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Evaluation of Different Lining Materials for Seepage Lose Control on Water Harvesting Structures at Raya Valley, Northern Ethiopia

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Abstract
Water harvesting has been practiced for many years in several regions globally and is mainly used for domestic or agricultural purposes. Water harvesting with tanks and ponds is one option to increase water availability and agricultural production at the household level. Seepage loses through soils has a great influence on their stabilities and performances water harvesting, and seepage control is a critical technological issue. A field experiment was conducted for two consecutive seasons (2013/14 and 2014/15) at Mehoni Agricultural Research Center, Ethiopia 12° 51'50" N latitude, 39° 68'08" E longitude and 1578 masl altitude with the objective to identify the best low cost lining material for water harvesting pond. Four treatments Compaction alone, Mortar, ash (local heater) and benthonites were used to evaluate the different lining materials for seepage loses control. Randomized completely block design (RCBD) with four replication was used. Results indicated that ash and compaction alone was gave lowest in seepage loses control and cheap in material and labour cost. Bentonite more reduced seepage loss, lower reduction in depth of the pond and expensive in material and labour cost as compare to the other lining materials. In the other hand mortar was gave relatively similar result in seepage lose control, lower reduction in depth, but cheapest in material cost than bentonite.
Keywords: Lining Material, Pond, Seepage, Water Harvesting

1. Introduction

Water harvesting and conservation systems are functions of different natural factors such as the amount and frequency of rainfall, climate, topography and properties of the soils. These natural factors can impose limitations on the efficiency of water harvesting activities (Kronen, 1994).

The expansion and rapid adoption of the water harvesting techniques in developing countries to improve yields of crops per a given land unit has been limited by the lack of expert technical knowledge and capital resources (Stephens and Hess, 1999).

Harvested water for irrigation needs to be managed and used efficiently (Panigrahi et al., 2001; Fox and Rockstrom, 2003). In order to achieve the best economic return from harvested water suitable crops that can provide maximum return and their growing patterns have to be chosen carefully. Water harvesting improves overall production, improves environmental quality, reduces cropping risk and enhances food sufficiency. The importance of managing harvested water in order to increase overall food production to alleviate famine in many areas of the developing world has to be institutionalized (Prinz, 1994; Yuan et al., 2003).

Deforestation and the expansion of desert to arid and semi-arid areas create moisture stress which aggravates land degradation and consequently leads to decline in food production. In order to bring sustainability to rural economies, water harvesting techniques and community based small-scale irrigation schemes are considered strategic development initiatives (Li et al., 2004).

According to reports of UN officials, Ethiopia is among the nine countries of Africa which possesses great potential for RWH. Though the technology dates back to the Axumite period (560 BC) (Fattovich 1990), it was only after 2003 that the Ethiopian government recognized its importance and promoted it on on-farm rainwater ponds.

A large number of water harvesting technologies have also been implemented with support from the Government of the Federal Democratic Republic of Ethiopia (FDRE, 2000). For instance, an assessment indicated that more than 300, 000 shallow wells, about 206, 200 house hold level structural ponds, 49, 311 community ponds, 5,635 cisterns have been constructed and a total of 32, 727 springs have been developed.

Ethiopia is known to be a water tower of Africa and water resource couldn't be a limitation for its agricultural development and domestic consumption. Reports from ministry of Agriculture indicated a total of more than two million households living in about 90 or more districts annually suffer from critical water shortage. These areas are highly drought prone and as a result the lives of more than 12 million people were badly affected by water shortage annually. Ethiopia is known to be a water tower of Africa and water resource couldn't be a limitation for its agricultural development and domestic consumption. The major challenge the country is facing in this regard is collecting and storing the resource when it falls as a rain, and efficient distribution and utilization when the rain stops (Rami, 2003).

Research reports (Hussien and Hanjra, 2003) have confirmed that RWH directly boosts yields and gives farmers the ‘water security’. This implies that RWH users could be engaged in enhancing productivity inputs.

