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

Abstract

Farm ponds are becoming a popular way of harvesting runoff. This water is later used in exercising supplemental irrigation as well as providing water for livestock during the dry spells. The major challenge experienced by pond owners is the huge loss of water emanating from evaporation and seepage. The objective of the study is to compare different lining materials that can be used in ponds to reduce seepage losses. Some of them include: a water-soluble nanotechnology- based compound, Terrasil used together with Zycobond, a submicron acrylic co-polymer emulsion treated soil then used to line ponds among others. Clay and a combination Terrasil treated soil and a thin geomembrane were other material used for lining. The lining efficiency was highly dependent on the soil type because sandy loam soil gave disappointing results for all tests while black cotton soil was quite promising. 0.6649, 0.6226, 0.5642 & 0.27968 were the storage efficiencies for clay, Terrasil, Terrasil & geomembrane, and control lining respectively for black cotton soil while sandy loam soil extremely failed recording low efficiencies of 0.2608, 0.04998, 0.00987& 0.00135 for Terrasil &geomembrane, Terrasil, clay and control pond respectively. A sensor was used to monitor soil moisture which showed rapid changes in moisture in the sandy loam soil whereas the changes in the black cotton soil were slower.

Affordability of each material was also evaluated in consideration of how much efficient the material was in seepage reduction. The cost incurred in lining the pond was inversely proportional to its storage efficiency. Some linings had low seepage but the cost related was very high. E.g. Black cotton Terrasil lined pond. The lining on the clay had great impact on seepage reduction yet not expensive. Most of the water quality parameter results from ponds lined with different materials ranged in the required standards for irrigation and livestock but caution should be taken when used for human consumption.

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CHAPTER ONE

INTRODUCTION TO THE STUDY

1.0 Introduction

Rain water harvesting is a common practice in various parts of the world. The water collected is used for supplemental irrigation in order to mitigate stress and sustain agricultural production at household level. This in turn makes farmers less vulnerable to drought and less reliant on outside assistance (Rami, 2003). Water resource management in water stressed areas should entail management of all rain water including water from roof catchments and runoff that flows through the landscape in a short period of time.

Agricultural water management is generally perceived as a key step towards improving low yields by small scale farmers in sub-Saharan Africa. The focus would be managing storm surface runoff into water harvesting system or into soil instead of diverting stable river flow for storage in dams. Construction of ponds in individual farmer`s field or on community basis for harvesting of runoff water when it is excess and using the stored water for irrigation and other purposes when there is deficiency of water is a very effective and efficient method of facing the challenge of water scarcity in rain fed areas (Michael ,1978). This would provide a win-win solution in the provision of opportunity to secure crop production.

The major challenges faced regarding collecting and storing the resource when it falls as rain is efficient distribution and utilization when the rain stops (Rami, 2003) due to the many losses such as evaporation into the atmosphere, seepage and misuse through ineffective irrigation methods. Pond lining and sealing are some of the methods are used to control seepage of water from reservoir which can be employed based on the kind of reservoir on layers, economic studies and availability of materials and equipment in the region (Shehata, 2006). Pond sealing and lining is the process of installing a fixed lining or mechanically treating the soil in a pond to impede or prevent water loss. Some of the technologies that been innovated in an attempted to prevent seepage losses include: lining with clay, use of manure or bio sealing, use of chemical, using geo membrane polythene for lining, lining with concrete and also table salt all of which have various cost, durability and effectiveness problems. To ensure adaption, the study under research addresses the biophysical and technical appropriateness as well as the economic viability of ponds.

The research is carried out in an arid and semiarid area which experiences erratic rainfall. The infiltration capacity is low as well as vegetation cover is sparsely distributed which contributes to high runoff generation in the area during the rainy season. The topography of the area is suitable for runoff harvesting and storage in farm ponds. This would minimize runoff dissipated to the river channels which contributes to flash floods. Long term benefits such as sediment storage and thus erosion control would be realized in the long run.

1.2 Statement of the problem

Storing runoff in ponds for supplemental irrigation to aid in food production is a common practice in many areas. Evaporation challenges especially in the ASALs and seepage problems are frustrating farmers through reduction in volume and deterioration in the quality of water. The intended aim of achieving food security from harvesting rainwater is therefore not reached. The technologies introduced in ponds don’t seem to give long lasting solution to evaporation and seepage problems. For example the geomembrane is expensive and has a shorter lifespan especially when exposed to the environment due to adverse degradation mechanism such as rich natural presence of ultraviolet rays, degradation from photo- oxidation and increased temperature degradation due to thermal – oxidation(Rowe et al,2002 ; Koerner et al, 2012).But it has also been acknowledged that exposed geomembrane have greater degradation than buried ones showing the need of combining different lining for optimum results. Moreover, use of manure to line results into seepage reduction but in turn contaminants the water rendering it unfit for domestic consumption and fish rearing. The presence of organic materials reduces oxygen level due to decomposition. Periodic application is also required in order to achieve maximum seepage. Laboratory studies show that clay can be used a potential lining material (Almanza et.al., 1988). However, use of clay might not be suitable in hostile environment e.g. in industries; hot brine can cause clay to flocculate making them more porous.

1.3 Objectives of the study

1.3.1Main objective

To test the ability of Clay, Geomembrane and Terrasil & zycobond to seal ponds of varying soil type.

1.3.2 Specific objectives

i. Compare the storage efficiency of ponds after lining with different materials.
ii. Assess the effect of lining on water quality.
iii. Relate cost incurred in lining and the corresponding improvement in storage efficiency.
iv. Evaluate the effect of lining on the soil moisture.

1.4 Research questions

i. Is there a difference in efficiency of ponds after sealing the ponds with different materials?
ii. What is the infiltration rate in the different ponds?
iii. Does the cost incurred, cause corresponding improvement in storage efficiency?

1.5 Significance of the study

The study under research is of great importance in that it will offer a long-term solution in reduction of loss of useful water in on farm rainwater harvesting structures and other seepage related problems such as water logging and increased salinity especially in Arid and semi-arid areas thus increasing useable water for supplemental irrigation hence promoting food security. Moreover, it adds unto the list of available seepage reduction lining materials and solves some challenges encountered on use of other lining. Terrasil also in increases compaction and stabilizes any type soil, increases its strength hence can be applied in dam embankment, canals, bunds etc. The information will also be useful for agricultural and water extensions services when advising farmers on seepage control.

1.6 Justification of the study

Farmers have been making attempts to bridge crop failure through harnessing water in on farm ponds. Unfortunately, losses from the ponds are always large causing ponds to disappear during the dry periods. This reduces the water intended for supplemental irrigation. If losses can be prevented; the carry over storage is more effective and will last longer. This would be achieved by lining the ponds using available, effective and affordable materials. It would promote crop production by increasing available water for irrigation hence enhancing food security.

Poverty and hunger eradication is a dominant issue that can be mitigated through supplemental irrigation which will aid in the production of subsistence food. Economic units that could be used in food aid programs can used in other sectors e.g. ministry of agriculture to provide extension services and fertilizer.

