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# Rainwater harvesting: An option for dry land agriculture in arid and semi-arid Ethiopia

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**Subsistence rain-fed agriculture has been widely practiced for many centuries in Ethiopia and this sector has been highly dependent on rainfall. Thus, rainfall remains the crucial component of the weather elements for improving agricultural productivity. Extreme climatic conditions and high inter-annual or seasonal variability of this weather element could adversely affect productivity, because rainfall controls the crop yields and determines the choice of crops that can be grown. One of the reasons for low crop production in semi arid areas is marginal and erratic rainfall exacerbated by high runoff and evapotranspiration losses. Rainfall in terms of amount and frequency in a growing season is essential for planning and management of agricultural practices. To avert this problem, the successive Ethiopian government (from the time of Aksumite kingdom to the present) and the local community practiced different water harvesting techniques. The *in-situ* and *ex-situ* rainwater harvesting techniques have shown significant impact on improved soil moisture, runoff and ground water recharge; and increased agricultural production, which in turn reduces risks and deliver positive impacts on other ecosystems. Besides, rainwater harvesting has a potential of addressing spatial and temporal water scarcity for domestic consumption, agricultural development and overall water resources management. High water loss through seepage, lack of awareness and being very labor intensive to irrigate the whole fields by pumping the water manually from the pond and applying directly to the crop has been the main challenges of adopting harvested water technologies.**

**Key words:** Rainfall, runoff, semi-arid Ethiopia, soil moisture, water harvesting, yield.

## INTRODUCTION

Agriculture is the main economic activity in sub-Saharan Africa (SSA) supporting over 67% of the population, out of which 60% depends on rainfed agricultural practices; generating 30-40% of the country's Gross Domestic Product (Rockström, 2002). However, rainfall is poorly distributed in these countries (Ngigi, 2003). High losses occur due to high surface runoff during high intensity rains, poor crop rooting conditions, past and present soil erosion and evaporation losses from soil, and crop canopy in particular during pre-planting and early crop stages (Rockström, 2003). Uncontrolled runoff can cause damaging flash floods; severe erosion; increased water

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turbidity and substantial water loss. These losses of valuable water resources increase food insecurity and societal poverty, which are the greatest threats to sustainable development in the region (Ngigi, 2003; Temesgen et al., 2007). This implies that erratic rainfall patterns has been the serious challenge of food production in these areas (Fischer et al. 2004), and this will be further worsened by climate change which is expected to increase rainfall variability in many African countries that are already at least partly semi-arid and arid (Ngigi, 2003).

The primary limiting factor for crop-yield stabilization in semi-arid regions is the amount of water available in the crop rooting zone (Lal, 2001). Rainfall intensity in Sub-Saharan Africa can often be greater than the infiltration rate and the water holding capacity of the soil, which can trigger an excess of runoff (Rockström, 2002). In Sub Saharan Africa where rainfall is low, unpredictable and also expected to decline due to climate change, rainwater storage in farm ponds, water pans, subsurface dams, and earth dams is gaining importance as a supplement to irrigation and livestock watering (Ngigi, 2009). It is also an effective strategy to manage floods *in-situ* and *ex-situ*, particularly in high rainfall areas like the Ethiopian highlands. Hence, rainwater harvesting (RWH) could be used to satisfy water demands during dry spells and to create opportunities for multiple uses. De Fraiture and Wichelns (2010) estimated that 78% of water consumed by crops comes directly from rainfall. It is believed that rainfall, if managed properly, is the remaining potential source for feeding the current huge population of the world as there are limitations to further increase of the area under irrigation (Rockström, 2003). This calls for increased attention towards rain fed agriculture or a green revolution (Rockström et al., 2009).

Subsistence rain-fed agriculture has been widely practiced for many centuries in Ethiopia and over 80% of the population's livelihood is contingent upon this sector which contributes ~45% to the national GDP, on average (Bewket, 2009). The Ethiopian agriculture is characterized by extreme dependence on rainfall, low use of modern agricultural inputs and low output levels. The sector is highly vulnerable to drought (Bewket, 2009), which is the single most important climate related natural hazard impacting the country from time to time for many decades. Ethiopia has significant rainfall and it is the ultimate source of water with surface water, ground water and other water sources. Based on grid-based average annual rainfall and the land area, the study estimates that Ethiopia receives about 980 billion (~1 trillion) $m^3$ of rainfall a year (Awulachew, 2010). While Ethiopia has abundant annual rainfall, the rainfall varies spatially, temporarily and inter-annually (yearly cycles). About 80 percent of rainfall occurs between June and September, while yearly variability can also be significant (e.g., about 30% average variation year over year). Consequently, increasing rainwater storage capacity and improving water control and rainwater management techniques, especially rain water harvesting, are critical to ensure that Ethiopia gets maximum use of its rainfall (Awulachew, 2010).

