Performance Evaluation of Technical Aspects of Ex-Situ Rain Water Harvesting Systems at Wag-Lasta, Northern Ethiopia.

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Abstract

Water shortages in semi-arid areas of eastern Amhara are the extreme constraints for agriculture. Rainfall is tremendously variable; therefore, the harvesting of rainwater is important to safeguard improved crop production. A study was conducted with the objective of characterizing and evaluating performance and assessing the most pertinent issues related to existing rainwater harvesting (RWH) systems in Wag-Lasta areas. For our study, twelve rainwater-collecting structures (i.e., seven functional and five non-functional ponds) were selected from six kebeles at sekota and lasta districts. Primary and secondary data were used to collect and evaluate with descriptive statistics to assess the technical performance of rainwater harvesting ponds through field observations, direct measurements and interviews with pond owner, zonal and woreda experts, and kebele development agents. The technical performance evaluation showed that the collected runoff and system efficiency were negligible for the constructed rainwater-harvesting pond of the study site. Of the harvested water, 21.54%, 12.96% and 27.71% were used for irrigation, other purposes and lost as evaporation, respectively. This indicates that the efficiency of runoff storage was below one. The average sedimentation rate was 0.43% in the storage ponds. Comparing across ponds, the performance of silt traps ranges from 8.3% to 86.6%. The average water productivity of crops under irrigation was 4.94kg/m^3. Poor selection of sites, lack of maintenance, and technical standardization were the main issues that resulted in a non-functional pond, and although some of them were effective with low performance. Improving the maintenance operation of the ponds and additional training and encouragement of farmers on the planning and construction of ponds help to increase the efficiencies of the ponds.

Keywords: *Catchment area, Efficiency, Pond, Rainwater harvesting, Technical performance*

Introduction

Ethiopia is one of the nine nations in Africa with plenty of water potential for rainwater harvesting. This potential could feed 520million people of the country (Kassahun, 2007). Despite what might be expected some challenges hinder this potential to make it realized. Keeping and preserving this precious resource, when it falls abundantly from the sky and then to temporally store it and distribute it properly for efficient use during needed is a prerequisite.

Water harvesting history in Ethiopia took us back to 560 BC in the Axumite kingdom. There is a starting effort of this practice on increasing crop production through government-initiated soil and water conservation programs (Habtamu, 1999). The 1971 74 drought disasters were the main drivers of this continuous effort, which were intended to come up with opportunities; like employment, to the victims (Ngigi, 2003, Seyoum, 2003).

Annual rainfall of Ethiopia ranges between 2700mm in the Southwestern plateaus and less than 200mm in some parts of the Northern and Southeastern lowlands with a further decrease to 100mm in the Northeastern lowlands. Overall, the mean yearly precipitation of the country is approximately1090mm (Hugo, 2003). Besides, 70% of the absolute arable land in Ethiopia gets yearly precipitation of less than 750mm (Seyoum, 2003, Temesgen, 2012). On the other hand, an estimated 110 billion cubic meters rainwater lost each year through surface runoff (Wubetu et al., 2016). This corresponds to a 1m deep square pond with side lengths of 330 km.

Some rain-fed parts in the Amhara region, which receive low rainfall, suffer from insufficient and variable rainfall and resulting in unreliable crop yield. In these areas, water productivity is too low that the vast majority of them are gone from the soil through surface evaporation and surface runoff (Roba et al., 2022, Araya and Stroosnijder, 2010, Rockström et al., 2010). According to Abegaz and Mekoya (2020), Shefine (2018), Hugo (2003), the variability of yearly precipitation in Amhara and Tigray is high ranging from 20% to 40%. Similar to other regions the variability is high but the quantity of precipitation in the region is not the main problem; rather the collection and storage of runoff and rainwater are the main issues.

In practice, extension experts propose household ponds and shallow wells for irrigation to produce fruits, and vegetables, which should help the individual farmer to obtain additional income and increase household consumption. This means planting root vegetables in the summer season and extending the growth period into the dry season where better crop prices are achieved. Vegetable production under irrigation using simple bucket is feasible for plot sizes ranging from 150-200 m^2. Lack of labor force and water limitations in the ponds during the late crop growth stages are the main causes that hamper the use of this system for boosting irrigated production using ponds (Rämi and OCHA-Ethiopia, 2003).

The main drivers of misusing the water harvesting ponds are physical, technical, and socio-economic and policy gaps. To have reliable rainwater harvesting schemes, the storage volume must be assessed carefully whether it meets the seasonal irrigation demand. For rainwater harvesting in all areas of Amhara region, the capacity of the ponds is 129m^3 (SMIS, 2016), which are promoted under some projects of government and donor agencies without proper analysis of the storage volume required by a household considering demand, catchment area, and rainfall variabilities and soil conditions.

The government of Ethiopia has made investments both financial and material for the expansion of RWH ponds. This makes it unmotivated for farmers to build and use RWH systems because of the higher demand for investment costs. Besides, knowledge inadequacy in terms of which size, how, where, and when these structures have to be constructed is very evident. This work is undertaken to identify the specific gaps in the current water harvesting systems (specific to ponds) in the Wag-Last area of Amhara region in all the technical aspects. Therefore, this research was showed to characterize and evaluate the performance of selected household RWH and assess the most significant problems relevant to the existing RWH systems.