There would also be increase in water supply that will reduce the pressure induced in existing water resources, therefore causing a decline in water resource related conflicts.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

In this chapter, the aim is to review various issues which in one another will help the key factors that influence seepage. This includes the past studies where all important contributors to the issues related to the study. A number of studies have been carried out in an attempt to reduce seepage in water storage facilities. The effectiveness, cost and durability of each method varies.

2.2 Basic principles of pond construction and sealing

Holtan (1950), discussed fundamental principles of pond construction and sealing. When an impervious layer is placed at the bottom of the pond, effective sealing may be attained by packing an impervious core in the fill. It can also be achieved by spreading and compacting a surface blanket of impervious material on the face of the fill. A bag-type seal may be used where an impervious layer is not accessible or where such a layer is not continuous. The compacted, impervious blanket should cover the pond bottom, sides, and fill extending above the high-water level. To control excessive seepage or "blowout" failures, the sealing layer must have sufficient strength to support the head of water above it as well as have low permeability.

Holtan's tests (1950), illustrated that compacted blankets of sandy loam soil materials should be most satisfactory. A good combination of strength and impermeability could be expected from about 1 foot of compacted sandy loam. The ideal material should have from 70% to 95% of sharp sand and 5% to 30% of clay and silt is required to improve the gradation of particle sizes. Compacting the material at optimum moisture content helped improve the strength and sealing effect. Puddling increases the seal. However, it reduced the strength of the material and increased the tendency for blowout failures. Addition of colloidal clay such as bentonite, which acts as a dispersing agent in clays of the same electronic charge, improves the seal of sands but excessive amounts destroy the soil strength.

Clay and other additives have been tested for sealing farm ponds and canals, anonymous (1960). Some tests portrayed treatment benefits, though the duration of the effects was uncertain. Where soil aggregation is responsible for high seepage, pond sealing may be attained by dispersing some of the aggregates so as to clog the soil voids in deeper-lying layers with dispersed clay. Surveillance indicates that the trampling by animals lessen seepage, through puddling and dispersion as well as by compaction of the soil aggregates to form an impervious layer below the trampled zone.

Past tests with tripolyphosphates, Dale, (1960) which have a dispersing effect on sesquioxide-bonded soil aggregates, showed that tripolyphosphates and similar chemicals may be used to improve pond sealing. The method used will be effective only if the pores are suitably fine beneath the disturbed or dispersed zone to entangle the fine particles. The appropriateness of the seal also depends on the pond bed which has to have adequate depth and strength to provide resistance to blowout failures.

Holton, (1950) did tests on chemical dispersants. The dispersants studied were hexametaphosphate and tripolyphosphates (condensed phosphates) as well as sodium silicate (Waterglass). The effects of the hexametaphosphate were remarkable. Tripolyphate test and Waterglass were not appealing. Soda lime and ammonia treatment gave an insignificant decline in conductivity. The dispersing effect of the condensed phosphates of sodium was as a result of formation of soluble complexes with the multivalent cations in the soil, which are responsible for binding clay particles in stable floccules and aggregates. The activity of the flocculating polyvalent cations is reduced and replaced by the monovalent cation sodium. Also, the condensed phosphate is strongly absorbed on the clay particles. Some of the problems related to sealing ponds with some chemical treatments include contamination of the water which may render it unfit for irrigation or use by animals. Moreover, dispersed clay or other colloids in the water may lower the value of the pond for stock consumption. Also, dispersion may increase erosion of the soil at the water-line, especially if it is achieved through animal trampling.

Holton, (1950) tested manure from farm animals to see if it had a sealing effect in addition to trampling by the animals. Manure was suspended in the water used to measure hydraulic conductivity with time. The decline attained over a period of one or two weeks was insightful. Further tests with ammonia in solution proved that this constituent of the manure was not responsible. The sealing effect was probably attributed to some complex organic material. Conversely, tests with organic gums and acrylic polymers gave unsatisfactory results. Suspended clay or ground hay in the water caused an increment in sealing but to a lesser degree than that of manure.

2.3 Tests with Emulsions

Some asphalt-water emulsions and a commercial emulsion were tested for the effect on soil sealing, Holton, (1950). The results with asphalt emulsions, either mixed with the soil or suspended in the water, was not appealing. The decreases obtained had a little difference compared to those obtained by working and compacting the soil to the same extent in a slightly wet condition. Tests with the commercial emulsion indicated that it reduced the flow rate about 60 or 70%. These results were consistent with the claims of the distributors of this material. However, for sealing farm ponds, a more effective method or material is needed.

Bouwer, H., Rice, C. (2000) carried out a laboratory column study of sealing pond bottoms with muddy water. Four columns were established to set these principle in the first column, a layer of loam soil at optimum moisture content (OMC) for compaction was placed on drained silica sand and mechanically compacted before filling the column with water. In the second column, same amount of loam was added as slurry in one application .and filled with water. In the third column the same amount of soil was added in five split slurry application and filled with water .In the fourth column same total amount of soil was added in 15 split slurry application .The hydraulic conductivity k of the silica sand in the columns were noticed to lower as the slurry application increased .The result were 719 cm/day ,701cm/day ,652cm/day and 624cm/day for column 1,2,3& 4 respectively .A further decline in hydraulic conductivity from 1000 to 0.2 cm /day was recorded on addiction of sodium carbonate .This is because when sodium salt is added to clay soil the clay particles change from coagulated calcium to disperse sodium – clay hence reduction in hydraulic conductivity (Praft and Suarez , 1990)

Lentz, R.D., Kincaid, D.C. (2001) carried out experiment to investigate the efficacy of water –soluble polyacrylamide solution(WSPAM) and cross- linked PAM granule(XPAM) treatment in reducing infiltration into soils. Five treatments were applied on the lower side slopes of reservoir basin as two with pure treatment each, another two with treatment and sodium chloride (Nacl) each and one control. The result showed that seepage rates were more lowered when Nacl was added to the treatment than for XPAM only applications (Lentz, 2007). The 100mgl^{-1} applied to the soil and allowed to dry, decreased water inflow rate of water by 0% to 90% packed soil columns varying as a function of soil texture and sodium content (Lentz ,2003).WSPAM and XPAM treatment demonstrated reduced seepage by an average 50% relative to controls.

Getanah ,M and Trigae , (2013) in a study titled as “Comparative analysis of lining materials for reduction of seepage in Vertisol and luvisol soils “ tested the permeability rates in ponds lined with different materials and one which was not lined as control .The various type of lining used included clay lined ,geo membrane lined ,soil plus cement lined and table salt lined .The salt lined pond showed the best storage efficiency followed by geomembrane lined pond .Salt caused pore plugging and formed a cement like structure which impedes water flow and water infiltration into the soil (Silva and U Chida , 2000) hence the high storage efficiency .A water quality analysis was conducted for the salt lined pond and the salinity found to be fit for the water to be used for irrigation because increasing salinity affects growth mainly by reducing the plant ability to absorb water (Robert and Richard , 1999) . The cost analysis in the different ponds in terms of labour and material required which was highest in the soil plus cement lined followed by geo membrane lined, clay lined, salt lined and not lined respectively.