The term rain water harvesting (RWH) is used in different ways and, thus, no universal classification has been adopted (Ngigi, 2003). However, it can be defined as capturing and storing seasonal excess runoff and diverting it for household and agricultural uses (Hatibu and Mahoo, 1999). RWH refers to all technologies where rainwater is collected to make it available for agricultural production or domestic purposes (Liniger et al., 2006). Nigigi (2003) also defined rain water harvesting as a method for inducing, collecting, storing and conserving local surface runoff for agriculture in arid and semi-arid regions. It is considered as the single most important means to increase agricultural productivity and provide a source of domestic water supply in drought prone areas (Getaneh and Tsigae, 2013). This makes cultivation of crops twice or more a year possible, as well as the possibility for supplementary irrigation when rains stop early. Rain water harvesting includes roof water harvesting, *in-situ* water harvesting, run-off harvesting, flood water harvesting and subsurface water harvesting (Finkle and Sergerros, 1995).

The sustainability of RWH is based on reliable water supply and production, effectiveness of water use (increase rainwater productivity) and minimal negative impacts on natural resources (Pachpute et al., 2009). RWH systems are generally categorized into two; *in-situ* water conservation practices, small basins, pits, bunds/ridges; and runoff-based systems (catchment and/or storage) (Awlachew et al., 2005) (Figure 1). The storage system is usually used in supplemental irrigation. The *in-situ* systems, which enhance soil infiltration and water holding capacity, have dominated over storage schemes in Ethiopia until recently. Surface runoff from small catchments and roadside ditches is collected and stored in farm ponds holding an average of about $60m^3$ of water. *In-situ* rainwater harvesting techniques (IRWHT) that aims at maximizing benefits of rainfall where it falls are tremendously used and produce good results, especially in semi arid zones (Li et al., 2000; Tian et al., 2003; Li et al., 2006; Ito et al., 2007; Oloro et al., 2007; Rockström et al., 2009 and Vohland and Barry, 2009). Ngigi (2003) attributed the dominant use of IRWHT to its simplicity, low cost and can be practiced in all land use systems.

Improved rainwater management for agriculture has many potential benefits in efforts to reduce vulnerability and improve productivity (Awulachew et al., 2005). As a result of RWH and irrigation development, Ethiopia's agricultural sector has witnessed consistent growth since 2003. For instance maize production has expanded at 6% per annum and the aggregate export value across all commodities has grown at 9% per annum as well as underpinning an 8% annual growth rate in GDP

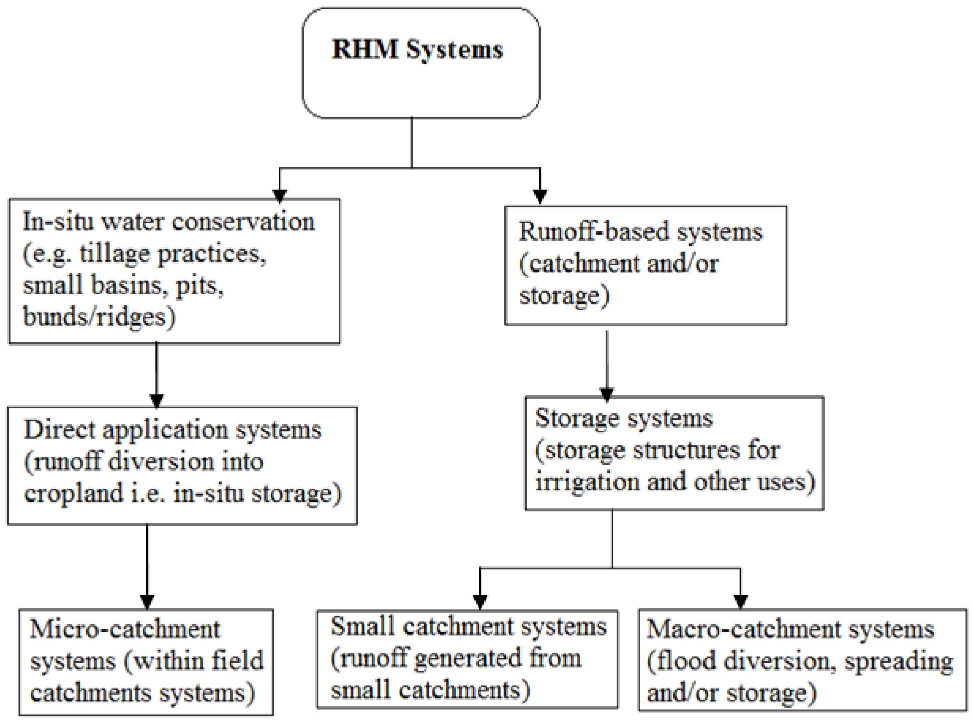


**Figure 1.** Adopted classification of RWH systems (Ngigi, 2003).

(Awulachew, 2010). In terms of increasing irrigation potential incrementally to the formal irrigation component, through RWH and better water management, the study estimates that RWH can provide an additional 0.5 M ha in irrigation. Thus, *in-situ* agricultural water management including RWH is crucial to improve smallholder livelihood and income in Ethiopia.

Frequent dry spells and droughts exacerbate the incidence of crop failure and hence food insecurity and poverty (Awlachew et al., 2005). The need to improve food production in Ethiopia cannot be overemphasized. In addressing the problems of rainfall variability, the recurrent droughts and food insecurity, the government of Ethiopia has given top priority to a variety of water harvesting programmes to supplement the rain-fed agriculture. Therefore, rainwater harvesting has been recognized as a promising way for improving the water availability for crop production, domestic use and water for livestock in the arid and semi-arid parts of the country. This paper therefore, reviews the present status of RWH researches in the light of an option for dry land agriculture in the arid and semi-arid Ethiopia.