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). Hence technologies providing good protection towards seepage loss have been given a priority (Rami, 2003, Goshu, 2007). With a view of this, some research works have been conducted to identify the best lining materials that substantially reduce water lose due to seepage. The study was conducted with the objective to identify the best low cost lining material for water harvesting pond.

2. Materials and Methods

2.1. Description of experimental area

The experiment was carried out under Mehoni Agricultural Research Center during the season of 2013/14 and 2014/15 for two consecutive years. It is situated at an altitude of 1578 meter above sea level (m.a.s.l). The area is characterized by bimodal rainfall pattern with a short rainy season (belg) and (kirmet), a long term average rainfall of 300 mm, and its average minimum and maximum annual temperature is 18 ^{0}C and 32 ^{0}C, respectively. Geographically the experimental site is located between 12° 51'50" North Latitude and 39° 68'08" East Longitude. The soil textural class of the experimental area is clay with pH of 7.1-8.1 (MehARC, 2015).

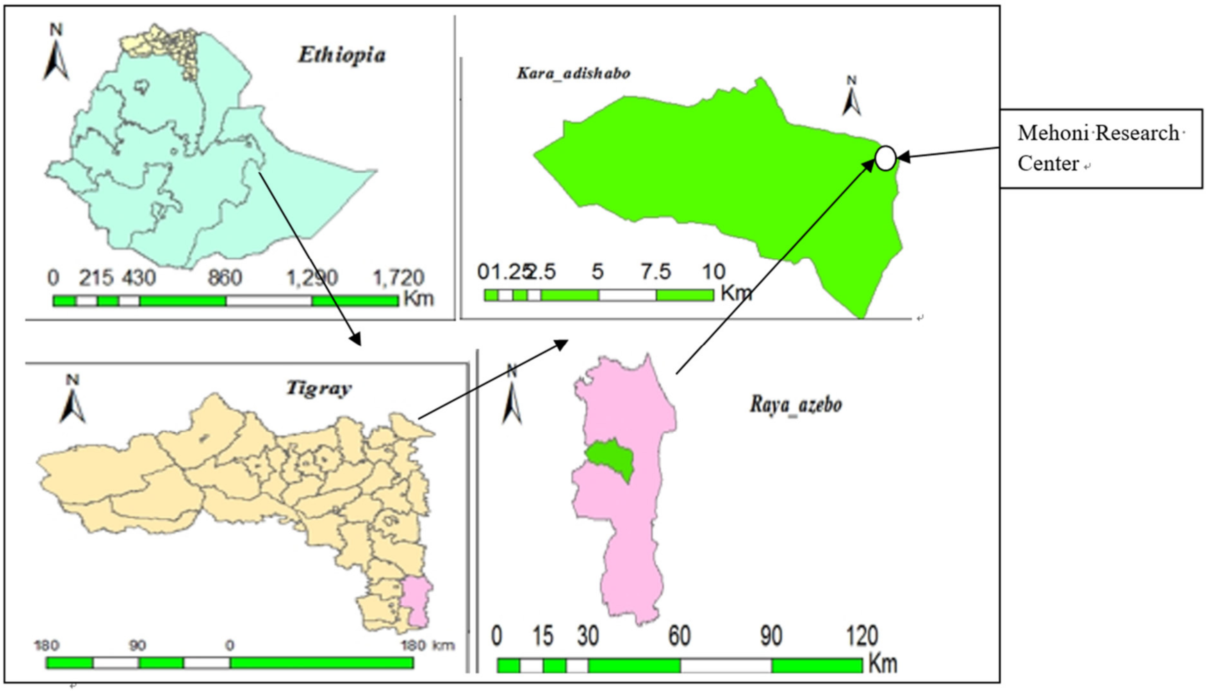

Figure 1. Map of the study area

2.2. Experimental treatment and design

The experiment included four treatments of different lining materials are compaction alone, mortar, ash (local heater) and benthonites.

Table 1:- Treatments description

Treatments	Description
Treatment 1	Mortar
Treatment 2	Compaction alone
Treatment 3	Ash (local heater)
Treatment 4	Benthonites

2.3. Field experimental design

The experiment was designed as a single factor experiment in randomized complete block (RCBD) arrangement with four replications. A 17 m by 14 m experimental field was cleared and prepared. The slope of the land was managed less than 1 % and a total of sixteen ponds in square shape were excavated. Each pond of 1.1 m^3 capacity was dug to 2 m apart. 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 that part which covered by water and the hydraulic depth, for maintaining a constant water head.