Blauw et.al, Deltares, Volker Staal en Funderingen and the Technical University of Delft (2009), developed an innovative method of Biosealing to reduce seepage. A baseline test was conducted in November , 2008 along Austrian Danube at the storage reservoir Greifenstein to control seepage because the dam did not retain sufficient water at many locations .Three months after the injection of the nutrients there was decrease in water flow through the dike ,indicating that the bio seal had started clogging the leak path .An environmental impact assessment was carried out and it was found that injecting nutrients cause an increase in bacteria but the number of bacteria had decreased to initial values before injecting the nutrients thus no negative impacts on the environment Coddington, T., Peralta, M., and Phelps, R.P. (1989). In a study termed "seepage reduction in tropical fish ponds using chicken litter " applied the litter at the rate of 125 , 250 ,500 and 1000kg $ha^{-1}wk^{-1}$ total solid respectively for five months in Panama .Each treatment was repeated three times .They found out that seepage reduced at each rate applied but reduction was more rapid in ponds receiving he highest rate of chicken litter .Before litter application mean seepage for all ponds ranged 27 to 37 mm day $^{-1}$; after application of the litter it ranged from 8 to 17mmkg^{-1} a 54 – 76% in reduction in seepage .Maximum reduction in seepage occurred during 1st month within the three highest application rates but reached a limit where all applications did not result in more seepage reduction. A comparative study was carried out to estimate the best low-cost combination of lining materials in Makhamalad farm, Wegh college of Agricultural Engineering and Technology, Rahuri, India. The farm reservoirs were facing seepage problem having an infiltration rate of 317 mm/day-1.Individual infiltration rates of the lining materials were determined and were found to be 317 ,22.10,20.51, 12.69 and 12mm/day-1 for field soil, river soil, cow dung, black cotton and gypsum respectively. Upon testing different sequences of lining materials, the best combination found to have minimum infiltration rate of 1.14 mm composed of cow dung placed as the first layer followed by black cotton, river soil and gypsum.

According to a project carried out in the upper Deschutes River Basin of Central Oregan to evaluate the effectiveness of different lining materials and construction techniques in reducing seepage from canals with severe angular subgrade conditions. (Swihart et.al., draft 1994). Canals in this area had fractured Basalt bottoms hence lost 30 to 50 percent of their water to seepage. The seepage rates were noted to decline from 195 to 1280 L/m^2 to 0 to 36L/M^2upon lining the canals with a combination of geosynthetic, soil, concrete, elastomeric coatings and sprayed–in–place form.

Stabniker, V., Naeimi, M., Ivanor, V., and Chu,J. (2011) carried out a research about , "Formation of water impermeable crust on sand surface using Biocement ,which is a mixture of Calcium salt ,Urea and Bacterial suspection that hydrolyses urea leading to production of a carbonate and an increase in pH level.A decrease of 10^{-4} m/s to 1.6 – 10^{-7} m/s in the permeability of the biocemented sand was recorded on application of 0.6g of Ca per cm^3 of the sand surface hence can be used to in areas with sandy soil to reduce seepage .

"Laboratory investigation of soil stabilized with a Nano chemical", carried out by Lekha, B.M., Goutham, S., and Shankar, A.U. (2013) states that the behavior of black cotton soil with and without stabilization was studied. The stabilizer used Terrasil was cured for 7-28days and used for different dosages. After the chemical reaction, the soil surface becomes impervious, the soil mass densified by minimizing the voids between particles. At the end of the research the CBR values were noted to raise with raise in percentage of stabilizer and penetrability of the soil treated with Terrasil found to be nothing.

In a paper titled "scientifically surveying the usage of Terrasil chemical for soil stabilization" by Patel, N.A. Mishra, C.B. and Pancholi, V. (2015) emphasized that authority should use local material and correct soil properties using an additive to enhance strength of structure such as roads, ponds& levees etc. Soil engineering properties (with and without stabilizer) examination were given 1st focus standard compaction ;four days soaked California Bearing Ratio , permeability test and cyclic loading test according to codal procument utilizing Terrasil as a stabilization as an altered measurement i.e. 0.0041% by dry aggregate weight of soil test according to the convection of Zydex industries, Vadodara .The results showed designing properties got modified and CBR stabilized layer samples increased considerably ,which reflects the lower thickness in correlation with natural characteristics soil properties and additionally expense is diminishing which advantage to road designer ,policy makers and pavement designers .

Lekha,B.M., Goutham, S., and Shankar, A.U. (2013) in a study titled ”Fatigue and engineering properties of chemically stabilized soil for pavement” showed the behavior of Black cotton soil with and without adjusted as pondered .Terrasil was utilized as a stabilizer for distinctive measurement and cared for 7-28 days .The soil mass densified by minimizing the voids in the middle of the soil particles and making soil surface impermeable CBR qualities raised with the raise in rate of stabilizer . Permeability was zero for treated soil. The study showed that in measurement of Terrasil as a stabilizer brought about a decrease of consistency cutoff points, hence brings impermeability.

2.4 Terrasil

Terrasil is a water-soluble nanotechnology-based compound .it is 100 % organosilane, UV and warmth steady, receptive soil modifier to stabilize and waterproof soil subgrade produced by Zydex industries in Gujarat. Ingredients used to process the compound include Hydroxyalkyl- alkoxy – alkysily compounds (65%- 70%), Benzyl alcohol (25-27 %) and Ethene glycol (3-5%). It works with all type of soils and makes it extremely less impervious to water. It chemically reacts with water cherishing silanol gatherings of soil to form stable water repellant alkyl – siloxane bonds and structures a breathable in-situ layer.

2.5 Zycobond

It is a sub-micron acrylic co-polymer emulsion with a long life of 10 plus years of bonding soil particles. It is recommended to be mixed with Terrasil solution for one step expansibility control and bonding to strengthen and stabilize soil. It imparts water proofing and resists water ingress through unpaved areas like slopes and shoulders

CHAPTER THREE

DESCRIPTION STUDY AREA OF THE STUDY AREA

3.1 Introduction

The research area is located at Kitui county (Kenya)and the study will be specifically conducted in a higher learning institution farm, South Eastern Kenya University (SEKU). The area is classified as arid and semi – arid. The area is considered to have "moderate problems" as far as water resource are concerned and also experiences occasional water supply and quality problems with some adverse events during severe droughts. The location of the ponds is near a seasonal river, Mwita Syano River. Two different sites, one with Black cotton soil and another one with sandy loam soil were selected for pond siting. Five ponds were used for every soil type.