## RAINWATER HARVESTING TRENDS IN ETHIOPIA

Over centuries, generations of farming communities in Ethiopia have developed different farming technologies that can provide a basis on which to build improved land husbandry (Alamerew et al., 2002). The history of water harvesting in Ethiopia dated back as early as the pre Axumit period (560 BC) (Habtamu, 1999). It was a time when rainwater was harvested and stored in ponds for agricultural and water supply purposes. Anthropologist Fattovich (1990) have documented evidences of the remains of ponds that were once used for irrigation during this period. A roof water harvesting set-up is still visible in the remains of one of the oldest palaces in Axum; the palace of the legendary Queen of Sheba. Other evidences include the remains of one of the old castles in Gondar, constructed in the 15-16th century, which used to have a water harvesting set up and a pool that was used for religious rituals by the kings.

In south of the country, the Konso people have had a long and well established tradition of building level terraces to harvest rainwater to produce sorghum successfully under extremely harsh environment; low, erratic and unreliable rainfall conditions (Hailemichael, 2011). It is indeed one of the wonders of this country and it has been practiced for millennium; a symbol of struggle for survival by the Konso people against the adversaries of nature (Figure 2). Hailemichael (2011) shows, everyone in the farming system acquires the skill of terrace construction as part of routine farming practices. Thus, rainfall is simply redirected through carefully constructed walls and channels. Researchers noted that this is a country where indigenous knowledge and practices are acknowledged to the extent that the ‘Konso


**Figure 2.** Indigenous hillside stone terracing and mixed cropping *in-situ* soil and water conservation practices at Konso southern Ethiopia (A) (Hailemicael, 2011) and Half-moon ponds, promoted for water resources conservation in Tigray, northern Ethiopia (B) (Mekonnen and Haile, 2010).

cultural landscape' has been recognized as a UNESCO World Heritage Site (Alamerew et al., 2002.). Efforts over the last decades to promote water harvesting have produced some bright spots particularly with micro-watershed interventions, which include water harvesting as part of an integrated participatory approach to sustainable land management. In addition to that, there are different half-moon ponds, promoted for water resources conservation in Tigray, northern Ethiopia (Figure 2B) (Mekonnen and Haile, 2010)

Ethiopia's agriculture is predominantly rainfed with a potential of nearly 3.5 million ha of land suitable for irrigated agriculture (Awulachew et al., 2005; Awulachew and Merrey, 2007). The population has grown dramatically over the last three decades, increasing from 25 million in the 1960s to nearly 90 million in 2014 leaving a pressure on the agricultural land, forests and the environment at large. Thus, rainwater harvesting and management (RHM) play paramount roles for increasing gain yields and support the growing population (Awulachew, 2010). The RWH techniques most commonly practiced in Ethiopia today are runoff irrigation (run-off farming), flood spreading (spate irrigation), *in-situ* water harvesting (ridges, micro basins, conservation tillage, etc.) and roof water harvesting.

The importance of these techniques, though dates back in the antiquity, has not been recognized until very recently, following the devastating drought and famine of the 1980s (Alem, 1999). RWH is a simple low-cost technique that requires minimum specific expertise or knowledge and offers many benefits. It has regained importance as a valuable alternative or supplementary water resource in Ethiopia (Desta, 2003). Utilisation of rainwater is now an option along with more 'conventional' water supply technologies, particularly in rural areas, but increasingly in urban areas as well. RWH has proven to be of great value for arid and semi-arid countries or regions like Ethiopia where more than 66% of the country is categorized as arid and semi-arid (Georgis, 2000; 2002; Rockström, 2000; Rockström, 2001).

The development of irrigation and agricultural water management holds significant potential to improve productivity and reduce vulnerability to climactic volatility in any country (Awulachew, 2010). Although Ethiopia has abundant rainfall and water resources, its agricultural system does not yet fully benefit from the technologies of water management and irrigation (Georgis, 2000; 2002). The majority of rural dwellers in Ethiopia are among the poorest in the country, with limited access to agricultural technology, limited possibilities to diversify agricultural production given underdeveloped rural infrastructure and little or no access to agricultural markets and technological innovations (Awulachew, 2010). A field experiment was conducted under natural rainfall conditions to investigate the effects of farmyard manure and straw mulch on runoff, soil loss, *in-situ* water conservation and yield and yield components of an improved bread wheat variety (HAR-1480) grown on vertisol of Sinana area, south- eastern Ethiopian highland. The results revealed that there was a highly significant difference (P<0.0001) between the treatments regarding their effect on runoff depth, soil loss and *in-situ* water conservation (Birru et al., 2012).

