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Low cost and Efficient Lining Material for Seepage Lose Control on Water Harvesting Structures at Holetta Catchment, Ethiopia

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Abstract: **The experiment was conducted at Holetta Research Center to identify low cost and efficient lining material for seepage control on water harvesting structures. Three year (2014-2016) field experiment was implemented to analyze the effect of different lining materials on water storage ability of water harvesting structures. The experiment was arranged in a Randomized Complete Block Design (RCBD) with four replications. Four treatments namely; T1 (Mortar), T2 (Ash), T3 (Compaction), T4 (Bentonite) were used for the study. The daily water depth was measured and the seepage rate was calculated. Then, the data was analyzed using SAS. The overall analysis for the three years data showed a high significance difference (<0.01%). The seepage rate of Treatment 4(Bentonite) is 37.60cm/day which is about 58% lower than the highest seepage rate. The economical analysis of the lining materials were performed by calculating and comparing the cost and benefit of each treatment. The cost of the treatment includes material and labor cost. The Benefit is evaluated based on their storage capability or seepage rate. The higher cost is obtained when using mortar which is 1706.33 birr/ m^3 where as the least cost (150 birr/m3) is obtained when using compaction alone. The cost analysis for lining material showed that the mortar costs higher during execute of the experiment years and the cost of compaction are least. The three years data showed that bentonite have a least seepage rate and it can hold water for a longer period. Comparing the installation cost, bentonite is not the least price but it is about 75% less than the highest price. Therefore, both the physical and cost benefit analysis indicated that bentonite performs best to harvest water for a longer period and to minimize seepage lost under the bed of the water harvesting structures and it is recommended for soil characters related to the study area considering least seepage rate and affordable price. Further study on different soil characters and climatic condition is recommended to verify and expand the result.**

Keywords: **Bentonite, efficient, lining materials, low cost, seepage rate, water harvesting.**

1. INTRODUCTION

Water harvesting systems have been successfully utilized by people in some parts of the world where water shortage exists. The application of water harvesting techniques although potentially high is still actually low in practice in Ethiopia. In order to meet the water demand for various purposes, sustainable systems of water harvesting and managing should be developed. Local approaches and indigenous experiences have to be encouraged and be applied easily at both village and household levels (Mitiku and Sorssa, 2002).

Water harvesting, which includes in-situ moisture conservation and small water storages, is and will continue to be the priority intervention in the water stressed areas of Ethiopia. This intervention has high potential for enhancing the productivity of the rain fed agriculture, recharging of the groundwater, and to some extent growing vegetables in small plots. Cistern and dugout ponds (for human and livestock water supply) are the dominant indigenous water harvesting structures used in many parts of Ethiopia for small scale irrigation and domestic and livestock water supplies. In 2003, many small ponds with a capacity of $150m^3$ - $182m^3$ were excavated for the purpose of supplementary irrigation. The ponds were constructed by mobilizing people with support from the Government and NGOs. The ponds and water tanks ($60\ m^3$) are owned by individual households, which make the operation and maintenance relatively simple. For reasons associated with the cost and the poor technical performance, replication of these measures, on the own initiatives of the farmers, is rare. Therefore, there is a need for the identification and promotion of low cost but structurally safe and stable water storage (Leul, 2006).

Water harvesting technologies have been quite helpful in rehabilitating degraded hill sides in Harar where it has so many advantages: the first advantage is conserving water for seedling establishment in the upstream area while the other is protecting the down streams from flood damage (Dereje, 2006). Despite the very important roles played by the water harvesting technologies to attain food security, some critical problems yet require immediate actions. The structural failures are connected with poor design, water loses due to evaporation and seepage, low technical capacity and subsequently low adoption by users (Rami, 2003: Goshu, 2007, Asegedew, 2005).

Development and execution of water harvesting schemes is considered as a valid strategy for food security in the country. Due emphasis is given to drought prone and highly moisture stressed areas. Accordingly, a total of about 70,000 water harvesting structures of different size were constructed only in Tigray and Amhara regions in 2002. But this effort of the regions is not free of challenges. Limitation of experience to such types of activities and absence of skilled manpower, errors in structural design, use of poor quality construction materials brought various failure histories in some areas. Leakage occurred in large number of structures and it was difficult to store harvested water as aspired by users. This didn't imply water harvesting scheme is worthless in Ethiopia, but rather it gave a good lesson for future undertakings in controlling structural failures and seepage (Rami, 2003).