3.2 Location

South Eastern Kenya University in Kitui county is located at lower Yatta plateau. The area has a latitude of 1.2500000 and 37.583300 longitudes. The part of Kenya`s foreland plateau has an elevation of 922m above sea level (Bernard and Thom 2011; wisner 2000). The administrative location of the study area Kitui Rural constituency, Kwa Vonza ward. The institution holds a vast land of 10,000 which is a good representation for the study (CRA, 2011)

3.3 Climatic conditions

3.3.1 Rainfall

The area experiences Bi- modal rainfall both of which is erratic and unreliable. Rainfall in this area occurs practically only during the rainy season. The long rains occur between May and June & short rains between September and October. The reliability for long rains is 40% and 60% for the short rains. The mean annual rainfall between rainfall is between 300 mm to 800 mm.

3.3.2 Temperature

The area experiences high temperatures throughout the year ranging from 14 degrees to 34degrees Celsius. The hottest months of the year are between January and February and September and October. July is the coldest with temperatures falling as low as 14degrees Celsius and September the hottest to a high of 34degrees Celsius. The maximum mean annual temperature ranges 14 degrees and 22degrees Celsius.

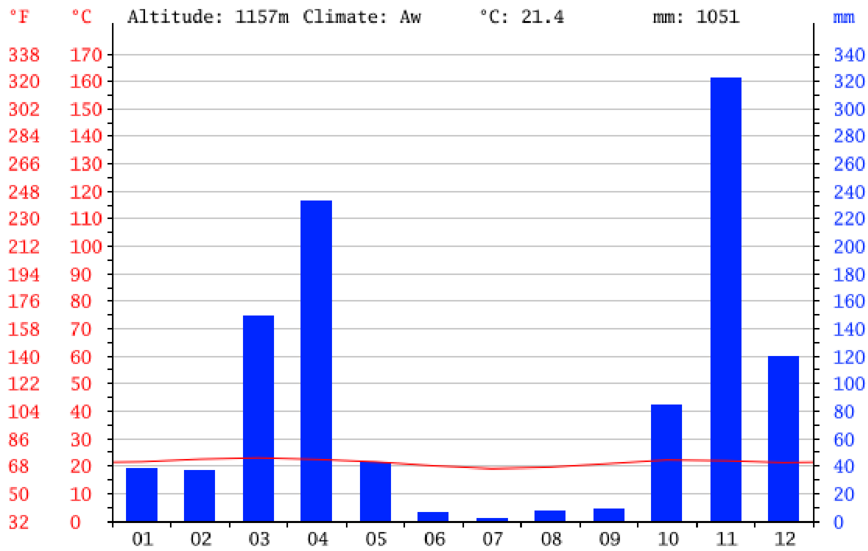

Figure 1: Climatic conditions of Kitui County Adopted from Hunnik (2010)

3.4 Soils

In Kitui county, the dominant soil groups are alfisols ,oxisols and lithic soils (Barber et al .,2000 ;Lerberg ,2002) .The soils in this area reflects largely metamorphic parent material and the rainfall regimes that contribute to their formation (Barber et al .,2003 ;Ojany and Ogendo 1999). Soils are generally of low fertility and many are highly erodible (Barber et al., 2003). The ultisols and alfisols are susceptible to sealing (crusting), which increases runoff and makes the clay soil hard to plough by the end of the dry season (Barber et al., 2003). On rough estimate only 20% of the soils in Kitui area well drained, deep, friable red and brown clays of good fertility. More than 60 % of the region has very erodible relatively shallow, sticky, red black and brown clays of variable fertility. On steep slopes, 20% are poorly drained, shallow stony soils of low fertility (Bernard et al, 2003).

3.5 Land use/ cover

The total land under food production is estimated to be 292,830ha that of cash crop being 6,520 ha and 62,170ha under farm forestry. The average farm size for small scale crop farming is 4.38 ha and 50ha for large scale. There are 10 gazetted forest and 10 non gazetted forest totaling to about 188, 000 forest cover under different ownership, which is crucial for climate change boosting agriculture in the county.

3.6 Vegetation

The dominant vegetation of this part of Kenya is dry bush trees in lower regions and in higher areas savannah scattered trees (Ominde, 2001). The hills were forested but were cleared due to desired agricultural land (Harrey,2000; Owako , 2000; silberfein ,1999). At higher altitude (above 1700) characteristics vegetation includes remnant ever green forest (podocarpas spp) and bracken, mist forest and evergreen thick clumps in grasslands. The most widespread vegetation type in this area especially Kitui semi- arid deciduous thicket and bush land particularly Acacia /Commiphora associations in the 800 to 1200 elevation range. In the dry areas below 900, Sansereria, thorn bush grade into semi desert bush grades into semi desert vegetation (Ojang and Ogendo ,1999; Owako, 2000).

3.7 Population

The region is characterized by rapid population growth. The county average population density is estimated to be 46person / km^{2}i populated areas and 26person / km^2 in less populated areas. The Kitui rural constituency in particular of 30,782 and has a population density of 33 person /km^2. The county is food insecure and the food poverty rate is reported to be 55.5 %. (Census, 2009)

3.8 Geology

The Kitui region is an eroded basement complex broken by residual hill masses and occasionally overlain by tertiary volcanic (Bernard and Thom ,2011; Wisne, 2000). It is made up highly weathered rocks hence the vast amounts of sand in rivers, valleys and water pathways

3.9 Hydrology

This part of Kenya forms an environmental gradient of decreasing altitude (from 2100 m to 440m, increasing temperatures and decreasing moisture (from 1270mm to 381) average annual rainfall from west to east. (Ojany and Ogendo ,1999 ; Owako ,2000 ;porter ,2011). Elevation controls the quantity of the rainfall at the regional scale whereas topography strongly influences rainfall distribution at the local scale (Moore, 2003; Porter,2000). The soils in this area are poorly drained hence infiltration is less and much runoff is generated in a rainfall event. Horton overland flow occurs creating flash floods which last for about 8 hrs.

3.10 Socio economic activities

Kitui has a vast of resources including: wildlife, livestock, forest and minerals (large deposits of coal and limestone in Mui basin and Mutomo/Ikutha respectively). Main economics involves livestock keeping. The livestock breed kept are: Cattle; Zebu Boran, Sahiwal Freshian and Agishire, Goats; East African, Galla, Torgenberg and sheep; Black-headed, passion and red Masai. Poultry farming is also largely practiced. About 87.3% of the households are engaged in crop production. Main crops produced are maize, green grams, beans, cowpeas, millet, tobacco, cassava, mangoes and sorghum. Business and all forms of industries are also practiced in the area. Tourist sites in the area are also an economic entity in the area (Creco ,2012).

CHAPTER FOUR

RESEARCH METHODOLOGY

4.1 Introduction

The research methodology discusses an experimental comparative study of various lining materials in two different type of soils. Five ponds of the same shape, size and capacity were constructed for each soil type (Black cotton and sandy loam). Two of the ponds were lined with Terrasil and Zycobond chemical, one pond with a combination of Terrasil & Zycobond and a thin geomembrane, another with clay and one will serve as control. This was replicated for each soil type. A laboratory model was also set up to investigate the infiltration characteristics of the lining material in a controlled environment hence increasing research accuracy level.