## TYPES OF RAINWATER HARVESTING

### *In-situ* rainwater harvesting

*In-situ* RWH, a technique which involves the use of methods that increase the amount of water stored in the soil profile by trapping or holding the rain where it falls (Alamerew et al., 2002; Ngigi, 2003). This may involve small movements of rainwater as surface runoff in order to concentrate the water where it is most wanted. It is sometimes called water conservation and is basically a prevention of net runoff from a given cropped area by holding rainwater and prolonging the time for infiltration. This system works better where the soil water holding capacity is large enough and the rainfall is equal or more than the crop water requirement, but moisture amount in the soil is restricted by the amount of infiltration and or deep percolation (Hatibu and Mahoo, 1999). *In-situ* water harvesting methods that concentrate soil water in the rhizosphere for more efficient use by plants are critically needed for moisture stress areas. It means rainwater is conserved where it falls, whereas *ex-situ* water harvesting systems involve transfer of runoff water from a “catchment” to the desired area or storage structure (Critchley and Siegert, 1991). Land and water conservation interventions on sloping lands include bench/fanya juu terraces, retention ditches, stone lines, vegetative buffer strips, contour bunds, contour farming and other activities that reduce loss of runoff water. They are primarily used to reduce soil erosion and to improve rainfall infiltration and conservation in the soil profile (Bossio et al., 2007).

*In-situ* rainwater conservation technologies are distinct from runoff farming systems in that they do not include a runoff generation area; instead it aims at conserving the rain where it falls in the cropped area or pasture (Alem, 1999). The most commonly implemented technology is conservation tillage which aims to maximize the amount of soil moisture within the root zone. A number of cultural moisture conservation practices such as mulching, ridging, addition of manure, etc could fall under this category. Small field/farm structures such as tied ridges/bunds within cropped area that conserve direct rainfall without ‘external’ outside cropland boundary, that is, no distinct catchment area, except overflow from upstream sections also falls under this category. *In-situ* rainwater conservation technology is one of the simplest and cheapest and can be practiced in almost all the land use systems. *In-situ* water conservation systems are by far the most common (Rockström, 2000) and are based on indigenous/traditional systems (Reij et al., 1996; Leisa, 1998). The primary objective has been to control soil erosion and hence, manage the negative side effects of runoff soil and water conservation measures, that is, to ensure minimal runoff is generated. The positive effect of *in-situ* water conservation techniques is to concentrate within-field rainfall to the cropped area (Rockström, 2002).

In a semi-arid context, especially with coarse-textured soil with high hydraulic conductivity, this means that *in-situ* conservation may offer little or no protection against the poor rainfall distribution (Rockström, 2000). In such cases, the farmers will continue to live at the mercy of the rain. In effect, the risk of crop failure is only slightly lower than that without any measures. However, soil improvements and management would enhance realization of better yields.

Agronomic practices such as the use of farm yard manure (FYM), timely weeding and mulching are used to enhance water availability in the soil by improving the water holding capacity and reducing soil water evaporation. Mulch and manure treatments had a highly significant effect ($P<0.0001$) on *in-situ* rainwater retention (Birru et al., 2012). The results demonstrated that *in-situ* soil moisture conservation increased significantly for 6 ton $ha^{-1}$ mulch as compared to the control treatment. Soil moisture storage in the 6 ton $ha^{-1}$ mulch treatment was 216.11 mm, which was 39.15 mm higher in comparison to the control. However, the mean soil moisture storage for 4 ton $ha^{-1}$ straw mulch (STR) was 215.40 mm, which was statistically at par in comparison to that retained at 6 ton $ha^{-1}$ straw mulch treatment.

The average rainwater depth retained for 6 ton $ha^{-1}$ farmyard manure application (181.81 mm) was significantly higher than that retained under control treatment (176.96 mm). The results further indicated that soil moisture storage was increased by 22.1, 21.7, 19.0, 2.7, 0.74 and 2.53% for STR-6, STR-4, STR-2, FYM-6, FYM-4 and FYM-2, respectively, as compared to the control (Birru et al., 2012). From these results one can understand that leaving crop residues could have the potential to conserve much of the incoming rainfall and contribute towards sustainable crop production by alleviating the impacts of drought spells which frequently occur in the growing season. The main limitation of this technique is its high labour demand, especially on steep slopes where proper structural measures are required. Some amount of training and site-specific design/layout is also needed. In one example from the Anjenie watershed of Ethiopia (Akalu and Adgo, 2010), long-term terracing increased yields of teff, barley and maize significantly. In contrast, cultivation on steep un-terraced hillsides had negative gross margins.

Similarly, Vancampenhout et al. (2005) obtained positive yield results and increased soil water holding capacity using stone bunding on field crops in the Ethiopian highlands. Rockstrom (2003) reported that in-situ RWH had a significant effect on grain yield and by using this system in Burkina Faso they were able to increase the yield of sorghum from 715 kg $ha^{-1}$ to 1,057 kg $ha^{-1}$. Micro-basin water harvesting structures (e.g., half-moons, eyebrow basins and trenches) have also been proven to be effective in improving tree survival and growth in degraded lands. Experiences from northern Ethiopia have shown that these structures improved tree survival and growth significantly compared to non-treated landscapes (Derib et al., 2009). The seedlings grown in micro-basins were thicker, taller and more productive than those grown in normal pits, suggesting a need to integrate tree planting with soil water management.

