which should be considered during the development of new, or improvement of existing, spate irrigation schemes. The traditional intakes are superior in their site location, flexibility, and sediment-control capability. However, they have been frequently damaged by floods resulting in loss of continuous irrigation supply. The modern structures, albeit strong enough to withstand the impact force of the largest floods, suffer from large sedimentation problems. Farmers of Aba'ala Plain have been struggling with sedimentation and floodwater-management problems associated with their modern and traditional intakes. The objective of this research is, thus, to study the existing flood and sediment management practices and identify alternative options for optimum management of floods and sediments in the Aba'ala Plain, Afar. Aba'ala is the largest plain in the arid lowlands of Ethiopia where a combination of traditional, improved and modern spate irrigation systems are practiced. Extensive fieldwork was undertaken leading to measurement and collection of primary data including discharge, sediments and river cross sections. Interviews and focal group discussions were also employed and these generated deeper insights into O&M activities. In addition, Alluvial Friction Predictor and Sand Transport Predictor of SHARC model were employed to generate sediment concentration of the floodwater. Delft3D, a hydrodynamic model, has been used to simulate flow patterns and sedimentation under the existing condition and for different improvement options. For the existing condition (scenario-I), results of the model simulation showed high sediment deposition and low floodwater abstraction rate. Consequently, only 41 and 23% of the command areas under the modern and traditional intakes can be fully irrigated during the bad flood season. The high intake diversion rate and the reduced sedimentation around the intake were achieved with the improvement options under scenario-II (four consecutive bed stabilizers, a 30 m guiding wall upstream of the modern intake and reinforcement of the traditional intake). However, this scenario has a potential to cause conflict between upstream and downstream users as the result showed a decline of water level (15 cm) at the downstream intake. Therefore, scenario-III is recommended for a maximum floodwater diversion and minimum sediment deposition with a fair share of water between upstream and downstream intakes. This scenario would consist of open gabion reinforced multiple intakes with a 78 m long guide wall upstream of the modern intake, a 30 m long guide wall upstream of the traditional intake and a series of four bed stabilizers upstream of the diversion point.

Key words: *Spate irrigation, flood, sedimentation, intakes, canals, Delft3D, optimizing, modeling*

1. Introduction

The arid lowlands of Ethiopia form one of the most vulnerable and food-insecure regions in the world. Out of a population of 11 million, about 3.4 million who live in the arid lowlands of Ethiopia depend on food aid. Droughts in the years 2000, 2005, 2008 and 2011 raised the number of food-aid dependent people to 5.7 million in 2011. As the results of the droughts during those years, distress sales of livestock and other assets was a common phenomenon in the areas affected by the drought (Mehari et al. 2013). Aba'ala, located in the arid lowland area, had been affected by severe droughts and famine for years (Kifle 2004). There is no perennial water source to support crop production in the area. However, Aba'ala receives intense short-duration floods coming from Didiba Derga-Ajen highlands in Tigray Regional State. Efficient and effective diversion and distribution or storage of the floodwater would make water available in Aba'ala Plain that is inhabited by agropastoralists. Spate flow was considered to be the most economical and the only resource of water for crop production (spate irrigation), livestock production and domestic uses.

Spate irrigation is one type of water management applicable to arid regions bordering highlands. It is a largely neglected and forgotten form of resource management, in spite of its potential to contribute to poverty alleviation, adaptation to climate change and local food security (Steenbergen et al. n.d.). Tesfai and Sterk (2002) defined spate irrigation as runoff farming that makes use of floods originating from episodic rainfall in macro-catchments in the highlands, which are diverted by temporary or semi-permanent structures to irrigate fields.

In the Aba'ala Plain, both traditional and modern spate irrigation systems are practiced, in which short-duration floods with large discharge are used to irrigate land by spreading floodwater across cropland, rangeland or dryland-forest. In some cases, the floodwater may be used to recharge shallow groundwater, which makes it possible to tide over a drought period and make use of the floodwater (Mehari et al. 2011). Managing the floodwater is the major challenge to make spate irrigation sustainable and productive for reasons such as occasional large volume, destructiveness and high sediment load.

The traditional diversion structures and canals in Aba'ala Spate Irrigation scheme were frequently damaged by large floods. The farmers in the area have for years struggled to rebuild the intakes and water distribution structures on time to make efficient use of subsequent floods. Their effort in this daunting task had been an exercise in futility; several flood use opportunities were lost due to failures to maintain and sustain the structures. Consequently, limited soil moisture (moisture stress) contributed to poor crop stand and yield, a common phenomenon in the Aba'ala Plain.

Spate irrigation is as much about sediment management as it is about water management (Van Steenbergen et al. 2010). Spate flows usually carry high sediments, which deposit around diversions blocking intakes and canals or are transported to the fields causing rapid rise of the command areas. However, it should be noted that these sediments can be a source of valuable plant nutrients that maintain soil fertility (Tesfai and Sterk 2002; Lawrence 2008; Van Steenbergen et al. 2010).

There was no serious problem associated with sediment under the traditional system since much of the sediments at the vicinity of the structures is washed away during high floods. Moreover, a study made by Lawrence (2008) too indicated that traditional intakes were less affected by sedimentation than the modern intakes; they are washed away by the large volume and high velocity of floods when the concentration of coarse sediments is high.

In Aba'ala spate irrigation schemes, the problem of sediment deposition is more pronounced with modern diversion and intake structures. The effort made to modernize the scheme was focused on increasing volume of diverted floodwater without due attention to the sediment deposition at the vicinity of the structure and the resulting negative effect on the level of abstraction and structural deterioration and damage to the same. Moreover, the scouring sluices have never operated since the construction of the scheme; the above issues combined with poor design of the diversion weir (conventional irrigation type design) led the structure to be completely filled with sediments in a single flood.

In general, lack of sediment control and inefficient management of floodwater are the two major and serious problems that farmers at Aba'ala Plain face in sustaining crop and livestock production under spate irrigation.

The failure and inadequate functioning of the diversion and intake structures have made floodwater and sediment management problems common and persistent in the entire canal network and the irrigated fields. The poor design that channeled floodwater to one or at most to two canals at the headwork also exacerbated the sedimentation problems. Lack of operational rules for the scheme has seriously affected the effective and efficient (uniform water distribution) utilization of floodwater. Furthermore, efforts made to manage floodwater and control sedimentation to date, have been structural. The government and donor organization(s) that effected the construction of the structures never analyzed and learned lessons about the possibilities of alternative spate irrigation system options with regard to layouts, structural designs, operational strategy, rules and regulation on floodwater use, and exit strategies.

Re-examination of the current practice of spate irrigation in order to develop alternative solutions to the problems faced is the order of the day: to make effective practice of spate irrigation (through efficient layout, remedial work, proper construction, adoption of locally maintainable structures); considerations of alternative years/seasons (good, or moderate or poor flood year/season); and different scenarios (as is, required changes). Hence, this study was undertaken with the following objectives:

1. Major objective: To identify alternative options that would optimize floodwater and sediment management in the Aba'ala Plain where spate irrigation is practiced as a major means of food security.

2. The specific objectives:

- To determine the flood discharge and rate of sediment deposition at and around the intakes.
- To evaluate the design of traditional and modern diversion and intake structures in light of sediment management.
- To evaluate the adequacy of diverted floodwater to meet water requirement of crops grown under the scheme considering good, moderate, and poor year/season.
- To simulate and recommend suitable design options (improvements) for efficient and effective floodwater and sediment management.

2. Materials and Methods

2.1. The Study Area Location

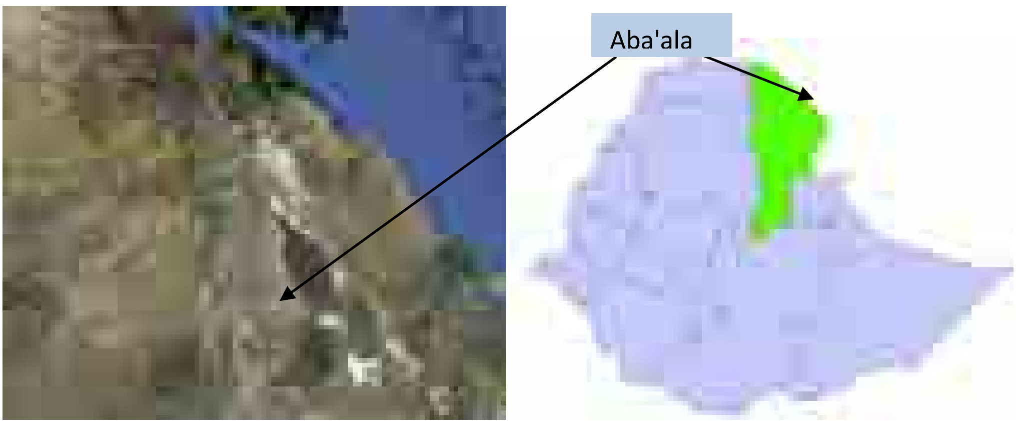
The study was conducted in Aba'ala Woreda, in Afar National Regional State, located between 130 15' and 130 30' N latitude and 390 39' and 390 53' E longitude (Figure 5.1). The major part of the Aba'ala Woreda is an extension of the rugged escarpment of the Rift Valley, which runs from north to south bordering Tigray. The woreda under the study covers an area of 1,700.00 km^2 approximately, and has a total population of 37,963 (20,486 males, 17,477 females) (CSA 2007).

2.2. Climate, Land Use and Topography

Aba'ala has a semiarid climate with a maximum temperature of 33.00 °C occurring in June and a minimum temperature of 11.60 °C occurring in November.

The study area receives a bimodal rainfall ranging from 315 to 450 mm.year^{-1} (with an annual average rainfall of 340 mm). The main rainfall takes place in a short period of time, three to four hours, with heavy storms lasting a few days, and this is followed by droughts during the critical periods of crop growth (Kifle 2004). The long rains usually occur from mid-June to mid-September. The short rains usually come in March and April.

Figure 5.1. Location of study area.



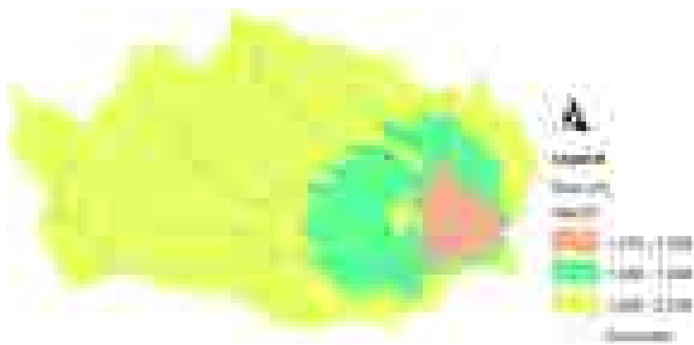
Diress et al. (2003) classified the land use of the area into 93.00% of grazing lands, 5.50% cultivated land, 1.20% wasteland and 0.53% riparian. Thirty three per cent of Aba'ala Woreda is floodplain of which 16.80% is under cultivation. The remaining 67.14% is ridges and hills mainly used for grazing or browsing.

The study area consisted of flat plains occasionally intercepted by hills and a series of elongated ridges surrounded by high broken hills with very few outlets joined to the other areas (Abebe and Solomon 2012). The altitude of the area varies from 1,300 to 1,700 meters above sea level (m asl) with an average elevation of 1,500 masl (Addis et al. 2001).

2.3. Water Resources

There are four rivers, two perennial and two seasonal, that supply water to the study area. May Shugala and May Aba'ala are the main perennial rivers, while Murga and Liena are seasonal rivers. The highland of Didiba Derga-Ajen, Tigray, with an annual rainfall ranging from 450 to 750 mm, is the main source of flow for all streams and recharges both surface water and subsurface water in the Aba'ala area (Kifle 2004). According to Abebe and Solomon (2012), Aba'ala Subbasin (UTM 596,184.8 E and 1,475,931 N) with a total area of about 55,470 ha is situated in two regions; the upland where the floods originate, highlands of Tigray Region, and the low-lying plain where spate irrigation is being practiced in the Afar Region (Figure 5.2).

Figure 5.2. Aba'ala Subbasin with the plains marked green.



2.4. Irrigation and Agronomy

Though the duration is short, the intensity of rainfall in the area is usually high leading to a large volume of runoff. However, the high rate of evaporation makes the available rainfall water insufficient to sustain crop growth, flowering and seed formation and maturity (Addis et al. 2001). Therefore, the agropastoralists in the Aba'ala Woreda depend heavily on the floodwater coming from the highlands of Didiba Derga-Ajen to grow and produce crops. Floodwater is diverted to the farmland through either temporary diversion structures (traditional), improved (gabion) or modern (concrete). During the study period, there were more than 30 primary canals supplying floodwater to the Aba'ala Plains for a variety of crops such as sorghum, maize, barley, teff, enguaya and sebere (local beans).

Two diversion intakes, meant to irrigate two separate areas of 176 and 140 ha, both located at May Shugala River, were selected for this study. The traditional diversion intake was made of earthen materials, stones and brushwood, while the modern intake was made of concrete (Figure 5.3).

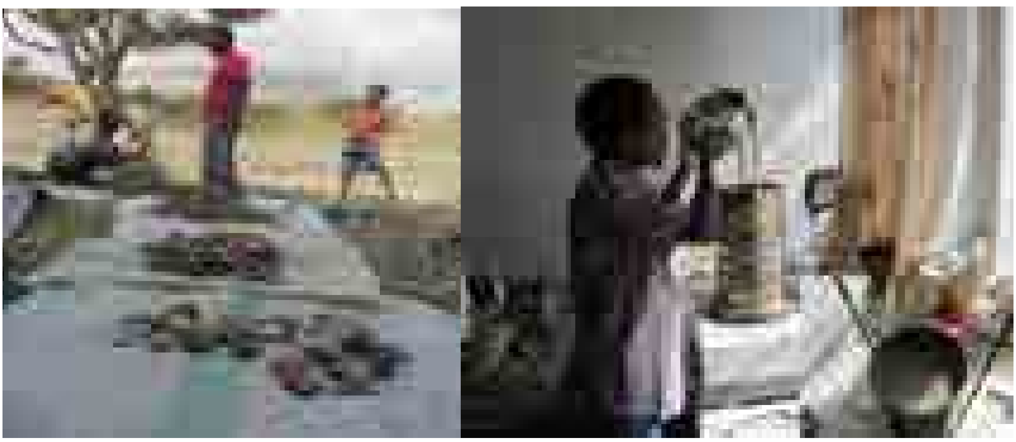
Figure 5.3. Modern diversion weir (left), traditional diversion before maintenance (right).

2.5. Data Collection and Analysis

2.5.1. Riverbed Material

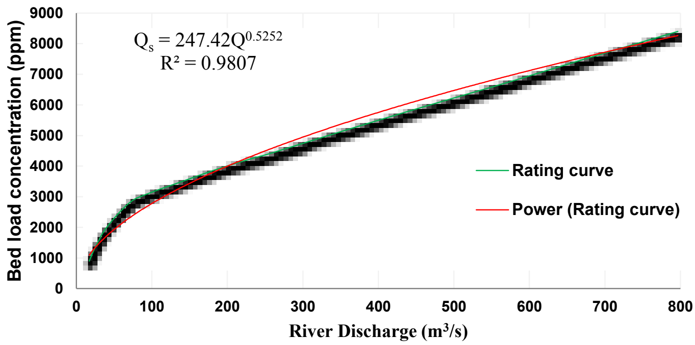
To develop the grading curve of the sediment bed-material and to determine mean value of D84, ten separate sediment samples were taken from four cross sections at different locations along the river route. The samples were taken in such a way that they represent low-flow canals, areas of sediment deposition and areas of erosion. Since the surface of the riverbed was dominated by coarse bed-material with wide variability in size, samples were taken by digging a pit to a depth of 1 m with cross-sectional area of 1 m^2. Size classification of bed-material was partially accomplished in the field through hand sieving to separate large materials, while separation of fine-grained materials was made in the laboratory (Figure 5.4).

Figure 5.4. Separation of sediments into different size classes in the field and laboratory.



Sediment concentration was generated using sand transport predictor, DORC module SHARC software package. Comparison of the different alluvial friction predictors made with the observed values indicated that van Rijn alluvial predictor had best fits with the observed values; thus this was used to generate depth and velocity values for the sediment concentration calculation. Sediment concentrations at different discharges gave the sediment (bed-load) rating curve shown below (Figure 5.5).

Figure 5.5. Sediment (bed-load) rating curve.



2.5.2. *River surveying*

Field survey was made using Total Station Method to collect data associated with the longitudinal and cross-sectional dimensions of the river. The surveying covered a distance of 1.50 km along the length of the river route. Measurements included 11 cross-section elevations along the entire length of the flood route.

2.5.3. *Discharge*

2.5.3.1. *Floodwater discharge and hydrographs*

As all the rivers were not gauged, the estimation of discharge was based on flood mark information collected from young, middle-aged and elderly farmers in the study area through interviews, and joint measurements of the height floods reached during good, moderate and bad years or seasons during field visit.

To generate floodwater discharge rates, measurements made, calculated values from the measured parameters, such as mean river cross section, wetted perimeter, mean slope, mean D84, and appropriate coefficients together with Manning's and Bathurst Equations were employed; The used equations are given below.

$$Q = \left(\frac{1}{n}\right) \times A \times R^{0.67} \times S^{0.5} \quad \textit{(Manning Eq.)} \tag{2.1}$$

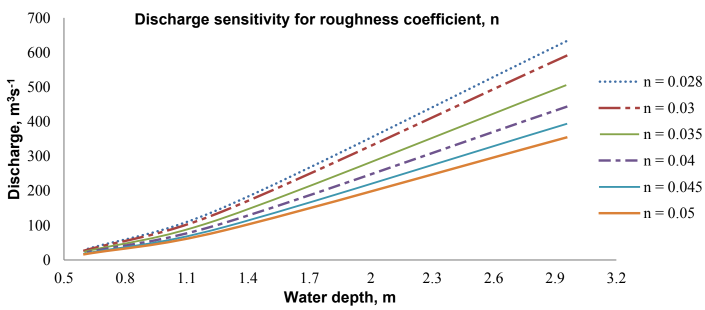
$$Q = A \times D^{*} \times (gRS)^{0.5} \quad \textit{(Bathurst Eq.)} \tag{2.2}$$

$$D^{*} = \left(5.62 \times \log\left(\frac{d}{D_{84}}\right) + 4\right)$$

Q = Discharge
A = Cross-sectional area
R = Hydraulic radius
S = Slope
n = Manning roughness coefficient
D* = Particle parameter
g = Acceleration due to gravity
d = Mean flow depth (approximately the same as the hydraulic radius, R)
D84 = Size of the bed material for which 84% of the material is finer (m)

However, it is recommended that the roughness coefficient be estimated using D84 value of the riverbed material along the slope area reach (Arcement and Schneider 1989) due to the very fact that the discharge computed using Manning's formula is highly sensitive to roughness values especially at increased water depths (Figure 5.6).

Figure 5.6. Sensitivity test for roughness.

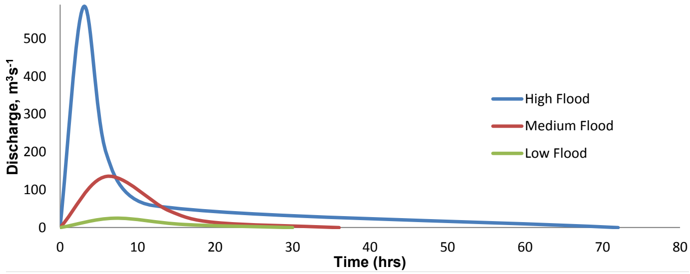


The value of Manning Roughness coefficient (n) for gravel bed rivers ranges from 0.028 to 0.05 (Arcement and Schneider 1989). From sensitivity analysis, it was found that the discharge computed using Manning's formula was highly sensitive to roughness values. Hence, Bathurst formula, which considers the D84 to estimate the riverbed roughness, was selected for further investigation during the course of this study, thereby minimizing the uncertainties in using Manning's formula.

2.5.3.2. Hydrographs

Flood hydrographs were required to develop time series flow data which will be used in Delft3D model. In addition to the flood marks, the time to peak and time to end of the high, medium and low floods were identified during the interviews made with the farmers. According to the suggestion of Wateryemen.org (2003), a standard hydrograph for rivers with mountainous catchments is characterized by a time constant where it is changed (increased) when the discharge declines to one-third of the peak, and again when the discharge declines to one-tenth of the peak. Hence, combining the data collected during farmers' interview and the suggestion made (Wateryemen.org, 2003), an incoming flood hydrograph shown in Figure 5.7 had been generated for the river.

Figure 5.7. Actual spate flow hydrograph.



2.6. Desired Discharge at Intake and Canals

The discharge desired at the intakes was estimated by considering the type of crops grown, total command area of the intake, irrigation rotation and the irrigation time. Focal group discussions and collection of x, y coordinates of points bordering irrigation fields were carried out to identify the type of crops grown, irrigation rotation, and size of command areas. ArcGIS was employed to develop a map of the scheme (Figure 5.8) with details of the command area for each canal.

Figure 5.8. The traditional and modern diversions with their canal network.

The rate of discharge required at each secondary canal offtake was calculated by taking a maximum seasonal crop water requirement of three crops: sorghum, maize and pea (Brouwer and Heibloem 1986). The gross seasonal water requirement of sorghum, maize and pea was calculated to be 1,300, 1,600 and 1,000 mm, respectively. Irrigation time was selected considering indigenous farmers' practice and the number of floods occurring during the bad and good seasons. Table 5.1 shows the required discharge to meet the water requirements as calculated following standard procedures.

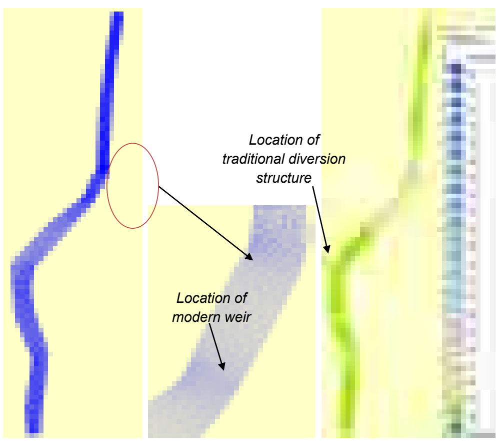
Table 5.1. Required discharge calculation on the basis of crop water requirements of the canals.

Name of Intake	Name of Canal	Area (ha)	Irrigation time (hour)	Required Q in m3/s (Bad season)		
				Sorghum	Maize	Pea
Gira Mahber	Mesgid	51.00	48.00	3.84	4.72	2.95
	Abo Amin	22.00	48.00	1.66	2.04	1.27
	Halefom Hadush	8.00	48.00	0.60	0.74	0.46
	Abo Adhana	31.00	48.00	2.33	2.87	1.79
	Demsash	56.00	48.00	4.21	5.19	3.24
	Via Scouring	8.00	48.00	0.60	0.74	0.46
	Total	176.00	-	13.24	16.30	10.19
Berhe Afle	Gira Fitsum	47.00	48.00	3.54	4.35	2.72
	Berhe Afle	31.00	48.00	2.33	2.87	1.79
	Berhe Keshi	12.00	48.00	0.90	1.11	0.69
	UN	5.00	48.00	0.38	0.46	0.29
	Demsash	42.00	48.00	3.16	3.89	2.43
	Total	137.00	-	10.31	12.69	7.93

2.7. Model Setup

To simulate the floodwater flow and sedimentation patterns along the river the Delft3D-RGFGRID model was set up for a river reach of 1.5 km length. In order to clearly observe the floodwater flow and sedimentation patterns grids around the diversion intakes were further refined locally. The quality of the generated grid was checked against the grid quality standards, like orthogonality and aspect ratio, in order to eliminate computational errors during model simulation. The grid was then edited until the desired orthogonality and smoothness were achieved. Finally, staggered grids of good quality with orthogonality values ranging from 0 to 0.07 (more than 98% lying below 0.04) and aspect ratio values of 1.0 to 1.98 were obtained to be used as a domain in the model simulation (Figure 5.9).

Figure 5.9. Generated grid for the river (left and middle) and its orthogonality (right).



The hydrodynamic and morphological process of the river was simulated by applying the Delft3D-Flow module. The domains for the flow model are imported from the RGFGRID and QUICKIN modules of Delft3D. To ensure accurate and stable simulation of the flow (including the secondary flow) and sediment transport a valid simulation time step is selected depending on the Courant (Friedrichs-Lewy) number (CFL) which is defined by:

$$CFL = \frac{\Delta t\sqrt{gh}}{\Delta x \Delta y} \tag{2.3}$$

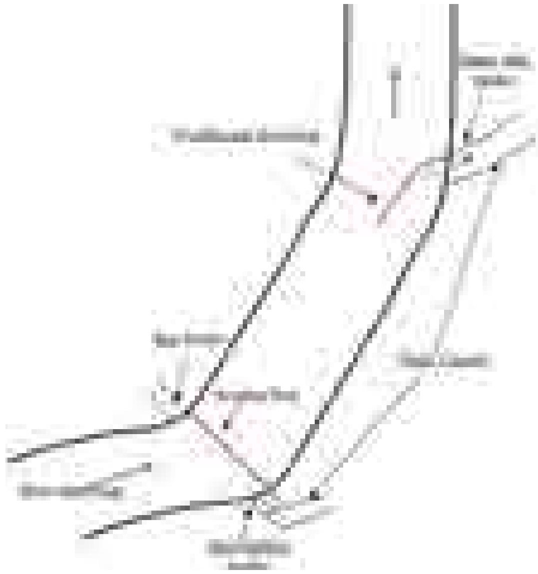
Where, Δt is the time step (in seconds), g is acceleration of gravity, H is total water depth, and Δx or Δy is the minimum value of the grid spacing in either direction (Hydraulics, 2011). To ensure stable model simulation, different time steps were selected for the simulations of different flood levels. All the simulation time steps were selected based on the recommendation stated on the delft 3D - flow manual.

