Impacts of Improving Water Management of Smallholder Agriculture in the Upper Blue Nile Basin

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Abstract

With its total area of about 200,000 square kilometers (km^2), which is 20% of the country's land mass, and accommodating 25% of the population, the Upper Blue Nile Basin (Abbay) is one of the most important river basins in Ethiopia. About 40% of agricultural products and 45% of the surface water of the country are contributed by this basin. However, the characteristic-intensive biophysical variation, rapid population growth, land degradation, climatic fluctuation and resultant low agricultural productivity and poverty are posing daunting challenges to sustainability of agricultural production systems in the basin. This calls for technological interventions that not only enhance productivity and livelihoods in the basin, but also bring about positive spillover effects on downstream water users. In this study, the farming systems in the basin have been stratified and characterized; and promising agricultural water management technologies, which may upgrade the productivity of smallholder rainfed agriculture while improving downstream water quality, have been identified. As a consequence, supplementary and full irrigation using rainwater and drainage of waterlogged soils are recognized as being among the promising agricultural water management technologies that can be easily scaled-up in the basin. The magnitude of the impacts of these technologies on the productivity of the upstream farming systems and the concomitant effects on the downstream water flow and quality are under investigation, assuming an assortment of scenarios.

Introduction

Currently, Abbay is one of the least planned and managed sub-basins of the Nile. About two thirds of the area of this densely populated basin fall in the highlands and hence receive fairly high rainfall of 800 to 2,200 mm per year. However, the rainfall is erratic in terms of both spatial and temporal distribution, with dry spells that significantly reduce crop yields and sometimes lead to total crop failure. The impacts of droughts on the people and their livestock in the area can sometimes be catastrophic. The population located in the downstream part of the Blue Nile, is entirely dependent on the river water for supplementary irrigation. Canal and reservoir siltation is a major problem exacerbating socio-economic burdens on poor riparian farmers together with the seasonality of the river flow. Solutions lie in improving agricultural practices and conserving water at all levels by all stakeholders: both within Ethiopia and downstream communities. Particularly, there is a paramount need for integrated agricultural water management to overcome the effects of water shortage in small scale agriculture, alleviate poverty and food insecurity; and avert the negative impacts of climate change in this part of the basin through improving rainfed system. As a component of the water demand assessment, identification of appropriate agricultural water management interventions, analysis of impacts on productivity and poverty alleviation as well as hydrology need to be carried out. This study therefore focuses on various indigenous and research based agricultural water management technological interventions suitable for small holder farmers in the Abbay basin, and attempts to quantify their impacts on productivity of the small holders agricultural as well as the overall livelihood of the farming communities. Therefore the overall objectives are to:

- Characterize the upper BNSB and establish 'homogenous' units of agricultural production Systems ;
- Identify agricultural water management technologies for upgrading the rainfed systems;
- Evaluate the impact of selected agricultural water management technologies on agricultural productivity, water availability and hydrology;
- Develop methodologies and decision support tools for improved agricultural water management in the basin.

Methodology

Location and biophysical settings

The Blue Nile basin covers an area of 311,548 km^2 (Hydrosult et al 2006b). It provides 62% of the flow reaching Aswan (World Bank, 2006). The river and its tributaries drain a large proportion of the central, western and south-western highlands of Ethiopia before dropping to the plains of Sudan. The confluence of the Blue Nile and the White Nile is at Khartoum. The basin is characterized by highly rugged topography and considerable variation of altitude ranging from about 350m at Khartoum to over 4250m a.m.s.l. (meter above sea level) in the Ethiopian highlands. The main stay of the economy in the upper part of the basin is rainfed small scale mixed agriculture. Although the total annual rainfall the area receives is relatively good, due to its unfavorable temporal and spatial distribution, agriculture is prone to moisture stress. Besides, the poor water and land management in the region exacerbates land degradation leading to low agricultural productivity and perpetuating poverty.

