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Socio-economic Potential of Rainwater Harvesting in Ethiopia

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Abstract

Clean water scarcity becomes a critical issue in many parts of Ethiopia due to the high population growth, water pollution and climate change. The high annual rainfall rates make rainwater harvesting one of the best options to mitigate water scarcity. This study was conducted to analyze the economic feasibility of water harvesting for individual houses in Dessie-town. The results show that the harvested water from a 60 m^2 roof can cover all non-potable water needs or can cultivate a small garden, 50 m^2, with some needed crops. Cultivating tomatoes and onions can increase the annual household's income by 5 %.

Keywords: water scarcity, population, non-potable water, income

1. Introduction

1.1 Problem Statement

Water is a very crucial element but finite and considered a limited natural resource. Ethiopia has suffered from the lack of clean and drinking water supply. Climate variability has a big influence effect on crop production in Ethiopia (Alemayehu & Bewket, 2016). However, Ethiopia's geographic location has provided it with a relatively high rainfall rates, which make rainwater as an additional water resources supply in Ethiopia (Feki et al., 2014). In some cities and according to water supply and sewerage enterprise, the water distribution systems supply drinking water by 20 litter per capita a day for four days (Feki et al., 2014). Due to the high pollution rates in most surface water in Ethiopia, surface water is not considered a safe or an economic water supply resource. Therefore water supply systems depend on ground water (Ali, 2012). The high rainfall amounts makes rainwater as a potential resource in Ethiopia, which increases the need for private and onsite water supply management initiatives. Ethiopia also facing a high adoption rate of water harvesting technologies around 42% (Wakeyo & Gardebroek, 2015). Moreover, there is a limited number of studies that evaluate the relation between rainwater harvesting and crops yield (Bouna, Hegde, & Lasage, 2016). Hence, good rainwater harvesting and management technologies are needed to improve rainwater-use efficiency and sustain rainfed agriculture in sub-Saharan Africa (Biazin, Sterk, Temesgen, Abdulkedir, & Stroosnijder, 2012).

1.2 Literature

The history of water harvesting in Ethiopia dated back to 560 BC when rainwater was harvested and stored in ponds for agricultural and water supply purposes (Getachew, 1990). However, Alison, Peter, Nick, Richard and James (2013) found that in rural areas, rainwater harvesting had a higher cost per household than other water supply solutions such as protected springs and boreholes with hand pumps (Alison et al., 2013). Feki et al. (2014) studied the potential of rainwater harvesting in multi-storey buildings in southern Ethiopia, by which they found that such systems can cover about 19.5 % of water demands and 84% of flushing water demand. Moreover, rainwater harvesting can contribute to sustainable agriculture, decrease the costs of supplementary irrigation and increase yields of crops in most semiarid lands Worldwide (Motsi, Chuma, & Mukamuri, 2004; He, Cao, & Li, 2007; Mourad & Berndtsson, 2011; Adham, Riksen, Quessar, & Ritsema, 2016). Rainwater harvesting is considered a good option for sustainable agriculture in terms of risk reduction and yield improvement (Kasso & Bekele, 2016; Dile, Karlberg, Temesgen, & Rockström, 2013). Teshome, Adgo, and Mati (2010) studied the socio-economic impacts of water harvesting pond on household income and rural livelihoods in Minjar Shenkora district of Ethiiopia. They found that planting onion made about 2000 US$/year contribution to the farmer's income. Selecting suitable water harvesting sites is considered a difficult issue (Adham et al., 2016). However, the selecting criteria takes slope, land use, soil type, rainfall and costs into account (Adham et al., 2016).

1.3 Study Area and Objective

In order to highlight the need for rainwater harvesting, this paper takes Dessie-Town as a case study. Dessie-Town is one of the top populated cities in Ethiopia (Figure 1). It is located in the north-central part of Ethiopia with a total population about 188000 and an annual rainfall about 1145mm (CSAE, 2015). Therefore, the main objective of this paper is to study the socioeconomic benefits of roof rainwater harvesting in Dessie-Town as a potential safe water resource that can cover some household's water needs and contributes in increasing household's income. According to their water consumptions, households can choose between using the harvested water for non-potable uses or for irrigation.

Figure 1. Ethiopia, Dessie-Town

The paper also aims at highlighting rainwater potential in Ethiopia in order to raise stakeholders' awareness regarding water challenges and opportunities in Ethiopia.

2. Method

2.1 Rainwater Harvesting

Most of the needed data was taken from Dessie town municipality, Central Statistical Agency of Ethiopia and published articles. According to the Dessie town municipality, Dessie town has about 17425 households and the average family members is 4. Most individual houses use tin sheets as roofs with an average area about 60 m^2. Each house has on average 50 m^2 garden, which is used for covering some household's vegetables need.