Materials and Methods

Description of the Study Area: The research was conducted for two years during 2018 and 2019 at Sekota and Lasta woreda. The geographical location of the study areas ranges from latitude 1319013 to 1414094 N and longitudes 500019 to 522735 E with an altitude of 1885 to 2407 m.a.s.l (Fig. 2). The rainfall was seasonal varying in-depth, space, and time. There is a short belg and heavy summer season, that occurs between late june and early september. The mean annual long-term rainfall in the study areas at Sekota and Lasta was 585.8 mm and 799.3 mm and both characterized with irregular and inconsistent in distribution (Fig.1). The mean minimum and maximum long-term temperature was 12.4 & 26.8 ^{o}c at Sekota and 13.4 & 24.8 ^{o}c at Lasta woreda respectively (Fig.1). The area is intensively cultivated and the production is subsistence farming. Rain-fed agriculture is the main practice in the study area. However, with the introduction of water harvesting structures like ponds, supplementary irrigation practices were performed. The main crops grown in the study area are sorghum, teff, wheat, barley, faba beans, garlic, potato, tomato, onion, pepper, cabbage and shallots.

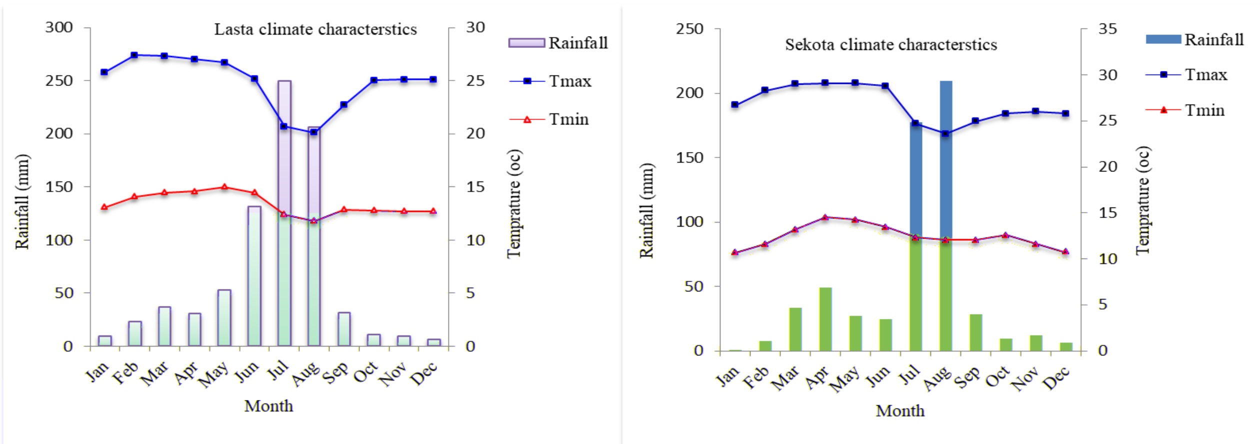

Figure 1. Climate characteristics of the study site

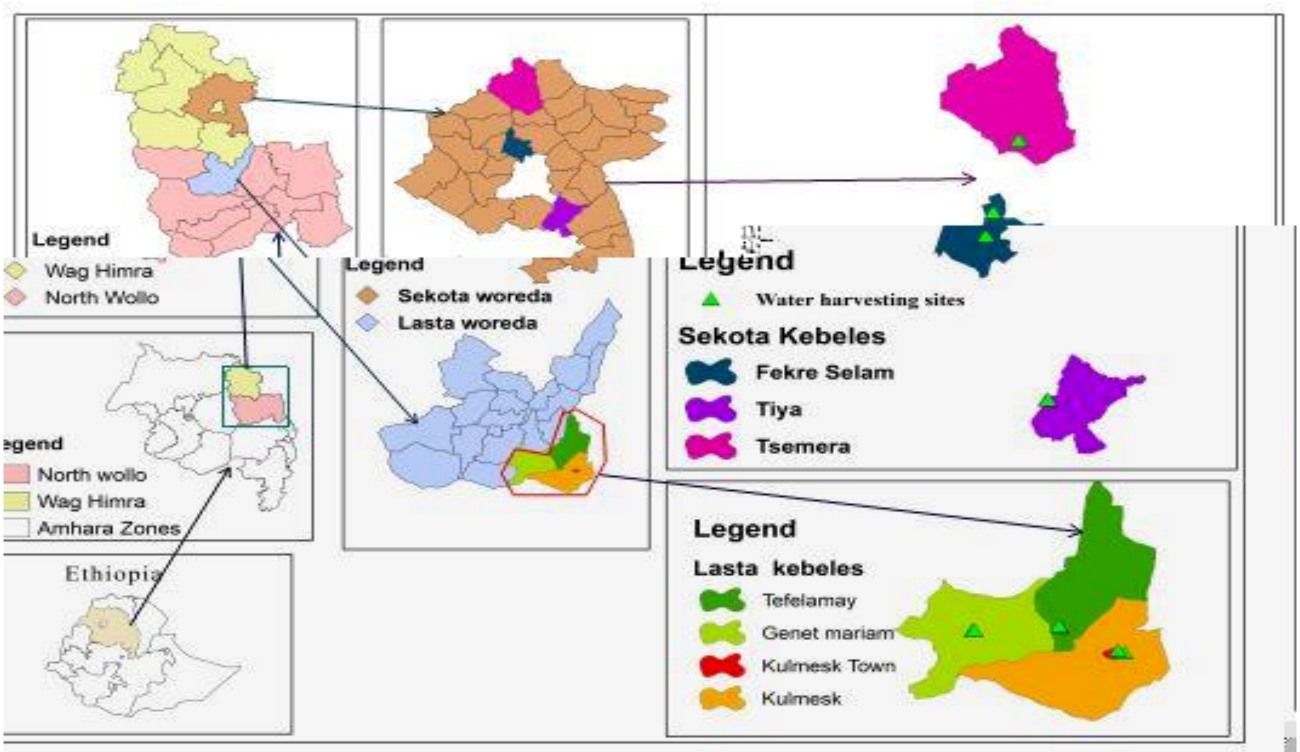

Figure 2. Location maps of the study areas

Selection of water harvesting ponds: The areas of study were selected based on the type, quantity, and distribution of the targeted rainwater harvesting systems from various agro-ecologies. Two agro-ecologies of the study areas were considered to pick the study woreda where the targeted rainwater harvesting structures are available. To select the kebeles with rainwater harvesting structures, field visits and discussion with zonal, woreda, and kebeles experts were held. Three kebeles were purposefully selected from each of the studies wored

harvesting structures in the selected kebeles were evaluated, characterized, and therefore categorized. Categories were done as good and poor in their existing relative performance.