Abbay river basin is one of the three sub-basins of the upper Blue Nile in Ethiopia (Fig. 1). Situated in the north-central and western parts of the country it forms a generally rectangular shape that extends for about 400 km from north to south and about 550 km from east to west. It is characterized by a high bio-physical variation, such as terrain (Fig. 2) and soil (Fig. 3). The intensively changing train which leads to varying agro-ecology within short distances does not only hamper agricultural development planning and mechanization, but also exacerbates the rate of land degradation. Corresponding to the variation in landscape and other soil forming factors such as climate and vegetation, the soils of the basin are also highly variable. However, only four soil types, Nitisols, Leptosols, Luvisols and Vertisols cover over 80% of the area. Apparently, these soils have various productivity limiting characteristics such as acidity, depth and permeability (Table 1).

Table 1 Area coverage of the major soil types in the basin and their corresponding limitations

Soil type	**Area (km^2)**	**% of the area**	**Limiting factors**
Nitosols	86,665	39.08	Acidity
Leptosols	52,529	23.68	Depth
Luvisols	31,494	14.20	
Vertisols	26,735	12.05	Permeability
Cambisols	11,234	5.07	
Alisols	9,238	4.17	
Phaeozems	2,707	1.22	
Fluvisols	1,188	0.54	

The basin covers a total area of 199,812 km^2 and has an average annual discharge of about 49.4 Billion Cubic Meter, measured at Sudan border (BCM). Extending over three regional states of Ethiopia including Amhara, Oromia and Benshangul Gumuz, it is the most important basin in the country by most criteria as it contributes about 45% of the countries surface water resources, accommodates 25% of the population, 20% of the landmass, 40% of the nations agricultural product and most of the hydropower and a significant portion of irrigation potential of the country (http://www.mowr.gov.et/index.php?pagenum=3.1). Originating from the centre of its own catchments around Lake Tana in the north, it develops its course in a clockwise spiral, collecting its tributaries all along its nearly 1,000 km length from its source, to the south of Lake Tana up until the Ethio-Sudan border (MoWR Master Plan: Abbay, 1999). Dabus and Didessa rivers that spring in western Ethiopia are the largest tributaries accounting for about 10 % and 8.5% of the total flow at the border, respectively.