According to the rainfall amounts and roofs average areas, we can estimate the rainfall that can be harvested using the following equation (Alison et al., 2013):

$$S = R*A*Cr \tag{1}$$

Where:

S= Harvested water from roof (m^3)

R= mean annual rainfall (m)

A= roof area (m^2)

Cr= runoff coefficient

The harvested water will be collected and stored in a storage tank. The cost required for the storage tank is reviewed from literature for domestic rainwater harvesting in east Africa according to the tank's material and size.

In this paper, we compare three collecting systems: Individual, collective, and public systems. Each of which has its own requirements, costs and benefits.

2.2 Cultivated Crops

The collected water will then be used to cultivate vegetables such as green maize, rape, potatoes, onions, tomatoes, and cabbages in two seasons. Table 1 presents the growing periods and crop's water requirements (CWRs) for these crops in Eastern and Southern Africa using CROPWAT 7 (Savva & Frenken, 2002).

Table 1. CWRs and growing periods of some vegetables in Ethiopia

Crops	Growing period	Crop's water requirements (mm)	
		Net irrigation (mm)	Total water need
Tomato	1/11 – 16/3	419	759
Onion	1/5 – 28/9	457	486
Cabbage	1/12 – 20/4	363	682
Potato	1/6 – 14/10	415	460
Rape	15/1 – 15/5	281	526
Green maize	1/8 – 29/12	612	786

3. Results

3.1 Estimation of the Harvested Water

The annual harvested water from one household's roof is estimated using eq. 1, taking 900 mm as the mean annual rainfall in Amhara region (FAO, 2015), the average roof's area 60 m^2 and the runoff coefficient 0.85:

$$S = 60 * 0.900 * 0.85 = 46 \ m^3$$

Therefore, the needed tank can be 50 m^3 (taking a safety factor of 1.1).

3.2 The Non-potable Domestic Use of the Harvested Water

According to (Feki, et al. 2014), the average basic daily domestic water demand in Ethiopia is 45 Lpcd (litter per capita per day), from which 70%, 31.5 Lpcd, is for non-potable domestic uses (washing dishes, shower and laundry). The harvested rain water can be used for this non-potable water consumption without any cost of treatment. Thus for a 4 person family the needed water for non-potable use will be:

$$4*31.5*365/1000 = 46 \ m^3$$

Theoretically, the harvested rainwater can cover all non-potable water needs at a family level. Therefore, in some areas where the drinking water systems have problems, rainwater harvesting can cover most of non-potable water family needs.

In some areas where drinking water systems are working properly, the harvested water can be used for cultivating vegetables.

3.3 The design of the Tank

The tank design depends on the end use of the collected rainwater.

Domestic (non-potable use): According to FAO (2015) the average (2011-2015) rainfall of Amhara region, in a ten days base starting from January, is presented in Fig. 2.

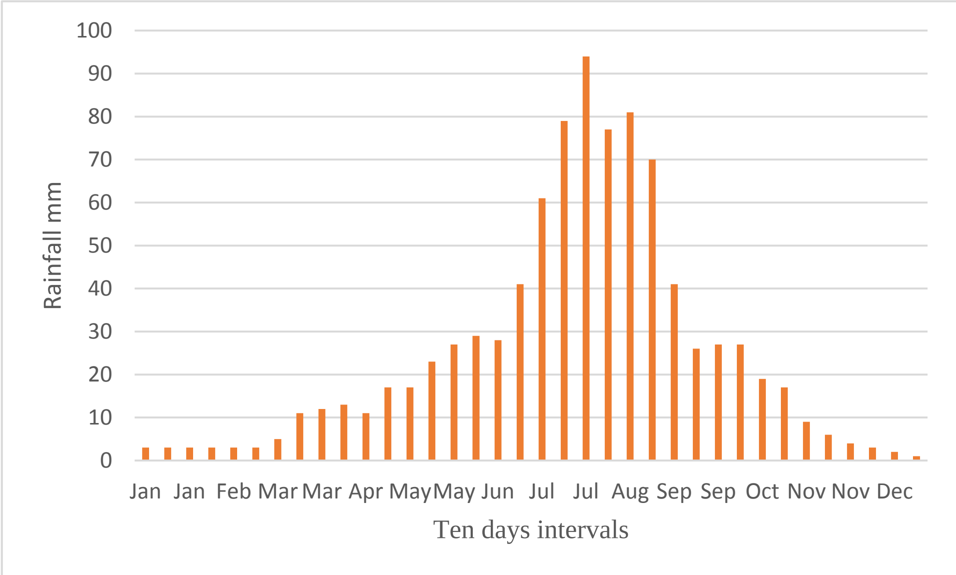

Figure 2. Average rainfall in Amhara region, Ethiopia

To design the tank, we will estimate the harvested water and the non-potable water needs in a ten days interval (Table 2).