In Ethiopia, many water harvesting structures have been constructed. The most critical of all the problems is the water loses due to seepage resulting from poor lining materials of the harvesting storage structures (Rami, 2003; and Tafa, 2002). Seepage takes place at the bottom as well as sides of the farm pond. It is normally high in sandy soils while it is low in loamy to clay soils. Further, seepage losses are higher in initial years of construction while it reduces slowly in one or two years due to normal siltation of clay particles coming along with the run-off water. Various sealant materials like cement, bentonite, polythene lining, brick lining, stone slab lining and few chemicals based on sodium have been tried and found effective. Normal water loss rate of 0.25cm per day is tolerable for farm ponds (Ashwani *et al*., 2010).

In many parts of the country, seepage loss reduction is mainly believed to be made possible by lining the surfaces of storage structures with geo-membrane (thick plastic sheet), reinforced mortar and compaction. The first two methods are effective but too costly to be afforded by a resource poor or even a medium income level of farmers. Compaction is less effective to meet required demand at household level (Goshu, 2007). There are also some other lining materials that can be tested for reduced seepage lose and further selected and subsequently promoted under farmers conditions. In this regard, uses of salt and household heater ash are among preferable materials used elsewhere in the world. With proper planning, site and suitable water harvesting technology selection, and installation, water availability at each plot of land can be maximized through adoption of water harvesting schemes at household level (Rami, 2003). Therefore, the general aim of this research was to identify the low cost and efficient lining material for water harvesting ponds.

2. MATERIALS AND METHODS

2.1 Experimental Site Description

The study was conducted at Holetta Research Center which is found at Holetta catchment located in the upper part of Awash River basin, Ethiopia. The study area lies at an altitude of 2069 - 3378 meters above sea level and located at a latitude range of $8^0$56'N to $9^0$13'N and longitude range of $38^0$24'E to $38^0$36' E. It is a catchment with drainage area of 403.47 km^2. The annual rainfall of the study area ranges between 818-1226 mm. The climate of the study area is described with the air temperature ranging from 6^0C to 23^0C with the mean of 14 ^{0}C.

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Table 1: Long term average monthly climatic data at Holetta Catchment

Month	***Maximum Temperature (^0C)***	***Minimum Temperature (^0C)***	***Relative Humidity (%)***	***Wind speed (km/hr)***	***sun shine (hr)***	***Rain fall (mm)***	***Reference Eto(mm/day)***
Jan	23.4	3.7	50	4.15	8.53	18.45	3.61
Feb	24.1	5.3	50	4.58	8.33	34.95	3.98
March	24.5	7.0	52	4.93	7.35	58.85	4.17
April	23.4	8.5	56	4.91	6.69	76.49	4.03
May	24.5	8.1	55	4.76	6.96	64.54	4.02
June	22.4	7.8	68	3.45	5.34	115.91	3.21
July	20.3	9.2	80	3.11	3.03	245.78	2.57
August	19.5	9.1	81	2.87	2.95	257.27	2.57
September	20.5	7.6	72	3.30	4.59	126.31	2.99
October	21.8	4.7	56	4.23	7.42	22.84	3.59
November	22.6	2.3	50	4.42	9.00	9.71	3.59
December	23.1	2.2	49	4.10	8.95	5.61	3.44
Mean	**22.5**	**6.3**	**60.0**	**4.1**	**6.6**	**86.4**	**3.5**

Table 2: Physical and chemical properties of soil at the catchment

No	**Description**	**Result**
1	Texture	Clay loam
2	Field capacity	32.56 @60cm depth
3	Wilting point	25.03 @60cm depth
4	PH	5.24
5	Ece	21.11meq/100g
6	Bulk density	1.1g/cm^3

Table 3: Physical and Chemical Properties of Holeta River

No	**Description**	**Result**
1	Ece	211µs
2	PH	7.78

2.2 Experimental field set up

The experiment has been implemented for three consecutive years, 2014-2016 at Holetta agricultural research center. An experimental field of size 18*14 was cleared and prepared. The slope of the field was managed as low as less than 1 %. Sixteen ponds having a capacity of 1.1 m^3 capacity were excavated and each ponds are 2 m apart each other. For each pond 0.1 meter was left for free access of seepage lose monitoring mission. The bottom 0.1 meter was covered with the treatments and the rest 0.9 meter was filled with water.