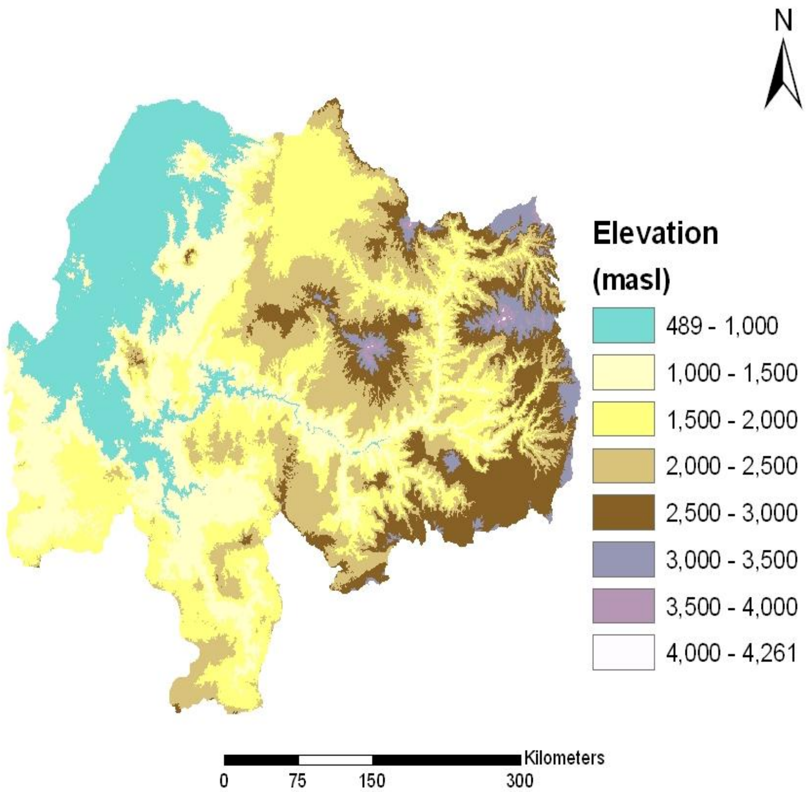

Figure 1: Elevation map of Abbay basin

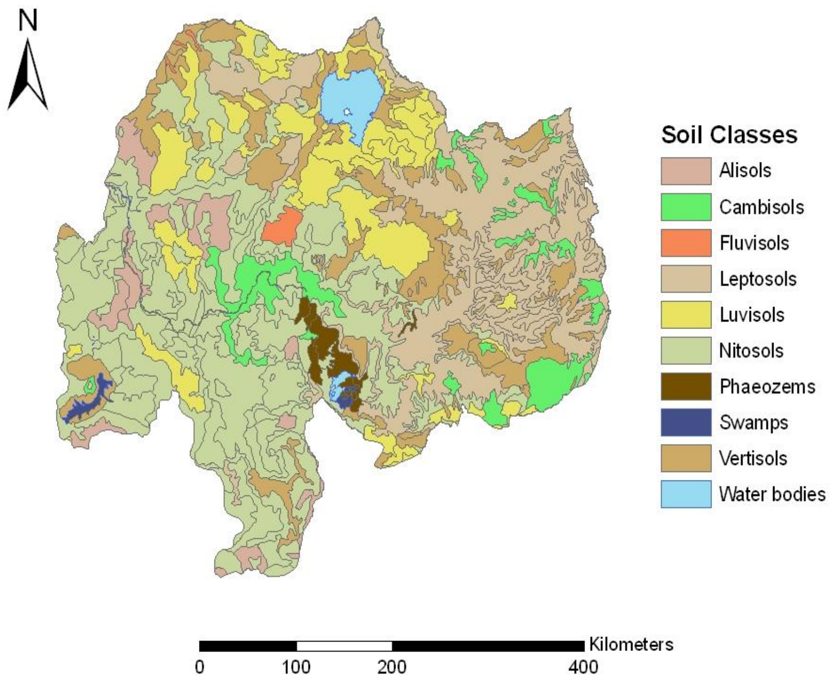

Figure 2: The major soil types of the Abbay river basin

Land use systems and agricultural water management

Although quite diverse land use systems are common, rainfed based agricultural land use dominates the basin. Over 80% of the populations in the basin drive their livelihood mainly from small scale rainfed agriculture. Because of hazardous land use and poor land and water management systems, high population pressure, land degradation, small land holding and highly variable climate, agricultural productivity in the basin is increasingly challenged. High population pressure, lack of alternative livelihood opportunities and slow pace of rural development are inducing deforestation, overgrazing, land degradation and declining agricultural productivity.

Poor water and land management in the upstream part of the basin reduces both potential runoff yields and the quality of water flowing downstream. The result is a vicious cycle of poverty and food insecurity for over 14 million poverty-stricken people in the uplands, and for millions of downstream users. It is widely recognized that improved water management in the Abbay catchments is key to improving both upstream and downstream livelihoods. Better water and land management will help increase water availability and alleviate the impacts of natural catastrophes such as droughts and reduce conflicts among stakeholders dependent on the Nile.

Methodology

Stratification and characterization

The farming system of the basin has been classified into homogenous units based on the Basin Master Plan Study (BCEOM, 1998). The approaches of Westphal (1974; 1975) were adopted. Accordingly, the major farming systems of the basin were described, but additional subsystems have been identified based on the major types of crops grown, vegetation, altitudinal variation, and cultivation practices. Also, the soil types of the farming systems were identified based on the basin master plan soil data (Figure 1) and the farming system data (Figure 2) using ArcGIS. The productivity of the farming systems under the current management systems have been determined based on district level CSA reports (CSA, 2007). Potential agricultural water management technologies suitable for the areas within the basin were identified based on a survey report conducted earlier in the country (Makonnen et al., 2009).

Data capturing and analytical tools

We used AquaCrop (FAO, 2009) and using SWAT to analyze the impacts of the technologies on water consumption, crop production, runoff, water balance and land degradation in the basin. Data on climatic parameters, crop characteristics, soils and land managements were collected from secondary information and were analyzed under various assumptions and scenarios.

Preliminary Results

The farming systems

The determinant factors that compel farmers to decide for one farming system or another could be a matter of further investigation. Apparently, environmental factors such as soil and climate play a vital role, while socio-economic factors including access to market for inputs and outputs, and exposure to productive technologies are also essential.