The upstream and downstream cross sections of the river and the intakes are defined as open boundaries in the model. A time series flow data derived from the flow hydrograph was used as flow condition for the upstream boundary. The Bathurst discharge formula was employed to calculate the discharge at different depths so as to generate the stage-discharge relation which was used as flow condition for river downstream boundary and the intakes. Having the riverbed material grading results, the sediment concentration was calculated by the Meyer-Peter-Muller sediment transport formula and then utilized for the upstream and downstream boundary transport conditions.

The default Van Rijn sediment transport formula in Delft3D is not applicable for this research as the size of riverbed material shows great variation and the mean sediment diameter is out of the validity range of the formula. Meyer-Peter-Muller formula was tested through extensive experimental research with uniform and nonuniform sediments and showed good predictions even outside its validity range (Van der Scheer et al. 2002). Thus, Meyer-Peter-Muller formula is selected and used in simulating the sediment transport in the river. The formula was added to the model by preparing a sediment transport formula file (*.tra).

The modern and traditional diversion structures were incorporated in the model as 2D weirs. Since the modern diversion weir is perpendicular to the flow direction, it was represented in the model by one U-weir. The traditional diversion is made of a curved earthen embankment partially along the flow direction and partially across the flow direction with an angle greater than 900 to the flow direction. Hence, it is schematized with a combination of U and V weirs. A file (*.2dw) containing the description about the location and dimensions of the weirs was prepared and used in the model simulation. Figure 5.10 shows the sketch of the diversions layout.

Figure 5.10. Layout of the diversions.



The files prepared for the sediment transport formula (*.tra) and for the local weir (*.2dw) were written in the additional parameters tab in the Delft3D-Flow module so that the model can read and replace the default van Rijn formula with the Meyer-Peter-Muller formula. Similarly, it will enable the model to include the influence of the weirs on the flow simulations.

There were no adequate data for model calibration and validation. However, according to recent research work done on Gash River of Sudan, the model has shown good results when used to simulate flow and sediments for spate flows of different magnitudes (Tsoka 2012; Zenebe 2012). Moreover, a calibration coefficient of 5.7 was used in the sediment transport formula as suggested to give better prediction by Kleinhans and van Rijn (2002) and Ribberink (1998).

2.8. Scenarios

After the schematization and setup of the model, three scenarios were examined in order to figure out the best alternative that could assure optimum floodwater and sediment management in the study area.

Scenario-I

The existing condition maintained is as follows; after the model was run for the existing condition, the problems related to flood management and sedimentation were identified and a set of possible improvement options were clustered in to Scenario-II and Scenario-III.

Scenario-II

Under this scenario four consecutive bed stabilizers at a distance of 180, 330, 430 and 570 meters were introduced upstream of the diversion point in order to fix the riverbed degradation/ erosion which is a source of sediment deposition around the intakes. The bed stabilizers were included in the model as a low weir of height 0.3 m. A guide wall (leaf shaped) of 30 m length was introduced at the center of the stream with the aim of concentrating the flow towards the intakes as well as creating secondary flow currents facilitating sluicing of the coarse bed materials towards the river.

Scenario-III

In this scenario the guide wall upstream of the modern intake is extended by 48 m further upstream and one additional guide wall of length 29 m is added upstream of the traditional intake. The objective of the extended guide wall was to reduce the width of the stream so as to create higher flow velocity and hence sediments could be reduced. The guide wall upstream of the traditional intake is meant for guiding low floods towards the intake enhancing its diversion capacity at low floods.

As the shape of the guide wall has to be defined along the orthogonal grid, it was not possible to put the exact shape of the leaf-shaped guide wall. However, it was attempted to schematize the guide wall resembling leaf-shaped as shown in Figures 5.11a and b.

Figure 5.11a Schematized guide wall.

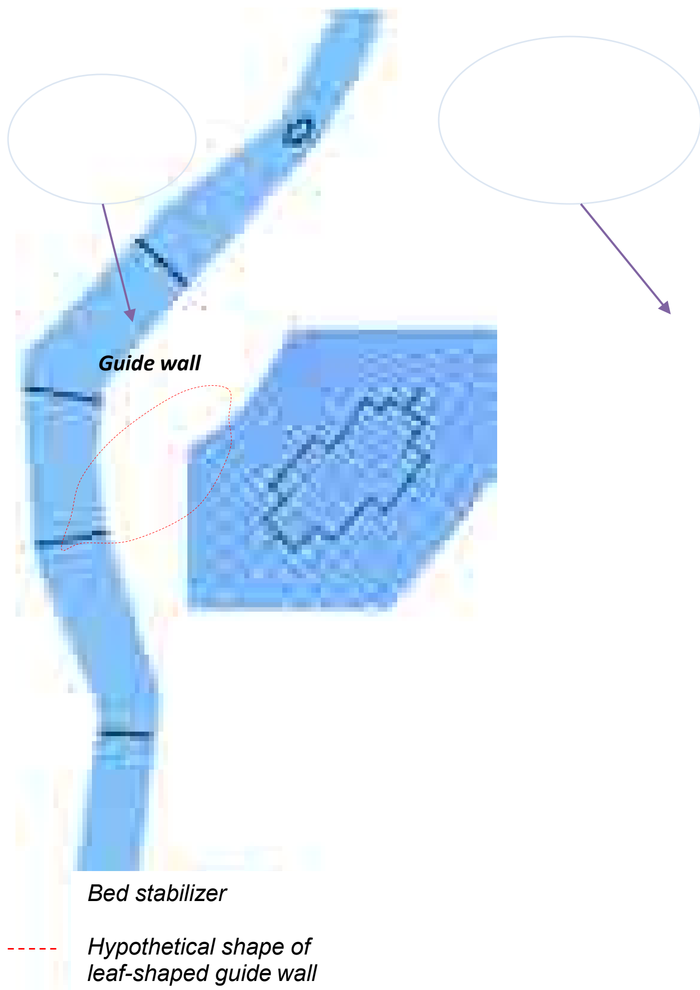
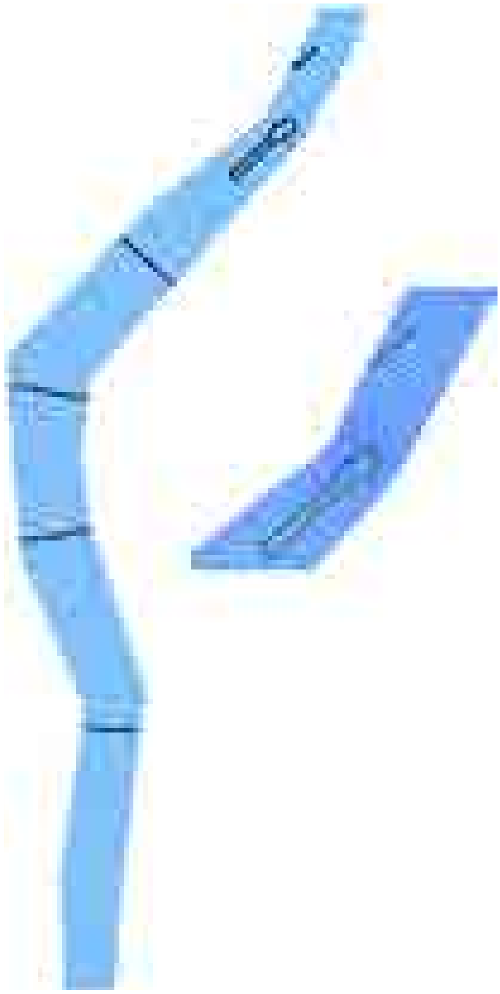


Figure 5.11b. Improvement options under scenario-II (left) and scenario-III (right).

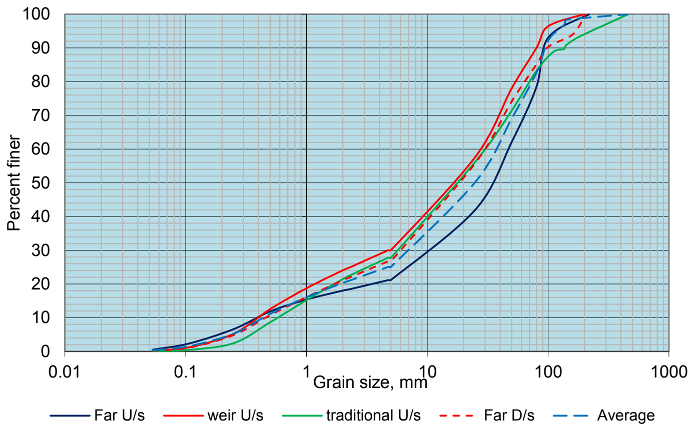


3. Results and Discussion

3.1. Grading Curves

As can be seen from Figure 5.12, the bed-material had sediments of varying sizes with a median diameter ranging from 16.00 to 33.00 mm with an average value of 25.00 mm.

Figure 5.12. Grading curves of sediment from riverbed.



3.2. River Survey

Figure 5.13. Mean cross-sectional area of the river at its most upstream part.

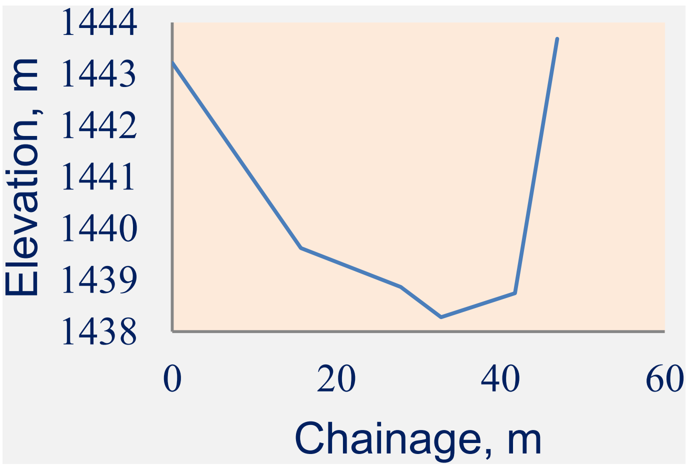
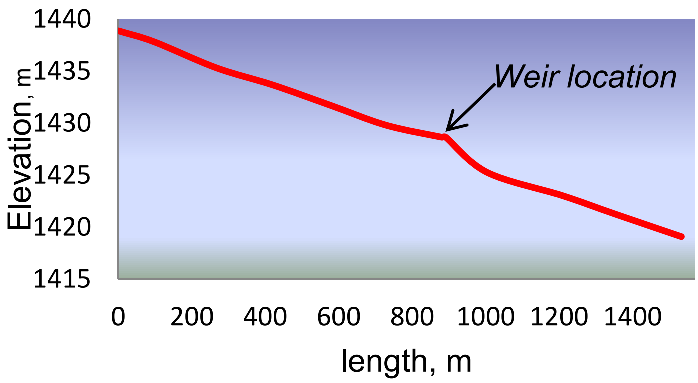


Figure 5.14. River cross section at far upstream (left) and riverbed elevation (right).



Measurement of riverbed elevation made along its length (longitudinal direction) indicated that the slope of the river ranged from 0.011 to 0.015 mm with an average value of 0.012 mm.

3.3. Discharge

Results of the river survey work and sediment analysis and use of equations 2.1 and 2.2 were utilized to estimate the incoming floodwater discharge. Table 5.2 shows discharge computed using Manning and Bathurst equations at upstream and downstream cross sections of the river reach.

Table 5.2. Discharge at upstream and downstream.

Cross section	Flood type	n	A (m2)	P (m)	R (m)	S (m/m)	Q (m3/s) Manning	D84	D*	Q (m3/s) Bathurst
X-1 (Upstream)	High	0.035	91.40	39.90	2.30	0.012	505.80	0.083	12.11	583.30
	Medium	0.035	34.70	30.20	1.20	0.012	121.20	0.083	10.43	135.30
	Low	0.035	10.90	19.10	0.60	0.012	23.70	0.083	8.71	24.90
X-11 (Downstream)	High	0.035	44.70	30.90	1.40	0.012	178.40	0.076	11.18	238.30
	Medium	0.035	19.90	25.00	0.80	0.012	53.30	0.076	9.73	68.50
	Low	0.035	8.80	23.40	0.40	0.012	14.30	0.076	7.89	16.90

3.4. Scenario I: Existing Conditions

3.4.1. Modern diversion

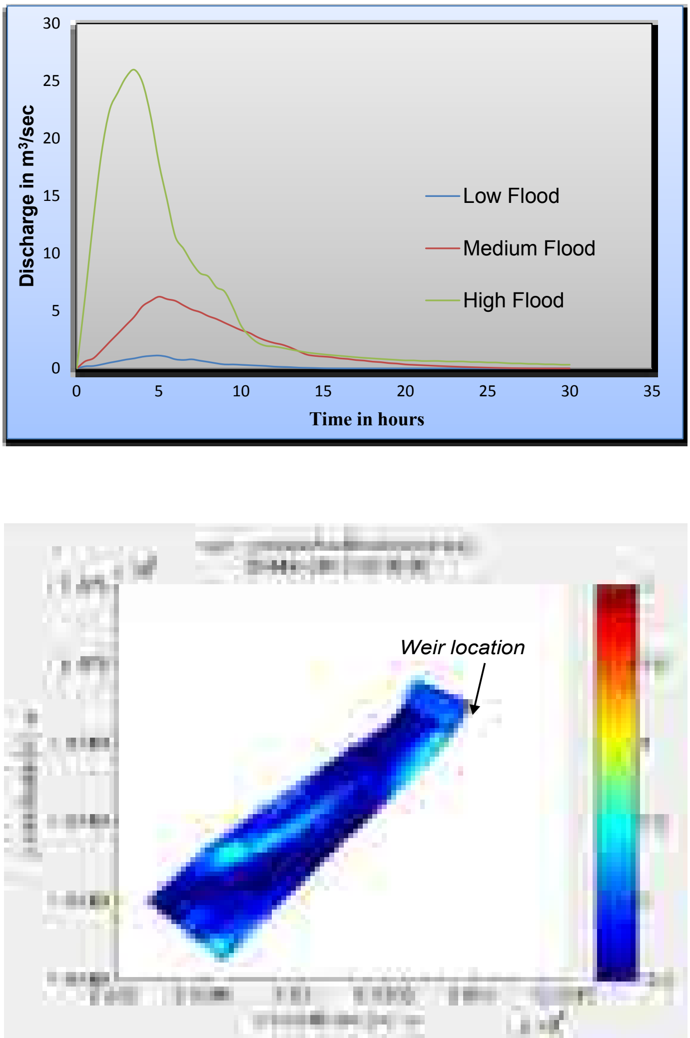
Delft 3D model run to simulate the floodwater levels of the river around the intakes under different flood events (high, medium and low) resulted in the development of the flood hydrograph of the intakes shown in Figure 5.15 (top). Figure 5.15 (bottom) indicates the level of sediment concentration. Table 5.3 shows the comparison of the required abstraction rate at the intakes with the maximum discharge that can be abstracted under the existing condition (Scenario I).

Table 5.3. Floodwater abstraction at intakes.

Flood type	Modern intake, Q req. 16.3 m3/s		Traditional intake) Q req. 12.69 m3/s	
	Max. floodwater depth (m)	Abstraction (m3/s)	Max. floodwater depth (m)	Abstraction (m3/s)
Low	0.34	1.12	0.37	1.75
Medium	0.99	6.23	0.97	23.57
High	2.72	25.49	1.03	26.58

As shown in Table 5.3, the discharge abstraction of the modern intake was considerably lower than the required abstraction rate during medium and low flood events. The maximum floodwater uptake of the intakes is 38.20 and 6.90% of the required abstraction rate during medium and low floods, respectively.

Figure 5.15. Modern intake inflow hydrograph (top) and cumulative erosion/ sedimentation (bottom).

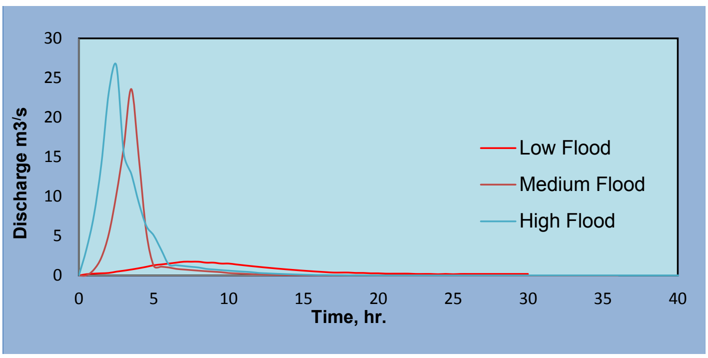


The main reason for the low abstraction rate was the deposition of sediments around the intakes that blocked floodwater flow towards the intakes. This was noted from the morphological simulation results of Delft 3Dn which indicated a possible sediment deposition of 46.00 cm around the intakes. Moreover, the intake was oriented at an angle of 900 with the direction of floodwater in the river, which was not the optimum point of view of floodwater and sediment management. According to the study done by Pirestani et al. (2011), the best intake angle for higher diversion efficiency and minimum sediment entry is from 115 to 1,350. Notwithstanding the lower and medium floods, simulation results indicated higher floodwater levels at the intake during high flood events that enabled the diversion of 25.49 m^3s^{-1} of floodwater as maximum at the intake under the existing modern structure scenario (Scenario I). Nonetheless, as per the model output the maximum abstraction rate indicated above occurred for a short period of time, not more than 10 hours as can be seen from Figure 5.15. The model output further indicated that the total volume of floodwater that could be diverted was 1.16 Mm^3 considering bad season, which could provide 41.00% of the 2.8 Mm^3 water demands of crops in the command area.

3.4.2. Traditional diversion

According to the simulated floodwater level, the maximum water uptake of the traditional intake could be 1.75, 23.57 and 26.58 m^3s^{-1} during low, medium and high floods, respectively (Table 5.3).

Figure 5.16. Traditional intake inflow hydrograph at existing condition.



The intake hydrograph (Figure 5.16) shows a small abstraction rate with a longer period of time at lower floods and high abstraction rates for short duration at medium and high floods. It must be noted that the abstraction time in general is half of the time available with the modern (5 hours) intakes. This was due to the very fact that the traditional diversion structures, which were made of earth/stone/brushwood, etc., collapsed shortly after the onset of high floodwater that generated an excessive amount of dynamic force beyond the capacity that the structure could withstand. This led to the loss of subsequent floodwater that could have been diverted to the main canals. The failure of traditional diversion structures at medium and higher floodwater was common in other countries where spate irrigation is practiced. In Eritrea, traditional diversion structures face minor and major damage as a result of large floodwater of 50 - 100 m^3s^{-1} while complete destruction is imminent at 100 m^3s^{-1} flood (Mehari, 2007). As shown in Figure 14, diversion of floodwater considerably reduced and tended to ease after 5 hours even if there was floodwater in the river. This implied that there was a very short period of time to divert floodwater and, hence, the cumulative volume of floodwater applied to the field was very small.

3.4.3. Performance of the schemes to irrigate their command area

As indicated in sub-sections 3.4.1 and 3.4.2, the diversion capacities of the intakes were very much below the desired ones. However, it was found necessary to do further analysis to quantify the total volume of water diverted and the area that could be irrigated so that the performance of the scheme could be assessed. With the volume of floodwater that could be diverted under any one of three anticipated years/seasons (good, average and bad), the command area which could be fully irrigated was estimated and given in Table 5.4.

Table 5.4. Command area under the existing condition (Scenario I).

Intake	Year/Season	Total volume diverted (Mm^3)	Area irrigated (ha)	Percentage of area irrigated
Modern (Command area 176 ha)	Good	6.63	414.68	236.00
	Medium	2.10	131.49	75.00
	Bad	1.16	72.66	41.00
Traditional (Command area 137 ha)	Good	4.41	275.6	201.00
	Medium	1.52	95.00	69.00
	Bad	0.51	32.00	23.00

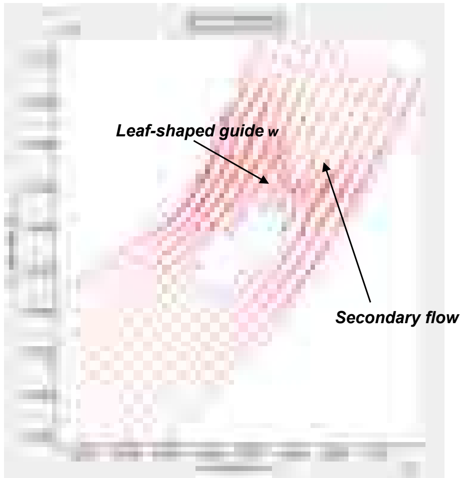
It is obvious that in the good season the diverted flood can easily satisfy the crop water demand of the command area. However, during average seasons it is possible to irrigate 75 and 69% of the command areas of the modern and traditional intakes, respectively. The model estimated that during the bad year/season, characterized with only two large floods, 72.66 and 32.00 ha could be irrigated using the modern and traditional intakes, respectively. These values could be lower as there is no irrigation rotation which allows utilization of all floodwater diverted at the intakes.

3.5. Scenario II: Reinforcement, Guide wall and Bed Stabilizer Intervention

In this scenario, three possible improvement options were examined to assess the effect of improvements on floodwater intakes and sedimentation: a leaf-shaped guiding wall upstream of the modern weir, four consecutive riverbed stabilizers and reinforcement of the traditional intake.

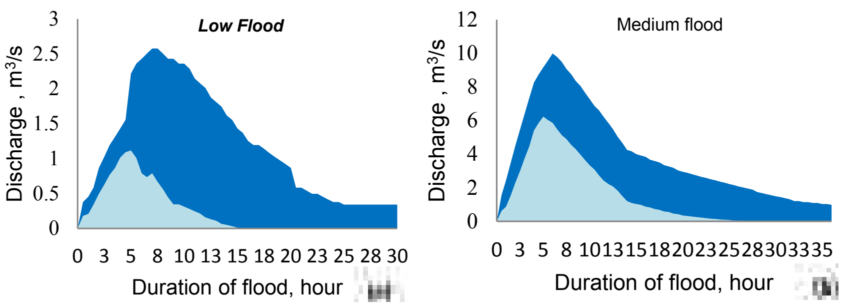
Figure 5.17 shows a leaf-shaped guide wall located at the center of the river to assure floodwater flows into both intakes situated on the left and right sides of the weir. The shape of the guide wall was to create an inner bend so that the entry of coarse sediments could be minimized due to the effect of secondary flow currents.

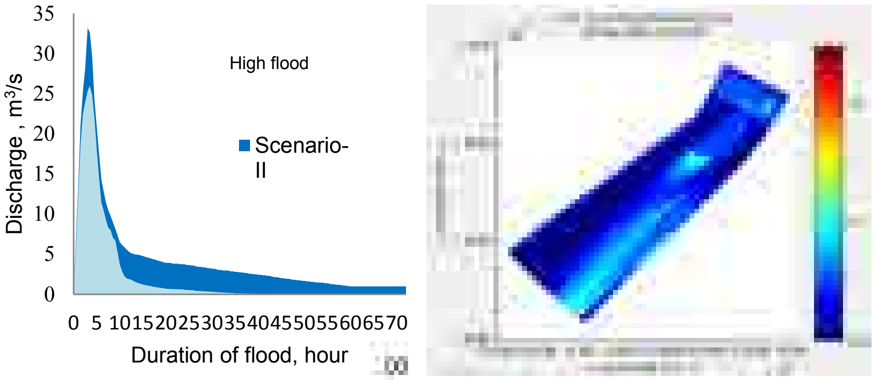
Figure 5.17. Effect of the leaf-shaped guide wall on flood flow pattern.



As can be seen from Figure 5.17 above, the floodwater flow is concentrated at the sides of the river thus raising the water levels at the intakes. As a result, simulated increments of floodwater level of 22, 38 and 58 cm were noted considering low, medium and high floods, respectively. The corresponding simulated hydrographs are shown in Figure 5.18. As can be seen from the figure below, the effect of the intervention was more pronounced in improving the floodwater uptake at low and medium floods than at high flood (see areas colored deep and light blue). Hence, this clearly indicates that the introduction of a leaf-shaped guiding wall upstream of the modern weir and consecutive riverbed stabilizers would only increase the cost of construction and maintenance if floodwater flow is expected to be high or under a good year/season situation.

Figure 5.18. Intake hydrographs of modern structure under Scenarios II (a and b) and Scenarios I and II (c) and cumulative erosion/sedimentation under Scenario II (d)

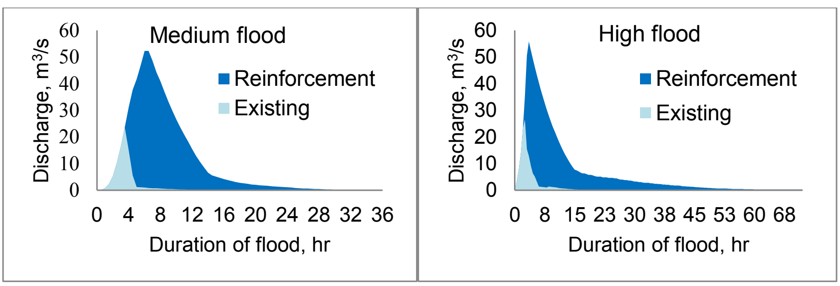




It must be noted that the increment in the level of floodwater at the intakes is the result not only of the guiding wall but of the bed stabilizers that minimized the sediment deposition around the intake by taking steps to stop erosion of the upstream riverbed that minimized the amount of sediments reaching the diversion.

