International Journal of Development and Sustainability
Online ISSN: 2168-8662 – www.isdsnet.com/ijds
Volume 2 Number 2 (2013): Pages 1623-1635
ISDS Article ID: IJDS13051508

ISDS JOURNALS

Special Issue: Development and Sustainability in Africa – Part 2

Comparative analysis of lining materials for reduction of seepage in water harvesting structures, Adet, Ethiopia

Menelik Getaneh [1*], Amare Tsigae [2]

[1] *Amhara Region Agricultural Research Institute, P.o.Box 527, Bahir-Dar, Ethiopia*
[2] *Adet Agricultural Research Center, P.o.Box 08, Bahir-Dar, Ethiopia*

Abstract

Rain Water harvesting is the artificial collection, storage and use of runoff or rain water. The water harvesting with tanks and ponds is one option to increase water availability and agricultural production at the household level. This experiment was designed to explore different lining materials that can improve storage efficiency of small household rainwater harvesting ponds. The experiment was conducted at Adet agricultural research center on two sets with luvisols and Vertisols, the two dominant soil types in the research farm between 2009 and 2011. On Luvisols four types of pond lining techniques were tested (clay lining (15cm thick), soil + cement lining (1:5 ratio), Table Salt (at a rate of 2kg/m^2) lining, and Geo-membrane). But on the Vertisols only two lining materials were taken (i.e. Clay lining (15cm thick), salt lining (at a rate of 2kg/m^2)). In both cases unlined pond was included as a control. Required data on daily variation of storage depth and water temperature was continuously monitored throughout the experimental period. Based on the result of analysis, the variation in storage efficiency was seen only in Luvisols. Application of salt considerably improved storage in these types of soils. But in Vertisols storage efficiency didn't show improvement with application of salt. Regarding the change in temperature, no significant variation was seen between treatments on both types of soils. Geo-membrane was also proved to have not as such significant change in temperature as compared to the other treatments. Furthermore, the cost of labour and salt is by far smaller for salt treated ponds than the other treatments. Application of salt improved storage efficiency of pond from 0.24 to 0.87 on Luvisols. Moreover, the cost of the pond is smaller as compared to other treatments.

Keywords: Rain water harvesting, Lining materials, Seepage

Cite this paper as: Getaneh, M. and Tsigae, A. (2013), "Comparative analysis of lining materials for reduction of seepage in water harvesting structures, Adet, Ethiopia", *International Journal of Development and Sustainability,* Vol. 2 No. 2, pp. 1623-1635.

Note: This is "In Press" version of the article and page numbers are not for citation purposes.

[*] Corresponding author. *E-mail address:* miniget@gmail.com

1. Introduction

The ever increasing food requirement of Ethiopian population cannot be alleviated by working only on the existing rain-fed based agriculture. Dependable and sustained food self sufficiency and food security at household level in Ethiopia calls for improved agricultural practices and development of irrigated agriculture. Irrigation scheme development should be done at various levels using different alternative water sources. This may require diversion of rivers, construction of macro and micro dams, and establishment of water harvesting structures at household level (Awulachew et al., 2005).

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).

Ethiopia has tremendous water resource potential as compared to many African countries. It has mean annual rainfall of about 1090mm even though it is unpredictable and increasingly erratic in its nature. Soil degradation is high and about 110 billion cubic meters of valuable surface water is lost from the country annually (Rami, 2003). Moreover, 4.6 billion cubic meters of estimated ground water resource is available in Ethiopia. This huge sum of untapped resource can be valuably used for enhancement of the agricultural production if proper mechanism is developed for its storage and utilization.

On the contrary, irrespective of this striking water potential, large scale dams and irrigation projects are not extensively constructed in the country. This is due to the costly nature and inherent large capital investment requirement of such projects. Hence, the federal government developed water harvesting schemes which can be adopted at household level with relatively cheaper cost using house hold labor. As a result, water harvesting tanks and ponds were proposed as practical and effective alternatives. Supplemental irrigation can be made possible by making use of stored rain water to mitigate moisture stress and sustain agricultural production at household level. This in turn makes farming families less vulnerable to drought and less reliant on outside assistance (Rami, 2003).

As a result, 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. 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). Hence, this research was designed with two objectives: 1) to quantify storage efficiency of water harvesting structure 2) to select lining material with reasonable cost and seepage loss.