Figure 1: Field layout and treatment application

Four treatments (Compaction alone, Mortar, Ash and Bentonites) were laid out in a randomized complete block design (RCBD) with four replications. The ponds were established in clay soil formation. The sides of all ponds were covered with zero seepage plastic sheets so that lateral water movement was controlled. The top of the pond was entirely covered with plastic to control evaporation lose from the pond and prevent any unnecessary addition of water from the rain or run off.

2.3 Treatment application

The four treatments that were used in this experiment are mortar, ash, compaction alone and bentonite. Each treatment was prepared and covered at the bottom of the ponds.

2.3.1 Mortar lined pond

The loosened soil was compacted to a dense, tight layer with a manual compactor of 15 Kg to a depth of knee height. The number of drops of manual compacter was made to about 200 times for each pond. The thickness of the compacted layer was 0.07 meter. After compaction the base was lined with mortar for a thickness of 0.02 meter as the first coating and slurry for thickness of 0.01 meter as a second and last coating. The surface of the plastered structures was covered by sack and water was spread two times a day for five days and was made ready for wetting.

2.3.2 Ash lined pond

Local heater ash was collected from local households that use to consume cow dung, crop residue and eucalyptus wood as fire wood. The ash was spread over the bottom of the ponds and compacted with a manual compacter to a thickness of 0.1 meter.

2.3.3 Compaction alone lined pond

The experimental field was wet and after checking the optimum moisture content, the pond was compacted to a dense, tight layer with a manual compacter. The thickness of the compacted layer was 0.1 meter. After compaction, the ponds were left free for day until the first wetting.

2.3.4 Bentonites lined ponds

Bentonite is fine-textured colloidal clay with as much as 90 percent of montmorillonite. When exposed to water, dried bentonite absorbs several times its own weight of water; at complete saturation, it swells as much as eight to twenty times its original dry volume. The powdered clay can be mixed with the soil or applied as a layer of pure clay that can be buried or left on the surface. The mixed or buried layer methods are generally more durable than the surface treatment. A minimum treatment rate of one pound per square foot (4.84kg/m^2) is recommended for soils containing small amount of sand but application rate application rates can be as much as three to four pounds per square foot (14.5 to 19.4 kg /m^2) in very sandy soil. For heavy soils, 14.7 kg per square meter is sufficient while soils with high silt and sand; 29 kg per square meter is required. For medium soils, the rate of the bentonite to be applied is 21 kg per square meter (Boyer and Cluff 1972; Rollins et al. 1970; Hadden, 1989).The granular bentonite was spread at the calculated rate over the area and be sealed.

2.4 Data collection

The data collected includes metrological and climatic data (rainfall, maximum and minimum temperature, relative humidity, wind speed, sunshine hour); physical properties of soil and water (Holeta River); and daily water depth at each pond. The method of data collection was both primary and secondary data collection.

Daily data was collected in three years 2014– 2016 for two consecutive months. The seepage depth was determined by measuring the depth of water in the ponds every day using staff gauge. After the depth of water is recorded, the seepage rate (cm/day) was determined using the following equation:

$$S = \frac{V}{A} \qquad \text{…………………………Equation 1}$$

Where, V= the volume of water seeped (cm^3/day)

S= seepage rate cm/day

A= Wetted surface area of the tank (cm^2)

The volume of water will be determined as:

$$V = \frac{\Delta h}{2}\left(A_i + A_{ii}\right) \qquad \text{………………… Equation 2}$$

Where,

V is the volume of water seeped (cm^3/day)

Δh Change in depth with in 24 hrs (m)

A_i and A_{ii} are area of water surface in two consecutive days

The mean wetted surface area of the ponds (A) is determined as:

$$A = \frac{A_i + A_{ii}}{2} \qquad \text{…………………………Equation 3}$$

Where,

A_i and A_{ii} are the wetted surface area of the pond in two consecutive days.