A total of 99 rainwater-harvesting ponds from households have been assessed initially in the study areas. These household ponds are located in Tsemera, Fekre Selam, Tiya, Genete Mariam, Tefelamay, and Kulmesk. Out of these, 12 rainwater-harvesting ponds were selected for comprehensive analysis and study. For a detailed study, two water-harvesting structures were selected in each kebele.

Data collection: Reliable and accurate primary and secondary data were gathered at household, kebeles, woreda, and zone levels using various questionnaires, data collection formats, and using direct measurements. In addition, the literature available was reviewed, and discussions with the concerned institutions were held.

Primary data: The required data were collected from the selected kebeles (Tsemera, Fekre Selam, and Tiya in Sekota woreda) and (Genet Mariam, Tefelamay, Kulmesk in Lasta woreda) and on the rainwater, harvesting structures using a structured and semi-structured questionnaire and direct measurements. The questioners were addressing zonal to Kebele agricultural experts. Additional information was collected through interviews and focus group consultations with the farmers and woredas. Data collectors were assigned to take daily measurement of rainfall, runoff, sediment yield, water consumed, evaporation, daily water level in the pond, and other related activities from water harvesting structures. To characterize the system, data on land use and land cover in the catchment, size, physical performance, and current capacity of each component of the system (i.e. catchment, diversion channel, and silt trap, storage and command area) were collected from the study kebeles.

Soil analysis: Soil samples for the bulk density determination and soil texture analysis were collected from the catchment, silt trap, and command area of each rainwater harvesting ponds.

Texture: Soil samples were collected from each water harvesting site's catchment, silt trap, and command field, from a depth of 0-30 cm using soil auger for textural analysis. It was because soil loss occurred mainly from the catchment surface and this depth was necessary for the study. For this determination, three composite samples were taken from each catchment surface, silt trap, and command area. The analysis of particle size was performed using the hydrometer method in the soil laboratory of the Sekota Dry-Land Agricultural Research Center and the texture group was determined using USDA textural triangle. The soil texture, along with the slope and land use, was used to estimate the surface runoff coefficient value.

Bulk density: For each water harvesting system selected for detailed analysis, the samples were collected from the catchment, silt trap, and command area using core-sampling methods. This sample depth of 0-15 cm was taken from the silt trap to assess the sediment's bulk density for analyzing sediment load. The soil sample is oven dried at 105oc for 24 hours. Then, the dry bulk density was obtained by dividing the soil's dry mass with the volume o

Once the sediment's bulk densities was estimated and total sediment (kg) was measured by multiplying the sediment mass per unit volume of water by total discharge, used to measure the annual sediment deposits (m3) in the water harvesting system and then calculating the sediment rate using equation 8.

Secondary data: The secondary information included several constructed rainwater harvesting systems, design and actual structural measurements, crop rotational history, list of observed problems, structural operational and maintenance status, irrigation methods, and type of water usage, crop selection, crop yield, and socioeconomic details. The information was collected from governmental organizations such as research centers, water offices, agricultural and rural development offices.

Sedimentation Analysis

Runoff Sediment Concentration: During the time of runoff harvesting, one liter of runoff sample was taken at the inlet and outlet of the silt trap and storage inlet. The sediment sampling done at the inlet was sampled using plastic bottles. For the water harvesting system, which has a silt trap, the runoff sample was collected from the inlet of the pond. The samples were collected for all rainstorms that include both low and high storms that could generate runoff. Each runoff sample was allowable to settle down after collection. The collected runoff was then filtered with filter paper and weighed to get the constant dry weight of the sediment after oven drying. The total sediment was determined by multiplying the sediment weight per unit water volume by the total runoff water collected in the pond. The amount of sediment deposited in the silt trap represents the difference between the inlet sediment and the trap outlet. Finally, mean sediment results were taken for trap efficiency analysis using equation (9).

Water input and output from the storage

Storage Level: The gross water production accumulated in the pond was estimated over the water harvesting area as the sum of runoff inflow and direct rainfall falling on the pond. The water level in the pond was assessed every morning and evening (8:00 AM and 6:00 PM) before and after the occurrence of rainfall using a graduated stick placed at the middle of the pond as a standard foundation. This measurement was done during rainstorms at which water samples for sediment concentration measurement were collected. This provided the sum of inflow that reached the storage pond after every occurrence of rainfall. Meanwhile, the amount of rainfall from the manual rain gauges mounted at the study areas were observed.

Water Abstraction: The water consumed was measured using graduated sticks before and after consumption using watering cane with a known 10 liters volume for either irrigation, livestock, or other purposes.

Crop water requirement (CWR): is an essential factor in water harvesting ponds design and involves irrigation and domestic water consumption. In the field, the Cropwat computer model was used to assess the crop water requirements of irrigated crops (pepper, tomato, garlic, carrot, cabbage, and onion). This method is the FAO penman-monteith equation for calculating evapotranspiration of reference crops, ETo (Allen et al., 1998). The CWR estimation depends on calculating the ETo values using the available climate data, and this was multiplied by Kc at different crop growth stages.

Equation (1)

Where, ETc = evapotranspiration of crops (mm / day)

ETo = reference crop evapotranspiration (mm / day)

Kc = coefficient for crops

The main function of the rainwater-harvesting pond was primarily for supplementary irrigation and annual fruit trees in the study areas.