2. Materials and methods

In the year 2009/10 the first set of ponds with four types of pond lining techniques were tested (clay lining (15cm thick), soil + cement lining (1:5 ratio), Table Salt (at a rate of $2kg/m^2$), Geo-membrane and Control) were constructed on Luvisols and in 2010/11 the other set of ponds was constructed on black (Vertisols) at Adet research station. Three treatments (i.e. control, clay lined and table salt treated ponds) were tested in the second set. These treatment combinations are selected because, most of them are currently in use for water harvesting in Ethiopia.

Before starting the actual excavation work, the lay out work was done first. Square plots of area 3mx3m were marked on the ground using pegs (Figure 1).

Figure 1. Land lay out work

Figure 2. Land leveling work

Figure 3. Edge of the pond

From the edge of these squares 0.5m area is marked around each square and leveling work is done only on this part rather than leveling the whole plot area (Figure 2). This area later served as the edge of the pond and as a zero level for the pond (Figure 3). Pond excavation work was then started step by step and layer by layer down to one meter depth. To attain the actual pond side slope of 1:1 (H: V) we followed two types of excavation procedures, refill and cut type (Figure 4).

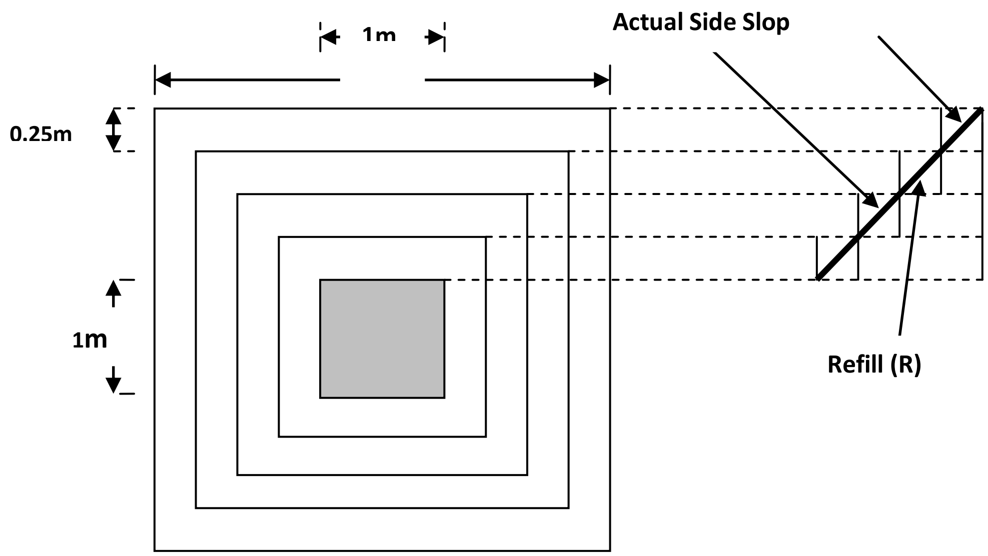

Figure 4. Pond construction technique used at Adet during 2009/10

For the cut type procedure 25cm was measured inside the 3m X 3m square area from the edges and marked by pegs at the four corners. The area was enclosed with Nylon rope and the remaining 2.5mx2.5m square area was excavated to a depth of 25cm. Again after maintaining 2.5mx2.5m square and level area, another 25cm is measured inside this square from each edge and 2mx2m square area is delineated. This square plot is again excavated to a depth of 25cm. This procedure is repeated up until a total of 1m depth and 1m X 1m square bottom area is obtained (Figure 5).

Figure 5. Step by step digging procedure followed during pond construction at Adet

Figure 6. Clay re-filling technique used at Adet

For the fill type ponds also the procedure was the same. The only difference was that at the inception the first square to start working on had a size of 3.5mx3.5m rather than 3mx3m as opposed to the previous condition. In the fill type ponds (i.e. Clay lined pond, Cement+soil filled ponds), the actual side slope 1:1 (H:V) was obtained by systematically filling the aforementioned materials.

For the clay fill pond, clay material (Vertisol) was transported to the area and step by step filling was done starting from the base by compaction (Figure 6). Small amount of water was applied during compaction to moisten and facilitate binding of the soil material. Then the set of stairways were re-filled carefully up until the desired side slope (1:1) and smooth surface was finally maintained (Figure 7).