Tillage normally assists in increasing the soil moisture holding capacity through increased porosity, increasing the infiltration rates and reducing the surface runoff by providing surface micro-relief or roughness which helps in temporary storage of rain water. Previous research results have shown that the depth of tillage is the most important factor controlling or affecting soil moisture characteristics (Hudson, 1987). Deep tillage helps to increase porosity, reduce surface sealing of the soil and permits roots proliferation to exploit soil water and nutrients at deep horizons (Kidane et al., 2012). Significant reduction of surface runoff and increase in crop yields have been shown to occur with increased depth of tillage.

Temesgen et al. (2012) conducted an experiment on the impact of conservation tillage on hydrology and agronomy on famer's fields from the year 2009-2010. The soil moisture measurements had been taken continuously at the lower and upper sides of each plot, for a period of one month only (due to vandalism). Although the measurement period is short, the sampled results clearly revealed that soil moisture in traditional tillage (TT) (average 34.6%vol.) is significantly higher ($\alpha = 0.05$) than that of conservation tillage (CT) (average 31%vol.) at 0-15 cm depth while the reverse holds true at 15-30 cm layer (33.5 and 31.6%vol.), in CT and TT, respectively. Similar studies have been conducted in an on-farm experiment in the northwestern highlands of Ethiopia (Kidane et al., 2012). There were significant differences ($P < 0.0001$) in soil moisture content between tillage treatments as well as in the upper and lower sides of the plots. Significantly, ($P \leq 0.05$) different soil moisture contents between the upper and lower sides of the *fanya juus* were observed under traditional tillage practice 0.305±0.003 and 0.323±0.003 $m^3$, respectively.

Temesgen et al. (2007) observed field trial on conservation tillage compared with traditional tillage in a moisture deficit area in Ethiopia. Sub-soiling along the same lines (STS) resulted in the least surface runoff (Qs =17 mm-season$^{-1}$), the highest transpiration (T =196 mm-season$^{-1}$) and the highest water productivity using total evaporation ($W_{PET}$=0.67 kg-m$^{-3}$) while TT resulted in highest surface runoff (Qs=40 mm-season$^{-1}$), least transpiration (T =158 mm-season$^{-1}$) and low water productivity ($W_{PET}$=0.58 kg-m$^{-3}$), respectively. Araya et al. (2011) reported runoff values of 46.3, 76.3 and 98.1 mm from *derdero* (DER), *terwah* (TER) and conventional tillage, respectively. There were significant differences ($P < 0.0001$) in infiltration rates in the soils between winged subsoiler (WS) and traditional tillage (TT) treated plots (Kidane et al., 2012). The initial and steady state infiltration rates under WS plots were 0.84±0.005 and 0.1±0 cm m$^{-1}$, respectively.

On the other hand, 0.54±0.006 and 0.05±0.004 cm m$^{-1}$ at 01 and 60 m were observed under the TT treated plots. The infiltration rate in the WS treated plots was twice higher than the TT tilled plots and this implies that implementation of conservation tillage is more important for *in-situ* moisture conservation. Temesgen et al. (2012) evaluated the hydrological and grain yield impact of conservation tillage on field experiment and they identified that more surface runoff occurred for traditional tillage compared to conservation tillage, and that the differences between the two was more in the wheat plot than in *tef*. The average reduction of surface runoff was 48% in the wheat plot due to the application of CT, with the daily averages of 4.8 and 2.5 mm d$^{-1}$ in TT and CT, respectively. In *tef* crop, the surface runoff reduction was 15% with an average of 4.5 and 3.8 mm d$^{-1}$ in TT and CT, respectively.

## ***Ex-situ* water harvesting**

### Water harvesting ponds

The occurrence of repeated drought and dependence on rainfall which has been erratic and uneven in Ethiopia over the past decades has resulted in a widespread crop failure which in turn has brought a growing awareness of the importance of small-scale water harvesting at both household and community levels (Haile, 2007). In order to alleviate the problem of recurrent drought and household food security, the government of Ethiopia has taken household level water harvesting ponds and shallow wells development as one strategy of the country's irrigation development (Haile, 2007). In Ethiopia, particularly in moisture deficit areas, irrigation development is considered. Therefore an absolute necessity and not an option has been adopted as the frontline strategy to bring about sustained food security due to its profound role in boosting agricultural productivity in highly rain dependent agricultural farming systems.

Moreover, since 2002, household level water harvesting irrigation development has attracted the attention of the policy makers due to the small initial investment, low government recurring cost, short development period, relative freedom of organization and freedom from management difficulties (Alem, 1999: Mekonnen and Haile, 2010). In an effort to address the problems of recurrent droughts and food insecurity, the government of Ethiopia has given top priority to a variety of water harvesting programs to supplement rain fed agriculture of which water harvesting ponds have been widely implemented (Alem, 1999).

Although advanced water harvesting systems has been introduced to Ethiopia, traditional ponds have been widely used for many centuries; some estimates it as early as 560 BC (Fattovich, 1990). Its inhabitants are used to harvesting rainwater for both human and livestock watering in most rural areas, particularly in the arid and semi-arid regions where annual rainfall is less than 600 mm (Alem, 1999). Ponds are simple to construct and can be managed by the community. Approximately 15 to 20 % of the people and over 80% of


**Figure 3.** Water harvesting ponds using Geomemmbrane and micro basins in Ethio-Somali Region (A) and Amhara region (B-D) Ethiopia, respectively (www.gcca.eu/2014).

the livestock in Ethiopia uses water from either rivers/streams and ponds (Alem, 1999). Currently, the Ethiopian government promotes the use of water harvesting technologies such as geomambrane in different parts of the country especially in the semi-arid and arid regions (Figure 3). However, the adoption and its successfulness have been disappointing due to lack of awareness of development agencies and farmers.