The harvested rainfall in m^3 (HRW_{10}) is estimated by using Eq. 2 for a ten days rainfall (Fig. 2):

$$HRW_{10} = \text{Rainfall in ten days} * \text{Roof area } (60\ m^2) * Cr\ (0.85) \quad (2)$$

The daily non-potable personal consumption is considered 31.5 Lpcd, so the household consumption in ten days in m^3 (WC_{10}) is:

$$WC_{10} = 10*4 * 31.5/1000 = 1.26\ m^3$$

According to Table 2, the best time to install the tank is at the 30 of May when the rainwater starts to cover the non-potable needs. Thus, assuming the 30 May is the start day of collecting and consuming from the tank, the size of the tank can be estimated accordingly Table 3. We first estimate the difference between the harvested water and the consumed water DS (m^3) in a ten days interval:

$$DS = HRW_{10} - WC_{10} \quad (3)$$

Table 2. Harvested rainfall and non-potable need in a ten days interval

Days intervals	HRW_{10} (m^3)	WC_{10} (m^3)	Days intervals	HRW_{10} (m^3)	WC_{10} (m^3)	Days intervals	HRW_{10} (m^3)	WC_{10} (m^3)
10 Jan	0.15	1.26	10 May	0.87	1.26	10 Sep	2.09	1.26
20 Jan	0.15	1.26	20 May	1.17	1.26	20 Sep	1.33	1.26
30 Jan	0.15	1.26	30 May	1.38	1.26	30 Sep	1.38	1.26
10 Feb	0.15	1.26	10 Jun	1.48	1.26	10 Oct	1.38	1.26
20 Feb	0.15	1.26	20 Jun	1.43	1.26	20 Oct	0.97	1.26
28 Feb	0.15	1.26	30 Jun	2.09	1.26	30 Oct	0.87	1.26
10 Mar	0.26	1.26	10 Jul	3.11	1.26	10 Nov	0.46	1.26
20 Mar	0.56	1.26	20 Jul	4.03	1.26	20 Nov	0.31	1.26
30 Mar	0.61	1.26	30 Jul	4.79	1.26	30 Nov	0.20	1.26
10 Apr	0.66	1.26	10 Aug	3.93	1.26	10 Dec	0.15	1.26
20 Apr	0.56	1.26	20 Aug	4.13	1.26	20 Dec	0.10	1.26
30 Apr	0.87	1.26	30 Aug	3.57	1.26	30 Dec	0.05	1.26

Then we can estimate the needed tank's volume depending on the stored water in all intervals. The stored water will be used when the rainwater doesn't cover the non-potable water needs. According to Table 3. The sored water can cover the non-potable water needs and the needed tank's volume is 19 m^3.

Table 3. The size of the harvested rainwater

Days intervals	HRW_{10} (m^3)	WC_{10} (m^3)	DS (m^3)	Stored water m^3	Days intervals	HRW_{10} (m^3)	WC_{10} (m^3)	DS (m^3)	Stored water m^3
30-May	1.38	1.26	0.12	0.12	30-Nov	0.20	1.26	-1.06	14.97
10-Jun	1.48	1.26	0.22	0.34	10-Dec	0.15	1.26	-1.11	13.87
20-Jun	1.43	1.26	0.17	0.50	20-Dec	0.10	1.26	-1.16	12.71
30-Jun	2.09	1.26	0.83	1.34	30-Dec	0.05	1.26	-1.21	11.50
10-Jul	3.11	1.26	1.85	3.19	10-Jan	0.15	1.26	-1.11	10.39
20-Jul	4.03	1.26	2.77	5.96	20-Jan	0.15	1.26	-1.11	9.28
30-Jul	4.79	1.26	3.53	9.49	30-Jan	0.15	1.26	-1.11	8.17
10-Aug	3.93	1.26	2.67	12.16	10-Feb	0.15	1.26	-1.11	7.05
20-Aug	4.13	1.26	2.87	15.03	20-Feb	0.15	1.26	-1.11	5.94
30-Aug	3.57	1.26	2.31	17.34	28-Feb	0.15	1.26	-1.11	4.83
10-Sep	2.09	1.26	0.83	18.17	10-Mar	0.26	1.26	-1.01	3.83
20-Sep	1.33	1.26	0.07	18.23	20-Mar	0.56	1.26	-0.70	3.13
30-Sep	1.38	1.26	0.12	18.35	30-Mar	0.61	1.26	-0.65	2.48
10-Oct	1.38	1.26	0.12	18.47	10-Apr	0.66	1.26	-0.60	1.88
20-Oct	0.97	1.26	-0.29	18.18	20-Apr	0.56	1.26	-0.70	1.18
30-Oct	0.87	1.26	-0.39	17.78	30-Apr	0.87	1.26	-0.39	0.79
10-Nov	0.46	1.26	-0.80	16.98	10-May	0.87	1.26	-0.39	0.40
20-Nov	0.31	1.26	-0.95	16.03	20-May	1.17	1.26	-0.09	0.31