Water losses through evaporation: This data was calculated using a pan evaporimeter at the study sites, and this value was multiplied by the pan coefficient to adjust from the water-collecting pond to the actual evaporation. The standard pan mounted was adequate for a thorough analysis of selected rainwater harvesting ponds to estimate the evaporation. The coefficient for the pan varies from 0.6 to 0.8 and the mean value of 0.7 was taken for our analysis.

Water Losses through Seepage: Seepage loss was determined as the difference between water input (rainfall and runoff) to the storage and water flow out from the storage (water consumed and evaporation losses) and available water in the storage.

Catchment Characteristics: Characterization of the main catchment variables was done to assess the current catchment that contributes runoff to the water-harvesting pond. Measurement of the catchment area was achieved using DEM derived from point data that was obtained with GPS. The catchment land use and land cover were assessed using field observation.

Structural Characterization: The structure type (trapezoidal, hemispherical), dimension (side slope, bottom and top width or diameter, structure height, length, and size), volume, structural stability, soil, and lining material were assessed and evaluated. It was determined whether the silt trap was used in the system or not. If silt traps exist in the system, its dimensions, frequency of cleaning, the position of construction relative to the pond, number of chambers, whether a mesh is used in the silt trap system were characterized and evaluated. The diversion channel was assessed and characterized by its dimensions (L*W*D) and performance (scouring, sediment depilation, surface roughness, etc.). Spillway availability, its functionality, and its appropriate location and dimension in the system were evaluated.

Irrigation Command Area: The existing size of the irrigable area, crop type, and irrigation purpose, method of irrigation, planting period, crop rotation system, and use of inputs (fertilizer, agrochemicals), weeding frequency, harrowing frequency, irrigation frequency and amount of irrigation were assessed and quantified.

Performance Evaluation: The main purpose of performance evaluation is to recognize deficiencies and recommend improvements to be made to enhance and sustain the quality and effectiveness of a system (Molden et al., 1998). The efficiency of the rainwater-harvesting scheme also requires a combination of runoff harvesting efficiency, runoff storage efficiency, and system efficiency (Goma et al., 2015, Gammoh and Oweis, 2011, Jones and Hunt, 2010). The water productivity, sedimentation rate, and economic efficiency of the performance can be evaluated (Arega, 2003). In general, a system's efficiency is calculated using its efficiencies. Efficiency factors were determined using the data collected to evaluate the system performance. The following equations were used to calculate the catchment-command area ratio, runoff harvesting efficiency, runoff storage efficiency, system efficiency, storage to excavated volume ratio, water productivity, and sedimentation rate.

1) *Runoff Harvesting Efficiency (RHE):* This can be calculated by the ratio of water harvested or input to storage and the amount of runoff in the catchment (Quraishi and Molla, 2013, Begashaw, 2005).

Equation (2)

2) *Runoff Storage Efficiency (RSE):* The ratio of the amount of runoff available in the storage to the amount of runoff input that reaches the storage unit. The ratio can be one if and only if no seepage and evaporation occur in the pond(Quraishi and Molla, 2013).

Equation (3)

3) *System Efficiency (SE):* It measures the effectiveness of the whole system that indicates how much of the runoff produced on the catchment of rainwater harvesting systems is consumed for irrigation or any other purpose. It is calculated as follows (Suresh, 2012).

Equation (4)

4) *Storage to Excavation Volume Ratio (SER):* If the ratio is one, then the storage is least economical (storage contains the same amount of water as excavated). The storage to excavation volume ratio is greater than one which is economically

feasible if the excavated soil is used to form a bank to store the water above the original ground level (Suresh, 2012).

Equation (5)

5) *Water Productivity (WP):* The ratio of a crop 's actual yield (kg) to the volume of water used for irrigation (m^3) for both rainfall and supplemental irrigation (Arega, 2003).

Equation (6)

6) *Relative Irrigation Supply (RIS):*

The ratio of the irrigation water (m^3

for irrigation was calculated using the penman monteith equation, based on the study area's crop type, soil, and climate. To contrast, the respective effects of the water harvesting system, a reasonable field application efficiency was cited from various pieces of literature.

7) *Sedimentation*

The sediment load and deposition have environmental and technical effects (Kirby et al., 2002). Loss of storage capacity will occur when the reservoir's effective storage volume is filled by a certain amount of sediment deposition. The rate of sedimentation is expressed in terms of the percentage of the reservoir's annual capacity lost through the formula (Suresh, 2012, Kirby et al., 2002).

Where, S = annual loss of reservoir capacity (%)

Sa = annual deposition of silt (m^3)

C = reservoir capacity (m^3)

The reservoir trap efficiency is the amount of sediment that is trapped in the storage and the total load that enters with the runoff. Using this equation the silt trap efficiency (STE) was determined (Suresh, 2012, Kirby et al., 2002).

Where, STE = silt trap efficiency (%)

S1 = the sediment entered into the silt trap (gm)

S2 = the sediment discharged out of the silt trap (gm)

8) *The Storage Capacity Of The Pond And Runoff Predictions*

The measuring tape was used to measure the top, bottom, and width of the trapezoidal water collection pond to assess the total storage capacity of the pond (SMIS, 2016). The formula used to calculate the size of the very common trapezoidal-shaped storage pond type.

Where, V= storage capacity m^3, H= water storage depth m,

AT= top area of storage= UL*UW, m^2 UL= upper length, UW= upper width

AB= base area of storage= BL*BW, m^2 BL= bottom length, BW= bottom width

For storage capacity of hemisphere-shaped water ponds (SMIS, 2016) was calculated as follows

Where, V= storage capacity, m^3 R= radius of the pond m & = 3.14

The amount of water collected from the catchment area is a function of the amount of runoff that is produced by the region's rainfall. Since not all runoffs can be used due to deep percolation, evaporation, and other losses, they do need to be multiplied by an efficiency factor 0.6 (Quraishi and Molla, 2013).