Broadly, the farming systems in the basin can be categorized into the mixed farming of the highlands and pastoral/agro-pastoralism of the lowlands. However, about nine distinct farming systems have been identified in the basin (Figure 4) although only four of them cover about 70% of the area (Figure 5). The cereal based crop cultivation, coffee and other tree crops complex together with enset and other root crops complex constitute the mixed farming system. Covering the largest portion of the area (over 90%), the cereal based crop cultivation can be further sub divided into the single cropping, double cropping and shifting cultivation sub systems, which cover about 60%, 10% and 20 % of the area. A smaller section of the area is under the double cropping cereal cultivation, which represents a system where two rainfed cropping seasons per annum is possible.

While tef, maize and sorghum account for about 50% of the single cropping system, barley dominates the double cropping system. Shifting cultivation systems which are practiced in the western and southern lowlands of the basin are persistently diminishing.

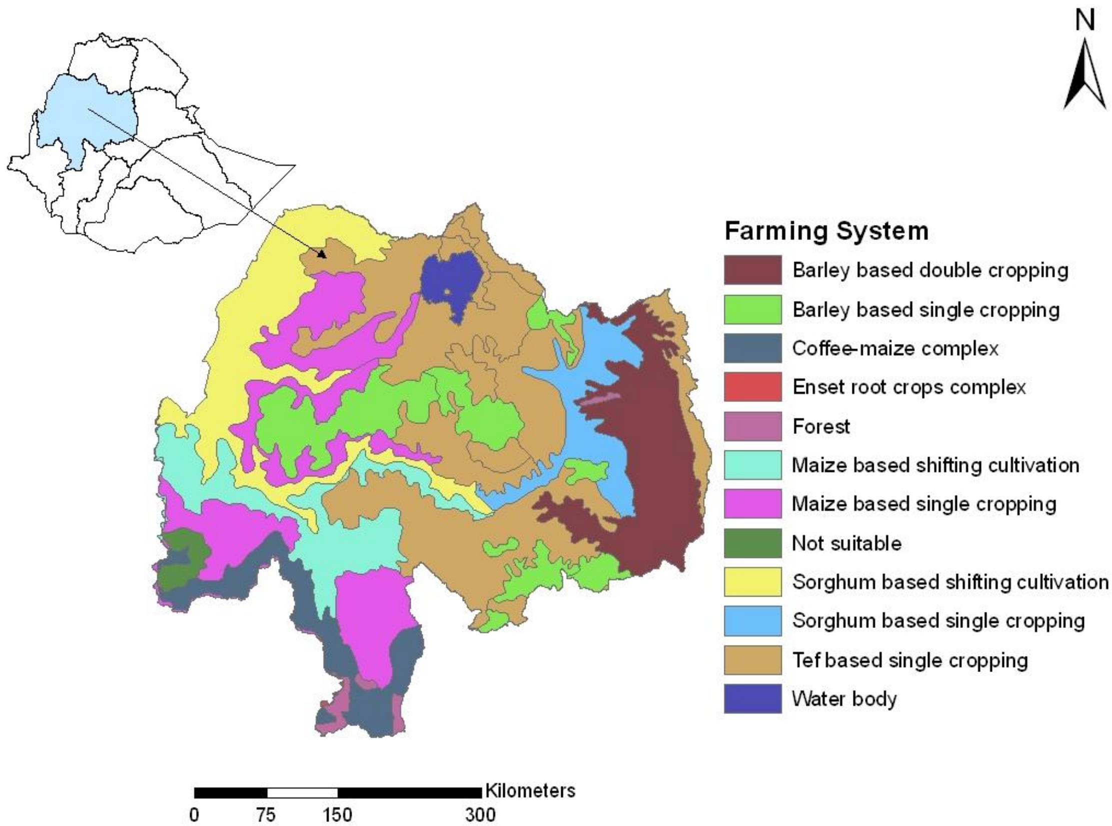

Figure 3: The major farming system of the basin

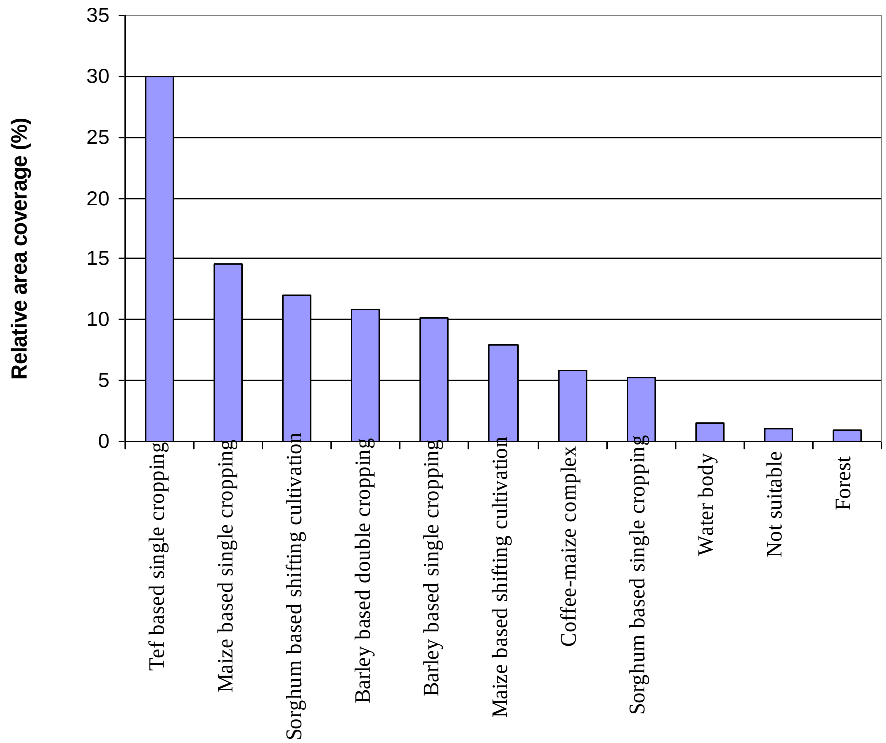

Figure 4: Relative area coverage of the farming systems

Characteristics of the farming systems

Cereal based-single cropping

Covering the largest part of the basin (62%), these farming systems encompass the cultivation of the major cereals grown in the basin including, tef, maize, sorghum and barley. The main characteristic of these systems is the production of crops from seeds, only once a year during the main rainy season. The production system can focus on production of either small grains such as wheat and tef or large grains such as maize and sorghum.

The small grain cereals

