International Journal of Agriculture, Environment and Bioresearch

Vol. 2, No. 06; 2017

ISSN: 2456-8643

ESTIMATING AMOUNT AND COST OF RAINWATER HARVESTED FROM A TYPICAL GREENHOUSE ROOFTOP IN KAJIADO COUNTY, KENYA

Cherobon Everlyne Koech [1], Kironchi Geofrey.[2], Kathumo Vincent M [3]

[1]EMEDEN Kenya Farmers Ltd. P.O Box 2444-00100 Nairobi, Kenya

[2]Department of Land Resource Management and Agricultural Technology (LARMAT), University of Nairobi. P.O. Box 29053-00625, Nairobi, Kenya.

[3]Department of Land Resource Management and Agricultural Technology (LARMAT), University of Nairobi.P.O. Box 29053-00625, Nairobi, Kenya.

ABSTRACT

Rainwater harvesting is one solution for agricultural production in water stressed agro-ecological zones. However rainwater harvesting is practical in locations where adequate systems to collect and store rainwater are available. Smallholder farmers in Kenya find the cost of harvesting and storing rainwater prohibitive. The study was conducted in Isinya Sub County Kenya, to promote sustainability of dryland irrigation agriculture by assessing the amount of rainwater harvested from greenhouse rooftop and the costs of storage in a dugout ditch. Three greenhouses were purposively selected. Gutters and pipes were installed to collect rainwater and conveyed to a ditch from where daily water levels were measured for six months. Daily rainfall data were recorded using rain gauges set on the experiment site. All the data were analyzed using descriptive statistical analysis packages. The results showed that average volume harvested from 1m2 surface area of rooftop raining 1mm of rainfall was 0.00075m3. It costed an average Kenya shillings 972 to store 1m3 of water in a dugout ditch compared to using plastic tanks whose average cost was Kenya shillings 7900 per 1m3. Rainwater harvesting and storage from greenhouse rooftops is a viable venture. Further research is needed on the potential offered by rooftops to harvest rainwater for agricultural production in water stressed agro-ecological zones.

Keywords: Costs, Greenhouse, Harvesting Rainwater, Rooftop, Storage

Introduction

Food insecurity is one of the major global problems that demands strategic intervention in the face of increasing human population and climate change upon the limited land and water resources (Gichuki 2002). One of those strategies is harvesting rain water to be used for irrigation in order to open up more land in arid and semi-arid places (Ngigi 2003). However rain water harvesting is only practical in locations where rainwater can be collected in sufficient quantities during a rainy season. Adequate and proper systems must be put in place and maintained well to harvest and store these water for use in crop irrigation. Smallholder farmers in

Kenya may find the cost of harvesting and storing water prohibitive. Availability of adequate surfaces for harvesting rain water may also not be easily available to most smallholder farmers. Other challenges associated with adoption of this technology include awareness, technical expertise and cost of installation (Ngigi 2003).

Isinya Sub County is located in a semi-arid ecological zone in the peri urban area of Nairobi city. This region has been receiving an influx of migrant population from Nairobi city who have adopted irrigated agriculture in Isinya Sub County. Irrigation by use of harvested rain water is one of the most growing popular rainwater scarcity mitigation strategies as recommended by research scientist on rain water harvesting as an alternative technology for water scarce communities (Ngigi, 2003 and Eruola et al., 2010).

UNEP (2009) has defined Rain Water Harvesting (RWH) as "the collective term used to indicate a wide variety of interventions that uses rainfall through collection and storage in soil or manmade dams, tanks or containers to bridge dry spells and drought." Similarly, Chanan et al., (2007) defines rain water harvesting as "the practice of collecting rain water from surface on which rain falls and storing this water for later use"

The concept of water harvesting has a long history dating to over thousands of years. Kumar (2000) indicates that the Indian people have practiced rain water harvesting for over 5000 years. Rain water harvesting offers important benefits such as provision of good quality water for plant irrigation, reduced storm water runoff from land to cut down on soil erosion and pollution of rivers and springs (Ngigi, 2003). Rain water harvesting offers a great potential for water savings and an alternative water source during drought. However there are limitations and drawbacks to adoption of rain harvesting by communities (Ngigi, 2003). For example, rain water harvesting is only practical in locations where rainwater can be collected in sufficient quantities during a rainy season. Adequate and proper systems must be put in place and maintained well. Sometimes this may be expensive especially for smallholder farmers. Other challenges associated with adoption include awareness, technical expertise and cost of installing such a technology.

According to research done by Li et al. (2000) there is need for more research and dissemination to facilitate effective and affordable rain water harvesting technologies to encourage and speed up adoption by smallholder farmers. Despite the benefit offered by rainwater harvesting limited research has been done to evaluate the quantity of rainwater that can be harvested from different surfaces including rooftops such as greenhouse tops. The interest of the researchers on rain water harvesting seem to be more on why farmers are slow in adopting this technology of rainwater harvesting despite the opportunities it offers. In this context, Kubbinga (2013) studied the potential of rain water harvesting in assisting smallholder farmers in Eastern province, Kenya.

He established that costs were a major economic constraint, yet the benefits seem to outweigh these and other social costs. His study highlights the importance of further research on the costs and benefits of rainwater harvesting.

Similarly, Feng He (2007) evaluated the determinants of farmers' decision in adopting RWH in China and found factors that determine either positively or negatively the farmer's decision to adopt the technology. Among these include access to finances and credit. Li et al., (2000) also concurs with the above observation and recommends that to be successful rain water harvesting need to be implemented alongside related technologies and agronomic practices. Examples relating to economics of rain water harvesting has also been done. For example, Barron et al., (2008) reviewed studies in the cost benefit analyses on various technology adoptions by smallholder farmers in sub-Sahara.