The enforcement of the traditional intake on the existing structure, in such way that it could withstand the impact of increased dynamic force of floodwater, brought about a significant increase in the volume of floodwater diverted as the intake was capacitated to abstract for a longer period of time with no damage. The reinforcement resulted in strengthening the existing diversion which was in the range of 0.6 to 1.0 m in height, top width being about 1.00 m and the bottom width to be fixed after checking slope stability of the canal. The design of the diversion could be modified in order to make it capable of withstanding the impact of the force of floodwater at the discharge level of 238 m^3s^{-1}, which was the estimated discharge at the downstream of the traditional diversion. However, it should be noted that the increased height could cause diversion of more floodwater that can damage the canals and command area; the height increment must be made with most care. Figure 5.19 shows the change in shape of the traditional intake inflow hydrograph at medium and high floodwater flow situations.

Figure 5.19. Intake hydrograph of reinforced traditional structure.



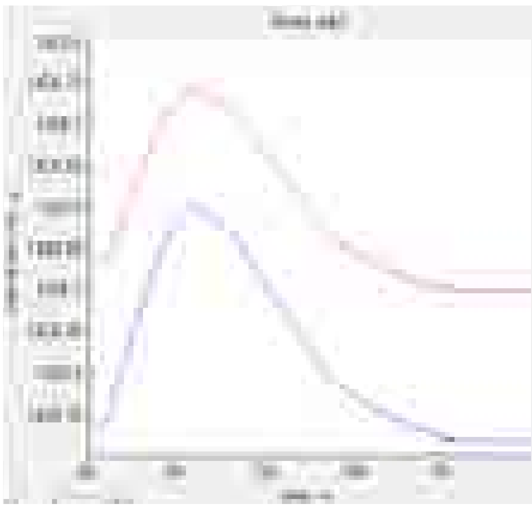
The simulated volume of floodwater made available as a result of reinforcement was large, and the scheme could irrigate all the command area even during the bad season. The simulated improvements made on the structures, both traditional and modern ones, improved the level of floodwater that could be diverted to the farms.

Nonetheless, it must be noted that change in the schemes may have negative implications on the existing traditional water use and share regulations and rule; people tend to cultivate more as a result of increased floodwater availability in the area.

Simulation under Scenario II indicated that the set of interventions sought would reduce the level of floodwater by 15 cm (see Figure 5.20) at the intake located downstream of the traditional intake. This would imbalance in floodwater sharing between upstream and downstream users and may lead to a conflict over the meager water resource, in the area. However, this reduction in floodwater level was not because most of the floodwater was diverted at the modern intake, rather it appeared the floodwater would be flowing far away from the intake during low floods.

Sediment depositions were observed in front of the leaf-shaped guide wall, even after interventions under Scenario II, which could affect the flow pattern in the river and block the flow of consecutive floods to the intakes.

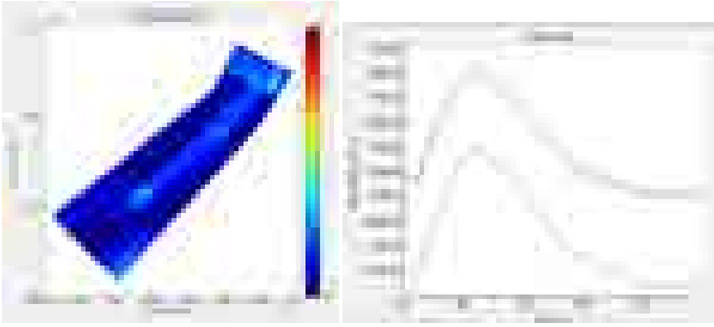
Figure 5.20. Upstream and downstream floodwater level at the intake under the existing traditional structure (red) and under Scenario II (blue)



3.6. Scenario III: Extending the Leaf-Shaped Guide Wall and Introducing Another Guide Wall Upstream of the Traditional Intake

To overcome the drawbacks of scenario-II, the leaf-shaped guide wall was extended by 48 m further upstream and one additional guide wall of 29 m was introduced upstream of the traditional diversion. The model simulation showed that the sediment deposition was reduced as can be seen from Figure 5.21; the fact that the depth of sediment is almost zero everywhere, guaranteed the desired pattern of floodwater flows.

Figure 5.21. Sediment deposition after scenario III (right) and floodwater level at the intake of the existing structure (red), Scenario II (blue) and Scenario III (green)



Similarly, the provision of a guiding wall upstream of the traditional intake adequately minimized the decline in floodwater level observed under scenario II. As shown in Figure 5.21, the floodwater level in the traditional intake is brought to a level which is slightly higher than the existing condition during the low floods. As a result, the desired floodwater abstraction rate was obtained and the sediment deposition around the intakes alleviated. However, it does not necessarily mean that the scheme is capable of supplying enough floodwater to meet the water requirement of the crops in the command area. Hence, the effect of the interventions was analyzed by comparing the area being irrigated under existing conditions with the area that could be irrigated after the intervention.

Under the average flood year/season, applying scenario II and scenario III could enable the scheme to fully irrigate all the command areas without any moisture stress. However, during the bad year/season, full irrigation is possible for 84 and 95% of the command areas through the improvement options defined as scenario II and scenario III, respectively (Table 5.5).

Table 5.5. Command area under the existing condition (Scenario I).

Scenario	Year/ Season	Total volume diverted (Mm^3)	Total area irrigated (ha)	Percent area that can be irrigated
I	Good	6.63	414.68	236.00
	Average	2.10	131.49	75.00
	Bad	1.16	72.22	41.00
II	Good	16.24	1,015.28	577.00
	Average	5.38	335.97	191.00
	Bad	2.36	147.75	84.00
III	Good	18.57	1,160.80	660.00
	Average	6.23	389.67	221.00
	Bad	2.67	167.09	95.00

4. Conclusion and Recommendation

The following major conclusions and recommendations are drawn from the study with regard to optimization of flood and sediment management in Aba'ala spate irrigation.

4.1. Conclusions

- Higher sediment deposition of up to 46 cm around the modern intakes made the abstraction rate to be limited to 7 and 38% of the required 16.3 m^3s^{-1} at lower and medium flood events. Likewise, the traditional intake diverted 14% of the required 12.69 m^3s^{-1} abstraction rate at lower flood events.
- At higher flood, the modern intake is capable of diverting at a rate of 25.5 m^3s^{-1}. However, diverting flood equal to or greater than the required 16.3 m^3s^{-1} was possible for short durations (4 hours) due to the fast rising and fast declining nature of the incoming floods.
- A higher abstraction rate of 23.6 and 26.6 m^3s^{-1} was observed in the traditional intake during medium flood and high flood, respectively. However, diverting at higher rates is shortly halted after 6 hours due to collapse of the diversion as a result of the impact of force of floods.
- In an average flood season, the modern intake can divert 75% of the required 2.8 Mm^3 of floodwater while the traditional intake diverts 69% of the required 2.2 Mm^3 of floodwater. In a bad flood season, the percentage is declined to 31% in the modern intake and to 25% in the traditional intake.
- Reinforcing the traditional intake (leaf-shaped guiding wall and bed stabilizers) resulted in a better flood and sediment management practice by reducing sediment deposition to almost zero around intakes. However, this failed to ensure equitable sharing between upstream and downstream intakes as a water level decline of 15 cm was seen in the traditional intake at low flood levels.
- Putting up a 78 m long guide wall upstream of the modern intake and bed stabilizers together with a 29 m long guide wall upstream of the traditional intake gives good results in terms of improving diversion capacity of both the intakes and assuring a fair share of water between upstream and downstream intakes.
- The command areas under both intakes can be expanded by 100% if the interventions listed under scenario III (extended guide walls upstream of modern intake, bed stabilizers, guide wall upstream of traditional intake and reinforcing traditional intake) are applied.

4.2. Recommendation

- For better floodwater uptake, reduced sedimentation and fair share of floodwater, the modern intake should be equipped with the extended guide wall and bed stabilizers with a guide wall upstream of the traditional intake.
- As the bed stabilizers can raise the water level, it is recommended to build multiple intakes at the section of the river rehabilitated with bed stabilizers so as to increase the overall diversion efficiency.
- Some modification of width and side slope should be done to ensure stability and strength of traditional intakes. However, the height must be kept as fixed traditionally (0.6 - 1.0 m) to control damage of command area as a result of higher flood diversion.
- Regular inspection after every flood is recommended for any sediment deposits upstream of the extended guide wall.

- Simulations were done based on a single flood event. For future research, it is recommended to study the hydrograph for at least one season and test the seasonal floodwater flow and sediment deposition patterns.
- Further research needs to be done to verify the inputs, flood discharges and sediment concentration used in this research. It is also recommended to calibrate the model before using the results for any decision making.
- Design of diversion structures must be based on the fundamental principles and construction done by qualified contractors.

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Predicting Runoff Yield using SWAT Model and Evaluation of Boru Dodota Spate Irrigation Scheme, Arsi Zone, Southeastern Ethiopia

Ehitaferahu Teso,[1] Tena Alamirew[2] and Megersa Olumana[3]
[1]East Shoa Zone Irrigation Development Authority, Adama, Ethiopia
E-mail ehitaferahuteso@gmail.com, +251-911-88-91-17
[2]Water and Land Resource Center (WLRC), P.O. Box 8707, Addis Ababa, Ethiopia
E-mail: tena.a@wlrc-eth.org +251-922-47-01-13
[3]Tshwane University of Technology p/Bag X68, Pretoria 0001, South Africa
E-mail: DinkaMO@tut.ac.za

Abstract

For strategic planning and decision making on water-related development projects systematic assessment of the availability of water resources is imperative. Nevertheless, such information is rarely available for many of the subbasins in Ethiopia. Hence, ungauged catchments need to be modeled using hydrologic models. This study was initiated with the objective of calibrating and validating SWAT model on Keleta River gauged watershed (about 761.89 km^2) so that it can be used to predict runoff on a monthly, seasonal and annual basis, and evaluate the Boru Dodota spate irrigation scheme that has a similar hydrometeorological condition with the Keleta Watershed. Keleta River's observed flow data were used for sensitivity analysis, model calibration and validation. The result of model performance analysis demonstrated a good agreement between the average monthly simulated and measured values: Nash-Sutcliffe model efficiencies (NSE) of 0.71 for calibration and 0.73 for validation periods. Moreover, the coefficients of determination (R^2), 0.73 and 0.76, were obtained during the same period. The calibrated parameter on the gauged catchment was in turn used to estimate runoff yield of the ungauged catchment. The simulated mean monthly and average annual water yields of the Boru River Watershed were found to be 0.53 and 6.4 m^3s^{-1}, respectively. The 70% dependable wet season water yield of the catchment was 3.41 m^3s^{-1}, and crop water requirement of the command area was 1.2 $ls^{-1}ha^{-1}$. The water yield from the catchment can irrigate only 2,842 ha of land out of the pre-designed 5,000 ha of land of the Boru Dodota spate irrigation scheme. In conclusion the SWAT model can be used to analyze ungauged watershed runoff yield in areas that have similar hydrometeorological characteristics as those of the Keleta Watershed in the region. The information obtained can then be used to redesign the spate system or a conventional irrigation system.

Key words: *SWAT, spate irrigation, PUB, ungauged catchment, runoff prediction*

1. Introduction

Water is a key driver of sustainable development and poverty alleviation. It is an input to almost all production in agriculture, industry, energy and transport. Ethiopia has nine wet and three dry river basins. The annual runoff and groundwater potential from nine river basins are estimated to be 122 BM^3 and 40 BM^3, respectively. The Awash River Basin is among the nine river basins which cover a total drainage area of 110,000 km^2 and contribute 4.6 BM^3 of annual runoff (Getaneh 2011).

Most water-scarce (the semiarid, arid and desert) areas in Ethiopia are crossed at least with ephemeral rivers. In addition, some such areas are neighborhoods of highlands with enormous but unpredictable runoff. Making use of such disastrous, unreliable and erratic floods in conjunction with the rainfall on the agricultural fields is challenging. An initiative is needed to efficiently utilize the flood resource from the upper land to supplement the rain-fed agriculture on the lower land (Demissie et al. 2010), i.e., the development of spate irrigation. In developing spate systems, it is important to understand the entire hydrology of the system: the baseflow, subsurface flow and groundwater and the pattern of spate floods. This will dictate the potential yield of the area to be irrigated. However, spate floods can have very high peak discharges generated in wadi catchments through localized storms. The extreme characteristics of wadi hydrology make it very difficult to determine the volume of water that will be diverted to fields and hence the potential cropped areas (Steenbergen et al. 2010).

One of the challenges in water resources development in Ethiopia has been the paucity of hydrological and meteorological data. On top of this, analyzing the historical events is difficult because of a lack of historical runoff records from the ephemeral rivers. In the absence of measured data, watershed models serve as a means of organizing and interpreting research data while also providing continuous water-quality predictions that are economically feasible and time-efficient.

Although empirical formulas are adopted, this simply simulates rainfall-runoff relationships developed not exactly in the same agroclimatic zones. There is great uncertainty on the estimation for it does not consider the complex interactions that take place in the watershed.

A comprehensive understanding of hydrological processes in the watershed is the prerequisite for successful water resources management and environmental restoration. Due to the spatial and temporal heterogeneity in soil properties, vegetation and land use practices, a hydrologic cycle is a complex system. As a result, mathematical models and geospatial analysis tools are required for studying hydrological processes and hydrological responses to land use and climatic changes. The Soil and Water Assessment Tool (SWAT), a physically based semi-distributed model, was selected to analyze the yield of the ungauged Boru River Watershed with respect to quantity of runoff. SWAT has the ability to characterize complex, watershed representations to explicitly account for spatial variability of soils, rainfall distribution, and vegetation heterogeneity and shows the effects of different land management practices on surface runoff and sediment yield (Arnold et al. 1998).

The Boru Dodota Spate Irrigation Scheme is one of the areas with a semiarid climate in the Oromia Regional State Arsi Zone, Dodota District. The area faces frequent crop failure due to the erratic nature of rainfall. Boru Dodota uses spate irrigation to divert floods up to 6 m^3s^{-1} of the ephemeral Boru River to supplement the rain-fed agriculture on 5,000 ha (Aman 2007). In the Boru Dodota irrigation scheme the periods of flood and crop production coincide. However, due to the unpredictable nature of the flood from the subbasins and the rainfall on the scheme, a substantial size of the command area is left without irrigation (Demissie 2010). The hydrologic processes of the watershed were not analyzed because of the absence of hydrologic information, such as surface runoff, baseflow, seasonal water yield, the magnitude and return period of extreme events. Farmers' indigenous knowledge, visual observation and empirical formulas were used to estimate peak flows and baseflow, which are the basis for structural design and used for deciding the supplemented area (Aman 2007). This study was initiated to triangulate the assumption adopted in estimating the surface runoff, baseflow, and seasonal water yield upon the system design development.

The general objective of this study is to create an understanding of how hydrological models can be utilized to solve challenges on catchments characterized in the absence of hydrological data. The runoff yield of the ungauged Boru River Watershed was estimated and the parameters used for the Boru Dodota spate irrigation scheme evaluated. The specific objectives were to calibrate and validate a SWAT model on monthly time step at gauged Keleta River Watershed; estimate monthly, seasonal and annual runoff yields and water balance of the ungauged Boru River Watershed using the SWAT model at the headwork, and evaluate Boru Dodota Spate Irrigation Scheme.

2. Materials and Methods

2.1. Description of the Study Area

The Keleta-gauged and Boru-ungauged river watersheds are found in the southeastern part of Ethiopia in the Arsi Zone of Oromia Regional State. The watersheds originate from the Chilalo Mountain situated in the upper Awash River Basin. Boru (Wadi) River drains to Keleta River below the gauging station as shown in Figure 6.1. The watersheds are geographically situated between 7°55 - 8°16′ N latitude and 39°17′ - 39°34′ E longitude and 7°55′ - 8°11′ N latitude and 39°16′ - 39°22′ E longitude, respectively. They cover a total drainage area of 761.9 km^2 and 74.8 km^2, respectively. The minimum and maximum elevations of the watersheds are 1,600 m, 4,183 m, 4,039 m and 1,865 m, amsl, respectively. Rainfall in the downstream of the Boru Watershed (Boru Dodota Spate Irrigation Scheme) is erratic and dry for much of the year (Aman 2007). Boru Dodota Spate Irrigation Project was designed to provide supplemental irrigation water for about 5,000 ha of potential irrigable land using the 6 m^3s^{-1} designed flood generated from Boru and other micro watersheds (Aman 2007).

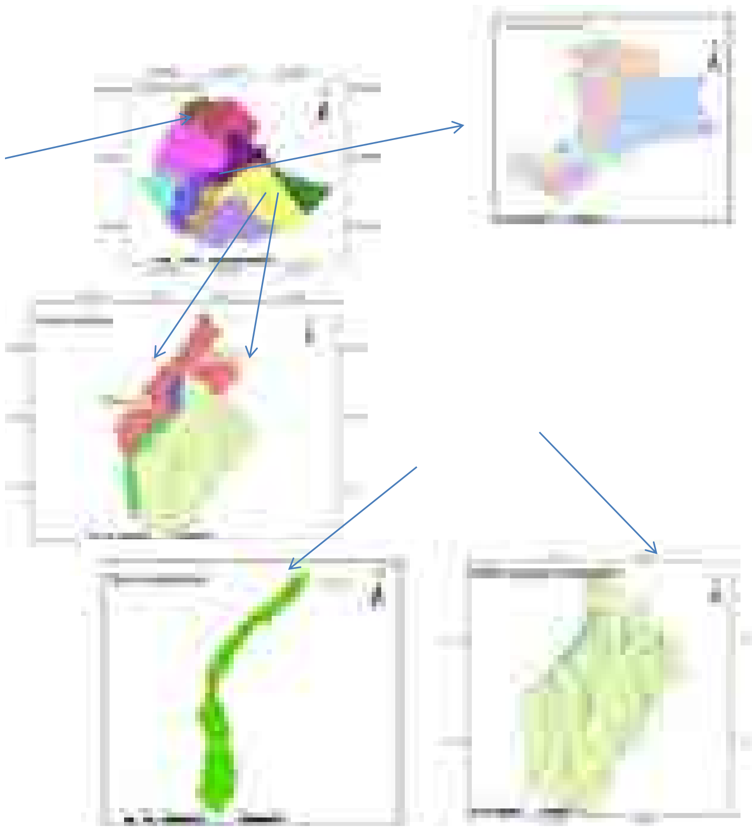
2.2. Description of the SWAT Model

SWAT was developed to predict the impact of land management practices on water, sediment and agricultural chemical yields in large, complex watersheds with varying soils, land use and management conditions over long periods. The model is a basin-scale, continuous-time model that operates on a daily time step. It is physically based, computationally efficient, and capable of continuous simulation over long periods (Gassman et al. 2007). In SWAT, a watershed is divided into multiple sub-watersheds, which are then further subdivided into hydrologic response units (HRUs) that consist of homogeneous land use, management, and soil characteristics. The HRUs represent percentages of the sub-watershed area and are not identified spatially within a SWAT simulation. Alternatively, a watershed can be subdivided into only sub-watersheds that are characterized by dominant land use, soil type, and management (ibid). The review of SWAT model applicability to the local situation indicated that the model is capable of simulating hydrological processes with reasonable accuracy and can be applied to large ungauged watersheds (Kebede et al. 2006). SWAT is currently applied worldwide and is considered as a versatile model that can be used to integrate multiple environmental processes, which support more effective watershed management and the development of better-informed policy decisions (Gassman et al. 2005). The simulation of the hydrology of a watershed is classified as the routing phase and the land phase of the hydrological cycle that controls the amount of water, sediment, nutrient and pesticide loadings to the main channel in each subbasin and simulates the hydrologic cycle based on the water balance equation (equ. 1) of Arnold et al. (1998) and Neitsch et al. (2005)

$$SW_t = SW_o + \sum \left(R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw} \right) \quad (1)$$

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

Figure 6.1. Major river basins of Ethiopia and location map of Boru and Keleta sub-wateshеds.



2.3 SWAT Model Inputs

2.3.1. Digital Elevation Model (DEM)

DEM was used to delineate the watershed and analyze the drainage pattern of the land surface terrain and subbasin parameters, such as slope gradient, slope length of the terrain and the stream network characteristics, such as canal slope length and width. The DEM with a resolution of 30 m was downloaded from Advanced Space Borne Thermal Emission and Reflection Radiometer Global Digital Elevation Model (ASTER GDEM) of the official website (http://www.gdem. aster.ersdac. or.jp/download.jsp) released by Earth Remote Sensing Data Analysis Center (ERSDAC) in collaboration with National Aeronautics and Space Administration (NASA) of the United States.

2.3.2. Land use and land cover (LULC)

The land use map and all datasets of the study area were obtained from the Ministry of Water and Energy (MoWE) of Ethiopia derived from satellite imagery and field data collection from 2004 to 2007. The reclassification of the land use map was made to represent the land use according to the specific land cover types. A look-up table that identifies the SWAT code for the different categories of LULC was prepared to relate the grid values to SWAT LULC classes. The major land uses of the study areas are illustrated in Figure 6.2.

2.3.3. Soil properties

A soil map and datasets on basic soil physico-chemical properties may be obtained from the Ministry of Water and Energy (MoWE 2007), Soil and Terrain Database for north-eastern Africa CDROM (FAO 1998), Harmonized World Soil Database (HWSD) and different irrigation design documents around the study area. Soils in the study watersheds are classified based on the revised FAO/UNESCO-ISWC (1998) classification system (Tables 6.1, 6.2 and 6.3).

2.3.4. Meteorological data

The SWAT model requires meteorological data such as precipitation, maximum and minimum air temperatures, sunshine hours, wind speed and relative humidity; these were collected from the National Meteorological Services Agency (NMSA) of Ethiopia for Kulumsa, Sire, Diksis, Huruta and Melkasa. Among these stations, the model used only Kulumsa, Melkasa and Huruta stations for the Boru Watershed (Figures in the Annex). All weather stations provided precipitation and minimum and maximum temperatures, whereas daily sunshine hours, wind speed and relative humidity were obtained from Melkasa and Kulumsa weather stations. Although much of the data had missing values, the SWAT model fills the gap by the weather generator model WXGEN embedded in Arc SWAT interface. The Penman-Monteith method, which utilizes the solar radiation, relative humidity and wind speed data records, was employed for estimation of potential evapotranspiration.

Finally, the quality of rainfall data was checked by cross correlating between the stations on a monthly basis. The correlation coefficient (r^2) ranges from 0.86 to 0.98. The result of the correlation coefficient (r^2) implied that all stations were positively and strongly correlated and there were consistent records among the stations.

2.3.5. Hydrological data

The only hydrological data required for sensitivity analysis, calibration and validation of the model, and the daily Keleta River discharge, were obtained from the Hydrology Department of the Ministry of Water and Energy of Ethiopia. The homogeneity of average annual daily flow data was tested using RAINBOW, which uses past flow data for analysis. The total daily discharge data of the Keleta River were separated into surface runoff and baseflow by using an automated baseflow separation and recession analysis technique (Arnold et al. 1999). The output was used to test whether the SWAT model reflects the basic observed water balance components (surface runoff and baseflow) at the gauging station or otherwise.

Table 6.1. Major soil classes of Keleta River and Boru River watersheds.

Name of soil unit	Code of the soil unit	Keleta Watershed		Boru Watershed	
		Area [ha]	[%] in weight	Area [ha]	[%] In weight
Chromic Luvisol	LVx	8,143.17	10.69	1,161.95	15.14
Chromic Vertisol	Vc	9,540.65	12.52	214.66	2.87
Dystric Nitosol	Nd	1,817.55	2.39	*	*
Eutric Cambisol	CMe	11,629.20	15.26	427.82	5.72
Eutric Nitosol	Ne	4,317.98	5.67	377.05	5.04
Eutric Rigosol	RGe	*	*	182.55	2.44
Eutric Vertisol	VRe	29,898.20	39.24	822.98	11.01
Lithic Leptosol	LPq	1,142.33	1.50	*	*
Orthic Luvisol	Lo	9,530.98	12.51	1,585.30	21.20
Vertic Cambisol	CMv	168.73	0.22	2,705.25	36.18

Table 6.2. Land use, SWAT codes and area coverage in Keleta and Boru watersheds.

Land use	SWAT code	Keleta Watershed		Boru Watershed	
		Area [ha]	[%] in weight	Area [ha]	[%] in weight
Forest -- Deciduous	FRSD	10,454.45	13.72	1115.38	14.92
Forest -- Evergreen	FRSE	5,658.80	7.43	815.14	10.90
Agric. Land – Generic (Mixed Farming)	AGRL	59,107.05	77.58	5547.04	74.18
Range – Brush (woodland)	RNGB	968.48	*	1.27	*

NB: * indicates soil type and land use not found in that specific area.

Table 6.3. Slope classes and percentage area coverage of Keleta and Boru watersheds.

Slope class	Keleta Watershed		Boru Watershed	
	Slope (%)	Area coverage (%)	Slope (%)	Area coverage (%)
I	0-10	43.13	0 – 10	39.8
II	10-20	37.57	10 – 25	43.33
II	20-30	12.44	25 – 40	10.18
IV	30-9999	6.86	40 - 9999	6.69

Figure 6.2. Soil map and its spatial distribution over (A) Keleta and (B) Boru watersheds.