The production of small seeded cereals such as tef, barley and wheat dominates this system, but a large variety of other grains such as finger millet, maize, sorghum, pulses, oil seeds and spices are also grown. The topography of the area where this farming system prevails varies from almost flat and undulating type in the central and western parts to steep slope and mountainous in the northern and eastern parts with very scarce vegetation covers. The areas within this farming system mostly receive adequate rainfall during the cropping season. Leptosols and Vertisols dominate the tef based single cropping and barley based double cropping farming systems areas (Table 2). Among the major potentials of this farming system for agricultural development is the availability of vast area of land suitable for mechanized farming (BCEOM, 1998). Besides, a substantial part of the irrigation potential of the country including small scale irrigation (Table 3) fall within this farming system. Consequently, developing small, medium and large-scale irrigation schemes with suitable crop and water management systems is believed to significantly enhance productivity of the system and improve the livelihood of the communities. In this regard, low cost agricultural water management technologies which can be constructed and managed by the local communities can play a vital role, at least in the short term.

The large grain cereals

Dominated by the maize based system in the south western and sorghum based system in the north eastern parts of the basin (Fig. 2), the large grain cereal cultivation system covers about 20% of the basin. While maize and sorghum are the dominant crops, a large number of other crops like tef, wheat, barley, finger millet, pulses and oil crops are also widely grown. The maize areas have generally gentle to flat slopes as opposed to the sorghum areas which are characterized by rough, steep slopes and mountainous regions that are largely devoid of vegetation cover. Nitisols followed by leptosols dominate both the maize based and sorghum based systems, with a higher extent of leptosols in the latter. In contrast to the maize area, which receives ample and dependable rainfall, the sorghum areas get erratic and unreliable rainfall.