3. RESULT AND DISCUSSION

In 2014-2016 experiment execution periods, sixteen (16) ponds in square shape were excavated and used to test the four treatments. The ponds were refilled every 24 hours and the data was taken as the same time in 24 hours. Then, the collected data was analyzed using SAS.

3.1 Seepage rate analysis

The seepage rate was calculated for the three years and analyzed using SAS software. Table 4 showed that the 2014 SAS analysis for different lining trial showed a highly significant different at 0.01 level of significance. As the table below shows, treatment 4 (bentonite) have a least seepage rate of 30cm/day and performed well as compared to others. Compaction is the last to maintain water as the seepage rate was 90cm/day which was three times higher than that of bentonite. The 2015 SAS analysis for the lining experiment showed that a highly significant different at 0.01 level of significance. As shown in the table below, treatment 4 (bentonite) have a least seepage rate of 16 cm/day. The seepage rates of the other treatments are at the same range which is about 5.6 times the seepage rate of bentonite. The 2016 SAS analysis also indicated that Treatment 4 (bentonite) is highly significance with a lower seepage rate. The overall analysis for the three years showed a high significance difference (<0.01%). The seepage rate of treatment 4(Bentonite) is 37.60cm/day which is about 58% lower than the highest seepage rate. Therefore, based on the seepage rate and storage capability, bentonite performs more efficiently than the other lining materials tested.

Table 4: Effect of different lining materials on seepage rate in 2014-2016

Lining Materials	Seepage rate (cm/day)			
	2014	**2015**	**2016**	**Over Year**
Treatment1 (Mortar)	89.9[a]	89.87[a]	82.45[a]	87.42[a]
Treatment 2 (Ash)	70.58[b]	89.77[a]	86.05[a]	83.24[a]
Treatment 3 (Compaction)	90[a]	89.77[a]	86.09[a]	88.62[a]
Treatment 4 (Bentonite)	29.9[c]	15.81[b]	69.68[b]	37.60[b]
CV(%)	31	16	25	24.25
$LSD_{0.05}$	4.89	2.17	4.16	32.5

3.2 Economic Analysis

The economical analysis of the lining materials were performed by calculating and comparing the cost and benefit of each treatment. The cost of the treatment includes material and labor cost. The benefit is evaluated based on their storage capability or seepage rate. The higher cost is obtained when using mortar which is 1706.33 birr/ m^3 where as the least cost (150 birr/m3) is obtained when using compaction alone. The cost analysis for lining material showed that the mortar costs higher during execute of the experiment years and the cost of compaction are least. The cost of bentonite is moderate as compared to ash and compaction but it is 75% less than the cost of mortar.