A

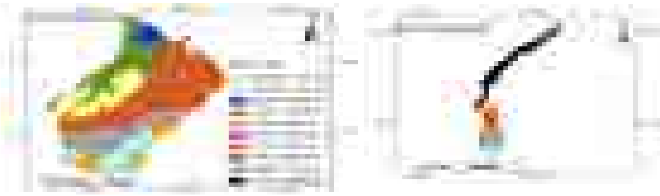
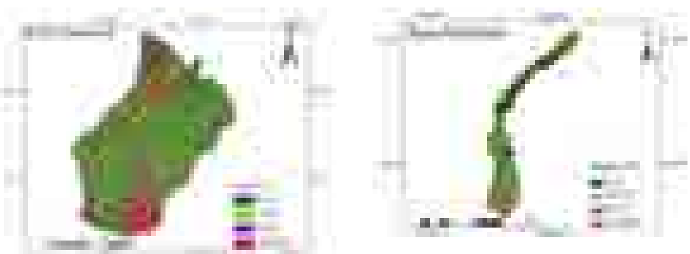


Figure 6.3. Land use map and its spatial distribution over (A) Keleta and (B) Boru watersheds.

A B

Figure 6.4. Land slope map and its spatial distribution over (A) Keleta and (B) Boru watersheds.

A B



2.4 Model Setup

2.4.1. Watershed delineation

Automated watershed delineation embedded in Arc SWAT interface was used to delineate the watershed. Delineation of the watershed and sub-watershed was done using Digital Elevation Model (DEM) data. DEM was imported into the SWAT model and projected to UTM zone 37, projection area of Ethiopia. A mask was manually delineated over the DEM in order to extract the specific area, to delineate the boundary of the watershed and digitize the stream networks in the study area, which reduce the time of processing and burn-in a polyline stream dataset that in turn helps the subbasin reach to follow the known stream reach. In this study, the minimum threshold area of 1,522 ha and 233.4 ha were used to define the stream network for Keleta and Boru watersheds, respectively. This threshold area was used to define the minimum drainage area required to form the origin of a stream and to decide the number of subbasins within the watershed. Lastly, watershed outlet and inlet definition, watershed outlet or gauged point location and calculation of subbasin parameter were made.

2.4.2. Hydrological response units

After watershed delineation, subbasins were subdivided into areas having unique land use, soil and slope so-called hydrologic response units (HRUs). Even if the individual fields with specific land use, soil and slope were scattered over the subbasin, when lumped together they form HRUs. The land use, soil and slope datasets were projected into the same projection as DEM. After projection of the land use, soil and slope datasets were reclassified, overlaid and linked with the SWAT databases and ready for HRU definition. To define the distribution of HRUs, multiple HRU definition options were selected. The threshold level set for land use, soil and slope was used to define the number of HRUs within the subbasin as well as the watershed. In addition to land use and soil, HRUs were also classified based on slope classes. For these specific areas, multiple slope classification was used and the classifications were made based on the suggested minimum, maximum, mean and median slope statistics of the watershed. The minimum threshold area of 5% for land use over the subbasin area, 10% for soil class over the land use area and 10% for slope over the soil area were used. The land use, soil and slopes percentage areas covering less than the threshold area level were eliminated, and then the remaining areas were reclassified so that 100% of the land area in the subbasin could be used in the simulation.

2.4.3. Sensitivity analysis

After all the input (temporal and spatial) data required for the SWAT model were properly loaded, the parameter sensitivity analysis was done using the Arc SWAT interface for the whole catchment (Van Griensven et al. 2006). Twenty-six hydrological parameters were tested for sensitivity analysis for the simulation of the streamflow in the study area. Here, almost all the default lower and upper bound parameter values were used. In addition to hydrologic parameters, observed monthly flow values of Keleta River were used. The sensitivity analysis was made using a built-in SWAT sensitivity analysis tool that uses the Latin Hypercube One-factor-At-a-Time (LH-OAT) algorithm (Van Griensven 2005). After running a sensitivity analysis, the sensitivity parameters were categorized into four classes based on their mean relative sensitivity from very high to low.

2.4.4. Calibration and validation

During the calibration process, model parameters were subjected to adjustments in order to obtain model results that correspond better to the measured datasets. After the sensitive parameters were selected, the model simulates the stream flow using default parameter values for the years 1990-1995. The default simulation outputs were compared with the observed stream flow data on Keleta River. In this study, manual calibration followed by automatic calibration were made on a monthly basis from January 1, 1992 to December 31, 1995 until the average simulated value came closer to the measured value. Periods from 1990 to 1991 were used as warm-up periods. Automatic calibration makes use of a numerical algorithm to increase the performance of the model and to optimize the numerical objective functions. In manual calibration for each simulation result and parameter change, the corresponding performance evaluation criteria were compared against the preset values. This procedure continued until the acceptable calibration model performance statics $r^2 > 0.6$, ENS > 0.5 and D >±15 (Santhi et al. 2001; Moriasi et al. 2007) were achieved. After the simulation result for the calibration period had fulfilled the above statistical criteria, validation was performed for an independent period of records from January 1, 1996 to December 31, 1998. This period was preferred for validation due to better quality of data records. Therefore, the results were compared against an independent set of measured Keleta River discharge.

2.4.5. Model performance evaluation

In order to evaluate the model performance relative to the observed data, the following three performance measures were used during the calibration and validation periods: Percent difference between simulated and observed data (D), Coefficient of determination (R^2) equation (2) and Nash and Sutcliffe simulation efficiency (ENS) equation (3).

$$r^2 = \frac{\left(\sum [X_i - X_{av}][Y_i - Y_{av}]\right)^2}{\sum [X_i - X_{av}]^2 \sum [Y_i - Y_{av}]^2} \qquad (2)$$

where, X_i is measured value, X_{av} is average measured value, Y_i is simulated value, and Y_{av} is average simulated value.

The r^2 value measures how well the simulated versus observed regression line approaches an ideal match and ranges from 0 to 1, with a value of 0 indicating no correlation and a value of 1 representing that the predicted dispersion equals the measured dispersion (Krause et al. 2005).

Nash and Sutcliffe simulation efficiency (ENS) indicates the degree of fitness of observed and simulated data, given in equation (2).

$$E_{NS} = 1 - \frac{\sum_{i=1}^{n} (X_i - Y_i)^2}{\sum_{i=1}^{n} (X_i - X_{av})^2} \qquad (3)$$

where, X_i is measured value, X_{av} is average measured value, Y_i is simulated value, and Y_{av} is average simulated value.

The value of ENS ranges from one to negative infinity. The ENS indicates how well the plot of observed versus simulated value fits the 1:1 line. The closer the model efficiency is to 1, the more accurate the model and if it is between 0 and 1, it indicates deviations between measured and predicted values. If ENS is negative, predictions are very poor, and the average value of output is a better estimate than the model prediction (Nash and Sutcliffe 1970).

The percent difference (D) measures the average difference between the simulated and measured values for a given quantity over a specified period (usually the entire calibration or validation period) and it is calculated using equation (4).

$$D = 100\left(\frac{\sum Yi - \sum X_i}{\sum Xi}\right) \tag{4}$$

where, X_i is measured value and Y_i is simulated value. A value close to 0% is best for percent difference (D).

2.5 Transferring calibrated parameters of gauged catchments for ungauged catchments

After thorough calibration and validation of the SWAT model for the gauged Keleta River Watershed, the final calibrated parameter was used to predict runoff and water balance component of the ungauged Boru Watershed, which have similar hydrometeorological conditions. The Keleta River gauged watershed and Boru River ungauged watershed had the same HRUs definition from the minimum threshold level of 5% land use, 10% soil unit and 10% slope. The calibrated hydrologic parameters for the gauged Keleta Watershed were used to change the hydrological parameters in the SWAT model to correctly estimate runoff for the ungauged Boru River Watershed.

3. Results and Discussion

3.1. Watershed Delineations

The gauged Keleta River and the ungauged Boru River watersheds, as shown in Figure 6.3, covered the total drainage area of 761.9 km^2 and 74.8 km^2 and subdivided into 29 and 15 subbasins based on the minimum threshold area of 1,522 ha and 233.4 ha, respectively. Multiple HRUs were defined based on the minimum threshold level of 5% LULC, 10% soil unit, and 10% slope classes. The overlaid land use soil and slopes form 165 and 96 HRUs for Keleta and Boru watersheds, respectively.

3.2. Baseflow Separation

Baseflow separation result using the baseflow filter program by Arnold and Allen 1999 on an annual basis indicated that about 58% of the observed Keleta River discharge was contributed from the subsurface flow. The contribution of baseflow to Keleta River discharge exceeds the surface runoff. In contrast, the simulated flow at Keleta River is estimated as 61.3% of baseflow over the calibration period, whereas it is 60.9% over the validation period. Since the simulated baseflow had agreed with the estimated measured value with little deviation given different uncertainty, the model properly reflected the basic water balance components, such as baseflow and surface runoff.

3.3. Sensitivity Analysis

Among the 26 hydrological parameters selected for sensitivity analysis for simulation of streamflow in the study area, 18 were found relatively sensitive. Accordingly, the more sensitive parameters considered for calibration were: Baseflow alpha factor (Alpha-BF), Curve number (CN2), Threshold depth of water in the shallow aquifer (GWQMN), Effective hydraulic conductivity in the main channel (CH-K2), Plant evaporation compensation factor (ESCO), Available water capacity (SOL_AWC), Soil depth (Sol_Z), Leaf area index for crop (Blai), Deep aquifer percolation fraction (Rchrg-Dp), Maximum canopy index (Canmax), Threshold water depth in shallow aquifer (Revapmn) and Surface runoff lag time (Surlag). Among the baseflow parameters, baseflow alpha factor (Alpha-BF) is the most sensitive over the surface runoff parameter Curve number (CN2) (Table 6.4).

3.4. Model Calibration and Validation

For the calibration period of 4 years (1992 -1995) the simulated monthly flows showed good agreement with the observed monthly Keleta River discharge with a coefficient of determination (R^2 = 0.73), Nash Suttcliffe model efficiency (ENS = 0.71), and percent difference (D = -13.32%). However, the model underestimated the peak monthly flow for the whole calibration period; it followed the trend of observed monthly Keleta River discharge and gave a good response to extreme rainfall events, which resulted in high runoff volume. Table 6.4 illustrates the final calibrated parameter values. The hydrographs of simulated and observed flow values on a monthly basis are shown in Figures 5 and 6.

The SWAT model also successfully validated streamflow for an independent period (1996 – 1998). The model has strong predictive capability with R^2=0.76, ENS=0.73 and D =13.19; the values fulfilled the statistical model performance criteria $R^2 > 0.6$ and ENS > 0.5 recommended by SWAT developer (Santhi et al. 2001).

Generally, the above information showed that the performance of the model increased during the validation period more than during the calibration period. Even though the model underestimated the peak monthly flow for 1997 and overestimated it during 1998, the shape of the hydrograph of simulated flow was the same as the shape of hydrograph of measured monthly Keleta River discharge. The peak values gave a good response to extreme rainfall for the validation period. The hydrograph and the scattered plot of simulated and observed monthly flow values associated with rainfall for the validation period are illustrated in Figures 6.5 and 6.6, respectively.

Table 6.4. Sensitivity flow parameters and final calibrated fitted values.

Flow parameter	Sensitivity rank	Upper and lower bounds	Calibrated value
Alpha BF	1	0.0 to 1.0	0.5274
CN2	2	±25	-0.92491
Gwqmn	3	0.0 to 1000	-82.374
Ch-K2	4	0.0 to 150	93.043
Esco	5	0.0 to 1.0	0.21964
Sol_Awc	6	±25	19.176
Soil_Z	7	±25	9.993
Blai	8	0.0 to 1	0.45106
Canmax	9	0.0 to 1.0	1.569
Rech_Dep	10	0.0 to 1.0	0.0043145
Gw-Revmn	11	0.0 to 100	42.3420
Surlag	12	0.0 to 10	0.6709

Table 6.5. Summary of model performance evaluation for calibration and validation period on monthly time steps.

Mean annual water yield (mm)			Monthly model efficiency measures		
Period	Observed	Simulated	r^2	ENS	D (%)
Calibration	300.82	262.74	0.73	0.72	-13.32
Validation	234.13	267.31	0.76	0.73	13.91

Figure 6.5. Hydrograph of simulated and observed average monthly flow overlaid with monthly rainfall for the calibration period.

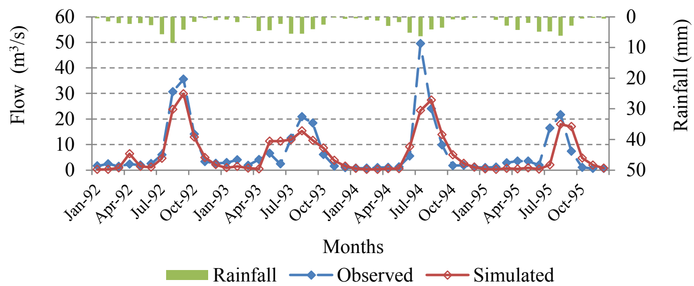
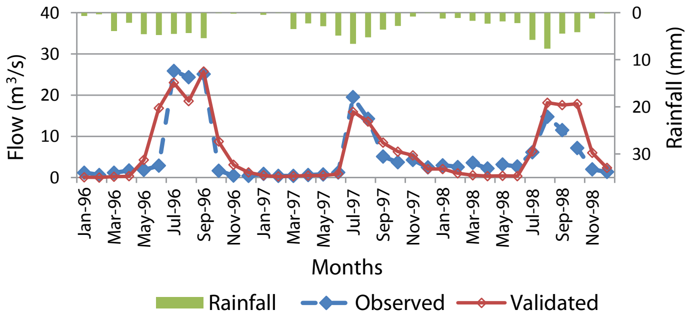


Figure 6.6 Hydrograph of simulated and observed monthly flow overlaid with monthly rainfall for the validation period.



3.5. Boru Dodota Water Yield Simulation

3.5.1. Monthly and seasonal water yield simulation

SWAT water yield simulation result for the period (1994 – 2010) showed 0.53 m^3s^{-1} and 6.4 m^3s^{-1} of mean monthly and annual average water yield, respectively. The result is summarized on a monthly and seasonal basis (dry, wet and intermediate season). The 70% dependable water yield indicated 0.28, 1.01, 3.4 and 5.14 m^3s^{-1} for dry, intermediate, wet seasons and annual basis, respectively. Therefore, among the dependable water yield for the above season, the water yield estimated during wet seasons was important for the spate irrigation scheme.

3.5.2. Average annual water balance components of ungauged Boru River Watershed

The SWAT model can also estimate average annual basin values for different water balance components of the ungauged Boru Watershed. Precipitation was the input, whereas surface runoff, lateral soil flow, groundwater flow, shallow aquifer recharge, deep aquifer recharge and actual evapotranspiration were outputs. The sum of surface runoff, lateral soil flow and groundwater contributions minus transmission loss (water lost from tributary channels in the HRU via transmission through the bed and becomes recharge for the shallow aquifer during the time step) is the total water yield or streamflow that reaches the headwork, whereas the change in soil water storage is the difference between inflow and outflow. The simulated annual water balance components of the Boru catchment are indicated in Table 6.6; 73.9% of the annual precipitation is lost through evapotranspiration from the watershed for the respective period.

Table 6.6. Average annual simulated hydrologic component for the Boru Watershed (1994-2010).

Water balance components	Amount in (mm)
Precipitation; Precip	868.40
Surface runoff; Sur_Q	57.91
Lateral soil flow contribution; Lat_Q	24.78
Ground water contribution to stream flow; Gw_Q	146.05
Revap or shallow aquifer recharges	0.00
Deep aquifer recharges, Rchg-Deep	0.63
Total water yield; Twyld	228.01
Percolation out of soil; Perc	145.92
Actual evapotranspiration; ET	641.60
Potential evapotranspiration; PET	1085.20
Transmission losses; Tloss	0.73
Change in soil water storage	-2.57

Table 6.7 and Figure 6.6 indicate the variability of simulated monthly water yield across subbasins for different land use, soil and slope classes. Subbasin 4 and subbasin 5 with agricultural land generic, Vertic Cambisol, and 10-25% slope, and subbasin 13 and subbasin 15 with forest deciduous and forest evergreen land use, Chromic Luvisol and Orthic Luvisol soil types and 0-10 and 10-25% slopes were estimated to have a high average water yield. This was because subbasins 4 and 5 are cultivated lands. Nevertheless, subbasins 13 and 15 were covered by forest; the area received a high amount of rainfall and generated more water than others could generate. In contrast, subbasins 4 and 5 (slope 10-25 %) had similar soil type and land use, but different slope from that of subbasin 1 and subbasin 3 (slope 0-10 %), which had contributed the least amount of water yield.

Figure 6.7. Estimated average monthly water yield across each subbasin.

Table 6.7. Variation of monthly water yield across subbasins for the period (1994-2010).

Subbasin	Area coverage (km^2)	Water yield (mm)	Subbasin	Area coverage (km^2)	Water yield (mm)
1	2.34	14.13	9	2.99	15.24
2	10.00	15.59	10	4.06	15.79
3	5.58	14.17	11	4.85	17.05
4	4.51	33.68	12	2.08	14.57
5	6.45	33.69	13	2.34	19.51
6	0.23	14.89	14	18.98	16.97
7	1.93	14.88	15	5.31	20.04
8	3.13	15.83			

3.6. Evaluation of Boru Dodota Spate Irrigation Scheme

Results of the SWAT model showed that the drainage area covered by the ungauged Boru River Watershed up to the headwork is 74.8 km^2; the watershed covered 50 km^2 as indicated in the design documents. In Boru Dodota Spate Irrigation Scheme, since the periods of flood and crop production coincide, the wet season (June-September) dependable water yield (3.41 m^3s^{-1}) was an important yield compared to yields in other seasons. The peak discharge and design discharge were 112 and 3.41 m^3s^{-1}, respectively, whereas these were 100 and 6 m^3s^{-1} in the previous design (Aman 2007). The crop water requirement of the command area is 1.2 $ls^{-1}ha^{-1}$ (Aman 2007), whereas 3.41 m^3s^{-1} discharges can only fulfill the crop water requirement of 0.68 $ls^{-1}ha^{-1}$, to supplement rain-fed agriculture on 5,000 ha of land. The remaining 0.52 $ls^{-1}ha^{-1}$ was expected from the precipitation on the command area. However, the precipitation of the area is so erratic in nature that it should have been given less consideration so that the 3.41 m^3s^{-1} discharge for 1.2 $ls^{-1}ha^{-1}$ can irrigate only 2,842 ha of land. The irrigable area of Boru Dodota Spate Irrigation Scheme covers 5,000 ha of land (Aman 2007), whereas the Boru River water yield should irrigate 2,842 ha of land. According to Demissie et al. (2010), information from Dodota District discloses that in 2008 and 2009, 1,821 ha and 1,686 ha of land were irrigated, respectively. The output of the model and the pre-designed discharge (Aman 2007) were different in the drainage area, peak and design discharge, canal capacity, irrigable area and in different hydrologic parameters of Boru River watershed.

Therefore, a great variation in canal capacity such as canal width, canal depth, canal hydraulic radius, canal width over depth ratio, wetted perimeter and all other design parameters were changed because of variation between the pre-designed discharge (6 m^3s^{-1}) and the model output (3.41 m^3s^{-1}). Therefore, all other irrigation structures incorporated in the project should have been redesigned based on the model output.

4. Summary and Conclusion

A comprehensive understanding of hydrological process in the watershed is the prerequisite for successful water resources management and environmental restoration. To analyze the yield of the ungauged Boru River watershed with respect to quantity of runoff yield, the SWAT model was selected. The performance and applicability of the SWAT model were evaluated through a sensitivity analysis, model calibration and validation. After modeling the gauged Keleta River watershed, calibrated parameters were transferred to the ungauged Boru River watershed by lumping the parameters having the same hydrologic response unit (HRUs) to predict runoff for Boru Dodota Spate Irrigation Scheme.

The SWAT model performs well in predicting runoff yield if properly calibrated and validated for the gauged river catchment and transferring the calibrated parameters to the ungauged catchment. Therefore, despite the data scarcity, the SWAT model is a potential tool to simulate the hydrology of ungauged watersheds in Ethiopia that have similar hydrometeorological conditions with those of the gauged watershed. The calibrated parameter values of Keleta watershed can be considered for further hydrologic simulation of the watershed and in developing neighboring catchments. All irrigation structures in Boru Dodota Spate Irrigation Scheme should have been redesigned and reconstructed based on the model output. In order to irrigate the remaining area, a storage reservoir is recommended. Future studies on Boru watershed modeling for the Boru Dodota Spate Irrigation Scheme should address the issues related to sedimentation. Accurate sampling and measurement of sedimentation parameters need to be addressed by responsible bodies to evaluate best management practices and climate change impacts on the availability of water resources.

Acknowledgments

SIDA (Sweden International Development Association) provided financial support and Dr. Abebe Fanta, AGRA Coordinator at Haramaya University provided laptop computers. Mr. Alemayehu Abate trained and guided SWAT model and provided useful materials. Mr. Daniel Alemayehu at Adama Science and Technology University assisted in general application of GIS software. Mr. Abebe Demissie supported and provided useful documents and materials on the watershed. Mr. Girma Senbata and Ms. Shitaye gave moral support for the success of the study. Oromia Water Mines and Energy Bureau gave valuable support. Ethiopian Ministry of Water and Energy provided hydrological data, soil and land use map; National Meteorological Services Agency provided meteorological data, and Arsi Zone Water, Mines and Energy office offered a general overview of the project area. Mr. Gudisa Dirirsa my husband, provided his constant and never-ending concern, support and encouragement. I am thankful to all of them.

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Appendix

Table A1. Mean monthly-observed discharge (mm) at gauged Keleta River Watershed.

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
1992	5.6	8.1	5.1	7.9	6.9	8.5	20.9	107.7	121	49.4	11.4	9.2	362
1993	10	13	6.5	14	23.0	8.1	43.8	73.5	62.5	21.5	5.3	3.2	284.0
1994	2.6	2.3	3.4	3.5	4.3	19	174	84.4	33.3	6.1	6.3	4.1	343.0
1995	3.3	3.6	10	12	12.2	6.5	57.6	76.1	25.1	3.8	2.1	2.3	214.7
1996	4.1	2.0	4.1	5.9	6.4	9.8	90.9	85.5	89.3	5.8	1.7	1.4	307.0
1997	3.1	1.2	1.4	2.0	2.7	4.3	68.6	50.1	17.3	13.0	14.9	8.6	187.2
1998	10.4	8.1	12.6	7.4	11.1	9.1	21.5	51.8	39.2	25.1	7.0	4.8	208.2
Mean	5.6	5.4	6.1	7.5	9.5	9.3	68.2	75.6	55.4	17.8	7.0	4.8	272.2

Table A2. Simulated average monthly water yield (mm) of gauged Keleta River watershed.

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
1992	0.8	1.7	4.0	28.0	5.0	3.5	13.5	69.0	89.3	37.1	12.4	5.1	269.3
1993	2.5	8.5	2.5	2.6	49.7	33.5	40.6	47.7	35.7	27.2	10.6	4.1	265.0
1994	1.6	0.6	1.4	1.6	2.0	33.6	78.3	87.5	39.6	16.4	6.6	2.7	271.7
1995	1.0	0.9	2.6	2.8	1.9	1.1	5.7	62.2	39.3	12.0	4.3	1.9	135.6
1996	0.1	0.0	0.7	1.0	15.1	57.1	80.9	65.2	93.12	30.7	10.8	4.3	357.2
1997	1.8	0.8	1.2	1.6	1.8	2.9	56.0	47.7	28.7	22.0	18.9	7.3	190.5
1998	7.2	3.3	1.9	1.2	1.5	1.2	22.3	63.8	59.8	62.8	21.0	8.1	254.2
Mean	2.2	2.2	2.0	5.5	11.0	19.0	42.5	63.3	54.8	29.7	12.1	4.8	249.1

Table A3. Indices for sensitivity classes.

Class	Index (I)	Sensitivity
I	|I| 1.00	Very high
II	0.20 |I| < 1.00	High
III	0.05 |I| < 0.20	Medium
IV	0.00 |I| < 0.05	Small to negligible

Source: Lenhart et al. (2002).

Table A4. General performance ratings of flow on a monthly time step.

Performance rating	ENS	D
Very good	0.75 <ENS< 1.00	D< ±10
Good	0.65 <ENS<0.75	±10 < D < ±15
Satisfactory	0.50 <ENS<0.65	±15 < D < ±25
Unsatisfactory	ENS <0.50	D > ±25

Source: Moriasi et al. (2007).

Figure A1. Average monthly rainfall distributions in gauged Keleta watershed.

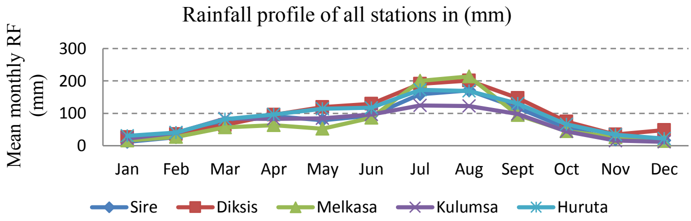


Figure A2. Mean monthly minimum and maximum temperature profile.