4.2 Pond construction and lining

Pond construction involves land survey and clearing of vegetation from the pond excavation site. It also involves pegging out the pond and excavating pond area. Pond sealing and lining is the process of installing a fixed lining or mechanically treating the soil in a pond to impede or prevent water loss

4.2.1 Pond making and Lining procedure

Pond setup and soil sampling: The layout work of the ponds on the ground was done first with the dimensions of 3.6m by 3.6 m for each pond with a spacing of 5m in between the ponds. Soil samples were taken at depths of 0.25m,0.5m 0.75m & 1.0m respectively for each pond for laboratory investigation. The following physical soil characteristics were carried out; soil texture, permeability and bulk density.

4.2.2 Pond construction

The pond was excavated from the middle where the center part of 1m by1mby0.75 was dug out first and then the slope side were made in reference to the 0.75m depth at the middle in order to attain uniformly formed slopes. The size of the slope from the bottom to the corner was 1.989m and the height of the slope is 1.5m. The soils excavated from the ponds was placed on the suitable side of the pond and later used to line the ponds

Figure 2: Casuals during the pond construction

4.2.3 Pond lining

1. Terrasil lined pond

Terrasil application

In the application of Terrasil the following procedure was followed "manual hand mixing and applying in layers" which involved:
A heap of the dry soil to be treated was placed besides the pond approximately 1.5 -2.2 m^3 for 1 pond. The soil was crushed by breaking the lumps such as to make it in fine form. The 10 buckets of the fine soil were mixed with cement to make a homogenous layer. The mixture was then spread on the pond sides and evenly compacted. A mixture of Terrasil & Zycobond and water solution at a ratio of 1:400 was sprayed on the compacted layer as a top coat. A similar procedure was replicated for the other layers until a thickness of 150mm was attained. A drying interval of 2 – 3hours was allowed before placing the other layers. On completion, the pond lining was allowed to dry for 2-3 days before pond testing in water

Figure 3: Compacting a mixture of soil and cement mixture layers applied on the pond size.

Figure 4: Spraying Terrasil on the compacted layers.

2. Clay lined pond

For the clay fill pond, clay material was transported to the area and lining was done starting from the base by compaction. Lining of the pond sides was done in layer to allow better compaction .Small amount of water was applied during compaction to moisten and facilitate binding of the soil material at OMC (Optimum Moisture Level). Then the gentle sloping sides were lined carefully up until the desired slope thickness (150mm) and smooth surface was finally maintained

Figure 5: Clay lined pond.

3.Geomembrane and Terrasil lined pond

A thin geomembrane was placed skillfully on the pond surface and was then overlaid by layers of soil treated with Terrasil and Zycobond

Figure 6: A pond lined with geomembrane and covered with field soil on top.

4. Control pond

This pond was left unlined for the purposes of comparison

4.3 Observation

The changes in water depth was observed by placing a concrete footed pipe with a tape on the outside at the center of each pond, which enabled monitor decline in the water level of the pond.

Figure 7: A pipe with a tape attached on the outside to help monitor water level.

4.4 Measurement

This was achieved by use of a PlantCare Mini-Logger, which is a maintenance-free sensor which records soil moisture and soil temperature. The sensor is based on micro thermic measurement of soil moisture. It has a specially developed felt material in moisture balance with the soil acts as the interface between the surrounding soil and the sensor. To measure the moisture level, the sensor is briefly heated and the cooling-down time, which varies depending on soil moisture, is determined. The sensor's cooling-down time thus provides a reliable statement of the soil's moisture content.

4.5 Sampling

Soil and water samples were collected for laboratory tests. Water samples were taken for each treatment and a reference sample. Soil samples were collected for two types of soil (sandy loam and Black cotton soil)

4.6 Laboratory model

A laboratory test was constructed to investigate the infiltration rate of the lining material used to reduce seepage in ponds. The material used in making the model included; Hollow cylindrical containers (5litres), stands, sieves and collecting containers and measuring cylinder. The hollow cylinders were vertically placed on the stand and the lower circular ring was covered with a 2mm sieve was attached Below the stand empty containers were kept to collect the outflow water from the hollow cylindrical container. Individual lining materials 5cm thick were then added to each hollow cylinder but clay lining compaction was not done due to size of the container. A measured quantity of water was poured on the upper part of the model and allowed to pass through the lining for 24hrs and was then collected on the empty containers. A measuring cylinder was used to quantify the outflow from the cylinder.

Table 1: showing dimensions of the model.

Figure 8: laboratory model setup

This model was used investigate the effects of lining materials on the infiltration rate in a controlled environment.

4.5 Data analysis

4.5.1 Measures of Central Tendency

Measures of central tendency (also called averages) have been used in analysis of data. In this study, the arithmetic mean will be applied. According to Lane 2008, the arithmetic mean of a series of values is arrived at by summing up the values and then by dividing by the number of values.

$\bar{X} = \sum X/N$……………………………………………………………………………...Eq. 3

Where $\bar{X}$ = Arithmetic mean

$\sum X$ = Sum of values in the series

N = Number of values in the series

Mean was used to calculate mean weekly evaporation and infiltration rates losses.

4.5.3 Analysis of storage efficiency

$$\boldsymbol{Storage\ efficiency} = \frac{\boldsymbol{water\ input - loss\ (seepage + evaporation\ )}}{\boldsymbol{water\ input}}$$

The following formula was used to calculate the ability of ponds in storing water. The water input and the losses incurred (seepage and evaporation losses) were evaluated in order to obtain each pond storage capacity.

4.5.4 Economic analysis

$$PEC = \frac{Cost\ of\ construction}{Storage\ volume \times storage\ efficiency}$$

The consideration of the economic requirement of a lining material in relation to how much water it can save is critical factor for lining acceptability. A lining should be affordable to all economic groups and be able to reduce seepage losses effectively.

4.5.6 Plant Care Data viewer software

Plant Care Data Viewer software enables the optimal display and analysis of the data recorded in the Plant Care mini-logger. It is used to obtain a graphic view of the moisture and temperature levels on one or several Mini-Loggers as well as data averages.

CHAPTER FIVE

RESULTS AND DISCUSSION

This chapter provides the results on the analyzed primary data and graphical output of the Plant Care data viewer software. It also comprises of a discussion of the findings in reference to the objective of the study.

Table 2: Daily storage efficiency of ponds lined with different materials on a Black cotton site at SEKU**.**

5.1 Storage efficiency

Date	Terrasil lined pond 1	pond 2	Terrasil and Geomembrane lined	clay lined	Control
28-01-17	0.5576	0.9048	0.8889	0.9653	0.8966
29-01-17	0	0.89779	0.8337	0.9412	0.8513
30-01-17	0	0.8928	0.8184	0.90625	0.7692
31-01-17	0	0.84	0.80337	0.9047	0
01-02-17	0	0.7857	0.7333	0.8875	0
02-02-17	0	0.7368	0.5	0.7476	0
03-02-17	0	0.5455	0.5	0.6316	0
04-02-17	0	0	0	0	0
05-02-17	0	0	0	0	0
Average	0.06120	0.6226	0.5642	0.6649	0.27968

The following analysis was carried out to assess the ability of the ponds lined with different materials to store water. Daily water levels were collected to show help calculate changes in storage capacity. The losses incurred due evaporation were assumed to be constant for the entire test. Clay-lined pond showed the highest storage efficiency. This may be attributed to the fact that clay is impermeable when wet, as the particles expand and fill the pore spaces. The problem associated with clay is that it cracks when dry. Therefore, water fluctuations in the pond would results to cracking of the lining thus reduction in storage efficiency in the future.