The ponds were digging in clay soil formation having and the sides of all ponds covered with zero seepage plastic sheets so that lateral water movement were checked. To control evaporation lose from the pond and prevent any unnecessary addition of water from the rain or run off, the pond top was entirely be covered with geo-membrane.

2.4. Treatment preparations

Mortar:
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 thicknesses of the compacted layer were 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 spread two times a day for five days and made ready for wetting after 7 day apply the treatment.

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

Compaction alone
The field was wet and by 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. The compaction the ponds were left free until the first wetting.

Benthonites:
The loosened soil was compacted to a dense, tight layer with a manual compactor of 15 Kg to a depth of knee height. The thicknesses of the compacted layer were 0.08 meter. After compaction the base was lined with benthonties for a thickness of 0.02 meter.

2.5. Data collection

The data were collected for this activity is seepage rate. The rate is measured the amount of water leaked from the ponds per day. It was determined by measuring the depth of water in the ponds every day using ruler. After the depth of water is recorded, the seepage rate (Cm/day) was determined using the following equation:

$$S = \frac{V}{A} \tag{1}$$

Where
V= the volume of water seeped (cm^3/day)
S= seepage rate cm/day
A= Wetted surface area of he tank (cm^2)

The volume of water was determined as:

$$V = \frac{\Delta h}{2}\left(A_i + A_{ii}\right) \tag{2}$$

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:

$$A = \frac{A_i + A_{ii}}{2}$$

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

2.6. Data analysis

Analyses of variances for the data recorded were conducted using SAS 9.1 statistical software carried out using least significance difference (LSD) test at 5% probability used for mean separation when the analysis of variance indicated the presence of significant treatment differences.

3. Result and Discussion

The required data on daily variation of seepage rate differences was continuously collected for two seasons. Data analysis work was done using SAS software. Result of analysis was summarized and presented for each parameter.

3.1. Surface area reduced

The analysis of variance revealed were significant (P <0.01) affected by the different treatments.

Mean values for surface area reduced per pond were increased from the benthonites, mortar and ash to compaction alone with the values of 17.6, 20.63, 24.68 and 26.62 cm/day respectively (Table 2). From the analysis of variance was obtained compaction alone having highest reduction in surface area, were as benthonites was gave the lowest reduction in the surface area of the pond. This result was indicated benthonites have the capacity of less seepage to the vertical direction as compare the other treatment. Statically there were no statically differences between ash and compaction.

Benthonites were saved in surface area reduction with 33.9%, 28.7%, and 14.7% as compare to compaction alone, ash and mortar respectively.

3.2. Depth reduction per day

Results showed that compaction of pond reduction per day (15.85cm/day) were higher than the other treatments. In the other case, benthonites was recorded lower reduction (9.36cm/day) in depth in each of two consecutive days, followed by mortar and ash. This due to higher binding behaviour of benthonites reduced daily seepage loss. Statistically no significant differences observed between ash and compaction of the pond.

3.3. Volume reduced per day

As indicated in the Table 2 compaction of pond was recorded higher (418.08cm^3/day) reduction of volume per day as compare of the other treatments. The lower rate (174. 22 and 232.312cm^3/day) reduction of volume per day per ponds were observed in benthonites and mortar followed by ash. In the reduction of volume per day between benthonites and mortar there were no significant differences.

3.4. Seepage rate

Table 2 indicated that there was highly significant variation on seepage rate among experimental treatments at 1% level of significance. Seepage rate was significantly influenced (p<0.01) due to different types of lining materials. The maximum seepage rate of 15.85cm/day was obtained from compaction treatment of ponds and followed by ash with the value of 13.95cm/day/pond. The minimum seepage rate of 9.36 and 11.31 cm/day/pond was observed from benthonites and mortar respectively due to higher capacity of seepage loss control. This result was agreed with (Silva and Uchida, 2000) pore plugging and cement like structure in-turn impedes water flow and water infiltration into the soil.