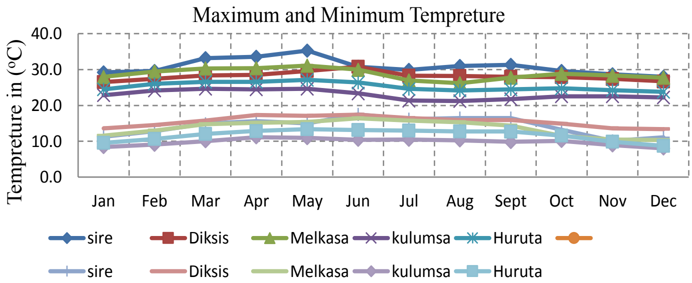


Figure A3. Mean monthly runoff at the gauging station of Keleta River.

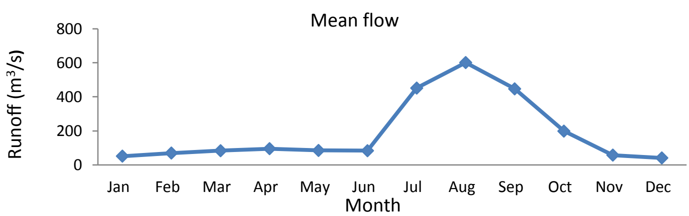


Figure A4. Rescaled cumulative deviations from the mean for the total annual flow of Keleta River.

Section 4
Regional Experiences

Overview of Challenges and Opportunities of Spate Irrigation Development in Oromia Region

Yohannes Geleta (yohketi@gmail.com)
Irrigation Engineer and Environmentalist
Oromia Irrigation Development Authority Study & Design Process Owner

Abstract

Spate irrigation in Oromia, Ethiopia is not new. The challenges and opportunities in spate irrigation development in the region are effective design of headwork, conveyance system and silt management. Living with all these challenges, Oromia Irrigation Development Authority has constructed systems that are irrigating tens of thousands of hectares benefiting tens of thousands of households. This chapter concludes that to make modern spate irrigation development sustainable and more beneficial, improvements to designs and engineering are required.

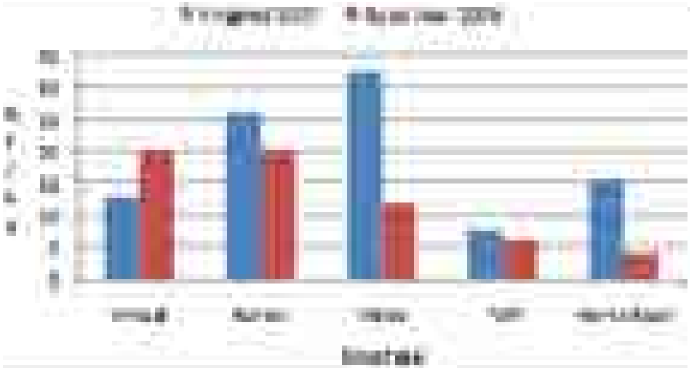
Key words: *Spate irrigation, supplementary irrigation, headwork, conveyance system, silt management*

Introduction

In general spate irrigation is not new for Ethiopia and specifically for Oromia. It is branded as 'Gelecha' in Afan Oromo. Different expert meetings in Ethiopia estimate the spate potential of the country to be 140,000 ha which area is believed to be underestimated. More than 40% of this resource is believed to be found in Oromia region, dominantly in lowlands of Oromia: Harer, Borena, Guji, Bale and other part of the region. It is agreed that spate irrigation has a significant yield increment when compared to a good year rain season and nonirrigated crops (Kebebew et al. 2008).

Farmers in lowlands of Oromia have experienced spate irrigation for subsistence farming, for pasture; recently, some private investors are asking for spate land for commercial farming. Having this in mind, the regional government intervened to modernize or increase the efficiency of traditional spate irrigation. The main challenges in spate irrigation are proper and sound headwork, conveyance and distribution system and silt which the beneficiaries can manage. Comparison of spate and rain-fed irrigation is shown in Figure 7.1.

Figure 7.1. Comparison of spate and rain-fed irrigation.



Spate irrigation is a risky business especially when it is modern: It is the major option where rain-fed and conventional irrigation systems fail to address crop production. High investment but unpredictable return for equitable water distribution and silt are major challenges at the headwork and main canal.

Material and Method

The region has vast experiences in spate irrigation - Boru Dodota, Hargeti, Billilo, Ija Gelme Wako and many projects irrigating up to 5,000 ha. These schemes have different types of headworks, conveyance systems and management.

Results and Discussion

Spate Classification in Oromia

Spate in Oromia is classified as lowland and midland or supplementary spate. In midland spate (Boru -1,200 m a.s.l, Hargeti, Billioo) flow originates from the highland area and can last in duration from hours to one or two months with different quantities, frequencies and timing. In such cases, conflict is minimal. Lowland spate (Ije Gelme Wako) is mostly short duration flood/flow. Both types are exercised in the region in a small scale, but in many places where there are no wadis, roadside flood diversion is common.

Agroecology of Oromia

Oromia is classified in three agroecological zones as seen in Figure 7.2; highland (>2,500 m a.s.l), tropical humid (1,500 -2,500 m a.s.l) and lowland (<1,500 m a.s.l). The rainfall pattern in the lowland area is erratic with uneven distribution, which makes rain-fed irrigation difficult as shown in Figure 7.3, which also shows representative rainfall distribution in the lowland of Oromia.

Figure 7.2. Agroecology of Oromia.

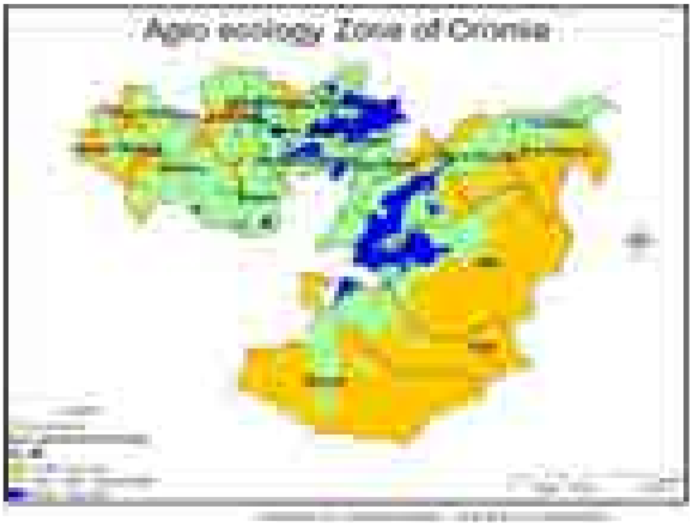
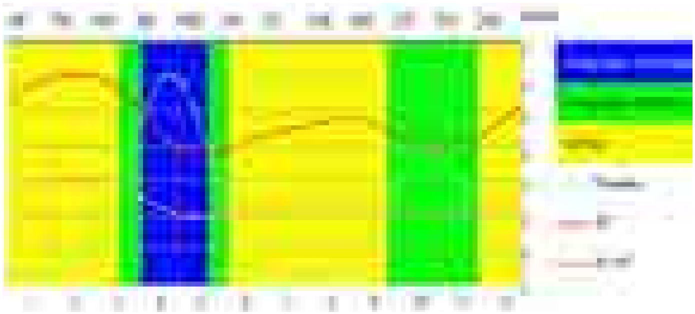


Figure 7.3. Representative rainfall distribution in the lowland of Oromia - Retrieved from FAO-Loclim.



Spate Headwork

The headwork of spate irrigation can be generally classified as modern and traditional, each with its own benefits and challenges. The traditional irrigation headwork is temporary or seasonal; its location can be changed according to the command area maximum head, but it is also easily eroded and requires frequent maintenance. The modern headwork is fixed in location, in maximum water intake ability, and in intake level. Even if the modern headwork reduces the beneficiary's routine construction of the headwork, it does not allow the option of changing the location, level and maximum intake of flood.

To optimize the above characteristics, the region has exercised different types of headwork: conventional, deflector, simple intakes and silt minimizing weirs. Despite all these experiences the region is not satisfied with existing headwork types; some are costly, some enable silt impact, some cannot effectively address spate floods and so on. Figure 7.4 shows different types of headworks exercised in the region.

Figure 7.4. Different types of headworks exercised in the region.

Conveyance system, other structures and drainage

The conveyance, hydraulic and drainage structures of spate irrigation pose the main challenge in the region, especially in modern irrigation. Critical decisions must be made on factors by which to design canals, with issues including canal capacity, command area size, varying levels of flooding (minimum, typical) and varying flood frequency, among others. Similar issues are also true for hydraulic structures. Drainage is also still a debate, requiring decisions on whether a drainage system is needed and, if so, at what level. Silt and water management, including organizational management of the scheme, are also a challenge. Given these challenges, the region has tried to design and construct different types of canals and structures, though it is still looking for better approaches and designs. Figure 7.5 shows the canal systems in the region.

Figure 7.5. Canal systems in the region.

Silt management

The common challenge in both modern and traditional spate irrigation is silt. Silt in spate irrigation can be said to be both a curse and a blessing. In the perspective of the agricultural development, silt is beneficial, whereas for the headwork, canals and structures, it is a problem. Silt has been observed in spate projects in Oromia: there is siltation in 30-45% canals and 20-40% of structures (Yohannes et al. 2009). To maximize the blessing and minimize the curse, the region exercised proper headwork and canal design to manage silt. A reliable design approach has not been achieved as yet.

Capacity Building

The region has also conducted different national and international capacity-building trainings and workshops in collaboration with different stakeholders and universities. These trainings have been given for more than 60 experts, mainly form the Oromia regional line department, based on other regions and foreign experts.

Discussions

The design approach has to be sorted out and researched. Modern spate irrigation could minimize routine construction, allow flexible flood intake, different intake-level regulation systems and conveyance systems, while adopting nonsilting, non-scouring velocity for big discharges in earth canals, at low cost and with hydraulically effective structures.

Conclusion

Despite the strong challenge, the region has constructed systems for 10,250 ha at nearly 93 million Ethiopian Birr, benefiting more than 20,000 households. Currently, three supplementary spate projects are under construction at 8.5 million Ethiopian Birr, which can irrigate 350 ha to benefit 700 households. An additional 17 projects are under study and designed by consultants. This will need more than 271 million Ethiopian Birr. Thsee projects can irrigate nearly 31,000 ha and can benefit more than 31,000 households. This is even with the challenges raised above.

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Transition from Traditional to Modern Spate Irrigation: The Case in Kobo – Girana Valley, Amhara Region

Belay Zegeye,[1] Debebe Lijalem[2] and Aschalew Kassie[3]

[1]MSc in Hydraulics and Hydropower Engineering, Amhara Design and Supervision Works Enterprise, Email: belayzegeye@yahoo.com
[2]MSc in Engineering Hydrology, Amhara Design and Supervision Works Enterprise, Email: dlijalem@yahoo.com
[3]Msc in Soil Science, Amhara Design and Supervision Works Enterprise, Email: aschalew.kassie@yahoo.com

Abstract

In Ethiopia spate irrigation is on the increase due to public interest as well as farmer's initiative. Though there are newly introduced areas, there are some spate irrigation practices that have been in use for several generations. The technology is in increasing the arid parts of the country. Kobo-Girana Valley is one of the historically practiced areas, having ample potential for spate irrigation. A potential assessment made by Amhara Design and Supervision Works Enterprise showed that an area of 51,668 ha has been identified as a potential for spate irrigation in the Kobo-Girana Valley. In order to reduce the challenges in the traditional system the newly introduced modern spate irrigation also has some limitations that require further research and design considerations. The main problem in the traditional system is frequent damage of structures and labor-intensive mismanagement of silt and water. In similar ways, the modern schemes are also underutilized due to mismanagement of the schemes and absence of proper openings for removing silt and excess water.

Key words: *Spate, Kobo Girana Valley, traditional, modern spate*

1. Introduction

Spate irrigation is a form of water management that is unique to semiarid environments, particularly where mountain catchments border lowlands (Steenbergen et al. 2011). In Ethiopia spate irrigation is on the increase in the arid parts of the country. The development of spate irrigation in Ethiopia is driven by both public interest and farmers' initiatives. Some spate irrigation systems have been in use for several generations, but in almost all areas spate irrigation has developed recently. One of the potential areas and historically beneficiary area of spate irrigation in Ethiopia is the Raya-Kobo-Girana Valley. In the Raya Valley alone traditional spate irrigation extends to 21,000 ha (Kidane 2009). Traditional spate irrigation practice in the valley is done in plain areas following intermittent rivers found around the Kobo area starting from the Gobu River flows bordering Amhara (Figure 8.1) and Tigray regions to Amid Wuha found between Robit and Gobiye with small rural towns crossing the Tigray Woldya asphalt road (ADSWE 2012).

The traditional system consists of short free intakes. Floods are diverted from the seasonal rivers and directed to the cultivated fields to supplement the rainfall. The river water can be diverted before and after sowing. Before sowing, the farmers diverted the river water to their farms to enable the soil to hold the required moisture. The main diversion canal is called "Enat Melle" (Mother Melle) which starts as a small earthen embankment protruding into the flood course at an acute angle with gradually curving and thickening buildup that guides the flow to the cultivated fields. These main diversions are constructed at a convenient angle across the slope of the riverbed to divert the flood runoff and convey it into the command area.

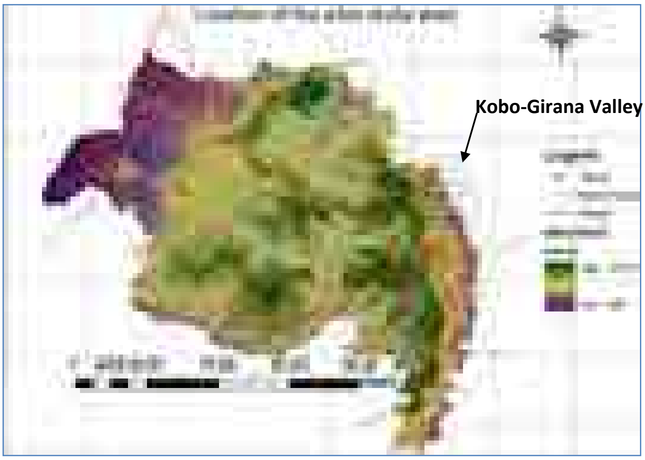
Even if the traditional spate irrigation in the area paved the way for other areas to practice the systems, the traditional spate irrigation system practiced in the Kobo-Girana Valley faces many challenges. The main challenges to utilize the floodwater under the traditional systems include labor-intensive nature; frequent requirement of maintenance; underutilizing of floods as the farmers divert only part of the flood to protect the canal systems and command area from erosion; wrong position of intake; no full control of floods at the headwork resulting in the creation of overtopping; absence of structures to control unwanted materials; poor management of floodwater and riverbank; and erosion of river bank. In this circumstance, improving existing traditional spate irrigation systems and developing new spate irrigation areas in the valley are attractive development options. A potential assessment made by Amhara Design and Supervision Works Enterprise (ADSWE) showed that an area of altogether 51,668 ha has been identified as a potential for spate irrigation in the Kobo-Girana Valley and some Ambassel woredas (ADSWE 2012).

Existing traditional spate systems still need to be improved to reduce the excessive labor input required to keep them operating and there are also identified areas in the valley where spate irrigation could be introduced to improve crop yields in marginally rain-fed areas. Improved flood diversion structures can contribute a lot to the stabilization of river banks and rehabilitating gullies. Even the adoption of simple and cheap technologies for flood diversion structures (gabions) rather than using traditional practices is preferable, as they are adapted to the local soil and climate. Demonstration of improved successful flood diversion structures may convince farmers to cooperate and contribute to the construction and development of plans to implement the technology.

Lack of sufficient skill and experience to study, design and implement spate irrigation technology in the region, difficulty of justifying investments in civil engineering works on systems dominated by low-value subsistence farming, underestimation of potential areas and absence of sufficient flood data in designing complex irrigation structures can be taken as future challenges for the development of modern spate irrigation in the study area.

This study aims to assess spate irrigation potential, traditional and modern spate irrigation practices and identify challenges in transition from traditional to modern community spate irrigation. The study area covers floodplain areas of the Kobo-Girana Valley in Kobo and Habru woredas, and some parts of Ambassel woreda. Modern schemes have just been introduced in the Kobo woreda at Gobu and Golina rivers. The following map shows the location of the valley area covered in the study.

Figure 8.1. Map of the Amhara region and location of the study area.



2. Material and Methods

The potential assessment and evaluation of modern schemes were done in May 2012 and September 2013, respectively. The assessment and identification of the potential of spate irrigation resources make use of GPS, digital photography, topographic maps produced at 1:50,000 scales, digital elevation models (30 mx30 m resolutions) of full coverage of the region, and different existing maps. Pertinent River Basin Master Plan study reports, site-specific water resources study outputs, policy papers, etc., were among others extensively consulted throughout the study and in report writing.

The study used mainly secondary data and information from different sources, properly reviewed, accordingly. Moreover, the study consulted responsible experts at the woreda level, individual farmers, and community groups about the advantages, constraints and challenges of spate irrigation and outputs obtained from it. In addition, it used data on farming practices and requirements, flood volume and the field survey.

Field visits were made on the existing spate irrigation sites to collect data on practices, opportunities, constraints and challenges in sufficient detail. Visualization and physical observation were also made about the flood condition and ways to divert it. Along with the land loss, widening and riverbank erosion problems were observed at field level, and reference pictures were captured to show evidence about problems, potentials and challenges.

Potential rivers and streams were identified, and proposed diversion sites were selected during the field visit and possible command areas were delineated using DEM and topographic maps in the midst of the ArcGIS environment. Runoff volume of selected rivers was collected from the Kobo Girana Valley development hydrology report and compared with the potential irrigable areas by spate irrigation technology. In this analysis, the limiting factor was found to be water resource as much of the potential flood goes away during peak flood time.

Introduction of modern spate irrigation in the valley has been planned by starting from upgrading the traditional spate irrigation system practiced by farmers, upgrading the existing river diversion and intake structures which were intended to provide baseflow water for irrigation to serve for flood irrigation and finally introducing spate irrigation to new sites where it has not been practiced as yet.

Evaluation of the modern spate irrigation schemes was started by evaluating the study and design documents and checking design considerations. The agronomical study considered climatic data at the meteorological station close to the command area, suitability of the topographic feature for spate irrigation, cropping pattern and cropping calendar based on farmers' traditions and climatic conditions.

Spate irrigation is entirely different from perennial flows, which rise very quickly and then recede within a period of hours or days. Spate systems need to be able to divert short-duration flood flows into gravity canal systems to ensure that sufficient amounts are abstracted in the time available to meet water demands and that the canal systems ensure command over the fields to be irrigated. The catchment yield is largely influenced by the highland rainfall of the watershed areas (Gidan and Lasta woredas). Hence, maximum rainfall events observed in the dry season (from February to April) of the highland area are considered for analyzing the potential runoff for spate irrigation, and hydraulic structures and scouring effects are designed by considering annual maximum daily rainfall data of the watershed area. Estimation of both spate flood and summer maximum flood has been done by using SCS-CN. In addition to the rainfall-runoff models, designers have considered flood mark levels in summers and dry-season period floods. Spate flood duration is estimated from local people's information and dry-season floods from hydrographs.

River sections are wide (example, Gobu-1 has 89 m of channel width at the intake site) and consists of a prematured and undefined channel. The cross section of the river is composed of thick unconsolidated and coarse alluvial deposits. Intake with bed bar aligned at 30-degree inclination across the main river channel has been designed in all schemes. This bed bar is below the riverbed that stabilizes the intake area and guarantees from possible lowering of riverbed elevation and serves also as a cut off for abstracting more water to the intake. In selecting the position of the intake sites, designers consider farmers' traditional experience, river morphology and availability of sufficient driving head. Side spillway and scouring sluice openings are provided as part of the offtake canal. Scouring sluices are made to have a similar bed level to the canal bed level and the spillway openings attained an elevated sill level than the canal bed level based on their purpose. Both openings are designed to be regulated with a spindle mounted gate with easy operation. The irrigation infrastructure contains drop, division box, turnout and crossing structures like any conventional surface irrigation system to meet requirements of the topographic map and the water distribution system. The flow capacity of the intake is fixed by considering the total available water (TAW) required for 1 m root depth, project efficiency and flood recession time (Steenbergen et al. 2010).

$$Q^i = 2.77 \frac{AxW}{\delta xt} \tag{2.1}$$

where, Qi is the theoretical discharge (m^3/s^{-1}), A is the irrigable area (ha), W is the depth of application (assume 0.35 m), δ is the application efficiency (assume 40%) and t is the time of application (take 7 hours).

Gobu-1 River is an ephemeral river; during the rainy season the coming flood has a longer time of recession. For a command area of 380 ha and time of recession taken to be 7 days, depth of application is 0.35 m with an application efficiency of 40%, and the intake diversion capacity has been fixed at 5.5 m^3s^{-1}. Diversion capacity of other projects is treated in a similar fashion.

1. Results and Discussion

a. Traditional Spate Irrigation Practice in the Kobo-Girana Valley

The traditional spate irrigation systems are very flexible, as the location and layout can be easily adjusted to suit the changing wadi conditions. As the level of the command area rises, they can be easily moved upstream. In addition they are appropriate and of low cost. Furthermore, they are relatively efficient in water use and sharing between users (Embaye 2009). Spate irrigation in Kobo-Girana Valley was traditionally practiced in plain areas following intermittent and perennial rivers found around the Kobo area starting from Gobu to Amid Wuha rivers. The survey addressed about 19 streams and rivers found in Kobo, Habru and Ambassel woredas, and floods from six rivers are presently used for spate irrigation at different levels to supplement rain-fed crop production.

These six rivers are the Gobu, Legaharo (Figure 8.2), Abarego, Hormat, Amidwuha and Shele intermittent rivers, which have huge flood irrigation potential capable of supplementing rain-fed crops in Meher season (June, July, August, September and October) and to start cultivating land and cropping in Belg season (February, March, April and May). Farmers are not utilizing the flood properly, because they have limited capacity to manage the flood and sediment load. The nature of river morphology and bank formation is also challenging to guide floodwater to their farmland properly. Out of these traditional schemes, upgrading to modernized spate irrigation has been started in the Gobu River (Gobu-I and-II).

Golina and Alwha rivers are among the perennial rivers at present and used for irrigation cropping using modernized diversion weirs. However, the rivers have also huge flood potentials for spate irrigation and to supplement both rain-fed and irrigation cropping in the study area. Based on the estimates of the Kobo Girana Valley Development Hydrology Report, Golina and Alwuha rivers annually produce 61.80 and 66.47 Mm^3, respectively, of floodwater. Hence wide thinking is required to exploit the base and flood flow downstream of the existing irrigated land. A modernized spate irrigation scheme has also been under construction in the Golina River.

At the time of the field survey there was a flood from the upstream, while at one point there was no rain, and the study team was very much excited by the flood and spate irrigation practices of farmers. One big problem obtained from the observation was the inability of farmers to use the peak flood time because it was very dangerous to manage. In addition, small canal size, land grading and leveling problems were observed.

Figure 8.2. Progress of flooding from the dry Legaharo stream.

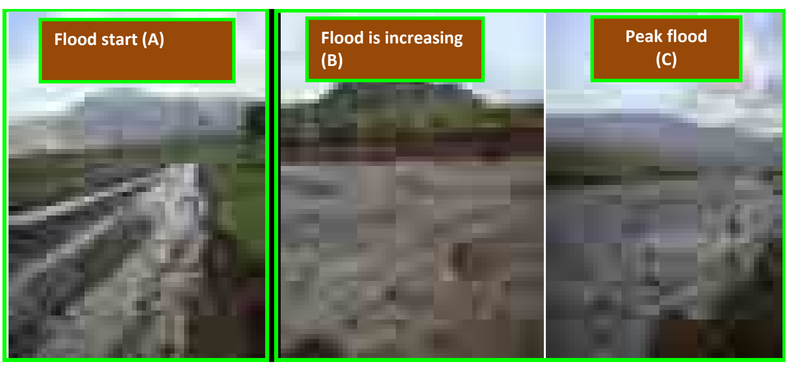
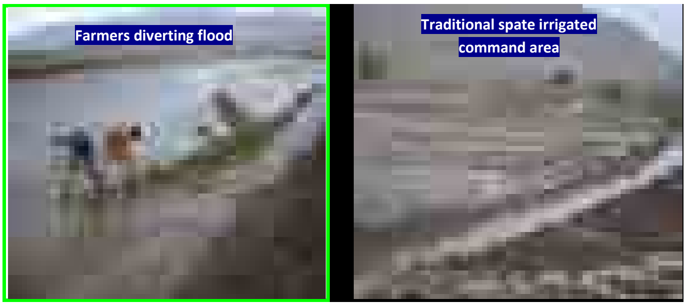


Figure 8.3. Farmers exercise flood diversion for spate irrigation.