Terrasil lined ponds had different storage efficiency despite having the same treatment this is because pond 1 site had cracked extensively thus contributing to the low storage efficiency. The Terrasil lined pond 2 storage efficiency was also relatively high as compared to the control meaning that Terrasil has sealing effect when used to line. It works by making surfaces less impervious to water by chemically reacting with water cherishing silanol gatherings of soil to form stable water repellant alkyl – siloxane bonds and structures a breathable in-situ layer. A combination of Terrasil and geomembrane lining gave a slightly less value for the average storage efficiency as compared to Terrasil and clay lining for this type of soil. This would be attributed to inappropriate placing of the geomembrane or existence of internal cracks.

Date	Terrasil lined pond 1	pond 2	Terrasil and Geomembrane lined	clay lined	control
28-01-17	0.2133	0.4498	0.7692	0.08885	0.01215
29-01-17	0	0	0.7288	0	0
30-01-17	0	0	0.6	0	0
31-01-17	0	0	0.25	0	0
01-02-17	0	0	0	0	0
02-02-17	0	0	0	0	0
03-02-17	0	0	0	0	0
04-02-17	0	0	0	0	0
05-02-17	0	0	0	0	0
Average	0.0237	0.04998	0.2608	0.00987	0.00135

Table 3: Storage efficiency of ponds lined with different materials on a sandy loam site at SEKU.

A combination of Terrasil and geomembrane recorded the highest storage efficiency in the sandy loam type of soil. This outcome was totally different from what was recorded in a similar test with black cotton soil and the discrepancy was contradicting. This is because Terrasil being a sealant reduced seepage and the geomembrane provided additional sealing. The Terrasil lined ponds in this case also had different storage efficiency because pond 1 lining was eroded when the pond was being filled with water.

When a comparison is made on the storage efficiency of the lined ponds and that of control, there is a significant difference noted. This proves that the lining material provide some level of sealing although very minimum.

The storage efficiency of ponds on the sandy loam soil was extremely low as compared to those on the Black cotton soil. This suggests that the effectiveness of materials used as liners as depends on characteristics of the underlying soil.

5.2 Cost analysis

The cost analysis helps in determining the affordability of the lining hence gives an insight on the acceptability of the material. This also assists in evaluating whether locally available materials can provide a suitable economic option.

The treatments on the two types of soils were replicated hence the cost of construction for each type treatment was the same. The cost of construction ranged from 4000 to 700.This is quite affordable in Kitui and other arid and semi-arid areas where the poverty prevalence is 63.1. The cost of construction and lining would even be much lower if farmers were to provide labour themselves.

The value of present effective cost per volume ranged between 130,929 (sandy loam control) to 6056.9 Ksh/m3 (Terrasil and geomembrane).as shown in table 4. It is clear that very low storage efficiency lead very high values of effective present cost per volume.

Table 4: Cost of construction and lining of ponds.

Treatment	Labour (no)	pond making (no)	Terrasil (litres)	Zycond (litres)	Cement(kg)	Geomembrane (m^2)	Clay (buckets)	Total (Ksh)
Terrasil lined	2	1	0.75	0.75	25			3183.50
Geomembrane and Terrasil lined	2	1	0.75	0.75	25	7.95		3978.5
Clay lined	2	1					30	3200
Control		1						700

Table 5: Present effective cost per volume for ponds lined with different materials at SEKU during 2016/08 to 2017/01.

Treatment	Cost (Ksh)	Storage Efficiency	Storage volume (M^3)	Present effective cost/volume(Ksh/m^3)
BLACK COTTON				
Terrasil lined Pond 1	3183.50	0.10455	2.2	13,840
Pond 2	3183.5	0.63889	2.2	2,265
Terrasil and geomembrane lined	3978.50	0.57803	2.2	3,129
Clay lined	3200	0.676085	2.2	2151
Control	700	0.32619	2.2	975
SANDY LOAM				
Terrasil lined Pond 1	3183.5	0.04	2.2	36,176
Pond 2	3183.5	0.08434	2.2	17,157
Terrasil and geomembrane lined	3978.5	0.29857	2.2	6,056.9
Clay lined	3200	0.01666	2.2	87,307.7
Control	700	0.00243	2.2	130,939

5.3: Infiltration rate of the lining in a control experiment

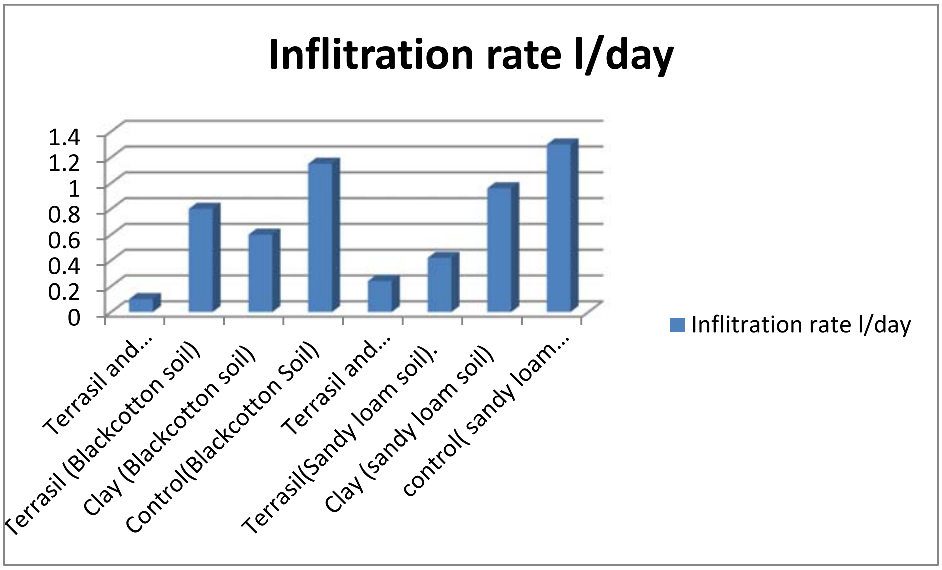

Figure 9: Infiltration rates of the lining from the laboratory model.