Similar to that of the small grain farming systems, not many farmers use the right type and quantity of fertilizers and improved seeds. The use of manure is established in maize areas, but often restricted to backyard farms. Crop rotation in maize areas of the western part involves legumes, but in the sorghum areas, the rotation is among the cereals. Land degradation and unreliability and shortage of rainfall are serious threats of the sorghum part (BCEOM, 1998). Thus, improving the rainfed agriculture through provision of efficient extension services and inputs, and implementation of suitable agricultural water management technologies, is believed to significantly enhance the level of production and productivity.

Table 2 The soil types in the dominant farming systems of the basin

Soil type	Tef based single cropping		Maize based single cropping		Sorghum based shifting cultivation		Barley based double cropping	
	Area (km^2)	% of the area	Area (km2)	% of the area	Area (km2)	% of the area	Area (km2)	% of the area
Alisols	266	0.10	11498	8.68	5901	8.28		
Cambisols	7701	2.85	4362	3.29	4414	6.20	5211	9.48
Leptosols	140369	51.91	15856	11.97	15263	21.43	42575	77.42
Luvisols	51367	19.00	10998	8.30	6024	8.46	641	1.17
Nitisols	38731	14.32	77099	58.22	34986	49.12	759	1.38
Vertisols	28032	10.37	8838	6.67	4254	5.97	5807	10.56
Total	270393	100.00	131888	99.59	70841	99.45	54993	100.00

Barley based-double cropping

A bimodal rainfall with the small rain resuming in January or February and extending to end of May; and the main rain starting in mid July and extending to mid September characterize the farming system. Although crops can be produced twice a year using the small and the main rains, both are not reliable due to climatic and edaphic factors. The onset and secession of the rainfall is highly variable that planning of agricultural activities is difficult. Besides, shallow soils (Letptosols) with limited water storage capacity cover over 70% of the area (Table 2). On the other hand, Vertisols, which have impeded drainage, are the second largest soil type covering over 10% of the area. Barley, wheat, tef and some pulses are widely grown in the farming system. The use of fertilizers and improved seeds is minimal, may be due to the unreliable rainfall, the subsistence nature of the farmers and highly degraded soils.

Despite the limitations, productivity can be enhanced with proper use of improved technologies. For example, moisture conservation measures and use of short duration crop varieties can improve the productivity of the crops during two rains on the letptosoil areas. On the other hand, enhanced drainage and harvesting of the excess water for supplementary or full irrigation, together with complementary technologies can significantly boost the productivity of the Vertisols.

Current productivity and limitations of the farming systems

Current productivity

Understandably, the livelihood strategy of the farmers in the basin is focused on production of food grains such as cereals, pulses and oilseeds, primarily for household consumption (CSA, 2005). Unfortunately, the productivity of the farming systems regardless of the crop types is miserably low (Table 3) (CSA, 2007). Evidently, the large grain crops gave the highest average yield across the farming system which is comparable to the national average, although that of Sorghum is slightly depressed. The overall grain productivity of the farming systems in the basin is less than 1ton per hectare. As the average land holding in the basin is less than 1 hectare per house hold, with the average household size of about seven, the level of crop productivity depicts the abject poverty in which the communities are entangled.

Table 3 Average crop productivity of the farming systems (100kg/ha) during the man cropping season (CSA 2007)

Farming system	Tef	Barley	Wheat	Maize	Sorghum	Finger Millet	Faba bean	Field pea	Average
Tef based single cropping	8.24	9.21	10.4	16.8	9.18	4.98	10.33	6.83	9.5
Maize based single cropping	7.28	6.25	7.13	22.04	12.92	9.89	6.81	4.18	9.56
Sorghum based shifting cultivation	7.26	4.89	6.46	20.68	10.93	6.53	6.13	2.66	8.18
Barley based double cropping	7.31	9.47	9.9	8.23	8.86	1.6	10.3	6.91	7.82
Barley based single cropping	8.97	14.81	12.23	18.05	12.88	10.97	12.06	8.78	12.34
Maize based shifting cultivation	5.77	5.18	6.53	20.38	13.72	6.86	5.17	3.69	8.41
Sorghum based single cropping	8.66	10.28	11.62	14.01	11.96	9.59	11.87	9.09	10.89
Coffee-maize complex	8.21	7.36	8.05	22.05	14.72	9.08	7.77	5.52	10.35
Average	7.71	8.43	9.04	17.78	11.90	7.44	8.79	5.96	9.63