The distribution of these ponds generally, is in the arid and semi-arid areas where the Sahelian climatic condition prevails. Traditional ponds are the major sources of water in the Ethiopian rift valley where ground water is deep and other sources of water are not feasible. These days, the use and promotion of ponds even for livestock watering is increasingly becoming difficult and challenging by the spread of deadly child-hood malaria, and for this reason most NGOs are unable to promote and support pond construction due to environmental constraints (Mekonnen and Haile, 2010).

### Roof water harvesting

Roof water harvesting is a system of collecting rainfall water from the roof of a building and storing it in some storage facilities for future use when there is shortage of water (Haile and Merga, 2002). Large scale and modern water supply schemes in rural Ethiopia remains a challenge owing to the unique and rugged terrain and the scattered settlement pattern of the rural people. One technique that appeals today that can be of significant importance in the development of the subsector is roof water harvesting at household level. This technique is so important in the rural highland areas where the terrain is rugged and the villages and hamlets are scattered. In such areas, it is difficult to think that communities can be served by centralized water supply schemes, at least it is expensive. Other sources require long walk and time for women and children to fetch water (Alem, 1999).

The roof water harvesting in Ethiopia has the advantage of being low cost, relatively simple in design (household technology), less laborious and time saving (Alem, 1999). It provides adequate water during the rainy season, a period when the rural people are busy with the farm activities and when there is shortage of labor. They are more appropriate in areas where there are no rivers, ground water sources and where rainwater is the only feasible means of water supply. The emergence of this technique these days is due to the increasing shortage of water from the conventional sources, shallow wells, perennial springs, rivers/streams. In earlier times, roof water harvesting practices were confined to urban areas only. However, its use in the rural areas are increasingly becoming important these days as more people in the rural areas are having corrugated roof houses.

## EFFECTS OF RAINWATER HARVESTING

### Soil moisture

Globally, the total volumes of water stored within the soil are huge, but at any given locality they are relatively small and quickly depleted through evapotranspiration. Because of this, in recent decades there has been increased interest in various *in-situ* rainwater management techniques that enhance infiltration and water retention in the soil profile (World Bank, 2006). It is important to note that RWH can be used to rehabilitate degraded land and retain moisture (FAO, 2001). Water harvesting retains moisture in-situ, through structures that reduce runoff from fields and hold water long enough to allow infiltration (Rockström, 2002). Improved in-field water harvesting can increase the time required for crop moisture stress to set in and thus can result in improved crop yields and have resulted in positive effects on soil fertility, moisture conservation and agricultural productivity (Alemu and Kidane, 2014, Kidane, 2014, Kidane et al., 2012).

These are techniques for improving the soil moisture by enhancing infiltration and reducing runoff and evaporation (Ngigi et al., 2005; SEI, 2009). An important potential of in -situ water harvesting is to limit nutrient leakage from the fields by controlling soil erosion (Herweg and Ludi, 1999; Gebremichael et al., 2005; McHugh et al., 2007; Gebreegziabher et al., 2009). Water can be stored in artificial constructions (e.g. water tanks, drums, jars, jerry cans, cisterns), in surface reservoirs (ponds, dug-outs, artificial reservoirs) and in the sub-surface as soil moisture or groundwater. Soil moisture conservation (recharge of shallow aquifers) is the key to high productivity (Herweg and Ludi, 1999). Hence, RWH is efficient in increasing the soil moisture for crops in water scarce areas (Ngigi, 2003). In addition, in the dry lands of the Tigray Regional State in northern Ethiopia, the regional government and the general population have been making efforts to control the degradation of natural resources since 1991. As a result, many soil and water conservation measures have been initiated, particularly for soil erosion control, including the construction of stone bunds to conserve *in-situ* soil moisture (Alemu and Kidane, 2014).

## Surface runoff

During rainy season, rainwater is collected in large storage tanks which also help in reducing floods in some low lying areas. Apart from this, it also helps in reducing soil erosion and contamination of surface water with pesticides and fertilizers from rainwater run-off which results in cleaner lakes and ponds (Rockström, 2002). The main characteristic of flood water harvesting is a turbulent channel of water flow harvested either by diversion or spreading within a channel bed/valley floor where the runoff is stored in soil profile (Critchley and Siegert, 1991). Harvesting runoff water for supplemental irrigation is a risk-averting strategy, pre-empting situations where crops have to depend on rainfall whose variability is high both in distribution and amounts. By using underground spherical tanks in cascades and having a combined capacity of 60 $m^3$, seasonal water for supplemental irrigation for an area of about 400 $m^2$ is guaranteed (Mtisi and Nicol, 2013). Indirect benefits of RWH in terms of reduced incidence of downstream flood damage had been noted (Johnson et al., 2001; Gleick, 2002).