The following graph showed the infiltration rates of the lining materials in the laboratory model. 1.5 liters of water was added to each experiment. A combination of geomembrane and Terrasil treated soil recorded low infiltration rate of 0.1 and 0.24 l/day for black cotton and sandy loam soil respectively. Terrasil treated black cotton soil had higher infiltration rate of 0.8l/day compared to 0.42 l/day of sandy loam soil treated with the same. Furthermore, the treatment using clay also varied for the two types of soil where it greatly reduced infiltration rate for black cotton soil to 0.6 and 0.95 l/day for sandy loam soil. The infiltration rates of the soil when no treatment was added were quite high at 1.15 and 1.3 l/day for black cotton and sandy loam soil respectively

5.4 Soil moisture

The soil moisture was monitored and recorded using Plant Care mini logger. It also contains a Plant Care Data Viewer application is designed solely for the visualization and analysis of the measurement. Plant Care Data Viewer displays the existing information and measurement values in clearly displayed form irrespective of the unit that supplied the data.

According to the Plant Care mini logger operating instructions on how the sensor measures soil moisture, the sensor is briefly heated and the cooling-down time which varies depending on soil moisture is determined. The sensor cooling- down time thus provides a reliable statement of the soil moisture content.

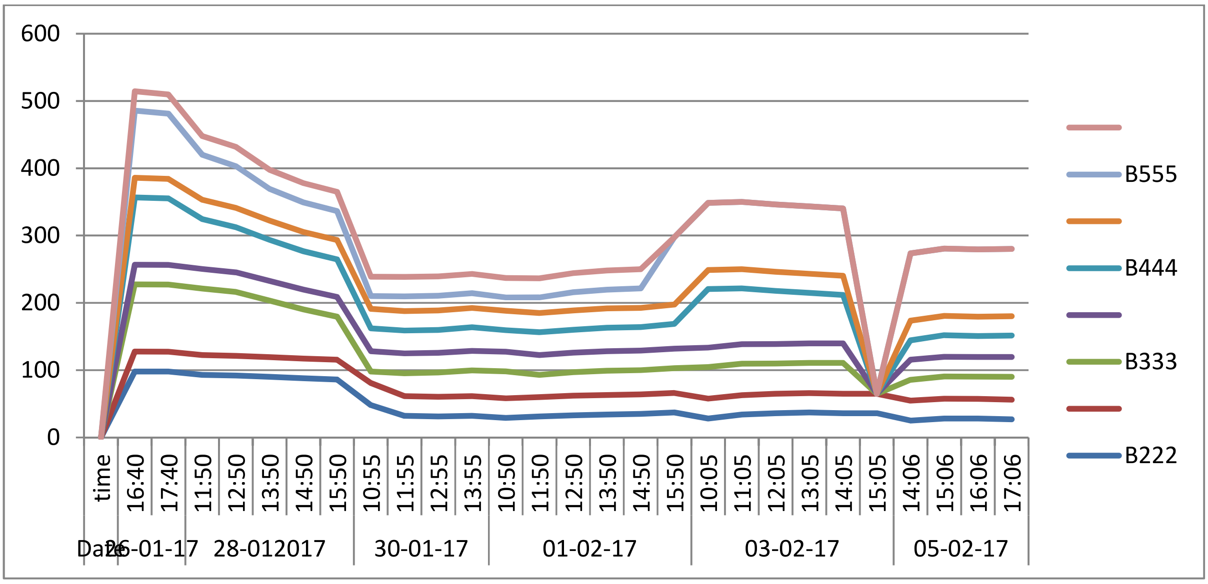

Figure 10: Soil moisture and temperature trends for Black cotton pond lined with different materials during 26/01/2017 to 05/02/2017 at SEKU.

The soil moisture in the figure above showed rapid changes at the initial periods and almost constant changes in the rest of the period expect for the control pond (B555) which showed quick changes in soil moisture. Black cotton soil holds water for long periods of time due to its good structure, high bulk density and low permeability. This soil characteristic helps maintain soil moisture and could have led to the behavior observed above.

Lining ponds in this type of soil reduced the seepage to an extent thus preventing percolation which would have led to loss of the soil moisture content in to the soil. If the soil moisture loss due to evaporation would be considered the rate of change would even be much lower. This is because in Kitui (where the project was located) has very high evaporation losses.

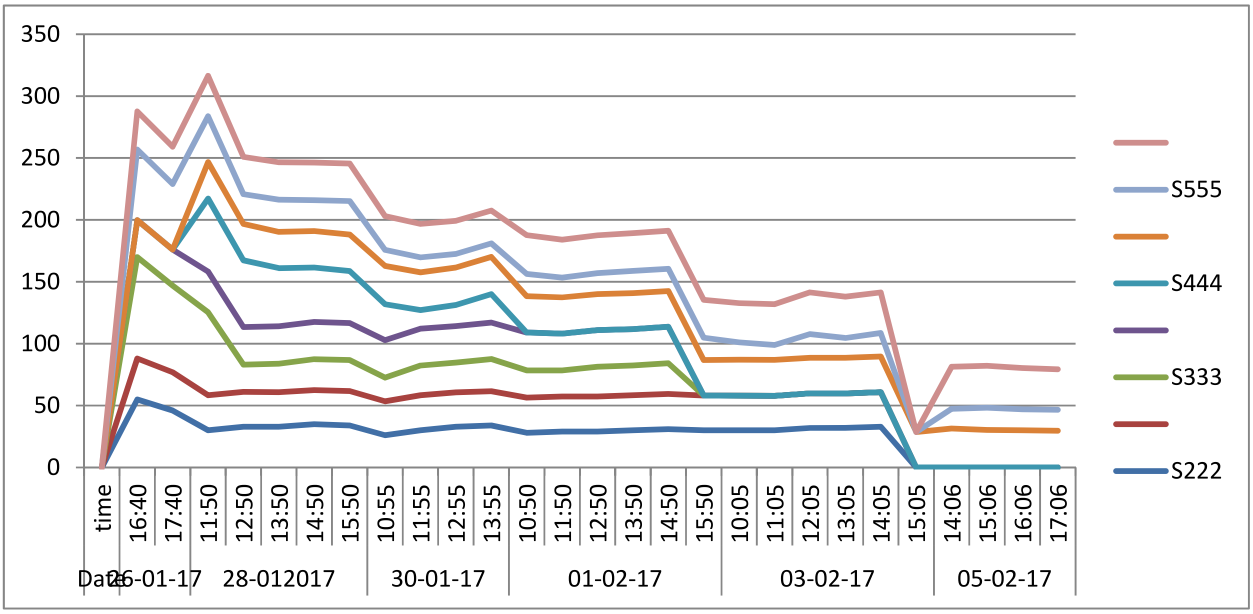

Figure 11: Soil moisture and temperature trends for sandy loam ponds lined with different materials during 26/01/2017 to 05/02/2017 at SEKU.

The figure above shows that the ponds located in the sandy loam site had very rapid changes in the soil moisture. This would be attributed to high drainage associated to soils with large proportion of silts e.g. sandy loam soil. This would also be caused by inability of the lining materials to prevent seepage from the pond allowing percolation of water into the deep hence leading to losses in the soil moisture.

Figure 12: A sensor used to monitor soil moisture.

5.4 Water quality

The treatments lead to various changes in water quality parameters as shown in the table below.

All treatments cause an increase in the pH and decrease in the calcium hardness of the water. Terrasil treatments caused increased in total alkalinity, color and dissolved& suspended &total solids. However, it also contributed into declined dissolved oxygen, Sulphates and fluorides levels. Clay treatment lowered turbidity levels.