Where, Q = discharge volume (m^3), RF =mean annual rainfall (mm)

A = catchment area (m^2), C = runoff coefficient, Eff. = efficiency factor.

Assessment of Issues of Water Harvesting Systems

The most important problem for the study of the household rainwater harvesting ponds was identified in line with the performance evaluation. The problems were established by interviews, field observations and direct measurements (such as silt depth, catchment slope, current dimensions, and channels) made.

Results and Discussion

Catchment Characteristics of Studied Ponds

Runoff from surface catchments was collected using the rainwater collection ponds with land surface and roof catchment (Table 1). The topography of the slope varies from 3 to 25 percent and the elevation of the catchment ranges from 1885 to 2407 m. Areas of the catchment for all rainwater storage ponds were greater than the command areas.

Table 1. Presents the catchment area, command area, land use & ground cover, and slope of each of the RWH pond under study.

Ponds	Catchment area (ha)	Command area (ha)	Land use & land cover	Average slope (%)
P1	0.58	0.043	Bare & bush land	15
P2	0.36	0.028	Cultivated	4
P3	0.47	0.005	Cultivated & bare land	9
P4	0.5	0.014	Bush land	25
P5	0.65	0.032	Grazing land	19
P6	0.6	0.005	Cultivated & roof	3
P7	0.52	0.002	Forest & grazing	15
P8	0.57	0.036	Cultivated & bush land	10
P9	0.62	0.025	Bare, bush land & road	17
P10	0.54	0.017	Bare, bush land & road	18
P11	0.52	0.036	Cultivated, shrub, bush & road	16
P12	0.54	0.023	Forest & road	25
Mean	0.539	0.022		14.7
Std	0.076	0.013		7.1

Dimensions of Ponds

Diversion channels: The earthen channel diversion was used to divert the runoff from the catchment to the silt trap or directly to the storage (Fig 3). The channel was constructed using earthen material with a width of 0.25 to 0.53 m and a depth of 0.18 to 0.32 m and was desi

Table 2. Silt trap dimensions of RWH ponds under study

Pond	Length (m)	Width (m)	Depth (m)	Remark
P1		Damaged		Two-chamber
P2	2.3	1.15	0.85	Two-chamber
P3	2.3	1.15	0.85	Two-chamber
P4		Damaged		Two-chamber
P5	2.9	1.15	0.8	Two-chamber
P6	2.9	1.15	0.8	Two-chamber
P7		No silt trap		
P8		No silt trap		
P9		No silt trap		
P10		No silt trap		
P11		No silt trap		
P12		No silt trap		

The Dimension and Storage of Ponds

Studied ponds have been developed with different storage capacities, depending on the volume of water to be harvested and the accessibility of construction materials (Table 4). The Geomembrane plastic sheet with the required size of 13.5x 13.5 m was used in the study site after digging soil to cover the floor and wall of the pond. The plastic was placed on a very well-shaped and smooth trapezoidal rainwater storage surface. The government gave the plastic sheet with the least cost. The typical depth for the hemispheric form of

the table 3.

Table 3. The dimension, storage volume and status of the ponds at the study site

Ponds	Dimension (m)*	Side slope (H: V)	Storage volume (m^3)	Status
P1	D= 6, B=3, d=3		No storage	Non-functional
P2	T= 8, B=3, d=3	2:1	97	Functional
P3	T= 7, B=4, d=3	2:1	93	Functional
P4	D= 6.5, B=6, d=2.7		No storage	Non-Functional
P5	D= 6, B=6, d=3		56.5	Functional
P6	D= 6, B=6, d=3		56.5	Functional
P7	T= 8, B=4, d=3	2.7:1	112	Functional
P8	T= 9, B=6.5, d=3	1.3:1	193	Functional
P9	T= 8, B=3, d=3	3.3:1	97	functional
P10	T= 9, B=3.5, d=3	4:1	No storage	Non-functional
P11	D= 7, B=3, d=3		No storage	Non-functional
P12	T= 8, B=3, d=3	3.3:1	No storage	Non-functional

** T= top width, B= bottom width, D= diameter, d= depth*

The existing capacity of the ponds was not designed based on the precipitation of the area. Therefore, the structures were not adjusted based on runoff diverted from the catchments and direct rainfall falling in the pond thereafter, the proportions need to be adjusted and corrected according to the catchment runoff (Table 4).

Table 4. Lining material and runoff coefficient in the study area based on total runoff from the catchment area.

Pond	Lining material	Catchment area (ha)	Runoff coefficient	Total runoff ,m^3
P1	Concrete	0.58	0.4	815
P2	Plastic	0.36	0.35	442
P3	Plastic	0.47	0.38	627
P4	Concrete	0.5	0.34	597
P5	Concrete	0.65	0.37	844
P6	Concrete	0.6	0.55	1159
P7	Plastic	0.52	0.36	898
P8	Plastic	0.57	0.38	1040
P9	Plastic	0.62	0.39	1160
P10	Plastic	0.54	0.39	1011
P11	Concrete	0.52	0.4	998
P12	Plastic	0.54	0.38	985

*Total runoff = P*A*C*eff., where, P is seasonal rainfall, C is the runoff coefficient, A is the catchment area (Quraishi and Molla, 2013).*

Command Area: The size of the command area was variable from farmer to farmer as shown in Table 11, varying from 0.002 to 0.036ha. According to the Bureau of Agriculture in the Amhara Region (BoA, 2003), the ponds were normally designed to irrigate 0.043ha of land using 129m^3 storage capacity. However, the study stated that the average land irrigated by the farmers was 0.019 ha which was not according to the plan since the water stored was used for perennial fruit trees and other purposes.

