Comparative Analysis of Lining Materials for Reduction of Seepage in Water Harvesting Structures at Adet, West Gojam

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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.

Key words: Rain Water harvesting, Lining materials, Seepage

Introduction

Irrigation is one means by which agricultural production can be increased to meet the growing food demands in Ethiopia. A study also indicated that one of the best alternatives to consider for reliable and sustainable food security development is expanding irrigation development on various scales, through river diversion, constructing micro dams, water harvesting structures, etc. (Awulachew et al. 2005).

Excluding the purely pastoralist areat !n psf!ui bo!: 1!X psfebt !x jui !b!upubm!pg!n psf!ui bo! two million households in Ethiopia are drought prone and regularly hit by severe water shortage according to the ministry of agriculture. This seriously threatens the lives of more than 12 million people. But Ethiopia is not the country poor in water. The challenge is keeping and preserving the precious resource when it falls abundantly from the sky and then store and distRibbute it wisely for efficient use when the rains stop (Rami, 2003).

Fui jpqjb t!n fbo annual rainfall reaches approximately 1090mm. However, 70% of the total arable land receives annual rainfall of less than 750mm, while an estimated 110 billion cubic meters of rainwater annually are lost through surface runoff (Rami, 2003). This is the equivalent to a one meter deep square pond with sides of 330km or a full river ten meters deep , 100 meters wide and hundred and ten thousand kilometers long! The ground water resource is impressive as well, estimated at 4.6 billion cubic meters. Fui jpqjb t! water potential is huge and harnessing it is the challenge facing the government and the people of Ethiopia.

Nevertheless, large-scale dam and irrigation projects have not been widely implemented in Ethiopia as they have often proved to be too expensive and demanding construction and maintenance. Therefore, water harvesting tanks and ponds at the village or household level are proposed as a practical and effective alternative to improve the lives of rural people at little cost and with minimal outside inputs. In theory, household water harvesting can be done mainly through the effort of individual farmer. Use of stored rainwater could supplement natural rainfall and make farming families less vulnerable to drought and therefore less dependent on outside help in hard times (Rami, 2003).

Pof! pg! ui f! n bjo! qjmbst! pg! ui f! Fui jpqjbo! hpwfsonfou t! gppe! tfdvsjuz! tusbufhz! jt! ui f! development and implementation of water harvesting schemes mainly in the drought prone and chronically drought affected areas of the country. In Amhara and Tigray a total of approximately 70,000 ponds and tanks were constructed in 2002. Implementers on all levels struggle with a range of problems, many of which originate from the speed and scale on which the water harvesting program is being implemented. Flaws in the design of the structures, insufficient building experience, luck of skilled personnel and shortage of materials were some of the problems. Currently, a very large number of dpn qmfufe! ui bol t! tjn qmz! ejeo ut i pme! x bufs! boe! bsf! mfbl joh/! Ui jt! pg dpvstf! epfto ut necessarily mean that the concept is wrong. The water harvesting with tanks and ponds is one option to increase water availability and agricultural production at the household level (Rami, 2003). This work was designed with two objectives: 1) to quantify storage efficiency of each structure 2) to select lining material with reasonable cost and seepage loss.

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. Seven square plots of area 3mx3m were marked on the ground using pegs.

Fig. 1. Lay out of pond Fig. 2. Land leveling Fig.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. This area later served as the edge of the pond and as a zero level for the pond. 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.

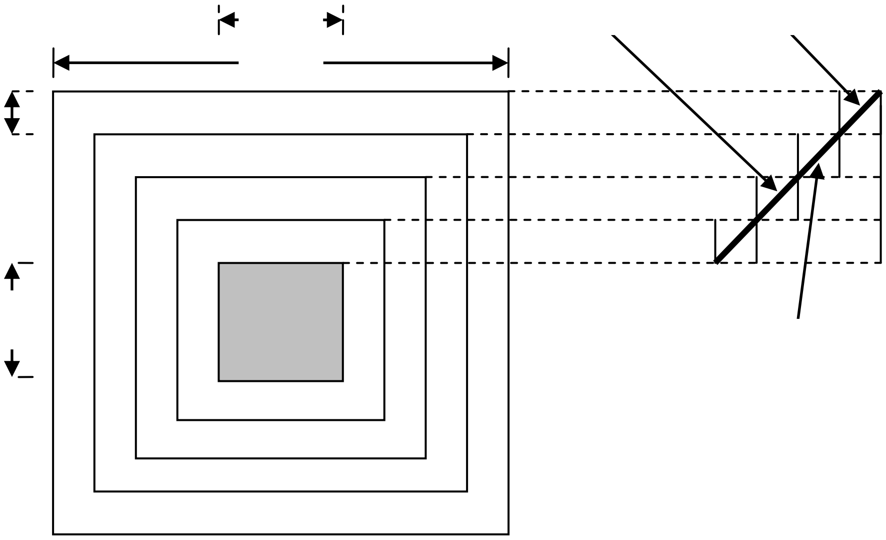

Fig.4. Pond construction technique used at Adet during 2009/10

For the cut type procedure 25cm was measured outside the 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.

Fig.5. Step by step digging procedure

Fig. 6. Clay re-filling technique used

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. 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.

Fig.7. Actual shape of clay lined pond

Fig. 8. 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.

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.

Fig.9. Geo-membrane lined pond

Fig.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.

The control pond is also excavated in the similar fashion by reshaping the subsequent stairs and was left untreated.

Fig. 11. Bare pond (Control)

Fig.12. Final Experimental Setup

Finally, the edge of all the ponds was constructed with stone masonry so as to avoid uncontrolled entry of external runoff into the pond. To monitor the daily water level (depth) in the pond, stationary graduated measuring bar was prepared from iron bar by painting, leveling and putting it into a 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.

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. Present Effective cost per unit volume (PEC)

It is defined as:

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

Results and Discussions

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.

1. Daily storage efficiency

a. 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 treatment 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 contrary, 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.

b. 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

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 2010/11

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

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.

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

Laboratory Experimentation

Fig. 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).

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).

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

Parameters	**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/100g	21.78	25.02	38.97	25.78
Exchangeable Ca	mleq/100g	16.47	7.02	28.08	8.19
Exchangeable Mg	mleq/100g	5.31	18	10.89	17.55
Exchangeable Na	mleq/100g	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					

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.

Conclusion and Recommendations

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 tupsbhf! jo! Mvwjtpmt/ Cvu! jo! Wfsujtpmt! tupsbhf! fggjdjfodz! ejeo u!tipx! jnqspwfnfou! xjui! 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.

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