Run-off harvesting from a catchment using channels or diversion systems and storing it in a surface reservoir-water pans/ponds (Rockstrom, 2000) has shown that, the yields and reliability of agricultural production can be significantly improved with water harvesting. In this system, surface runoff from small catchments or adjacent road runoff is collected and stored in manually and/or mechanically dug farm ponds. Although, this technique requires relatively high investment costs compared to *in-situ* systems. Evaluation of RWH in a surface reservoir in the four Great Horn of African (GHA) countries (Ethiopia, Kenya, Tanzania and Uganda) revealed that, it was slowly being adopted with high degree of success (Kiggundu, 2002). In northern Shewa of Ethiopia, runoff from farm lands is stored down streams in large pits for later use, for irrigating plants using watering cans (Alem, 1999).

## Ground water recharge

Methods for increasing groundwater recharge include pumping surface water directly into an aquifer and/or enhancing infiltration by spreading water in infiltration basins (World Bank, 2006). There are two main techniques of rain water harvesting namely storage of runoff on surface for future use and recharge to groundwater and shallow aquifer (MacDonald and Davies, 2000). Water harvesting can also have a positive impact on soil conservation, erosion prevention, groundwater replenishment and the restoration of ecosystems. Options for increasing groundwater recharge include constructing small dams or bunds, terracing, contour trenching, sub-surface dams and planting trees or planting vetiver grass (Gebremichael et al., 2005).

Soil storage has more advantage as it does not require lifting and water application to the root of each plant. It also contributes to the recharge of the ground water (Oweis et al., 2001; William et al., 1992). By deep ponding, moisture deficit for crops such as cereal grains, which are more needed by the farmers for their food security, is tackled. Soil storage has more traditional base and lower cost so that its adoption rate can be faster compared to deep ponding. Therefore, more emphasis needs to be given in the future (Desta, 2005). The same trend was also observed for available soil water for rain-fed crops. Water availability from rehabilitated gullies using check dams was the main source of surface irrigation water, which was supplemented by shallow and deep ground water wells. Groundwater levels in the wells increased up to 2.5 m, while the irrigated areas are increased and the number of hand-dug wells also significantly increased. Newly emerging springs and irrigated fields as well as increasing crop diversity and yields were some of the indicators of the improved water resources and supply (Mekonen and Brhane, 2011).

## Yield increment

One of the reasons for low crop production in semi-arid areas is marginal and erratic rainfall exacerbated by high runoff and evapotranspiration losses. The in-field RWH techniques has been shown to improve the yield of maize and sun flower on some benchmark ecotypes in South Africa (Henslley et al., 2000). RWH can be used to re-establish vegetation cover to improve crop growth in order to alleviate poverty and enhance food security. Successful interventions in rain-fed


**Figure 4.** RWH pond picture to prove the point that RWH facility can promote yields (Lemma, 2005 (B); Woldearegay, 2012 (A)).

agriculture in Somali Region Ethiopia have transformed the livelihoods of many poor farmers (FAO, 2001). Improved RWH may result in improved crop yields, food security and livelihood among households (Rockström, 2002). Supplementary irrigation increased crop yields by 20%. With RWH, farmers have diversified to include horticultural cash crops and the keeping of dairy animals. For instance US$ 735 (per ha) compared to US$ 146 normally is now earned from rain-fed maize (Mtisi and Nicol, 2013). This has contributed to food security, better nutrition and family income.

Most of the future growth in crop production in developing countries is likely to come from intensification, with irrigation playing an increasingly strategic role (Postel, 2003; IAASTD, 2009; FAO, 2011). Access to irrigation water is critical to raising and stabilizing crop production (Postel, 2003). Irrigation has direct benefits in terms of production and income. However, there have also been associated impacts whose costs may at times outweigh the benefits of production (Johnson et al., 2001; Gleick, 2002). One of the promising breakthroughs for upgrading rain-fed agriculture in the semi-arid lands remains on how efficiently small scale farmers can utilize practices such as RWH. It is viable in areas with annual rainfall as low as 300 mm (Ngigi, 2003). Besides increased yields, Ngigi et al. (2005) reports that RHM is also aimed at stabilizing variations in crop yields and ensuring food security. Lemma (2005) noted that the survival rate of trees in the irrigated areas of home gardens (84%) had shown a better result when compared to home gardens without pond. This implied that the availability of supplementary irrigation in the backyard has significant contribution on the survival of trees (fruit trees) in the home garden. For instance, about 75% additional yield could be obtained for green pepper and onion crops as compared to tomato crop, which had up to 83% yield increment obtained by using the effective water application method (Lemma, 2005) (Figure 4).

According to the study by Rämi (2003) in Tigray region, Wukro district boasts 30 ponds, mainly clay and plastic-lined serving a total of 80 households. Small gardens with peppers, tomatoes, maize and root crops, which were planted during the rainy season and freshly planted fruit and coffee trees were found around most of the ponds. In the Amhara region (north-western part of the country) from the total completed water harvesting structures, reaching 242,000 in number, over 42,000 have started production, as a result 21,194 ha of land is under irrigation and 148, 244 farm households are benefiting. Of this 14%, 21,194 are women headed households. Irrigated area in the region is primarily aggregated from shallow well, river diversion and spring development (Desta, 2005). In addition to that, according to the participatory rural appraisal (PRA) findings, sorghum yield in Kobo District, Northern Ethiopia doubled with availability of flood water. Similarly, pepper yields increase by up to 400% with application of floodwater (Alamerew et al., 2002).