Because of poor design, lack of a silt trap, and low pond storage, the farmers could not harvest water that could be harvested from the existing catchments. Therefore, by increasing the pond's storage capacity, farmers could produce more water and increase their irrigated areas. The main crops in the study ponds include vegetables such as cabbage, onion, and pepper. The nonfunctional ponds had no storage and unable to let water for crops so that no actual irrigated area was found.

Water Lifting Mechanisms and Application Methods: Farmers who use water-harvesting ponds used watering cane to draw water from the pond. So far, most of the farmers in the study area were not aware of how to effectively extract and apply the water. A water loss caused by poor application was so high. Most of the farmers interviewed were not satisfied with how they utilize the stored water. They felt that water harvesting is laborious, less efficient, and time-consuming.

The study conducted by Ngigi (2003) indicated that combining drip irrigation with a system of rainwater harvesting was economically viable and increase water productivity, and a farmer could recover the full investment costs within four years while making significant net income during the repayment period. In this respect, it is important to educate and advise farmers of the use of drip irrigation technology, so that the efficiency of water consumption can be dramatically improved (Hailemariam and Quraishi, 2012).

Soil Texture and Bulk Density: For each water harvesting system, three composite samples were collected from the catchment, command field, silt trap/diversion path, for soil texture analysis. The findings of the soil texture analysis showed that the mean composition of clay, silt, and sand in the catchment areas was 4.7, 11, and 84.3 percent, in the command areas 7, 15.2, and 77.8 percent, and the silt trap 4.3, 12.4 and 83.3 percent, respectively. The texture classification of the catchment, command area & silt trap was dominantly sand, sandy loam, and sand correspondingly according to the USDA soil textural triangle (Table 5). These groups of soil texture were used to determine the coefficient of runoff from which total runoff had been designed.

Soil samples were also taken from the catchment area, command area, and silt trap and study site water harvesting ponds using core sampling methods, to estimate the soil bulk density. An average of 1.87, 1.51, and 1.44 g/cm3 was found to be the bulk density of the

per unit volume of water by the total collected runoff. It was used to calculate the deposited annual sediment (m3) in the water-collecting pond and was intended to transport the sediment. The concentration of sediment in the silt trap and storage ponds ranged from 1.4 to 17.95 g/lit and 0.85 to 42.5 g/lit respectively (Table 6). Compared with the other ponds, the sediment concentration for the pond (#p11) was high (42.5 g/lit).

Table 5. Textural class of the catchment area, command area, and silt trap

Ponds	Particle size distribution											
	Catchment area				Command area				Silt trap			
	Sand (%)	Clay (%)	Silt (%)	Textural class	Sand (%)	Clay (%)	Silt (%)	Textural class	Sand (%)	Clay (%)	Silt (%)	Textural class
P1	91	3	6	Sand	87	6	7	Loamy sand	93	1.4	5.6	sand
P2	65	20	15	Sandy clay loam	67	10	23	Sandy loam	65	13	22	Sandy loam
P3	83	6	11	Loamy sand	81	6	13	Loamy sand	87	2	11	Sand
P4	93	2	5	Sandy loam	75	6	19	Sandy loam	91	2	7	Sand
P5	81	6	13	Loamy sand	87	6	7	Loamy sand	71	6	23	Sandy loam
P6	87	2	11	Sand	79	8	13	Loamy sand	93	1	6	Sand
P7	87	0	13	Sand	67	12	21	Sandy loam				
P8	86	3	11	Loamy sand	69	8	23	Sandy loam				
P9	85	0.7	14.3	Loamy sand	77	8	15	Sandy loam				
P10	89.8	2	8.2	Sand	85	4	11	Loamy sand				
P11	73	10	17	Sandy loam	89	6	5	Sand				
P12	91	2	7	Sand	71	4	25	Sandy loam				
Mean	84.3	4.7	11.0		77.8	7.0	15.2		83.3	4.3	12.4	

Table 6. Sediment concentration of storage ponds and silt traps, and bulk density

Pond	Sediment concentration (g/l)		Bulk density (g/cm^3)		
	At the inlet of a silt trap	At the outlet of a silt trap	Silt trap	Catchment area	Command area
P1	Damage		1.86	2.14	1.95
P2	1.4	0.85	2.50	2.72	1.80
P3	17.95	2.40	0.87	1.57	1.17
P4	Damage		1.63	1.70	1.17
P5	4.25	3.30	1.1	1.7	1.4
P6	2.4	2.20	0.73	1.40	1.59
P7	No silt trap	12.7			1.45
P8	No silt trap	3.85			-
P9	No silt trap	5.00			1.69
P10	No silt trap	7.85			1.50
P11	No silt trap	42.50			1.43
P12	No silt trap	4.30			1.44
Mean	6.5	8.5	1.44	1.87	1.51
Std	6.6	12.4	0.7	0.5	0.2

Evaluation of RWH Ponds Using Efficiency Parameters: In the study, seven functional rainwater-harvesting systems were evaluated using different criteria for technical performance evaluation. It also identified five non-functional rainwater-harvesting systems to classify the major problems that cause non-functionality.

Technical Performance Evaluation: The rainwater harvesting system's technical efficiency analysis indicated that the efficiency of runoff harvesting and system efficiency was low for the studied rainwater harvesting ponds with a mean of 0.13 and 0.03 respectively (Table 7). It is because the catchment areas for each rainwater harvesting ponds were wide and produced a high amount of runoff that could have been collected, but due to the limited storage capacity of the ponds, the actual volume of water collected was small. Besides, silt trap efficiency was found to vary from 8.3% to 86.6%. The average water productivity of crop used for stored vegetable production (tomato, pepper, onion, cabbage, carrot) was 4.94 kg/m^3 (Table 7).