Major constraints of the traditional spate irrigation system are:

- Construction of intake structures after every flooding.
- Small capacity of canals to accommodate high volume and velocity floodwater.
- Requirement of frequent maintenance, which necessitates a large labor force.
- Wrong position of intake and no canals to the end point of the command; only a small area of land close to the intake received floodwater.
- Lack of control over flood at the headwork, unnecessary over-flooding in cultivated lands.
- Inability to divert and use floods from flowing rivers with a deep riverbed. Hard to divert during peak flood time, so flood is not fully harvested.
- Lack of filtering structures to filter out unwanted materials.
- No more secondary and tertiary canals and structures to distribute the floodwater; inundation of the whole farm by a single flood intake favors some fields at lower micro-topography which receive more flood and ponding than the higher part.
- Lacks proper land grading and leveling.
- Unlined canals constructed near and following the river bank weaken the riverbank through seepage and cause erosion of the river bank and damage canals.
- No riverbank management and river training practices.
- No community integration or institution that mobilizes existing manpower resources or is beyond the capacity of the community.
- There is no flood information system to inform farmers about the arrival of heavy floods to the area without raining at the site.
- Lack of capital and skill to design and construct cross-drainage structures.
- Erosion of riverbank and widening of river channels.
- Inundations of the command area by boulders, sand and gravel.
- No experience in integrating groundwater and surface water (flood) irrigation and in recharge of groundwater aquifers. Poor floodwater management and control.
- Poor agronomic practices and crop selection as compared to the labor invested.

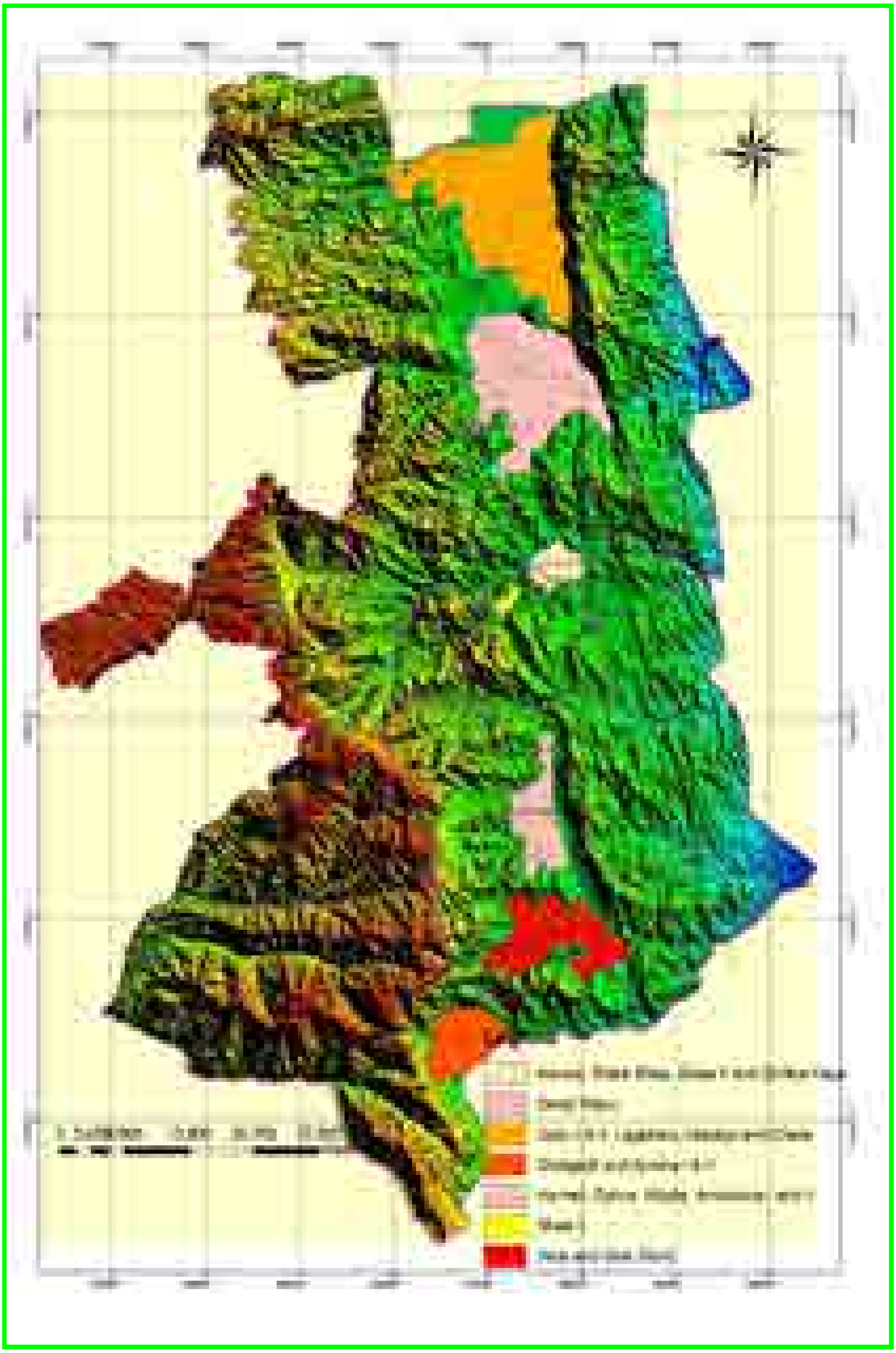
b. Spate Irrigation Potential in the Valley

The survey mainly included three woredas, Kobo, Habru and Ambassel at the eastern extensive plain area found east of the mountain chain of Gidan, Gubalafto and Ambassel. According to the survey in Kobo Girana Valley and Ambassel, spate irrigation is required to supplement rain-fed and irrigated crop production, and recharge groundwater aquifers. In general, the proposal includes the selection of 21 intake (headwork) sites and delineation of 51,668 ha of gross command area.

Table 8.1. Details of proposed sites (** & * describe irrigation structure and spate upgrading).

No.	Name of river	Woreda	Headwork site			Command area (ha)	Status	Development phase
			Easting	Northing	Elevation			
Golina Denkil Subbasin								
1	Gobu-I	Kobo	559,561	1,352,400	1589.43	18,627	Upgrading**	Phase II
	Gobu-II	Kobo	561,408	1,354,474	1531.37		Upgrading**	Phase II
2	Legaharo	Kobo	566,859	1,351,204			Upgrading*	Phase I
3	Abaerego	Kobo	567,160	1,349,339			Upgrading*	Phase I
4	Dikala	Kobo	568,882	1,344,424			Upgrading*	Phase I
5	Hormat	Kobo	568,580	1,339,265		14,267	Upgrading*	Phase I
6	Golina	Kobo	567,848	1,333,790			Upgrading*	Phase II
7	Woylet	Kobo	568,283	1,328,661			Introduction	Phase I
8	Amid Wuha, R	Kobo	571,100	1,325,090			Upgrading*	Phase I
	Amid Wuha, L	Kobo	570,047	1,324,712			Upgrading*	Phase I
Alwuha Subbasin								
9	Alwuha	Kobo	574,067	1,315,446		2,411	Upgrading**	Phase II
10	Shele I, Intake	Gubalafto	571,023	1,310,251			Upgrading**	Phase I
11	Shele Sihalu, R	Habru	574,840	1,312,918			Introduction	Phase I
12	Shele, L	Gubalafto	574,891	1,313,087			Introduction	Phase I
13	Chifra Keya	Habru	579,952	1,313,295			Introduction	Phase I
Millie Subbasin								
14	Derek Wonz	Habru	571,931	1,290,469		4,735	Introduction	Phase I
15	Wula Wonz	Habru	569,819	1,275,870		4,183	Introduction	Phase I
16	Gola Wonz	Habru	569,890	1,274,993			Introduction	Phase I
17	Godigadit	Ambassel	566,560	1,271,279		4,445	Introduction	Phase I
18	Ajwuha River I	Ambassel	567,533	1,267,734			Introduction	Phase I
	Ajwuha River II	Ambassel	564,346	1,268,257			Introduction	Phase I
Total						51,668		

Figure 8.4. Headwork and command area of proposed spate irrigation development sites.



c. Status of Modern Spate Irrigation Projects

In order to maximize the agricultural productivity of the valley area, modernization of the existing traditional system is needed based on scientific approaches, in addition to the traditional knowledge. This includes upgrading the traditional irrigation schemes so as to increase the water utilization efficiency and reducing the labor required every time the flood passed to construct temporary diversion bunds and canal structures by designing permanent structures and improving water and sediment management systems. The modern system, with permanent canals (primary and secondary) and branches, delivers water to the fields without entailing field-to-field irrigation and serves uniformly, whereas the traditional irrigation using earth dikes and canal intakes serves mainly the lower area (Bahamish 2004).

Out of the potential spate irrigation areas identified in the assessment of potential in the valley, the Regional Water Resources Development Bureau studied three schemes in 2011 and started implementation in 2012 with financing secured from the International Fund for Agriculture Development (IFAD). These schemes are Gobu-I, Gobu-II and Golina Spate Irrigation Projects. The consultancy service (study and design) work of the projects is done by Amhara Design and Supervision Works Enterprise (ADSWE) and is being constructed by the Organization for Rehabilitation and Development in Amhara (ORDA). Both of the schemes are under construction and simultaneously operating beside the constructed structures. In addition to the above-stated schemes, three additional projects (Weylet, Legeharo and Shele) are under detailed design stage with plans for implementation by 2014.

Though the above-stated projects are found under the construction stage, farmers started to utilize the schemes as most of the headwork structures were already finalized. During implementation time, the efficiency of modernized schemes has been tested both by farmers and experts. Both schemes have no construction quality problems. According to the farmers, the main advantage of the modernized system is having a stable headwork structure and ability to divert more water than the traditional one. Based on their performance, Golina (Figure 8.5) is best, Gobu-I (Figure 8.6) is next and Gobu-II (Figure 8.7) is the lowest-performing scheme. The main problem of the projects is silt management.

d. Golina Spate Irrigation Project

Golina River is among the perennial rivers with a limited baseflow. The proposed spate irrigation is planned to use both the baseflow and the floodwater. The headwork part of the scheme contains an intake mounted with trash rack, escaping canal opening, scouring sluice opening and intake head regulator. The trash rack is provided at the very entry of the intake to filter out unnecessary suspended and bed load into the canal system. The escape canal opening is provided next to the intake entrance point at a higher elevation compared to the canal bed level and is used to spill out excess water from the canal demand. Scouring sluice is provided just in front of the head regulator with equal sill level to the canal bed to erode the unwanted sediment load.

Figure 8.5. Golina spate irrigation project, headwork and canal structures.

Golina spate irrigation project is doing very well and can be taken as an exemplary scheme. Structures are stable, water is flowing into the system freely, gates are operating well and there is not much sediment accumulating in the canal system that might hinder operation. The possible reasons for the success of the scheme are: efficiency of the escaping canal and scouring sluices and proper management by farmers. The silt-escaping canal provided after the head regulator along the main canal has a significant effect in controlling sediment deposition. The Groyeens provided at the intake guide wall shifted the current flood direction away from the intake mouse and reduced the entrance of much sediment with the current flood.

e. Gobu-I Spate Irrigation Project

Even though Gobu-I spate irrigation is designed on no perennial river, the scheme is using both spate during “Belg” time and supplementary irrigation until the river flow ends after the main rainy season. The headwork part contains similar structures as in the Golina irrigation scheme. However, the system is less efficient than Golina and better than Gobu-II. The intake and main canal after the head regulator are entirely filled up with sediment. The canal is still conveying water into the field, because the canal is deep. Hereafter, it will be challenging to bear additional floodwater as it has been silted up to the top. As it is shown in the following picture, the opening at the head regulator has been closed fully by silt. Farmers are diverting water behind the retaining wall. Unless the system is managed well, the overtopping water along the canal route will saturate the riverbank and loosening it to create flood scouring and add surcharge pressure against the masonry structures.

Figure 8.6. Gobu-I spate irrigation project, headwork structures.

f. Gobu-II Spate Irrigation Project

Gobu-II spate irrigation is located 3.0 km downstream of Gobu-I. Both Gobu-I and-II do have traditional practices on the same river and the modernization is done by upgrading the traditional system. As in the above-mentioned projects, Gobu-II has got similar headwork structures but the main difference is that, both escaping and scouring sluices are located around the head regulator. In addition to this, escaping canal gate of the above schemes has not been installed as yet but the Gobu-II escaping canal is closed by gate. The intake and main canal after the head regulator are entirely filled up with sediment and no more water is getting into the field by using the provided structures. It needs serious attention.

Figure 8.7. Gobu-II spate irrigation project, headwork and canal structures.

The main problems in Gobu-I and-II:

a. *Scheme management:* Farmers are not well organized by water user associations; they are still trying to use irrigation water through individual effort. During excess flood time, the head regulator should be closed by opening escaping and scouring sluices. There must be someone responsible for closing and opening gates based on the flood situation and irrigation water demand. Since the Gobu-I escaping canal gate was not installed, it was open for the whole summer. As a result, Gobu-I has relatively low sediment deposited compared to Gobu-II. The head regulator and the sluice gates of the two schemes were closed for the whole summer season. That is why both intakes and head regulator openings are filled with silt, and farmers are forced to route water behind the retaining wall of Gobu-I. Hence, a lot of work is expected to enable the community to manage their scheme properly.

b. *Silt type:* Besides the amount of sediment, the particle size of Gobu-I and-II is courser than that of Golina. This makes the silt excluding mechanism challenging because sediment settles easily in the canal. Hence, proper escaping canals and silt excluder openings should be designed and provided.
c. *Missing of additional silt-excluding openings in the main canal:* From the three schemes, Golina has a good quality because of the additional escaping canals provided behind the head regulator. Both Gobu-I and-II do not have this and as a result of this, farmers find it difficult to manage silt in the main canal. If there are sufficient additional escape openings, it will be possible to use dredging when there is sufficient water in the canal. Otherwise, excavation will be the only solution to evacuate deposited silt. Even farmers confidentially recommend the importance of additional canal escapes.

2. Conclusion and Recommendations

The survey on identification of spate irrigation potential and assessment of farmers' experiences were made on representative sites from Kobo to Ambassel plain areas; this was meant to provide input data for decision makers to think about the detailed study and design of spate irrigation projects based on upgrading the existing traditional schemes and the introduction and extrapolation of lessons and experiences to other potential sites.

As per the field survey, the highlands provide substantial floodwater, sediment, gravel and boulders to lowlands while the lowlands are highly affected by severe flood hazards, riverbank erosion, and wastage of large cultivated land areas by boulders and gravel from river overtopping.

Altogether 21 potential flood diversion sites suitable for spate irrigation have been identified in the valley. Integrated spate irrigation through upgrading traditional spate and groundwater-based irrigation and introduction to new sites to support rain-fed and irrigated cropping in the area and further extrapolation are highly recommended.

The transition from traditional to modern systems is good, but needs great attention, as there are still unresolved problems, especially in design considerations and scheme management. The following ideas should be addressed by researchers:

a. *Soil moisture retention extent and depletion period:* The best moisture retention techniques and actual moisture depletion period for different soil and topographic conditions should be estimated through research rather than adopting from literature.
b. *Hydrology:* Since most spate areas connected to rivers are not gauged, designers of modern spate irrigation projects are managing spate hydrology based on farmers' information. The application of commonly adopted rainfall-runoff models should be checked for such kind of rivers which pass through deep alluvial formation on a wide and gentle river morphology aggravating excess percolation along the river channel. In the lower reaches of the rivers (Afar area), even peak floods disappear on a wide delta.
c. *The flood contributing area:* This has to be identified rather than just delineating the watershed area above the drainage outlet because the rainfall distribution in the lowland and highland areas is not similar; there is no smooth transition between the highland and lowland watershed elevation. Flood frequency, certainty, sufficiency, distribution, cropping patterns, land use and hydrological impacts of climate change need research.

d. *Silt screening mechanism:* Possibilities to screen courser sediment and take fine sediment with floodwater into the farm will be envisaged based on scientific approaches.
e. *Scheme management:* Community-based irrigation projects are supposed to be managed by the community using an institutional framework. Does the conventional irrigation water management procedure work on these kinds of schemes? The difference between traditional and advanced scheme administrative techniques needs to be evaluated and addressed to the communities.

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Spate Irrigation in Tigray: The Challenges and Suggested Ways to Overcome Them

Mehari G. Hiben[1] and Tesfa-alem G. Embaye[2]

[1]*Tigray Water Resource, Mines and Energy Bureau, P.O. Box 520, Mekelle, Ethiopia*
Senior Irrigation Design Engineer
hiben123@gmail.com (corresponding author)

[2]*Mekelle University, P.O. Box 231, Mekelle, Ethiopia*
Lecture in Water Resources and (Spate) Irrigation Management (I-GEOS) Coordinator
Spate Irrigation Network, Ethiopia
tesfa_alemge@yahoo.com

Abstract

The perception is that floods are natural but may lead to catastrophic outcomes. However, flooding contributes to livelihoods through spate irrigation, especially in East Africa and parts of Asia. Spate irrigation is a traditional practice of farmers, especially in the Raya Valley for supplementing rain-fed agriculture. Lowland areas are not only surrounded by mountains that are sources of flood and fertile sediments but characterized by deep and fertile soil suitable for agriculture as a result of ages old alluvial deposition. However, the diversion of floods has been a challenge to both farmers and engineers. This chapter addresses the bright spots and challenges of spate irrigation practices, and presents experiences in Tigray, where the regional governments, with support from donors such as IFAD, are supporting spate irrigation farmers. The chapter also notes the poor performance of schemes related to design, which have been directly adopted from the conventional irrigation schemes based on perennial river diversion design procedures without due considerations for the peculiar nature of spate flows, such as higher sediment concentration, and the uncertainties in estimating timing and frequency of the floods. The chapter makes recommendations to fill gaps, including on capacity building and training of experts.

Key words: *Spate irrigation, rain-fed agriculture*

1. Introduction

What is flooding? What is flood-based farming?

The perception of many people is that flooding is a natural process, which may lead to catastrophic results if it coincides with the presence of a vulnerable object. For example, a flood disaster may occur when human settlements coincide with excessive rainfall events, rise of water levels or dam breaks. This may occur once in a blue moon or frequently. The occurrence of flood disasters depends mainly on the topography, climate, rainfall distribution, watershed, economy, and land use of a certain region (Di Baldassarre and Uhlenbrook 2011). Historically, floods have been intertwined with the livelihood of human beings in at least two ways. First, they have cherished and have facilitated the emergence of early civilizations along riverbanks, as in Egypt and Mesopotamia. Second, they have been considered as evil acts or punishments from spiritual forces. Today however, flooding is a broad term that includes flash floods, river floods and coastal floods. Their negative effects are typically most severe in the poorest countries, where populations and governments are least able to deal with this scourge. In Ethiopia, chronic incipient environmental changes promoting flooding have been associated with lack of land use planning, poverty and non-sustainable land use (Moges et al. 2010).

In many ways the significance of floods is self-evident; it is reported that flood disasters account for about a third of all natural disasters in terms of their number and the economic losses. As explained above, flooding is a serious issue all over the world. The articles referred to above are in accord with one another to explain some adverse effects of flooding. However, this chapter aims to see the advantages of flooding. Furthermore, it will try to investigate the real challenges in utilizing floods to the optimum as much as possible as it is the only means of livelihood in some part of Tigray, especially in the Raya Valley. Therefore, spate irrigation in particular and flood-based farming in general constitute the process of utilizing excess runoff (floods) in areas where no other options are possible (Mehari et al. 2005a). In Tigray, particularly in the Raya Valley, there is a potential of 80,000 ha of land to be irrigated by flood-farming by the total runoff of about 170 Mm^3yr^{-1} generated from the highland catchments (Eyasu et al. 2012). This study shows how spate irrigation is vital for livelihoods and food security in the Tigray Region, and starts to create a center of attention for the government on flood-based farming.

2. Research Questions

General question: What were the most critical challenges of spate irrigation in Tigray?
Specific questions:

1. What were the bottlenecks in modernizing the infrastructure of spate schemes to improve the reliability and regularity of diverting large floods and distributing them to the downstream fields?
2. Do the design and layout of the modern spate headwork and infrastructure enable the allocation of water in proportion to the indigenous water rights and rules and guarantee fair water-sharing within and among the head- and tail-end farmers?
3. Do the intervention of modernization of the headwork and infrastructural design have an impact on reducing deforestation and do they ease the farmers from their indigenous, rigorous maintenance tasks?
4. Does modernizing spate irrigation contribute to improving the livelihood of the beneficiary farmers?

3. Research Methodologies

The methodologies used to address the above questions included:

1. Individual and group consultations and observations during a number of occasions when floods were disseminated, and structures were repaired and/or reconstructed.
2. Site visits during and after flood events to document the extent of fields irrigated and also to evaluate, if any, breaks caused to structures, canals and fields.
3. Field surveys with the help of farmers on spate irrigation scheme system layout before and after modernization.
4. Appraisal of design reports and other allied documents, and interviews with the engineers who were involved in the entire design and construction process to get background information on the initial phase of the modernization.
5. Exhaustive prearranged interviews with a representative of farmers, head of water user association, *water masters/"Abomai locally"* that represent the different community groups of floodwater users. Accordingly, a number of group discussions were also held. These activities gave insight into farmers' perceptions about the modernization, particularly with regard to the approach used, and the degree of effect of the inconsistency between the modern design and the traditional water-sharing arrangements.

4. Results and Discussions

For expediency, this section is divided into three parts. The first part will briefly outline the order in which events happened in the past decades that led to the modernization of the spate irrigation system and assess the initial phase of the modernization. The second part will attempt to highlight the challenges during the modernization process. The major topics discussed here include the extent of the total actual irrigated areas and the uniformity of their distribution; the impact of the discrepancies between the design requirements and the practical functioning of some of the main components of the headwork, the under sluice (scour), the breaching bund, the weir, the siphons and others; the effect of the noncoherence between the design and layout of the system, and the indigenous or local water-sharing provisions, uniformity of floodwater distribution, and the investigation of the consequences of some of the measures taken by the farmers to acquire supplementary irrigation. The third element tries to put forward answers to the question: Does the modernized spate system in Tigray attain its targets? If so, it also addresses why and how. This is done on the basis of findings on efforts made in improving spate schemes in Tigray.

4.1. The process of modernization

The then Commission for Sustainable Agriculture and Environmental Rehabilitation in Tigray (CoSEART), now Tigray Water Resources Bureau (TWRB) has taken the leading role in modernizing spate systems in Tigray. The Hara Spate Irrigation Scheme (Figure 9.1) was the first of its kind to be modernized not only in Tigray but in Ethiopia. Figure 9.2 shows modern spate systems in Tigray. The design includes the provision of gated offtake at 90° to the river flow and gated sluice scours. Furthermore, the system design includes the provision of inverted siphons, chutes, drops and division structures.

But this scheme was only able to serve a few flooding events due to sedimentation of the offtakes and siphons. Furthermore, beneficiary farmers were also neglected during the design and construction phases. Two years later, the modernization was due to be expanded to the Tirke scheme. The only improvement included into the Tirke scheme is changing the gated offtake into an open pipe (orifice type) (Figure 9.3). Similarly, after a few flood events, Tirke failed.

Figure 9.1. The Hara Spate System offtake and siphon.

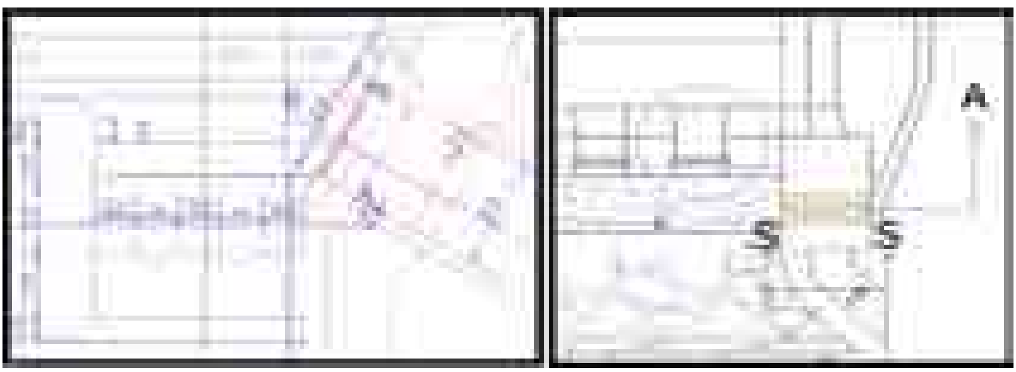
Later, the modernization was expanded to Fokisa, Beyru, Burka, Dayu, and Ula Ula with a major improvement to the offtake, i.e., widening the orifice and opening the canal, aligning it only at 120° and shifting the irrigation application time (in Cropwat) from 24 $hr.day^{-1}$ to 4 $hr.day^{-1}$. When we think of spate irrigation schemes, we should also consider a design which can supplement the total command area at least once at a time. Since the coming runoff is not reliable we should not think of a design which supplements the command area on a rotational basis, considering there is a big time gap between two runoff events. So it will be impractical to think of rotational irrigation on spate irrigation schemes, unlike river diversions which have water all the time.

Figure 9.2. Modern spate systems in Tigray (Embaye et al. 2012).

Recently, the operational design of Oda and Mersa schemes (which are in the design phase by Mekelle University, College of Dryland Agriculture and Natural Resources) considers practical irrigation intervals between floods and the diversion of floods using many small, open offtake structures. The developments on spate systems include but are not limited to:

1. Change the offtake type to open.
2. Avoid siphon/crossing structures that require pipes.
3. Change the layout of the diversion angle from 90° to 120°.
4. Enlarge the canal sizes.
5. Shift the irrigation application time from 24 $hr.day^{-1}$ into 4 $hr.day^{-1}$ and neglect the effective rainfall in crop water requirement calculations.
6. Limit the irrigation system design to the provision of only the main canal.
7. Maximum command area that can be irrigated by one headwork structure should not exceed 200 ha.

Figure 9.3. Open offtake design, closed and open types showing diversion angles as well.



Finally, it was learned that farmers' interests were limited to the construction of the headwork structure and provision of only the main canal. It was then followed by expanding the Tanqua Abergele wereda.