In Oromia region (central, eastern and western part of the country) the total irrigated land is 65,508 ha, when the plan was 68,565 ha (95.5% achievement). By this 343,953 (92%) households have become beneficiaries. Again 379 ha traditional irrigation through river diversion is under establishment on top of 31,311 ha that already exists. Of the total planned 216,290 ponds, 75% is in food insecure districts and the remaining 25% is in non-food insecure districts. The stored water apart from drinking and crop production, have been used for selling, making mud for house construction, making soil blocks and raising seedlings at the nursery (Desta, 2005). RWH has the potential to increase the productivity of cropland by increasing the yields and by reducing the risk of crop failure (Tesfay, 2011). Alemie et al. (2005) also reported 20,000, 10,000 and 12,000 kg/ha yield of tomato, pepper and onion respectively, due to efficient use of RWH technologies in Wukro and Mehoni Destricts, northern Ethiopia. The farmers managed RWH structures to increase the farm household's agricultural yield by improving the availability of water during the dry spell periods (Amha, 2006).

## CHALLENGES AND OPPORTUNITIES OF RAINWATER HARVESTING

The main challenges of adopting RWH technologies are that much of the harvested water is lost through seepage and thus it is not sufficient and it is very labor intensive to irrigate the whole fields by pumping the water manually from ponds and applying directly to the crops (Moges, 2009). The other challenge is to find ways of selecting and promoting appropriate RWH interventions that are well matched to the site-specific, biophysical and socio-economic circumstances (Gowing et al., 2003). The use of on-farm storage reservoirs faces evaporation and seepage losses and silting (Thome, 2005). It is important to minimize the adverse effects of these problems in the design of a surface-water storage facility. Silting may be minimized by arresting the silt and sand on the catchment area itself, mainly through controlling catchment erosion but also by installing silt-traps (Thome, 2005).

Rainfall distribution is another natural challenge of RHM systems. During extreme drought years, very little can be done to bridge a dry spell occurring during the vegetative crop growth stage, if no runoff producing events occur during early growth stages (Rockström, 2000). Despite significant efforts by the Government of Ethiopia and other stakeholders, improving agricultural water management from RWH is hampered by constraints in policies, institutions, technologies, capacity, infrastructure, and markets. Addressing these constraints is vital to achieve sustainable growth and accelerated development of the sector in Ethiopia (Awulachew, 2010). The challenge for agriculture in Sub-Saharan Africa is the variability in rainfall, characterized by high intensity storms, and high frequency of dry spells and droughts. RWH systems can turn these inherent challenges into opportunities.

Where there is no surface water, or where groundwater is inaccessible due to hard ground conditions, or where it is being over exploited, recharge alternatives should be implemented. In a very simplified sense, if a society is threatened or subjected to water scarcity it should respond by attempting to get and store more water using simple, inexpensive and traditional concepts of rain water harvesting technologies (Mupenzi et al., 2011). RWH systems operate on different scales (plot, field and catchment) to modify the water balance in order to increase the rainfall use efficiency (Gowing et al., 2003). RWH is one option to irrigate and produce high value crops to reduce poverty and food insecurity. The assumption is that producing high value crops enables farmers to get returns from selling the product and thus increasing their ability of generating income. For example, in Aleaku Gubantaboke Kebele (Bulbula District) some farmers ability of generating

income. For example, in Aleaku Gubantaboke Kebele (Bulbula District) some farmers have clearly confirmed the importance of RWH as best option for pepper (seedling) production. Realizing the importance of pepper in terms of cash returns, some farmers have already shifted from maize, teff and wheat to pepper and they reported a net return of US$502.26 per quarter hectare (Moges, 2009).

The Ethiopian highland has a large potential for RWH implementation on open woodland land use types to improve the water availability for livestock which has a nexus effect on water productivity. Other benefits of rain-water harvesting are that it makes water available at the point of consumption and reduces the need to pump or haul it over long distances thus saves time and human labour. The experience of RWH activities indicates that they could be used as catalysts for development in a bid to alleviating poverty and promoting socio-economic well-being of the rural people (Mbugua and Nissen-Petersen, 1995).

## CONCLUSION AND RECOMMENDATION

RWH has been implemented in many parts of Ethiopia since the time of Aksumite Civilization (560 BC) to the present. However, the adoption of the technology had been disappointing due to many challenges. The sustainability of RWH techniques largely depends on the livelihood improvements of farmers, especially those who practice traditional rain fed agriculture. The adopted RWH techniques had enhanced soil moisture, recharge ground water, reduced runoff and increased yield which in turn preserve the ecosystem.

The benefits of RWH technologies extend beyond rain fed farming to the whole ecological system. Therefore, external catchment based RWH had eminent potential of mitigating rainfall-related crop production risks in the arid and semi-arid regions in Ethiopia. Site specific well-managed RHM therefore, as well as irrigation application are keys in helping Ethiopia overcome major challenges including population pressure; food insecurity; soil and land degradation; high climate variability and low agricultural productivity.

## Conflict of Interest

The authors have not declared any conflict of interest.

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