Table 7. Technical performance efficiency of functional ponds

Ponds	RHE*	RSE	SE %	SER	WP kg/m3	RIS	SR %	STE %
P2	0.219	0.69	0.027	1	-	-	0.085	39.3
P3	0.148	0.69	0.025	1	4.8	0.25	0.24	86.6
P5	0.067	0.54	0.011	1	-			

Table 8. Loss of evaporation from the ponds

Pond	Water stored (m^3)	Average surface area (m^2)	Evaporation loss			Net harvested water	
			m	m^3	%	m^3	%
P2	97	32.3	0.942	30.4	31.34	66.6	68.66
P3	93	31	0.931	28.9	31.08	64.1	68.92
P5	56.5	28.26	0.925	26.1	46.19	30.4	53.81
P6	56.5	28.26	0.925	26.1	46.19	30.4	53.81
P7	112	37.3	0.725	27.0	24.11	85	75.89
P8	193	60.58	0.725	43.9	22.75	149.1	77.25
P9	97	32.3	0.717	23.2	23.92	73.8	76.08
Mean	100.71	35.71	0.84	29.37	32.23	71.34	67.77
Std	45.90	11.38	0.11	6.80	10.14	40.14	10.14

** Average area –) (Quraishi and Molla, 2013, Rämi and OCHA-Ethiopia, 2003, Te Chow, 2010), Where, A1= surface area when storage was full, A2= surface area at the end of december. The evaporation from pan (0.942m)*pan coefficient (0.7) = 0.659 m*

The magnitude of the loss from evaporation was usually related to the rainwater harvesting ponds' surface area. The net collected water was used for irrigation in the study areas and other purposes after the rainy season. Vegetables such as cabbage, onion, and pepper were crops grown by most households. During the growing period, the respective gross irrigation requirement was around 465.6, 525.6 & 745 mm at the Sekota site and 422, 469.5 & 650.9 mm at the Lasta site for optimum yield of cabbage, onion, and pepper in that order.

Pond Water Balance: The water balance results during July to December showed that the average irrigation and other consumption were 22.82 and 13.74 m^3 respectively (Table 9). The consumption represented 34.5 percent of the total average water collected. The owner of pond P6 used the stored water effectively with the high water productivity of crops because of the water balance, while pond P2 could not use efficiently the completely stored water. Storage of available water in P6 was minimum at the end of December. It is largely due to high use of irrigation. Farmers should produce short growing crops with increasing command area and allow good use of the stored water instead of exposing the stored water to evaporation for a prolonged period.

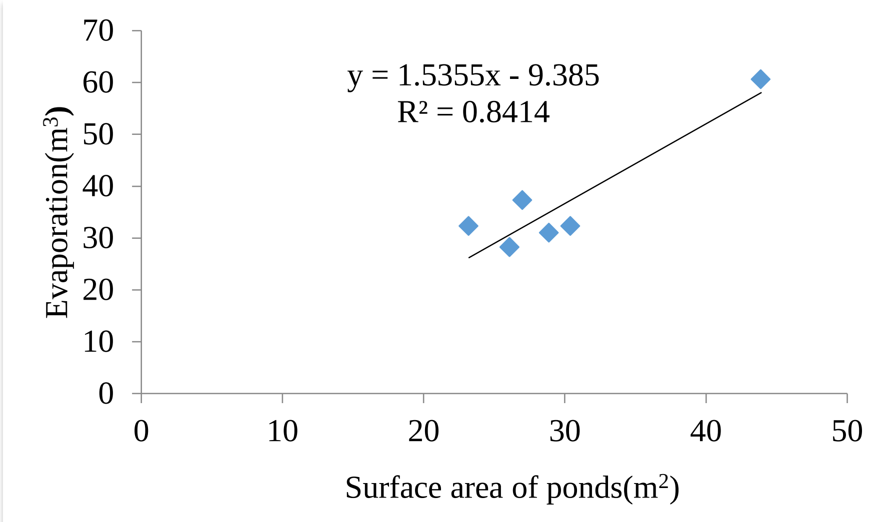

Figure 4. The relation between the pond surface area and the loss of evaporation

Table 9. Water balance of the ponds

Pond	Water harvested, m^3	Evaporation loss, m^3	Consumption, m^{3*}				
			Irrigation	Other purposes	Sum	OS, m^3	SA, m^3
P2	97	30.4	-	12	12	42.4	54.6
P3	93	28.9	15.75	-	15.75	44.4	48.6
P5	56.5	26.1	-	9.6	9.6	35.7	20.8
P6	56.5	26.1	21.6	-	21.6	47.7	8.8
P7	112	27.0	25.2	7.5	32.7	59.7	52.3
P8	193	43.9	31.2	30	61.2	105.1	87.9
P9	97	23.2	20.4	9.6	30	53.2	43.8
Mean	100.71	29.37	22.83	13.74	26.12	55.46	45.25

** OS= out of storage, SA= storage available*

Catchment to Command Area Ratio: Analysis of the catchment to command area ratio reveals that the catchment size on the current rainwater harvesting ponds was greater than the command area and its average ratio was 78.25:1(Table 10), which was far higher than the recommended 3:1 catchment command area ratio (BoA, 2003). The excess runoff coming from the catchment was then removed from the storage. The water collection ponds command areas in the study areas are to be increased. According to water harvesting ponds design by the Amhara region bureau of agriculture, 0.043 ha of land should be irrigated with 129m^3 of water (BoA, 2003). Yet the farmers had just 0.019 ha of irrigated land on average.