Table 9.1. Summary of the spate schemes in Tigray (Embaye et al. 2012).

S.No	Scheme Name	Location		Number Beneficiaries		Command Area		Project Cost		
		Northing	Easting	Male Headed HH	Female Headed HH	Designed	Actual	Headwork	Infra	Total
1	Hara	1374450	561400	726	558	400	0			
2	Tirke	1385928	564807			380	0			
3	Beyru	1390556	569354			500	50	187,837.09	975,647.47	1,163,484.56
4	Daya	1379013	565792	377	205	320	100-150	577,572.57	167,706.67	745,279.24
5	Buffie	1375094	576837			225	<50	186,984.08	407,654.60	594,638.68
6	Fokisa	1408091	561714			500	100-150	265,248.66	1,013,180.80	1,278,429.46
7	Tengago	1368040	558806	84	40	500	<50	218,302.06		218,302.10
8	Ula-Ula	1422402	572080			210	0	260,998.51	696,650.67	957,649.18
9	Burka	1422402	573967			280	100	249,805.36	339,624.61	589,429.97
10	Utu	1376027	559844					186,984.08	566,058.02	753,042.10
11	Durko	1463742	504797	60	4	400	new	1,222,802.02	2,341,648.98	3,564,451.00
12	Oda	1366964	558534	214	128	430	<50	1,349,744.25	3,066,299.23	4,416,043.47
13	Agbe	1493621	503579	100	8	400	new	3,048,386.31	994,633.69	4,043,020.00
14	Mersa	1355232	559734	114	100	350	new	1,330,170.69	1,870,655.70	3,200,826.39
15	Shiwata	1471522	495714	90	100	250	new	671,752.52	1,328,568.75	2,200,321.27

4.2. The challenges

The challenges of the modernizing of spate irrigation can be divided into three main categories. The first category is the institutional aspect. In this aspect, water user associations were simply formed for fulfilling donor's requirements. The establishment of these water user associations had disturbed the local rules and regulations, which had been effective in managing the flood distributions. During the first few floods, the modernization gave the immediate users an absolute right to use the diverted flood. However, this did not stay long. The canals and offtakes were filled in with sediments and shifted the power towards the downstream users.

Furthermore, the two initial schemes implemented were examples of limited involvement of beneficiaries. As reported by Haile (2009), spate irrigation modernization intervention works should be accomplished through the real participation of farmers and integrated to practically influence the planning, designing and construction processes so that successful modernized projects could be accomplished. Due to only partial community participation, the ownership was weak and not as strong as the traditional system.

The second challenge is related to design methodology and approaches. As there were no well-developed design guidelines and manuals specifically prepared for spate irrigation, the designers were forced to completely adopt from the conventional perennial flow diversion. Furthermore, little was known about spate irrigation, and spate characteristics were not considered during design. In this regard, the beneficiaries had a better understanding of the characteristics and complexities of the spate systems.

The third challenge is the way sediment control and management are addressed, as floods in spate area wadis carry high sediment loads. The main problem with sedimentation of offtake and canals is that this reduces the diversion capacity of the canal system, thereby significantly reducing the irrigated area (Lawrence 2008). Figure 9.4 shows sedimentation at the Fokisa offtake and canal systems. Sediment movement along the wadi in the command area might lead to excessive erosion at the wadi and lowering of the wadi level, or excessive siltation by courser and finer sediment particles. Rivers in spate flood periods lift and deposit huge quantities of sediment; there is constant change in bed levels, both in the river system and in the distribution network which causes frequent changes and adjustments of the system (Mehari et al. 2010).

Figure 9.4. Sedimentation at the Fokisa offtake and canal systems

5. Comparisons

To evaluate whether modernization significantly improved the livelihood of the beneficiaries, it is worth making comparisons between the traditional and modern spate systems in terms of both investment and operational cost, structural flexibility and durability, sediment control and management, wadi stabilization and environmental considerations.

5.1 Structural flexibility

As reported by Anderson (2008), traditional spate irrigation structures seem rudimentary, but they have been sustained for many years using only simple local materials and indigenous skills. Their advantage is their flexibility. Spate floods lift and deposit large quantities of sediment resulting in active change of bed levels, both in the river system and in the distribution network; there are frequent changes and adjustments of the system (Mehari et al. 2010). Traditional headwork structures can easily deal with the wadi-level changes either by moving upwards and/or removing the headwork structures (Mehari et al. 2006). The modern ones however, lack this flexibility (Eyasu et al. 2012).

5.2 Irrigation/Diversion efficiency

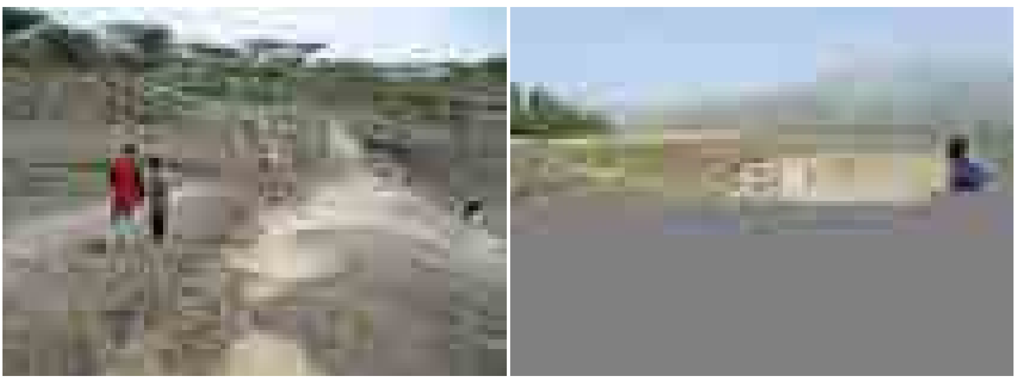
The diversion of the traditional systems is done using many, small offtake diversion structures; hence, they enable equitable sharing of water at many small diversion points and create fewer conflicts between most upstream and tail-end users (Eyasu et al. 2012). They are also relatively efficient in diverting the whole flood into the irrigated field using many small offtakes constructed along the wadi route. As far as the latter case is concerned, they are by far better than the modern ones. In the Raya Valley, the efficiency of the modern ones in terms of irrigation capacity has never exceeded 50% of the design capacity (Eyasu et al. 2012).

The services of the traditional systems are however, only limited to lower head diversions or shallow-depth wadis. As a result, it is almost impossible to construct them in deeper wadis (Zaqhloel 1988; Mu'Allem 1988). The modern ones enable easier diversion of floods in deeper rivers (Mehari et al. 2005a) like the Dayu Spate Irrigation System in Raya Valley. Though susceptible to sedimentation of the offtake and canal structures, if the offtake and canal routes are well dredged, the modern systems enable the diversion of higher discharges (very large floods). Very large floods, however, create considerable damage to the command area and canal structures.

5.3 Sediment control and management

According to IFAD (2005), not all modern spate schemes are an improvement over indigenous systems. Especially when farmers' views are not fully considered, the construction of modern engineered systems can worsen the operations for farmers. The modern systems divert all ranges of floods, including larger ones, which carry very high sediment loads (Mehreteab Tesfai 2002) that create considerable damage to the command area and canal structures. Lawrence (2008) has indicated that sediment concentrations rising to and exceeding 100,000 ppm or 10% by weight occur in floods in some wadis, and sediment concentration up to 5% by weight are common. The diversion of these higher sediment loads makes the life of the farmers difficult; farmers have to dredge higher sediment volumes both at the offtake and canal systems after every flood. As a result of failing to dredge before the floods, the systems will not irrigate the intended irrigation capacity. Studies undertaken by Embaye (2009, 2010) indicate that a volume of 8,350 m^3 sediment and 350 man-labor per season are required to dredge sediment from the Fokisa canal system. Figure 9.5 shows sedimentation at the Fokisa and Hara spate schemes. Traditional systems however, are helpful in avoiding sedimentation in cases of large floods (Anderson 2008) as the headwork structure is breached during higher floods.

Figure 9.5. Sedimentation at the Fokisa and Hara spate schemes.



5.4 Cost and durability

Traditional structures require low initial investment costs and are easy to construct. They however, utilize intensive labor for their O&M. As these structures are easily damaged by flood, a standby and enormous labor force is needed to maintain and reconstruct the structures almost after every flood. The modern schemes however, are designed and constructed to serve for about 25 years, though they are not yet all serving that long. As the modern structures avoid the periodic and yearly maintenance cost of the headwork and canal structures they have lower operational cost compared to the traditional ones. However, the other drawbacks of the modern spate systems are that their sediment dredging costs are high and they require high initial investment and highly skilled manpower for their design and construction (Steenbergen 2010).

5.5 Wadi stabilization

Even if the modern schemes are not effective in irrigating to intended capacity, they are very helpful in stabilizing the wadi level, which sustains the life of traditional systems upstream of the modern spate structures. These traditional schemes serve best when they are placed along bridge or culvert structures as these structures help in stabilizing the wadi bed (Mehretab Tesfai and de Graaff 2000; Eyasu et al. 2012). An example is the Harosha traditional spate system in the Raya Valley which is located immediately downstream of a bridge (Figure 9.6).

Figure 9.6. The Harosha traditional spate system having many diversion points along the wadi immediately downstream of a bridge (Eyasu et al. 2012).

5.6 Environmental considerations

Traditional spate systems have some drawbacks. They have a negative environmental impact in aggravating land degradation, as their construction requires the cutting of woods, bushes and shrubs. Big floods in these traditional systems destroy flood diversion channels and cause rivers to shift their course (Embaye 2009).

6. Conclusions

The existence of spate irrigation systems as a major source of food production in the Tigray Region, in particular in the Raya Valley, to a large extent, depends on whether current modernization activities transform them into competitive and credible sources of livelihood so that future generations will be encouraged to practice spate irrigation and invest in their development. In this regard, the overall objective set by the regional government is to understand the root cause of poor performance on spate systems and floods, indigenous water rights and agronomic practices, which among others, contributed to the impractical cropping patterns and rainfall assumptions, resulting in the underestimation of the net irrigation water requirement used for the design of the main canal head regulator gates; and the incorporation of inefficient weirs and siphons, which denied the farmers their upstream water right status and hence their ability to directly divert water from the wadi. These structures (weirs and siphons) also experienced sedimentation problems that further undermined the capability to sufficiently irrigate the irrigable area. The modern design layout did not provide the possibility to directly divert (from the wadi) the large floods.

Furthermore, as in the world's largest spate irrigation area in Pakstan, spate is seen as a nuisance (flood damage) rathern than as a potential benefit. The moderenized schemes have a failure rate of up to 65% (Khan 1988). Experience from Yemen also shows some drawbacks in floodwater management, which gives upstream users (farmers) absolute priority right (Girgirah et al. 1988). In Tigray, the tail-end farmers get the least amount of water due to lack of water management and knowledge barriers.

7. Recommendations

To fill the gaps identified in this article, capacity-building should be done focusing on three main aspects, as follows:

1. Development and dissemination of design guidelines and a manual that considers the special properties of the spate flows are mandatory to improve the efficiency of the modern diversion systems and increase the level of trust of the beneficiary farmers in the designs.
2. Flood-based farming should be mainstreamed in curriculums of universities that provide courses in water management so that researches can solve outstanding issues.
3. Short-term training should be given to engineers and water management experts currently working on spate irrigation.

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Flood-based/Spate Farming, a Practical Move Towards Ensuring Food Security in the Jarso Community, Konso Woreda, Southern Nations, Nationalities, and People's Regional State

Galunde Waketa Warotte (galunde@yahoo.co.uk) and
Gizachew Toraito Kussia (tenagnetesfaye74@gmail.com)

Abstract

The study has focused on the assessment of inputs, outputs and the outcomes of the project in terms of food production (availability) and access to food indicators at community and household (HH) levels. The question of project sustainability on outputs and outcomes is also a key issue addressed in this research. The key dependent variables explained are improvement in HH food production and access to food and the sustainability of project outputs. Endowments (availability, quality and size of farmland), rainfall, spate irrigation schemes and their management, supply of modern agricultural inputs, and asset building (livestock, income, food crop) were assessed as factors affecting the key variables. The study found that the spate irrigation beneficiaries of Jarso kebele experienced improvement of HH and community-level food security through modern spate irrigation structures and capacity building activities. Making the current food security status sustainable is identified as a challenge ahead. The chapter concludes with recommendations based on lessons learned from the case study.

Key words: *Food security, spate irrigation, food aid*

1. Introduction

1.1 Background

1.1.1 Woreda context

Konso Special Woreda is located in the Southern Nations, Nationalities, and People's Regional State (SNNPRS) of Ethiopia. According to FDRE Census Commission (2008:79), population is 234,987 out of which 95% dwell in rural areas and survive by subsistence farming. According to a baseline survey conducted by a consultant in 2006, the average family size was estimated at 6.5, higher than the national average (4.8). The special woreda consists of 48 rural and two town 'kebeles'[1] (Nuri Kedir and Associates, 2006: viii & ix).[2]

[1] 'Kebele' denotes lowest administrative unit (Constitution of Tigray, article 83).

[2] Nuri Kedir and Associates is a private development consultant firm commissioned by Norwegian Church Aid to conduct a base line survey in Konso Special Woreda.

Konso lies within the semiarid belt of Southern Ethiopia. An attempt has been made to collect medium-term (18 years) rainfall data from the National Meteorology Agency (NMA). The rainfall in Konso area is bimodal; the main rainy season falls in the months of March, April and May, with short rains occurring from September to November. The higher altitudes (Karat area), usually receive an amount of annual rainfall that ranges from 450 to 1,050 mm. Though reliable information is not obtained for lowland areas, it would be assumed that the lowlands receive below 450 mm of rainfall. The rains are erratic, with heavy and short rains followed by long dry seasons. The rainfall distribution across the years under consideration was highly variable. The average maximum and minimum temperatures for the last ten years (1998-2007) were 28.3 and 17.4 °C, respectively. The main economic base of the community is subsistence agriculture and the coverage of basic services such as health, potable water supply and primary education is low at 27, 34 and 35%, respectively (EECMY/SWS/DASSC[3] 2006: 8 and 9).

The average landholding for the households included in the sample is less than the national average of 1 - 1.5 ha. About 82% of the households experience food shortages even in a normal production year; food shortage appears to be prevalent in Konso Special Woreda. Continuous losses in the productivity of soil, erratic rainfall and low productivity, coupled with rising population growth have been continuously accelerating the deterioration in the food security status of the community (Nuri Kedir and Associates 2006: viii, ix).

Konso Special Woreda can be categorized among the woredas of Ethiopia that encounter persistent drought in combination with other factors resulting in chronic food insecurity.

The Ethiopian Evangelical Church Mekane Yesus (EECMY), the implementer of YFSSIFSP [4] has been actively engaged in food aid support for the drought-affected population of the woreda. Prior to the current project, the food aid support had rescued the lives of several thousands of people.

1.1.2 Project intervention area background

Jarso is the largest and most populous kebele in the woreda composed of 16 villages. Concerning the households and population, consistent and reliable information was not obtained. All the assessed secondary sources have presented different figures. Due to such controversies, this chapter used figures reported by the project office for this study. Accordingly, the total numbers of households and population are 5,000 and 32,500, respectively. According to the HH survey conducted for this research, only 35.5% of the respondents reported that they read and write; the majority (64.5%) are illiterate. The average HH size is 6.9, slightly higher than the woreda average (6.5). Out of the total population of sample HHs, 49.8% are found in the age category of 1-14 years, 47.2% in the age category of 15-64 years and 3% in the category of 65 years and above. This reflects the typical demographic structure of developing countries where the old age population size is very limited and the young (child) age population is higher.

[3] EECMY is a faith-based organization with a Development and Social Service (DASSC) wing in its organizational structure, commissioned for development work in the country.

[4] YFSSIFS stands for Yanda Faro Segen Sewate Integrated Food Security Project, which is the title of the project studied.

The main means of livelihood of the Jarso community is mixed farming through subsistence agriculture. Off-farm activities such as traditional beekeeping and weaving have been carried out to augment HH income. The latter is more common in Etikle, Geldime and Kube villages. Prior to the project, the community had suffered serious food stress and survived mainly by external food aid. In spite of the food insecurity problems in the area, Jarso is endowed with a huge potential of irrigable fertile land in the Yanda-Segen Valley and two seasonal flooding rivers crossing the land. As common to other inhabitants of the woreda, the Jarso community dwells in highland villages and is used to walking over 30 km to work on their farm plots in the lowland plain.

YFSSIFSP implementation was commenced in 2001 at a pilot level with the financial backing from the international NGO, 'Bread for the World' (BftW). The pilot phase was successfully implemented and achieved promising results that motivated the donor to extend its support for the next phase.

The title of the project is 'Integrated Food Security Project' as it is composed of diverse components. The main activities include irrigation scheme development, potable water supply, on-farm and off-farm income-generation activities, preventive health services, training in capacity-building, and maintenance and management of natural resources. The interventions aimed at promoting sustainable agricultural production, generation of income, access to markets and basic social services, as well as the improvement of nutrition. The number of the total spate irrigation beneficiary HHs is 2,200. Though the main focus is on spate irrigation, infrastructure development and agricultural extension, other activities stated above also have vital importance towards the intended outputs and outcomes.

Problem statement

Poverty alleviation and food security have been worsening over time; these are located among the ongoing development challenges of the government (Diao and Nin Pratt 2007: 206). Three decades back, droughts occurred at an interval of nearly ten years, but since the early 1980s, the country has experienced seven major droughts, five of which resulted in famine in which thousands of people perished. Recently, drought incidences have occurred at short intervals of time and are becoming common in many localities.

'Chronic food insecurity' (continuous inadequacy of diet resulting from lack of resources to produce or acquire food) and 'transitory food insecurity' (a temporary decline in a household's access to enough food) were mainly prevalent in northern and eastern parts of the country. But recently, food insecurity has expanded to other parts related to drought and contribute to increased frequency of famines, and intensity and numbers of the affected population. The factors that have contributed to such a deteriorating situation may vary from region to region or from one locality to another. Lack of rainfall, fragmented landholdings, dominance of subsistence production units, low adoption of improved production inputs and techniques, incidence of pests and diseases, dependence on rainfall (low irrigation development) and inappropriate policies are among the major threats to the country's agricultural development and food security at both national and local levels (Webb and Von Braun 1994; Adnew 2003: 14;).

The current economic policy of Ethiopia has aimed at two main issues: rapid and sustainable development and fair distribution of development benefits among citizens. The main strategy adopted to realize this policy is the Agriculture Development Led Industrialization (ADLI). Agricultural growth is accepted as a guarantee against food insecurity in the country. Food security strategy is also in place focusing on three important aspects: increasing food and agricultural production, improving food entitlement and strengthening the capacity to manage risks (Ramakrishna and Demeke 2002: 128).

As Morss and Gow (1985: 217) argued, "the principal objective of development initiatives is to generate self-sustaining improvements in human well-being". Despite the fact that a number of NGOs were involved in humanitarian aid and development activities in the Konso special woreda, the livelihood situation of the residents did not show any improvement. Lack of rainfall for a season may result in a profound disorder of people's way of life. The Ethiopian Evangelical Church Mekane Yesus has implemented an Integrated Food Security Project in Jarso kebele (one of the badly drought-hit 'kebeles' of the woreda) for the last 7 years. The money invested by the project was very significant at over Eth. Birr 12 million (US$1.2 million). The project performance reports indicate progressive and remarkable achievements of the implementation. The question is has the project intervention really brought change in breaking up the deep-rooted food insecurity? Is it worth being scaled up as 'a success story'? Are the improvements brought by the project intervention in Jarso area sustainable? What is needed to reverse the structural food deficit of the community and the persistent drought effects on the Jarso community?

This led to research with sound facts from the ground to answer the questions. The study has focused on the assessment of inputs, outputs and the outcomes of the project in terms of food production (availability) and access to food indicators at community and HH levels. The question of project sustainability on outputs and outcomes is also a key issue addressed in this research. The key *dependent variables* explained are *improvement* in *HH food production* and *access to food and the sustainability of project outputs.* Endowments (availability, quality and size of farm land), rainfall, spate irrigation schemes and their management, supply of modern agricultural inputs, and asset building (livestock, income, food crop) were assessed as factors affecting the key variables. Figure 10.1 shows a schematic representation of analytical framework.

Figure 10.1. Schematic representation of analytical framework.

Source: Author's own work.

2. Research Methodology

Konso woreda in general and Jarso kebele in particular, which hosted the project under consideration, were purposively selected as the study area. The issues considered for purposive selection were the following. First, Konso woreda is among the woredas severely affected by food insecurity in the country, whereas, Jarso is among four of the worst affected kebeles (Jarso, Aba roba, Gasargeo and Doha) by food shortage in the Konso woreda. Second, there were time and financial constraints to consider more areas. In fact, several factors might have affected the realization of food security in the project area such as availability, size and quality of land, dependence on rainfall, human capital, infrastructure, supply of agricultural inputs, agricultural extension services and stock/asset building including money. Nevertheless, certain explanatory variables such as farmland, rainfall, irrigation scheme development, irrigation scheme management, agricultural inputs and extension services and stock/asset building were selected due to time and resource constraints. I believe the data and the analysis from these data served the objective and answered the research questions.

2.1 Sampling procedure

HH was designed as an important unit of analysis so that an HH survey was employed to collect data before and after project intervention. The information was collected on the amount of production, landholding size, and assets such as livestock. As indicated earlier, Jarso kebele is composed of 16 villages out of which eight are direct beneficiaries of spate irrigation. The total number of HHs directly benefiting from spate irrigation is 2,200. Out of eight spate irrigation beneficiary villages, one is located very far from others so that only seven villages were considered and the total number of the HHs of these villages (1,459) was taken as a sampling frame. The researcher determined the sample size of only 93 households with a confidence level of 95% and a confidence interval of 10 due to time and resource constraints. Out of the seven villages, the samples were drawn from each village depending on the proportion of HHs each village had in relation to total HHs. Finally, a systematic random sampling method was used to select HHs for a semi-structured questionnaire.

In this survey, a two-stage sampling was used. First, purposive sampling was applied to select the study woreda and kebele, as well as villages. Second, systematic sampling was applied to pick up the 93 sample HHs.

2.2 Methods and tools employed for data collection

To minimize the problem of the lack and reliability of information, different methods (triangulation) of data collection were employed. Accordingly, a semi-structured questionnaire was designed and implemented to collect HH information on food production, stock/asset building, farmland size, irrigation water use, supply of improved agricultural inputs and agricultural extension services. Two focus group discussions, one at community level and the other at woreda level were organized. At community level, 16 HH heads participated. At woreda level, nine experts representing different woreda government and project offices participated. Key informants were selected from the community (12 persons), project staff (3 persons) and woreda government staff (3 persons) for in-depth interview regarding the “before” and “after” project food security situation, project results and sustainability. Observation was also an integral part of data collection particularly for irrigation schemes, and how they are managed for their sustainable function. I also observed farm plots and demonstration/nursery stations.

Secondary data on quantity of food production and rainfall (time series) and agricultural inputs supply were collected. Literature on food security is numerous, so this study is adequately supported by a literature review. Different books and academic journals related to this research from the International Institute of Social Studies (ISS) library and others sources were reviewed.

2.3 Data analysis

The information collected through the HH survey was coded and entered into a computer for analysis using SPSS and Microsoft Excel 2007 windows. The research focused on community and HHs as units of analysis and both quantitative and qualitative approaches were broadly used in the analysis. Data obtained from secondary sources like rainfall, construction-related and those data generated from HHs' survey were quantitatively analyzed using simple statistical tools such as tables and charts. As the main focus of the research was to identify the contribution made by the project towards the improvement of food security of HHs, certain categories like 'before' and 'after' project intervention, location, education status and sex of HH heads were established and analyzed.

3. Findings and Discussion

During the pre-project period (20-30 years), Jarso people lived with the worst food shortage known to them. Landholding size was small and fertility deteriorated. Land had less value towards social and economic security. Drought was a frequently occurring natural hazard along with erratic rainfall. Production was meager and hardly sustained the HHs until the next harvest season. Assets were continuously depleted as there was no chance for recovery. As a result, a vicious circle of food insecurity was the feature of pre-project Jarso community in general and the majority of HHs in particular.

Since the project intervention, the farmers have managed to grow and harvest twice a year. About 93.5% of the respondents confirmed that their average production obtained over the years (2006 –2008) had increased. Despite certain differences between male- and female-headed HHs, land productivity compared to the pre-project period in general has shown significant improvement (fourfold). Though the total size of land possession of sample HHs increased since the project intervention, the land under cultivation was only the newly acquired land in the lowland. The volume of production has considerably increased; the majority of the HHs started sufficient production at least for home consumption and the number of HHs that escaped from food insecurity through own food production is incredibly high. The spate irrigation beneficiaries not only escaped from chronic food insecurity, but also from chronic dependency on food aid experienced for the last several years. No one out of the sample HHs reported severe crop failure since they started practicing spate irrigation. According to EECMY/SWS/DASSC summary annual performance project reports (2006-2008), the cultivated area revealed a dramatic increase from 500 ha in 2005 to 3,250 ha in 2008. Likewise, community-level production (maize and sorghum) substantially increased from 20,000 quintals in 2005 to 130,000 quintals in 2008. The most recent reports of the project reveal that the spate irrigated land size increased to 4,950 ha. And the total amount of production increased to 247,500 quintals.

It was expected that land size and its level of fertility, irrigation schemes, and agricultural extension support activities could impact the HH food production. The project has developed modern irrigation schemes which enabled the farmers to access fertile land of the valley. Therefore, these two resources (land and spate irrigation schemes) are the main input factors that enabled the HHs to achieve higher food production (project output).