Table 2. Main effects of lining materials on Surface Area Reduced (SAR), Depth Reduced (DR) Volume Reduced (VR) and Seepage Rate (SR) per pond

Tre	SAR (cm/day)	DR (cm/day)	VR (cm^3/day)	SR (cm/day)
Mortar	20.63^b	13.11^b	232.31^c	11.31^b
Compaction alone	26.62^a	15.85^a	418.08^a	15.85^a
Ash	24.68^a	13.95^a	340.13^b	13.95^a
Benthonites	17.60^c	9.36^c	174.22^c	9.36^c
LSD (P=0.05)	3.00	1.92	74.5	1.92
CV	12.18	13.98	13.47	13.98

Means in columns followed by the same letter are not significantly different (P<0.05) according to LSD test; CV: Coefficient of variation; LSD = Least significant difference

3.5. Labour and material cost

The total labour and material requirement for each pond in Table 3 was indicated below. The higher labour and material cost for the lining material of benthonites (550 birr/1m^2 / Pond) was recorded. This is due to benthonites not easily available in the market and their cost also high as compared the other lining materials. In the other hand Compaction was recorded lower cost, followed by ash and mortar.

Table 3. Labour and materials used for construction of lining materials and their cost per one pond in the study area

Trea	Cement	Benotite	Labour	Geo- membrane	Total Cost (birr)
Mortar	32.5	-	125	225	382.5
Compaction alone	-	-	75	225	300
Ash	-	-	100	225	325
Benthonites	**-**	200	125	225	550

3.6. Compare between seepage rate and volume reduced

As indicated in figure 2 the reduction of the volume of the pond was having direct relationship with the seepage rate loses from the pond. Compaction of the pond were resulted the highest loses in seepage rate and volume reduction as compare of the other lining materials. In the other way benthonites was gave the lowest seepage rate loses and volume reduction.