Reasons for low productivity

The poor and declining performance of agriculture can be attributed to many interrelated factors including high population pressure, soil erosion and land degradation, unreliable rainfall, low water storage capacity of the soils and the catchments, crop pests and diseases, soil acidity, water logging, shortage of farm land, lack of improved technologies such as: improved varieties, soil fertility management (fertilizers, liming), water management (irrigation and drainage), soil and water conservation as well as farmers traditions. This calls for a comprehensive external intervention in terms of policy, institutions as well as technologies. The following session briefly deals with some priority technological interventions necessary to overcome the daunting challenges of productivity and sustainability prevailing in the basin.

Possible technological interventions and onsite and offsite impacts

Possible interventions technologies

In order to overcome the constraints and ensure enhanced and sustained crop production in the basin, integrated technological interventions is necessary. A range of technologies including improved crop verities and species, appropriate land use, improved land and water management practices etc. should be used in integration to benefit from their synergetic effects. The use of suitable agricultural water management technologies such as, water harvesting, supplementary and full irrigation using different water sources, drainage of water logged soils, which can also be supplemented with harvesting of the excess water to be used as supplementary or full irrigation may increase and stabilize the productivity of the rainfed agriculture with a possibility of growing during the dry seasons, which increases the land use intensity. Although a multitude of technologies can be considered, the most suitable and sustainable ones are those that can be constructed and managed by the local community with minor technical support. Identification of such technologies could be achieved through the involvement of the stakeholders including the farmers in the selection of site specific technologies. In line with this, some suitable agricultural water management technologies have been identified for scaling up in the basin and its environs through participation of the farming communities and other stakeholders (Table 4).

Traditional small scale irrigation from spring, river and other water sources has been practiced in Ethiopia since generations, but only by few farmers. Although a significant yield increase and productivity stability could be ensured without much investment and with less technical support. However, the widespread application was not sufficiently encouraged until recently. According to the Abbay basin master plan study document, a large area of land (over 41, 000 ha) can be developed by small scale irrigation using different sources of water ranging from rainwater harvesting to river diversions in the four major farming systems. On the other hand, a much larger area of land covered with vertisols (over 46000 km^2) (Table 5) can be developed by draining the excess water during the rainy season, and harvesting the drained water, which can be used for supplementary or full irrigation.

Rainwater water harvesting is when the precipitation is collected from a small/large surface area (catchments) and directed through channels to a storage facility or to a nearby field or retained at the site itself (in-situ). The rainwater harvesting techniques most commonly practiced in Ethiopia are run-off irrigation (run-off farming), flood spreading (spate irrigation), in-situ water harvesting (ridges, micro basins, etc.) and roof water harvesting (Getachew Alem, 1999), and more recently are ponds. The harvested water can be used for irrigation of crops, pastures and trees, and for livestock consumption. Among the goals of rainwater harvesting are increasing productivity of rainfed agriculture, minimizing the risk of crop failure in drought prone areas, combating desertification by tree planting, and supplying drinking water for human and animals (Finkel and Finkel 1986). In order to ensure sustainability by avoiding siltation, watershed management with reforestation and other erosion control measures are necessary. Improved watershed management encourages recharging of the groundwater which may enhance the possibility of shallow well exploitation. Because of their higher quality and availability during the dry season due to reduced evaporation loss, shallow wells can be used for prolonged period of time for crops, livestock and domestic consumption.