The irrigation component of the project also enabled the farmers to build and possess assets, such as livestock, improved houses with corrugated iron sheet roofing, radios and mobile phones. The survey result conducted four years ago indicated that a significant number of livestock was added to the existing flock through purchases. It found that the main income source of the households is crop production, specifically maize.

The establishment of irrigation schemes in general and spate irrigation schemes in particular at the appropriate standard and levels of management is not a simple task. With the exception of a few, many schemes of such kind constructed at different localities in Konso woreda were either terminated without proper completion or functioned only for a very short period of time. There are a number of factors contributing to such failure among which the lack of adequate plan and design is crucial. It happens that experts in the field used to produce irrigation development projects without a careful feasibility study and consideration of the local reality. Most often, these people come from big towns and have hardly any time or are less committed to sacrifice in the harsh local environment. Chambers' (1983: 10) expression of 'rural development tourism' may better explain such reality. However, YFSSIFSP managed to construct all the planned schemes, with the exception of one that was intended to be built on Yanda River, within the scheduled timeframe with only a minor delay. Therefore, the construction work was efficient and effective. Major factors that contributed to project success included the demand-driven nature of the project, ensuring of community participation to the maximum level and the 'community first, project second' intervention approach. In the course of implementation, the project was aware of the importance of involving the traditional leaders known as 'Kanta' in Konso. The traditional leaders were actively involved in the community coordination and mobilization.

The research also identified under-achievements and failures of the project. Initially, it was expected that different types of inputs like local capacity-building trainings, demonstration and introduction of improved varieties of seeds and provision of modern beehives and small ruminants would result in diversification of income and the asset base towards adequate access to food, and thereby contribute to sustainable food security. Despite the fact that the project exerted effort to diversify crop production (more focusing on cash crops) and HH income through the introduction of improved seeds (vegetables and fruit), the outcome was found to be below expectations. Over 30 volunteer farmers accepted and practiced modern beekeeping, but gained nothing and lost even the benefit they usually got from traditional beekeeping. In this regard the project faced a big challenge to convince other farmers to step forward for the modern beekeeping package. The project missed to apply a systematic approach and intensive follow-up that is needed for the adoption of new technological practices among uneducated or less-educated farmers, which requires patience. Concerning fruit trees, the main problem was the absence of markets. As demonstrated by the project and some farmers, Yanda-Segen Valley is conducive for fruit trees, like mango, orange and banana; these fruits are highly demanded at central markets of the country. The missing element in this package was market linkages.

Another important finding is that the project benefits were not fairly distributed between female-headed and male-headed HHs and between village 1 and village 2 inhabitants. The survey result indicates that male HH heads benefited more in terms of total harvest and land productivity. However, given the multifaceted problems of Konso women, and the failure of the research guide questions to sufficiently capture and disclose the extent of benefit for women in general and female-headed households in particular, further research is recommended.

The research has also found resource-based conflict as a crucial issue that, if not handled and resolved in a sustainable way, may very likely trigger the project outputs to perish. The survey has indicated that 26.9 HHs reported conflict as a major problem during the last 3 years (2006-2008). The response on conflict is the highest among the responses for various expected problems (Appendix Table A11).

4. Conclusion

This chapter entirely focused on two broad aspects of food security: availability of food and access to food. Increasing food production is a necessary step towards food security. The additional burden of agriculture on soil and water loss, together with a changing climate, urges us to think about the uncertainties of the future. While HH income affects food security directly by providing sources to meet HH food requirements, empirical studies indicated that HH income is inadequate (Chen 1994).

On 5th July 2004, during the seminar on "Innovative Approaches to Meeting the Millennium Development Goals in Africa" in Addis Ababa, the Ethiopian Prime Minister declared that Ethiopia would attain its objective of achieving food security within 5 years starting in 2004 by allocating more than 40% of its revenue towards this goal (Ethiopia 7 Days Update, 2004:9). However, the Millennium Development Goals report disclosed by FAO (2005:6) indicates that in sub-Saharan Africa including Ethiopia the situation on poverty and famine has been deteriorating further. During the focus group discussion held at woreda level, the discussants stated that despite huge government and NGO investments in Konso Special Woreda, the food security situation of the people has been profoundly deteriorating. Basically, escaping from food insecurity in woredas, like Konso, which have a structural food deficit and are prone to drought, is not as easy as general speeches made by politicians at conferences and at political centers would prophesy. It is also equally important to note that the country's gross economic growth is moving forward despite ongoing challenges to secure food at community, household and individual levels.

However, the spate irrigation beneficiaries of Jarso kebele have experienced a difference through the project intervention. The project has significantly contributed to the improvement of HH and community-level food security through constructing nine modern spate irrigation structures and capacity-building activities. About 2,200 HHs are currently food-secure after the project intervention. Apart from production, about 65.6% of the surveyed HHs benefited from temporary employment opportunities created by the project during construction. The project's output spillover effect has traversed into the neighboring kebeles and Karate town by stabilizing the local market prices of food crops.

Making the current food security status sustainable is a challenge ahead. Income diversification has been well initiated, but is not yet adequately flourishing. Food storage, the important food availability pillar, is not only lacking, but stakeholders do not conceive of its importance. Therefore, an integrated effort of all development actors is crucially needed to ensure sustainability of HH food security.

5. Lessons for Learning

A variety of literature stresses that farm size is an important factor in impeding or promoting production and even in access to food. This proposition is true in principle, but in the case of pre-project Jarso community, the social and economic value of land was less compared to the “after the project” value. What matters most is the productivity of land and the inputs that increase its productivity. Based on the research findings, the following recommendations are put forward as lessons for learning:

a) Local capacity-building through training was found to be one of the most important activities carried out during the first, second and third phases of the project. Nonetheless, the spillover effect is found not sturdy. The all-encompassing observation shows ‘formal and non-formal education programs’ as a missing link that the project failed to consider. Without educating the people, it may be possible to achieve remarkable results from an intervention, but sustainable improvement requires an educational backing. In this respect, the current low level in the enrolment of children in formal schooling should be improved. Non-formal education on farming, storage, nutrition, environment (watershed management and riverbank protection) and social security mechanisms should also be thought of and considered. To this end, appropriate strategies may require to be designed by pertinent stakeholders that fit the children and adults.

b) To reinforce the supply side, the government has a clear national strategy of maintaining sufficient food reserves. The larger stores found mostly in central zones and remote areas like Konso may benefit less at the onset of crop failure. It would be recommended to establish and strengthen local/community-based institutions to ensure local food storage, and thereby enhance the availability of an adequate food supply. This end could be achieved by strengthening the cooperatives (irrigation water user cooperatives and/or women’s saving and credit cooperatives). The realization of such an objective needs joint effort of the project and pertinent government bodies.

c) The research has placed resource-based conflict among the major problems that the community has encountered during the last 3 to 4 years. The conflicts occurred were very complicated due to the alliances established in supporting the frontiers. The efforts exerted so far by government and traditional leaders have not brought a sustainable solution. The Dara people are still in need of access to irrigable land in the valley. People who had migrated have been returning home and they also need land. Non-spate irrigation beneficiary villagers of Jarso also expect the same thing. The project may address some of the practical needs of the people, but the main issue is how to access the irrigable land along Yanda and Segen valleys, which are located in the boundaries of Birbirsa and Jarso kebeles. For the woreda administration, it is the right time to assess the available potential land, devise an appropriate strategy for discussion and ensure the active participation of traditional village leaders (Kanta) and church elders to realize long-lasting solutions. The number of spate irrigation beneficiaries compared to the Jarso community at large is 44%, compared to the woreda population that is only 6.1%. Since the flood irrigation of the two rivers and land potentiality in the valley are high, it is imperative to think of how to exploit these resources to tackle the structural problem of food in the woreda.

d) As discussed earlier, though the irrigation schemes are permanent structures built using an appropriate design, the farmers still practice flood irrigation in basins. This may eventually cause a salinity problem and force the beneficiaries to abandon their farms. The farming system is also traditional, demanding extensive labor. In line with growing income, it is likely to think beyond and plan for modern agriculture using machines like tractors. A tractor supplied by the project has started serving the farmers on a payment basis, which is promising. However, it needs proper handling and management. In this regard, the irrigation water user cooperatives may play substantial roles like providing tractors and linking producers to central markets. Therefore, they should be capacitated to the level to shoulder this responsibility.

e) The spate irrigation structures constructed by the project are well designed and properly built. The management and proper use of these schemes are not equally well done from the beginning. Riverbanks are not well maintained and the bylaws formulated and endorsed by the community on river bank management are toothless without formal legal backing from the government side. Unless serious attention is given, with all these constraints, it is fallacious to think of the schemes as long-lasting.

f) As already stated, the project is highly relevant and brought remarkable changes in the lives of the spate irrigation beneficiary HHs. This may represent the best exemplary practice not only in Konso woreda, but also in the other parts of the country with similar geographic settings. The 'community first, project second' intervention approach designed and implemented by the project has made a profound contribution towards effective community mobilization, in general and mobilization of traditional village leaders, in particular. The project holder EECMY/SWS and government counterparts would take this opportunity to advocate and replicate these valuable experiences in other intervention areas. 'Community first, project second' intervention approach has worked well, but the third key development actor has not played an active role. This is a potential treat for the project in general and the spate irrigation schemes in particular.

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Appendix

Table A1. Level of community participation at different project stages.

Project stage/cycle	No. of HHs that participated	Percent. of HHs that participated
Planning and implementation	8	8.6
Planning and evaluation	3	3.2
Implementation	23	24.7
Implementation and evaluation	20	21.5
Evaluation	5	5.4
At all stages	34	36.6
Total	93	100

Source: Computed from household survey 2009.

Table A2. Irrigation schemes, command area and number of beneficiaries.

Scheme site	Year of construc-tion	Type of weir	Canal length (km)		Command area (ha)	No. of benefi-ciaries
			Main	Secondary		
Geldeha	2005	Broad- crested	2.6	3.3	600	500
Orshale	2006	Full barrage	2.6	2.0	400	250
Itikle	2006/07	Weir + barrage	2.9	1.5	300	300
Kondo	2007/08	Weir + barrage	3.4	2.0	650	650
Mette	2007/08	Riverbed protection	3.0	5.3	900	650
Macha	2009	Full barrage	6.1	9.6	500	500
	Total		20.6	27.7	3,350	2,850[6]

[6] This number includes individuals who possessed land and paying land use tax in addition to HHs benefiting from modern spate irrigation.

Table A3. Average landholding size (ha) before and after project.

HH head Sex	Before project	After project	Total
Female	0.4	0.4	0.8
Male	0.9	0.7	1.5
Total	0.8	0.7	1.5

Source: Computed from HH survey 2009.

Table A4. Factors for harvesting twice.

Factors enabling for twice growing/harvest	HHs responded	Percent of HHs responded
Use of spate irrigation	51	54.8
Sufficient rain and use of spate irrigation	22	23.6
Use of spate irrigation and malaria control	10	10.8
Use of spate irrigation and agricultural extension services	10	10.8
Total	93	100

Source: Computed from field survey 2009.

Table A5. Annual production before and after project intervention for sample households.[7]

Type of crop	Production before project	Production after project (kg)			
		Location 1 (3)	Location 2 (4)	Total (5)	Difference (5)-(2)
Maize	28,350	127,825	38,210	166,035	137,685
Sorghum	28,210	16,960	2,125	19,085	(-)9,125
Beans	965	75	55	130	(-)835
Total	57,525	144,860	40,390	185,250	127,725

[7] Annual production for before project period is estimated by respondents on average basis irrespective of any specific year whereas for after project period, specific year has been indicated (2007/2008).

Source: Computed from field survey 2009.

Table A6. Percent of HHs responded to the type of crop they grew before and after project.

Type of crop	Before project	After project
Sorghum	25.8	0.0
Maize	9.7	63.4
Sorghum and Maize	64.5	36.6
Total	100	100

Source: Computed from HH survey 2009.

Table A7. Land productivity before and after project.

	Before project			After project		
HH head sex	Land size (ha)	Production (kg)	Productivity (kg)	Land size (ha)	Production (kg)	Productivity (kg)
Female	1.8	1,235	686.1	1.5	3,620	2,413.3
Male	76	56,290	740.7	59.8	181,630	3,037.3
Total	77.8	57,525	739.4	61.3	185,250	3.022

Source: Computed from household survey 2009.

Table A8. Percent of HHs responded to average annual production (before and after project).

Average amount of harvest	Before project intervention	After project intervention	
		Location 1	Location 2
Below 1,000 kg	78.5	11.4	26.1
1,000-2,000 kg	15.1	55.7	52.2
2,000-3,000 kg	3.2	18.6	8.7
3,000-4,000 kg	1.1	7.1	13.0
4,000 kg +	2.2	7.1	0.0
Total	100	100	100

Source: Computed from HHs survey 2009.

Table A9. Problem encountered as irrigation user (% of respondents).

Type of problem	Villages		Total
	Location 1	Location 2	
Waterlogging on farmlands	44.3	30.3	40.9
Unfair land distribution	21.4	13.0	19.4
Lack of participation in canal management	11.4	13.0	11.8
Waterlogging and unfair land distribution	4.3	17.4	7.5
Inadequate access to irrigation water	17.1	21.7	18.3
No response	1.4	4.3	2.2
Total	100	100	100

Source: Computed from household survey 2009.

Table A10. Livestock possession before and after project.

Type	Villages		After project	
	Number	Percent	Number	Percent
Oxen	36	6.1	69	6.4
Cows	108	18.4	199	18.5
Sheep	134	22.8	216	20.1
Goats	290	49.3	466	43.3
Heifers	4	0.7	45	4.2
Calves	0	0.0	71	6.6
Bulls	0	0.0	10	0.9
Donkeys	16	2.7	0	0.0
Total	588	100	1076[8]	100

[8] Total number indicated is only those purchased/obtained through other means during project intervention.

Source: Computed from household survey 2009.

Table A11. HH responses towards major problems encountered (2006-2008).

Type of problem	Frequency	Percent
No response	3	3.2
Lack of farm implements	4	4.3
Lack of land and money constraint	7	7.5
Lack of land and less access to irrigation water	14	15.1
Labor constraints	6	6.5
Lack of credit facilities	8	8.6
Money constraints	11	11.8
Lack of oxen	12	12.9
Epidemics of human and livestock	3	3.2
Conflicts	25	26.9
Total	93	100.0

Table A12. Konso area annual and monthly rainfall distribution.

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
1989	38.6	94.6	121.1	158.7	218.0	22.7	34.6	32.9	105.8	108.1	17.5	96.2	1,048.8
1990	11.5	150.9	178.4	197.9	64.8	10.4	10.0	11.9	41.1	50.8	28.2	16.9	772.8
1991	35.5	37.4	148.6	95.1	166.6	46.3	0.0	0.0	24.3	72.3	67.9	37.4	731.4
1992	0.2	23.3	59.7	159.5	138.3	67.4	42.6	4.9	92.4	112.4	39.0	35.4	775.1
1993	107.5	169.9	1.8	0.0	98.5	0.0	1.0	1.6	14.9	90.1	29.6	24.7	539.6
1994	2.5	4.2	81.8	171.1	137.0	16.7	29.7	69.3	15.7	109.3	64.6	16.7	718.6
1995	10.2	7.1	31.1	171.7	31.8	87.7	22.8	1.4	44.1	55.8	0.0	3.2	466.9
1996	32.7	24.0	161.1	205.4	74.0	76.7	19.8	35.8	94.9	80.6	10.1	0.0	815.1
1997	5.8	0.0	52.6	259.1	74.8	22.3	79.3	28.2	15.0	193.4	229.7	64.2	1,024.4
1998	122.9	125.5	45.1	118.3	123.9	53.9	1.5	23.0	40.1	120.7	32.2	0.0	807.1
1999	7.6	3.5	148.5	106.0	4.9	12.4	31.5	41.8	38.3	68.3	11.6	66.9	541.3
2000	0.0	0.0	28.3	87.1	98.2	5.0	10.3	18.3	17.9	76.8	37.5	68.1	447.5
2001	33.2	4.1	98.4	352.0	0.0	0.0	19.8	63.1	50.3	137.8	81.2	1.9	841.8
2002	43.0	15.7	86.9	112.0	77.9	14.0	0.0	3.4	43.1	92.9	28.2	228.7	745.8
2003	3.8	14.2	80.2	231.6	210.4	25.7	27.2	85.0	30.1	41.4	44.0	35.3	828.9
2004	33.4	13.0	54.2	112.6	123.3	4.9	6.2	0.3	56.3	42.1	83.5	33.2	563.0
2005	25.0	2.4	81.8	145.0	273.4	9.5	19.4	16.2	61.8	109.9	57.6	0.0	802.0
2006	0.0	65.9	142.2	x	41.9	32.0	5.0	100.3	14.6	141.2	181.8	75.4	800.3
												Average	740.2

Source: NMA.

Conclusion and Next Steps for Spate Irrigation Research

Simon Langan and Teklu Erkossa

Significance of the Workshop

Whilst spate irrigation is not a new concept in Ethiopia, over the recent decades there has been a resurgence of interest and use of such natural flood irrigation in the country. This renewed interest is being driven in part by the need to grow more food, in the context of increasing population and increasingly marginal land with the changes in availability of suitable soil moisture and rainfall.

This workshop was a novel experience for many in that it brought together a multitude of users, researchers and administrators to share experiences on designing, monitoring and operating spate irrigation practices in Ethiopia. The workshop was attended by 38 people drawn from 23 organizations serving government, universities, research institutions, local and international NGOs, and irrigation design enterprises, among others. This represents a significant body of experience, which generated a shared common understanding as well as innovative insights into both opportunities and constraints for spate irrigation. The experiences shared, in terms of information and knowledge, are represented in the preceding papers. Below, we provide an overview of the salient findings that emerged from the discussions. We also highlight key suggestions made by participants for next steps towards ensuring that spate irrigation continues to be strengthened by improved policies and practices that are informed by 'lessons learnt' from field experience and research.

Overview of the Main Findings and Potential Next Steps

1. In discussions relating to the challenge to realize the full potential of flood-based irrigation farming, participants made the following comments and observations:

    - High rainfall in upland areas provides adequate floodwaters for use in the adjacent lowland areas. There is a range of good and bad experiences based on the practice of spate as a traditional type of farming in the past. More modern spate irrigation can build on past experience as a contribution to reducing food insecurity in arid lowland areas. Over 60% of Ethiopia's land mass is in the lowland and has some potential for spate irrigation.

2. Participants discussed what needs to be done to enable Ethiopian spate irrigation farming to meet its potential. They highlighted the following points:

- There is a need to develop modern infrastructure that builds on the successes of past design and practice and minimize what did not work as well. Central to this, spate irrigation should be community-led to maximize ownership. This can be achieved by a participatory approach from the outset [early in the design phase]. A participatory approach ensures that local, indigenous knowledge relating to how rivers and floods are generated is used together with scientific and engineering principles to design, build and use flood-based structures for irrigation. There is also a need to adopt a more systematic approach that considers both upstream (water source) and downstream (water use relations), particularly in relation to such issues as erosion-sedimentation. To avoid conflicts, there is a need to further consider governance and institutional arrangements that maximize equity, reduce potential conflicts and encourage efficient, participatory development. In part, this relates to building capacity and raising awareness of spate irrigation farmers, development implementers and relevant institutions.

3. In relation to ensuring spate irrigation progresses and lessons from past practice on the most important aspects, participants responded:

    - There is a need to systematically document, monitor and evaluate both successes and failures from past and ongoing practices. A key suggestion from the meeting was to undertake a knowledge audit of what we know about spate irrigation, and as importantly, identify our knowledge gaps. Particularly, participants emphasized the need to draw on knowledge from both local government and community development experience and indigenous farmer practice to inform the design and implementation for new schemes. This will require designers and planners to spend more time in the field collecting relevant information. The group also suggested that there could be demonstrations or examples of good spate irrigation schemes, which others could learn from visits. On a related issue, opportunities exist for cross-country learning where spate irrigation is also practiced, such as, Pakistan, Afghanistan and Yemen. Exchange visits are particularly important in relation to addressing gender equity issues. Finally, the group suggested a need to replicate the experience of this workshop by creating a forum for further experience sharing and learning lessons, either from successes or failures, nationally or internationally. Effectively, participants recognized the need for regular networking on spate irrigation, which could build on the existing Spate Irrigation Network.

4. Participants shared their views on additional research needed to implement flood-based agriculture more effectively. They suggested the following:

    - Evaluation of current knowledge and best practices.
    - Improving knowledge of hydrology and sediment management in order to improve water and sediment management in spate irrigated fields. This in turn should be linked to agronomy in terms of rapid growth and maturity considering adequate soil moisture, and the potential for drought-resistant species.

- Primary studies on land suitability, spate agronomy (spate appropriate crops) and socioeconomic and institutional issues (equity, conflict, cooperation), including watershed management.
- Studies on the institutions, governance and management approaches in spate irrigation schemes.
- Relationship between spate irrigation farming and improvements to nutrition and livelihoods.

5. Finally the participants discussed the priorities for the next steps. There was an extensive discussion on the gaps and opportunities provided by enhancing spate irrigation in the future, and the discussions concentrated on five key areas where there is urgent need to:

- Audit and monitor all of the major spate irrigation schemes and their principal attributes using a standardized format to provide a baseline of what is working (or not), where and why.
- Continue to evaluate and monitor spate irrigation through an ongoing program of work related to the performance of this style of farming so that further development and evolution are based on lessons and evidence from existing practice.
- Increase the knowledge base on spate irrigation in Ethiopia, notably through a first step of undertaking a capacity audit specifically in relation to spate irrigation across a spectrum of people from farmers and development practitioners and extension agents, to policymakers, technical professionals/project designers, and the national and international research community. Enhancing the existing Spate Irrigation Network may be one vehicle to promote this.
- Mobilize resources to undertake these activities, in part through efforts to raise awareness among potential funding sources, including donors, on the contribution and additional potential of spate irrigation.

List of Participants

Name of contact(s)	Organization	E-mail address
Mekonnen Ayana	Arba Minch University	meko_amu@yahoo.com
Zerihun Anbesse	Arba Minch University	anbes421@gmail.com
Filmon Tquabo	Mekelle University	filmon0968@yahoo.com
Afework Mulugeta	Mekelle University	afework.mulugeta@gmail.com
Abebe Fanta	Haramaya University	fantaalemitu@gmail.com
Frew Abebe	Adama Science and Technology University	frew-is@yahoo.com
Mesfin Benti	Adama Science and Technology University	mesfinbenti@yahoo.com
Alemayehu Zewdie	GIZ	Alemayehuzewdie@yahoo.com
Damtew Adefris	Oromia WW Design Enterprise	damtewadefris@yahoo.com
Yohannes Geleta	Oromia WW Design Enterprise	yohketi@gmail.com
Adugna Jabessa	Oromia WW Design Enterprise	samiogeto@yahoo.com
Mehari Hiben	Tigray WW Design Enterprise	hiben123@gmail.com
Tewodros G/Egziabeher	Irrigation Development Department (Relief Society of Tigray)	michealtewodros@gmail.com
Birhanu Teshome	Tigray Agricultural & Rural Development	brehanutesh@gmail.com
Debebe Lijalem	Amhara WW Design Enterprise	dlijalem@yahoo.com
Belay Zegeye	Amhara WW Design Enterprise	belayzegeye@yahoo.com
Melese Sintayehu	Amhara Water Resources Development Bureau	melesesentayehu@yahoo.com
Taye Alemayehu	Meta Meta Research	taye@metameta.nl
Giego Garcia Landarte	Meta Meta Research	dgarcialandarte@metameta.nl
Mulugeta Chere	Dodota Sire District Irrigation Office	
Tsegaye Ayano	Arsi Negelle Irrigation Developmnet	
Tilahun Hordofa	Melkasa Reseach Centre	htilahun2010@gmail.com
Ehitaferahu Teso	Oromiya Irrigation Development Authority	ehitaferahuteso@gmail.com
Nigusu Bekele	Debre Zeit Research Centre	nigussy@fastmail.fm
Tesfaye Ertebo	Ministry of Agriculture	tesfayeerteebo@yahoo.com
Galunde Waketa	EECMY	galunde@yahoo.co.uk
Gizachew Toraito	EECMY	tenagnetesfaye74@gmail.com
Mulugeta Tesema	Mekelle University	mule4205@gmail.com
Gobena Dirisa	Ethiopia Institute of Agricultural Research	dirirsagobe@gmail.com
Teklu Erkossa	IWMI	T.erkossa@cgiar.org
Simon Langan	IWMI	S.langan@cgiar.org
Philippe Lemperiere	IWMI	
Yenenesh Abebe	IWMI	Y.Abebe@cgiar.org
Kata Molnar	IWMI	katamolnar87@gmail.com
Ewen LeBorgne	ILRI	E.LeBorgne@cgiar.org
Apollo Habtamu	ILRI	
Kahsay Berhe	ILRI	K.berhe@cgiar.org
Daba Dendena	IWMI	
Bruktawit Hailu	IWMI	

Postal Address
P O Box 2075
Colombo
Sri Lanka

Location
127 Sunil Mawatha
Pelawatta
Battaramulla
Sri Lanka

Telephone
+94-11-2880000

Fax
+94-11-2786854

E-mail
iwmi@cgiar.org

Website
www.iwmi.org

IWMI International Water Management Institute

IWMI is a member of the CGIAR Consortium and leads the:

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