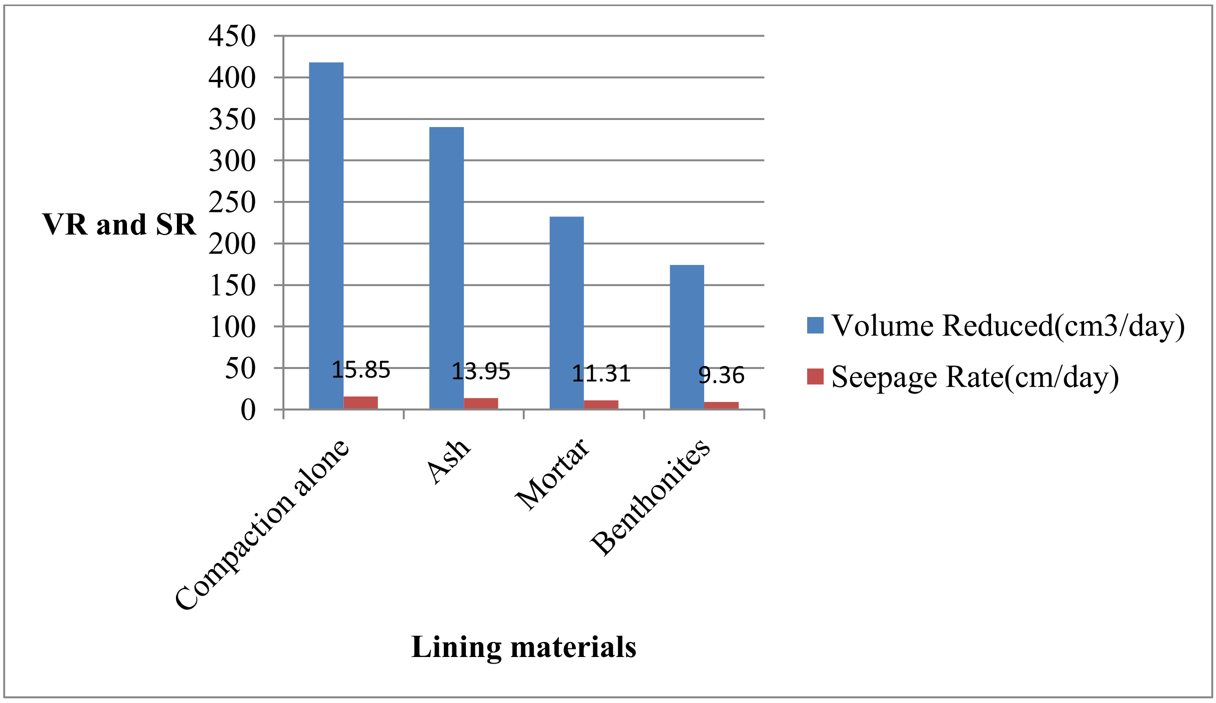

Figure 2. Compare between seepage rate and volume reduced with lining material

3.7. Compare lining materials and total cost

Total cost the sum of all labour and material cost per one pond that was used during the experimental season. As can be seen from figure 3 compacted pond resulte the cheapest birr/pond as compared with other lining materials and followed by ash and mortar. Benthonites was resulted the highest (550birr/pond) as compare the other lining materials.

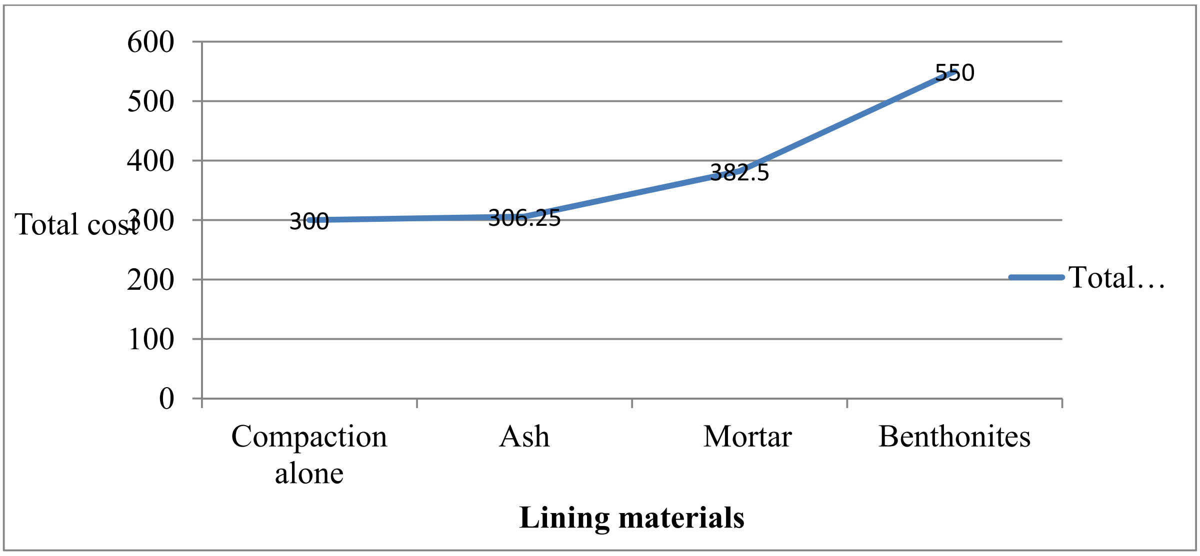

Figure 3. Labour and material cost of lining materials

4. Conclusion

This Experiment was conducted in Mehoni Agricultural Research center (MehARC) test station in 2013/2014 and 2014/15 to identify the best low cost lining material for water harvesting pond. Based on the results of the study, bentonite more reduced seepage loss as compare to the other lining materials. On the contrary, the cost of material and labour was higher than the other lining materials and was not easily accessible. Mortar was give comparatively good performances on seepage losses control and less material and labour cost as compare to bentonites. Ash and compaction alone was gave least in seepage loses control and cheap in material and labour cost.

Generally it can be concluded that, mortar was preferable in the study area based on the seepage loses control and material and labour cost.

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Competing Interests
Authors have declared that no competing interests exist.

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