3.4 Irrigation

The harvested water can be used in irrigation when drinking water systems cover all domestic water needs. Assuming the irrigated garden to be 100 m^2 and according to Table 1, each household can cultivate two crops each year. In the irrigation scenario the stored water will cover the irrigation needs that are presented in Table 1. The size of the tank can be estimated using the same procedure that was used for domestic water needs above (Table 4). According to Table 4 the best installation date can be the first of May and in order to cover the irrigation needs during the whole year the tank size can be around 21 m^3.

Table 4. Irrigation water estimation

Crops	Period	HW (m^3)	WC (m^3)	DS (m^3)	Tank (m^3)
Tomato	1/11 – 16/3	3	20.95	-17.95	
Onion	1/5 – 28/9	36.7	22.85	13.85	
No irr.	17/3-30/4 & 29/9 – 31/10	6	0	5.9705	20
Cabbage	1/12 – 20/4	3.85	18.15	-14.3	
Potato	1/6 – 14/10	35	20.75	14.25	
No irr.	21/4-31/5 & 15/10-30/11	6.8	0	6.8205	20.8
Rape	15/1 – 15/5	5.5	14.05	-8.55	
Green maize	1/8 – 29/12	20.9	30.6	-9.7	
No irr.	16/5 - 31/7 & 30/12 -14/1	19.2	0	19.2705	19

3.5 Cost-Benefit Analysis

The storage tank is the most expensive part of the water harvesting system. According to the research conducted on cost of tanks for domestic rainwater harvesting in Eastern Africa, the prefabricated tank costs around 5,500 USD for two tanks with **25** m^3 size for each, which is quite expensive and unaffordable in individual level for poor families. The average life time of the tank is 10 years and the cost will be 7,402 USD with an average inflation rate of 2%.

However, cement tank which is constructed underground costs around **351** USD for one tank with **25** m^3 size. This system has an extra cost of pump and energy. However, for poor families man power (hand pumps) can be used.

On the other hand, harvested water can be used for irrigating some vegetables, which has a potential of increasing households' income (USAID, 2013). The average yield and revenue of the studied vegetables at the

50 m^2 land area has been analyzed depending on local costs and markets taking the crops' gross margin GM, which is the difference between the gross benefits and the variable costs of growing a crop, as a main indicator to the analyses according to Hagos, Makombe, Namara, and Awulachew (2009). According the World Bank (2015), the average annual income per capita is about 550 USD, so we take 1100 USD as an annual income per a household. Table 5 shows that cultivating tomatoes and onions each year can increase the household's income by 5%. However, this percentage can be more if we include more areas and more roofs, which can be easy maintained by national authorities and NGOs who care about reducing poverty in Ethiopia.

Table 5. The increase of income from crops cultivation

Crops	GM/ha (USD)	GM/50 m^2	Income USD	Income increase %
Tomato	2765	13.825		
Onion	7416	37.08	1100	5
Cabbage	3231	16.155		
Potato	1812	9.06	1100	2.5
Rape	2200	11		
Green maize	1575	7.875	1100	2

4. Discussion

The polluted surface waters and the lack of water supply and management practices at the country level make private and personal initiatives one of the good solution to cover some of the water needs at a household level in Ethiopia. According to this paper, we found that Dessie town has a high potential for rainwater harvesting. The harvested rainwater can be stored in tanks to be used later for covering all non-potable water needs or cultivating vegetables. The available time and labors at a house level will help in implementing and operating such rainwater harvesting projects.

Women can be part of such small projects. So they can contribute to the household's total income. The results showed that cultivating tomatoes and onions at the private home's garden, 50 m2, can increase the household's annual income by 5 %. This result reveals the potential of using rainwater harvesting in irrigation, which can help poor people to sustain their lives and increase their incomes.

On the other hand, stakeholders including decision-makers can help in widening these kinds of initiatives and may offer some technical support by experts at the municipality and can offer some financial support like loans to implement the harvesting systems.

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