The change in water parameters caused by the treatments should be counterchecked with set standards for the intended water use such as drinking, irrigation and livestock for guidelines to the users and make necessary remedies. In this case, most of the parameters are within the range for irrigation and livestock but for drinking care should be taken.

Water parameters	Reference sample	Terrasil and geomembrane treatment sample	Terrasil sample	Clay treatment sample	Drinking water standards	Irrigation water standards	Livestock water standard
pH	5.6	6.36	6.26	6.96		5.5-9.0	6.0-9.0
Apparent colour, °H	15	40	41	15	5-25		
True colour, °H	10	35	30	15	20		
Conductivity, mg/l	1210	1170	1370	1204		250-2250	
Turbidity, F.T.U	40	41	48	9.5	5-10		
Calcium hardness, mg/l	295	185	245	170	75-200		
Total hardness, mg/l	444	312	456	298	300-600		
Total alkalinity ,mg/l	320	400	440	296	200-600		
Fluorides, mg/l	1.21	0.85	0.82	1.62	1-1.5	1.0-15.0	2.0
Sulphates, mg/l	225	20	5	270	200-400		
Dissolved oxygen, mg/l	3.03	1.19	1.58	3.08			
Chlorides, mg/l	620	600	720	690	250-1000		
Dissolved solids, mg/l	1180	2040	1600	1050	500-2000	2100	
Suspended solids, mg/l	20	250	200	80		200	
Total solids, mg/l	1200	2200	1800	1130	<2000	750-2000	
Nitrates, mg/l	0	0.5					
Iron, mg/l	0.8	1.2	0.6	0.3-1.0	5-20		

Table 5: Water quality analyses results for different treatment and required standards for various uses.

5.5 Conclusion

Terrasil proved to have an ability to seal ponds but not to the great extent claimed by the distributors. Furthermore, it does not work for all soil types because its experiment with sandy loam soil was quite disappointing. Moreover, use of locally available materials such as clay showed better sealing effect than the use of emulsion. Therefore, for sealing ponds, a more effective material is needed.

Each pond recorded different storage efficiency from the other. Compared to the control pond, the lined ponds in both cases showed higher storage efficiency. In the red soil sample, the storage efficiency was improved in the lined ponds but still very low.

The cost incurred in the construction and lining the pond was not very high and could be easily afforded by local people. A pond with a high storage efficiency resulted to a low present effective cost per volume thus making it a worthwhile investment and the converse is true.

Lining improved the adjacent soil moisture in the black cotton soil sample in that there were very slow changes in the soil moisture content which would be attributed to low seepage due to lining and the soil characteristic. Soil moisture content in the sandy loam soil was extremely poor hence not even lining helped in retaining soil moisture in this type of soil.

The treatments caused changes in water quality parameters. However, most variables levels allow water use for irrigation and livestock but care should be taken if the water is to be used for drinking purposes.

6.0 References

Agricultural, Phoenix, Arizona, H. Bouwer et al *Ecological Engineering* 18 (2001) 233 - 238

B.M Lekha, A.U.Ravi Shankar and S Goutham2002 *fatigue and Engineering properties of chemically stabilized soil for pavements Indian Geotechnical journal ,volume 43* ,issue I,2013 , 96 -104

Bouwer, H. ,Lukde, J. , Rice ,R.C 2001 . *Sealing pond bottoms with muddy water* . Ecological Engineering 18 (2) pp 233 – 238.

Fitsume, Y, Hordota ,T ,Abera,y. 2014 *Review of Water Harvesting Technologies for food security in Ethiopia :* challenges and opportunities for the Research .Journal of Natural Sciences Research ,.4(18) ,pp 40 -49

Hickey, M .E (1969), "*Investigation of plastic films for canals linings* ," Reclamation Research Report No. 19 , A water resources Technical publication .

IS: 2720, part viii [1987]: Determination of water content –Dry Density Relation using light compaction .

IS: 2720 (part xvi) – [1997]: laboratory Determination of CBR

IS: 1498 -1987, classification and identification of soils for General Engineering Purposes

Anonymous. 1960. *sealing earth dams*. Rural Research in Commonwealth

Scientific and Industrial Research Organizations, Australia. 32:10-11.

(2) Beasley, R. P. 1952. *characteristics of farm ponds*. Missouri Agricultural

Experiment Station Bulletin 566.

(3) Dirmeyer, R. D., Jr. 1961. *let's muddy the ditch water*. Colorado Farm and

Home Research 11(4).

Dirmeyer, R. D., Jr. and Shen, R. T. 1960. *sediment sealing of irrigation*

canals. Colorado State University CER60RDD33.

Holtan, H. N. 1950. *holding water in farm ponds*. SCS-TP-93.

Holtan, H. N. 1950. *sealing farm ponds*. Agr. Engr. 31:125-130, 133-134.

Johnson, H. P. 1960. study seepage from western iowa reservoirs. Iowa

Farm Science 15(10):14-690.

Kroth, E. M., Jamison, v. c., and Grogger, H. E. 1960. **soil moisture survey of some representative missouri soil types.** ARS-41-34. North Central Technical Committee on Soil Survey. 1960. soils of thenorth central region of the united states. North Central Regional Publication No. 76. Bu!. 544, University of Wisconsin.

Schwartzendruber, Dale. 1960. water flow through a soil profile as affectedby the least permeable layer. J. Geoph. Res. 65-4037-4043.

Lekha B .M, Goutham Savang, Chaital N Ravi Shankar (2011): *.A laboratory investigation on black cotton soil stabilized with non-traditional IOSR journal of mechanical and arid Engineering* (IOSR –JMCE e –ISSN: 2278 -1684 ,P –ISSN :2320 .334 XPP 07-13.

Mohammed Y. Fattah, ,Firas A.Salman and Bostun J. Nareeman (2011*): A treatment of soil using different additives* ,Acts montanisticaSlovaca

Phanikamar , V. ,Krishna ,G .S .,Swaroop , A.H.L 2013 *Sealing pond with clay layer* .International journal of Engineering and Innovative Technology .3(1) , pp 49 – 52 .

Rengasamy , P.,Mcleod , A.J. Ragusa ,S .R 1996 *.Effect of dispersible soil clay and algae on seepage prevention from small ponds* .Agricultural Water Management , 29 (2) pp. 117 – 127.

S.Ahmad ,M.Aslam, M.Shafiq, *Reducing water seepage from earthen ponds*,Agr.Water Manag.30 (1996) 69 – 76

Reginato , R, J. Myners , L .E,. Nakayama , F ,S. 1968 *Sodium Carbonate for Reducing seepage from ponds* WCL Report No.7 United states Water Conservation Laboratory , Agricultural Research Service ,US Department of

V. Ivanor ,J.Chu *,Application of microorganism to geotechnical engineering for bioclogging and biocementation of soil in – situ* ,Rev. Environ. Sci – Biotechnology .7 (2008) 139 – 153.