Table 10. Catchment to command area ratio of the ponds

Pond	C value	Catchment area, ha	Command area, ha	CCAR
P2	0.35	0.36	0.028	12.9
P3	0.38	0.47	0.005	94.0
P5	0.37	0.65	0.032	20.3
P6	0.55	0.6	0.005	120.0
P7	0.36	0.52	0.002	260.0
P8	0.38	0.57	0.036	15.8
P9	0.39	0.62	0.025	24.8
Mean	0.40	0.54	0.02	78.26

Issues Identified in Water Harvesting Ponds: This investigation showed that there were practical problems in the rainwater harvesting of ponds. The following issues were identified from field surveys.

1) *Poor Selection of the Site*

The failure of five rainwater ponds (P1, P4, P10, P11 & P12) was seen solely because of inadequate site selection and lack of maintenance. It has been shown that selection of the site was done quickly and without experience and the technical standards of the probability of runoff and water collection were neglected with the significance that a portion of the ponds did not hold water. Identifying potential sites suited to water harvesting ponds is therefore an important factor in achieving rainwater collection ponds. Thus, the absence of technical information such as precipitation, hydrology, and topography were the key factors contribute to the failure of water harvesting structures at those sites.

2) Lack of Technical Considerations

Technical standards and evidence were not considered during the planning and building of water collection ponds. For instance, the dimensions of the pond and the data about precipitation were not carefully considered. In addition, silt traps were not built to allow design standards, and even some ponds had no silt traps.

3) Operations and Maintenance

The primary reasons for the failure and low performance of rainwater harvesting ponds were unfortunate management and a lack of maintenance. The evaluation found that most of the ponds were inefficient because of inadequate construction and maintenance requirements. More or less rainwater storage ponds were completely silted up and silt traps destroyed. Once the physical construction of the rainwater harvest is in progress, the owner of the pond typically has to take over operation and maintenance. Numerous of the ponds surveyed used below their capacity only after the owner failed to fulfill his obligation.

Figure 5. Silt trap full of sediments

4) Sedimentation and Evaporation

Sedimentation and evaporation lead to reduce the capacity of ponds. These problems occur in most cases because of non-functional silt traps and inlet structures. On the other hand, the risk of sedimentation was still high, as most of the ponds were not properly constructed. The field observation showed that circular rainwater collection ponds were completely silted up and more or less filled with sediments about the depth of 60-170 cm. Effective management of the catchment and daily maintenance of silt traps and storage ponds may have avoided sedimentation of the channels before the onset of rain. Absolutely, the ponds did not have evaporation avoidance mechanism at all and therefore water loss was high due to evaporation.

Figure 6. Sediment-filled ponds

5) *Labor Shortage*

Ponds demand intensive labor. However, labor shortage is critical to construct the pond and maintenance of ponds. The small number of family members may be the causes of these problems.

6) *Financial Shortages*

The high labor costs of digging the pond, the high investment and operation costs of agricultural products such as vegetables and building materials (geomembrane sheet), and the lack of credit facilities were observed as the considerable problems under this type of rainwater harvesting pond. When the plastic sheet was torn out, farmers were unable to replace it due to financial constraints.

7) *Accessibility of Raw Materials*

Obtaining the source of geomembrane plastic coating, a lack of roof shelter and fence for additional ponds, which caused high evaporation and the fall of animals and children into the pond. The pond also a lack of water lifting and watering equipment, and knowledge about irrigated vegetable production were discovered to be due to either the failure of the rainwater harvesting ponds or the underlying efficient operation of the ponds.

8) *Lack of Follow Up*

These include a lack of management, a lack of skilled persons who could help with the maintenance of the pond, and other related problems, such as the stealing of geomembrane sheets and burrowing animals, and the damage caused by dogs when entering the pond. Hence, the training and supply of materials and the quick delivery of replacement parts to the recipients, instructions and procedures for the operation and maintenance of all components of the water harvesting system and the protection of the ponds from damage by providing fencing and covering of the pond are some of the remedial steps that can solve these problems. As also reported by (Rämi and OCHA-Ethiopia, 2003), many problems are facing the RH systems in the Amhara and Tigray regions, several of which stem from the speed and scale of implementation. Weak site selection, erosion, siltation, and pollution and uneconomical usage of water are among the reported problems (Girma, 2009). As a result, this study has shown that good attention was not paid to site selection, runoff, sedimentation, operation and maintenance and proper use of stored water due to lack of qualified labor, scarcity of building materials, finance during and/or after the design and construction of rainwater harvesting ponds.

Conclusion and Recommendations

Rainwater harvesting tends to be one of the most promising choices for smallholder farmers in areas where water scarcity is a problem. However, there is inadequate capacity in the area of study to plan, build, and maintain rainwater-harvesting ponds caused by low inefficiencies. Farmers have complaint about the repeated instances of the collapse of structures and their inefficiencies of the components. It can be addressed by raising farmers 'involvement and commitment and necessary extension services; non-functional ponds could be preserved and the overall system's efficiencies could be enhanced and farmers' income could therefore be greatly improved.

This research was generally recommended to:

- The capacity of storage ponds to lift RHE and SE should be increased.
- Some of the design approaches and parameters used for rainwater harvesting ponds such as site selection and rainfall-

- It is necessary to monitor, maintain, and assess the household rainwater harvesting
- Excavation of rainwater harvesting ponds involves care and expertise and should be constructed in compliance with appropriate requirements.
- To reduce the loss of evaporation and raise RSE, the storage ponds should be filled with sufficient cover and the ponds should be locked to keep children and animals away.
- Increasing the participation and commitment of the farmers would retain non-functional structures.
- All rainwater harvesting ponds should be treated with a silt trap.
- Not all RH ponds received spillway. Therefore, unnecessary runoff coming from the catchment should be disposed of by spillway.
- It is necessary to strengthen the technical capacity to design and construct, as well as the capacity of experts and farmers to sustain.

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