Table 4 Some promising agricultural water management technologies practiced in the sub basin and its environs

Technology	Description/merits
Small scale irrigation from springs and rivers	• Can be built by farmers • High level of ownership • Better operation and maintenance • Make structures permanent + enhance capacity
Shallow well development	• Provides reliable water- with continued recharge • Good water quality • Should be associated with catchments treatment • Terraces and trenches can allow recharge • Multiple uses including domestic water supply
Rain water harvesting	• Surface and sub-surface storage • Trapezoidal ponds found most suitable- with evaporation mitigation measures • Can be managed at household level
Surface drainage of Vertisols	• Use Broad bed and Furrows (BBF) • Constructed by Broad bed maker (BBM) designed and constructed at ICRISAT in (El-Swaify et al., 1985). • Introduced by ILCA and was modified to fit to the smallholder system • Recommended for successful cropping on Vertisols • BBM is drawn by a pair of oxen • It allows early planting and double cropping with/without supplementary irrigation • Yield increase of up to 200-300% reported

Source: Makonnen et al., 2009

A significant area of land in the basin is covered by the vertisols, which are characterized by very slow internal drainage with infiltration rates between 2.5 and 6.0 cm day^{-1} due to high clay content (Teklu et al., 2004), which leads to water logging, as a result of which early planting is not possible. Traditionally, many Vertisol crops are planted towards the end of the rainy season after the water is lost mainly to evaporation, to grow on residual moisture (Abate Tedla et al, 1988), which does not only significantly reduce the length of effective growing period, but also water productivity as much of the water is lost due to evaporation. However, several studies have shown that surface drainage allows early sowing enabling the full utilization of the potentially available growing period. Besides, the early-established surface cover may reduce soil erosion (El-Swaify *et al.* 1985; Abate Tedla et al, 1988; Astatke, A. and Kelemu, F. 1993; Teklu et al., 2004; Teklu *et al*. 2006) leading to ecological sustainability. Among the various alternatives, surface drainage technology, known as broad bed and furrow (BBF) constructed by broad bed maker (BBM) which was developed at ICRISAT in India (El-Swaify et al. 1985) and was later modified to fit to the smallholder system in Ethiopia (Astatke, A. and Kelemu, F. 1993) has been popularized in the major Vertisol areas of the country. The advantage of this technology can be amplified by harvesting the excess water, which can be used later on as supplementary or full irrigation of the subsequent crops, allowing multiple cropping per year on a piece of land leading to a better land use intensity.

Table 5 Estimated suitable area for small scale irrigation (ha) and surface drainage in the dominant farming systems

Farming system	Small scale irrigation (ha)	Surface drainage (km^2)
Tef based single cropping	27,480	28,000
Maize based single cropping	8,025	8,800
Sorghum based shifting cultivation	725	4,000
Barley based double cropping	4,850	5,800
Total	41,080	46,600

Possible impact of the technologies

The envisaged impacts of the selected agricultural water management technologies to be implemented in the upper part of the Blue Nile sub basin could be economical and environmental. The impacts are expected be revealed both in the upstream and downstream parts (Table 6). The technologies can potentially allow double or triple cropping in the upstream part of the basin, contributing to the food security and poverty reduction effort of the communities. Besides, the integrated watershed management interventions coupled with the technologies is believed to result in increased infiltration, reduced runoff, improved ecosystem functioning and a better human health and habitation. The concomitant effect on the downstream part could be flow regulation, with reduced peak flow and increased base flow; reduced sedimentation and a better water quality due to soil conservation at the upstream part; and increased surface runoff caused by surface drainage of the Vertisols since the water that was otherwise would have been lost as evaporation would contribute the surface flow.

Table 6 Possible impacts of the technologies

Technology	**Expected Impacts**	
	Upstream	Downstream
Shallow well + WSM	1. Reduced surface runoff and erosion 2. Double cropping possible 3. Increased crop productivity	1. Increased sub flow 2. Reduced peak flow 3. Improved water quality
RWH + WSM	1. Reduced surface runoff and erosion 2. Double cropping possible 3. Increased crop productivity	1. Increased sub flow 2. Reduced peak flow 3. Improved water quality
Surface drainage of Vertisols (BBF) + (WH)	1. Reduced evaporation 2. Increased ETc 3. Double cropping possible 4. Increased crop productivity	1. Increased runoff

WSM= watershed management; WH = water harvesting; BBF = Broad bed and furrows

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