Figure 7. Actual shape of clay lined pond

Figure 8. Actual shape of cement + soil lined pond

For cement +soil filled pond, cement and excavated soil material were mixed in 1:5 ratio. The bottom area of the pond excavated to 15cm depth and re-filling of the subsequent stairs started from the base of the pond (Figure 8).

For the remaining ponds (i.e. Geo-membrane lined pond, Table salt treated pond and Control), side slope was maintained by carefully re-shaping the subsequent stairs step by step. In the geo-membrane lined pond, the pond surface was covered with plastic sheet after smooth 1:1 (H: V) side wall was maintained. The edges of the plastic sheet were buried under soil by digging ditch around the edge of the pond (Figure 9).

Figure 9. Geo-membrane lined pond

Figure 10. Table salt treated pond

For the table salt treated pond, around 11.5kg of table salt was dissolved in water and applied on the pond surface at a rate of 2kg/m^2 during the first application. Again after a week the remaining 11.5 kg was applied (Figure 10). The control pond is also excavated in the similar fashion by reshaping the subsequent stairs and was left untreated (Figure 11).

Finally, the edges of all ponds were constructed with stone masonry so as to avoid uncontrolled entry of external runoff into the pond (Figure 12). To monitor the daily water level (depth) in the pond, stationary graduated measuring bar was prepared from iron bar by painting, leveling and with concrete footing. Totally, five ponds on Luvisols and three ponds on vertisols were constructed and filled with water and the respective data collection process continued accordingly. Finally, daily storage efficiency and Present Effective cost per unit volume, labour and material requirement were calculated for each pond.

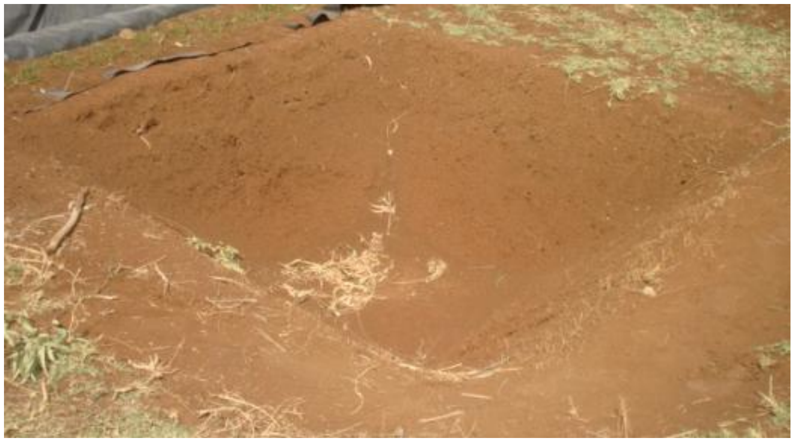

Figure 11. Control

Figure 12. Final Experimental Setup

2.1. Daily storage efficiency

The daily storage efficiency (SE) was calculated by making use of the relation indicated below.

$$SE = \frac{Water\ Input - Loss}{Water\ Input} \text{ ------------------------------------- } (1)$$

The storage efficiency of the two sets of soil types (Luvisols and Vertisols) was treated independently.

2.2. Present effective cost per unit volume (PEC)

It is defined as:

$$\text{PEC} = \frac{Cost\ of\ Constraction}{Storage\ Volume * Storage\ Efficiency} \text{ ----------- } (2)$$

3. Results

Required data on daily variation of storage depth and water temperature was continuously collected for two seasons. Data analysis work was done at the end of the season using simple t-test with SAS software. Result of analysis was summarized and presented in tables for each parameter.

3.1. Daily storage efficiency

3.1.1. Luvisol

The results of storage efficiency were subject pair wise comparison using t-test with SAS software. Results of analysis on Luvisols showed (Table 1), existence of significant difference in daily storage efficiency between the control and other treatments.

Table 1. Storage efficiency and temperature of ponds with different lining materials compared at Adet during 2009/10 to 2010/11 on luvisols

No.	Treatment	Storage efficiency	t-test (Prob.)	Temperature Change (^{o} C)	t-test (prob.)
1	Clay	0.29	*	9.2	ns
2	Cement+Soil	0.74	*	8.5	ns
3	Table salt	0.87	**	8.7	ns
4	Geomembrane	0.99	**	9.7	ns
5	Control	0.24		9.1	

**- Significant **- Highly significant ns- Non significant difference*

Salt treated pond showed better storage efficiency next to the geo-membrane lined pond. In this experiment table salt was applied in the soil to create sodium-induced clay dispersion on the soil. The principle works in such a way that dispersed clay particles within the soil solution can clog soil pores when the particles settle out of solution. Additionally, when dispersed particles settle, they form a nearly structure-less cement-like soil depending on the sodium concentration and clay type. This pore plugging and cement-like structure in-turn impedes water flow and water infiltration into the soil (Silva and Uchida, 2000).