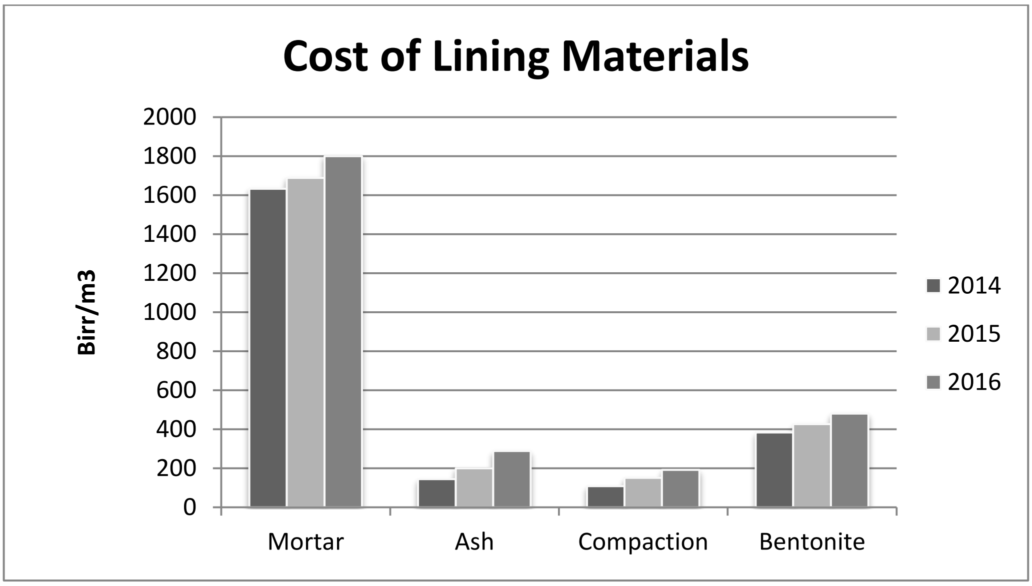

Figure 2: Average cost of different lining materials in 2014-2016

There are a lot of research findings to Bentonite clays have the ability to absorb water and expand from 10 to 15 times their original volume. This allows the plugging of pores in the soils and prevents water seepage. Wet clay will not withstand water pressure unless it is mixed with supporting soils. Bentonite clays are most effective on coarse-grained, sandy or silty soils. No more than one-half of the soils should be able to pass through a No. 200 sieve. Pond basins which have been sealed with bentonite should not be exposed to trampling by livestock (Hadden, 1989).

Bentonite may be added to a pond which contains water when draining is not practical. Granular bentonite may be distributed from a boat over the entire pond surface or over leaking areas. Powdered bentonite may be mixed with water to form slurry which may also be poured over the surface of the pond. This solution will sink to the pond bottom. Either application method will allow the expanding clay particles to plug crevices or soil pores by the pressure of the seeping water. Best results are obtained when the clay can be mixed with the bottom soils (Keese, 1988). Getahen 2013 report showed that on Luvisols application of table salt improves storage dramatically and can be used to improve storage efficiency of ponds. On the contrary, application of table salt brought no significant variation in storage efficiency on Vertisols. Hence, unlined pond is by far preferable.

Various concrete and masonry water harvesting structures (each 60 m^3 capacity) were first constructed on a trial basis in the Rift Valley (Near Nazreth - Oromia) in 1997 (Rami, 2003). The trial site consists of deep sandy soil with very deep ground water table and torrential and erratic rains. The dome-shaped concrete tanks (costing Birr 5000 in 2001) and masonry hemispherical ponds (costing Birr 3500 in 2001) were disseminated to many parts of the country especially to food and water insecure areas. In 2002 – 03 many of such structures were built mainly in Amhara Region. The merit of these structures, as observed from few successful ones, is that water loss due to seepage and evaporation is very low if properly constructed. Farmers extract water manually mainly using buckets/watering can and apply it directly to the micro basins of each tree, small furrows or to a drip system. The stored water is also used for domestic purposes and livestock when there are no better alternative sources (Leul, 2006).

4. CONCLUSION AND RECOMMENDATION

This research activity was conducted to identify the least cost and efficient lining material for water harvesting structures. Sixteen small ponds were excavated. The sides and top of the ponds were covered with plastic lining materials. Then, the bed of these ponds was covered with the four treatments (Compaction alone, Mortar, ash and Bentonites). The performance of these four treatments was tested for three consecutive years. The 2014 SAS analysis for different lining trial showed a highly significant different at 0.01 significance level. Treatment 4 (bentonite) have a least seepage rate of 30cm/day and performed well as compared to others. Compaction is the last to maintain water as the seepage rate was 90cm/day which was three times higher than that of bentonite. In 2015 & 2016, the activity was done at HARC site with the same treatments. The 2015 & 2016 SAS analysis for the lining experiment also showed that Treatment 4 (bentonite) is highly significance with a lower seepage rate. The overall analysis for the three years showed a high significance difference (<0.01%). The seepage rate of Treatment 4 (Bentonite) is 37.60cm/day which is about 58% lower than the highest seepage rate. Therefore, based on the seepage rate and storage capability, bentonite performs more efficiently than other lining materials tested. The three years data showed that bentonite have a least seepage rate and it can hold water for a longer period. Comparing the installation cost, bentonite is not the least price but it is about 75% less than the highest price. Therefore, both the physical and cost benefit analysis indicated that bentonite performs best to harvest water for a longer period and to minimize seepage lost under the bed of the water harvesting structures and it is recommended for soil characters related to the study area considering least seepage rate and affordable price. Further study on different soil characters and climatic condition is recommended to verify and expand the result.

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