On the other hand, analysis of the temperature change showed absence of significant difference between treatments. The change in temperature showed an increasing trend from the month of July to January. Water surface heating in geo-membrane covered ponds is not different from others.

3.1.2. Vertisol

As described earlier, only three of the treatments (bare/control, Table salt treated and Clay lined ponds) were taken and tested on Vertisols. Results of analysis proved (Table 2) absence of significant difference both in storage efficiency and change in water temperature between the control and other treatments.

Table 2. Storage efficiency and temperature of ponds with different lining materials compared at Adet during 2009/10 to 2010/11 on Vertisols

No.	Treatment	Storage efficiency	t-test (Prob.)	Temperature Change	t-test (Prob.)
1	Control	0.974		8.4	
2	Table salt	0.976	ns	8.6	ns
3	Clay	0.984	ns	8.2	ns

3.2. Present effective cost per unit volume

The value for the present effective cost varied between 522 birr/m^3 (for Soil + Cement) and 125 birr/m^3 (for salt treated pond). As can be seen from Table 3 salt treated pond resulted into least (125 birr/m^3) present effective cost per unit volume.

Table 3. Present effective cost per unit volume of water for ponds with different lining materials compared at Adet during 2009/10 to 2010/1

Treatment	Cost (Bir)	Storage efficiency	Storage Volume(m^3)	Present effective cost/volume (bir/ m^3)
I. Luvisol				
1. Clay lining	540	0.29	3.6	517
2. Soil +cement lining	1390	0.74	3.6	522
5. Table salt treated pond	391	0.87	3.6	**125**
6. Geo-membrane lining	790	0.99	3.6	222
7. Control	315	0.24	3.6	365
II. Vertisol				
1.Control	585	0.974	3.6	167
2. Table salt	750	0.976	3.6	213
3. Clay	915	0.984	3.6	258

3.3. Labour and material requirement

The total labour and material requirement for each pond (Table 4) was summarized below. The overall cost of construction is also indicated. The labour and material requirement is maximal for Soil + Cement lined pond.

3.4. Laboratory experimentation

Equal volumes of disturbed soil samples (Figure 13) were taken in four buckets from both soil types (Luvisols and Vertisols) and treated with table salt at a rate of 2 kg/m^2 under controlled / laboratory condition.

Table 4. Labour and materials used for ponds with different lining materials compared at Adet during 2009/10 to 2010/11

Treatment	Labour (no.)	Cement (qt)	Geo-membrane (m^2)	Sand m^3	Chicken mesh (m^2)	Table salt (kg)	Cost birr
I. Luvisol							
1. Clay lining	36		-		-		540
2. Soil +cement lining	26	2.5	-		-		1390
3. Table salt treated pond	23	-	-			23kg	391
4. Geo-membrane lining	26	-	16		-		790
5. Control	21	-	-		-		315
II. Vertisol							
1.Control	39						585
2. Table salt	48					23	750
3. Clay	61						915

Figure 13. Storage characteristics of table salt treated and un-treated soils compared at Adet during 2009/10 to 2010/11

Electrical conductivity of water sample, Texture, exchangeable sodium, calcium and magnesium of the soil were analyzed for each treatment after fifteen days and the results were summarized in the following table. Sodium adsorption Ratio (SAR) is a widely accepted index for characterizing soil sodicity. When SAR is greater than 13, the soil is called sodic soil. Excess sodium causes poor water movement and poor aeration.

ESP is also another index that characterizes soil sodicity. By definition, sodic soil has an ESP greater than 15 (Leticia et al., 2012).

Table 5. Results of laboratory analysis of stored water and soil samples at Adet during 2009/10 to 2010/11

Item	Unit	Luvisol control	Luvisol salt-treated	Vertisol control	Vertisol salt-treated
Clay + Silt	%	98	98	94	98
Silt	%	80	82	78	86
Clay	%	18	16	16	12
Sand	%	2	2	6	2
Texture	Class	heavy clay	heavy clay	heavy clay	heavy clay
Electrical conductivity (EC) of water	micro mhos/cm	36	**231**	44.8	**612**
Ca + Mg	mleq/100gm	21.78	25.02	38.97	25.78
Exchangeable Ca	mleq/100gm	16.47	7.02	28.08	8.19
Exchangeable Mg	mleq/100gm	5.31	18	10.89	17.55
Exchangeable Na	mleq/100gm	0.086	2.056	0.19	22.063
Sodium adsorption ratio(SAR) of soil		0.026	**0.581**	0.043	**6.15**
Exchangeable Sodium percentage(ESP) of soil	%	0.4	**7.6**	0.5	**46.2**
NB In clay soils exchangeable sodium percentage of 5 is considered high.					
Low salinity water 0< EC <=250, Medium salinity water 250< EC <=750, High salinity water 750< EC <=2250, Very high saline water 2250< EC <=5000 micro mhos/cm					

A measure of water salinity that is important for crop yield is Electrical Conductivity (EC). The higher the EC the higher the level of salts in the water and the more difficult it is to grow plants with that water. Increasing salinity affects growth mainly by reducing the plants ability to absorb water (Robert and Richard, 1999).

Electrical conductivity (EC) of water for table salt treated Luvisols (231 micro Siemens) is low implying low salinity level (Table 5). But samples taken from Vertisols (612 micro Siemens) show medium salinity. This implies that the stored water can safely be used for irrigation. Moreover, the exchangeable sodium percentage (ESP) is greater than 5 indicating presence of high exchangeable sodium in both types of soils. Moreover, ESP in salt treated vertisols is more than the critical sodicity level.

4. Conclusions

Significant Variation in storage efficiency was seen only in Luvisols as compared to the Vertisols. Clay filled ponds were seen to be less effective. This may be due to existence of internal crack in the structure and presence of loose interface between the two clay layers. On the contrary, application of Sodium Chloride

/NaCl/ considerably improved storage in Luvisols. But in Vertisols storage efficiency didn't show improvement with application of table salt. This could be due to absence of sodium-induced clay dispersion in the soil to create clogging of pores. Applications of salts disperse soil aggregates, which in turn reduce the number of large pores in the soil. These large pores are responsible for aeration and drainage. A negative effect from the breakdown of soil aggregates is soil sealing and crust formation (Stephen, 2002). Regarding the change in temperature, no significant variation was seen between treatments on both types of soils. Geo-membrane was also proved to have not as such significant change in temperature as compared to the other treatments. Hence, it will have no different evaporation as compared to the other treatments. Furthermore, the cost of construction is by far smaller for table salt treated ponds than the other treatments.

Laboratory assessment also vividly proved dramatic improvement of storage with salt application. Moreover, analysis result of the stored water after treatment showed low to medium salinity, implying the stored water can safely be used for irrigation. But its impact on crop should be assessed further in future research. Impact of salt on soils other than Luvisols and Vertisols should be seen further. The amount of salt to be applied and the effective duration/life span of the applied salt also needs further research. Moreover, the result should be seen at large scale by increasing the size and volume of pond and with introduction of different test crop having varied salt tolerances.

Generally it can be concluded 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.

References

Awulachew, S.B., Yilma, A.D., Loulseged, M., Loiskandl, W., Ayana, M. and Alamirew, T. (2007), "Water Resources and Irrigation Development in Ethiopia", Working Paper (123), International Water Management Institute, Colombo, Sri Lanka.

Leticia, S.S., Uttam, S. and David, E.K. (2012), "Soil Salinity Testing, Data Interpretation & Recommendation", Working paper (1019), University of Georgia, United States, 31 May.

Rämi, H. (2003), "Ponds Filled with Challenges: Water Harvesting Experiences from Amhara and Tigray", United Nations Office for the Coordination of Humanitarian Affairs-Ethiopia, UNOCHA – Ethiopia.

Robert, H. and Richard, T.K. (1999), "Water salinity and crop yield", Working paper (AG-425.3), Utah State University, Logan, UT 84322, United States, December.

Silva, J.A. and Uchida, R. (2000), Plant Nutrient Management in Hawaii's Soils, Approaches for Tropical and Subtropical Agriculture, College of Tropical Agriculture and Human Resources, University of Hawaii, Manoa, United States.

Stephen, R.G. (2002), "Irrigation water salinity and crop production", available at: http://anrcatalog.ucdavis.edu/pdf/8066.pdf (accessed 15 December 2012).