These studies formed the conclusion that individual farmers will not invest in a technology that does not yield financial returns, within an immediate time framework, preferably within one or two seasons, for the technology to be of interest to the smallholder farmers targeted. The smallholder farmers simply look at the costs and benefit in terms of total costs incurred compared to direct financial benefit. Labor costs is assumed and set at near or at zero.

In China, Yuan (2003) evaluated the economic feasibility of harvesting rain water to supplement irrigation in a semi-arid area. His findings were that it was economically viable if open spaces are used well to collect rain water and water saving mechanism is put in place to minimize losses and careful planning is put in place according to the rainfall events of the region including crop water requirements. Similarly, Godfrey (2009) undertook a Cost–Benefit analysis of evaluating internal and external costs and benefits of reusing grey water and concluded that the benefits were higher than costs. Ngigi (2005) found out that rainwater harvesting was economically viable for smallholder farmers to facilitate sustainable agriculture and livelihoods.

In the context of the present study, few studies have been done to evaluate possible quantity of rainwater that can be harvested from a given rooftop. Studies done by Eruola et al. (2010) undertook to assess the qualitative and quantitative aspects of harvesting rainwater from rooftops with different slopes. His findings were that there was a direct relationship between volume of water harvested and the slope of the rooftop. The steeper the slope the more the water harvested. Kumar and Mandal (2014) also set up a rain water harvesting system in a remote village in Bangladesh to evaluate the amount of rain water that could be harvested from a house roof top with a surface area of 40m2. The study region received 1800mm of rain annually and total amount harvested over a period of 4 months was 18840 litres. This translated to 0.261 litres of water from 1m2 surface area raining 1mm of rainfall. In a similar study Patil-Pawar and Mali

(2013) attempted to evaluate the potential for harvesting rain water from a roof top in a village in India, with geospatial techniques which included using the Gould and Nissen Formula (1999): S = R*A*Cr. The study revealed that, the total potential of roof rain water harvesting was estimated at 1175488.75 litres of water in the region with 1025mm annual rainfall falling on 1519.753m2 of corrugated iron sheet roof. This translated to 0.755 litres harvested from 1m2 surface area when it rained 1mm rainfall.

In order to make provision for climate change components, Kahinda et al., (2010) did a study that allowed climate change components to be designed within the rainwater harvesting component. The aim was to establish water volumes in percentages that could be saved by incorporating climate change factors in the design of rain water harvesting systems in different agro climatic zones. Sharma et al., (2009) evaluated the rain water harvesting potential of greenhouses within the horticulture farm including surface runoff and flood water in Athi River outside Nairobi, Kenya. The area experienced sodicity problems which necessitated identification of a clean source of water. The solution was rainwater harvesting, storage and usage. Rainwater harvesting provided 60% of its annual irrigation water requirement of an average about 300,000 m3.

A study by Kimiti (2007) differed from the current study in terms of methodology but similar in objectives. The study in Machakos to investigate the characteristics of rainfall and quantified how much water could be harvested from rainfall inputs. Data relating to rainfall were taken from The Kenya Meteorological Department. The missing data was estimated using the linear interpolation formula. Similarly, roof catchments areas were determined through exploratory survey of the area of study. The findings indicated high variability of temporal distribution of rainfall over the years in all stations. Farreny et al., (2011) did a correlation study between runoff and rainfall and found a high correlation of $p > 0.95$ and $p < 0.05$.

Other work include that of Patel et al. (2014) who carried out studies in Sanlkalchand Patel College of Engineering (SPCE), Visnagar India with the main objective of evaluating possible amount of water that could be harvested from campus rooftops. The annual rainfall was average of 750mm. The research team were able to harvest a total of 266,672.37m3 of rain water falling on 31,342.28m2 of surface area. This translates into 0.999 litres of water harvested from 1m2 of surface rooftop when it rained 1mm of rainfall. Similarly Olowoiya and Adeboye (2009) carried out a study in Abeokuta Nigeria and the findings were that with an annual mean rainfall of 1156mm it was possible to harvest annually approximately 74.0 m3 of rainwater per household whose rooftop was an average of 80m2. This translated to 0.800 litres of water harvested from 1m2 of rooftop when it rained 1mm of rainfall.

It can be seen from the above literature review that specific studies relating to measuring and quantifying actual amounts of rainwater collected from rooftops has not been carried out extensively. Most have relied on the Gould and Nissen Formula to evaluate potential of a given collection surface to collect specific amounts of rainfall. This study then will provide a base for building research on the potential offered by rooftops to harvest rainwater to be used by smallholder farmers in water stressed agro-ecological zones

2. MATERIALS AND METHODS

2.1. Study Area

Isinya sub County in Kajiado County was purposefully selected for carrying out the research because of its high density of population and the fact that its regions cut across two eco-zones IV and V. Isinya sub County comprises the Isinya and Kitengela regions. This region is located between longitude E36.72o and E37.12o and latitude S1.38o and S1.81o within altitude range of 1760 and 2023 meters above sea level. Its estimated total area is 1, 056km2 (KNBS, 2009). Isinya Sub County is also experiencing increasing influx of migrants to its northern region of Kitengela and Isinya. The migrants are small-scale farmers who are using green house and irrigation technologies. There is increasing adaptation to small scale and private irrigation schemes in the area (Thuo et al., 2001).

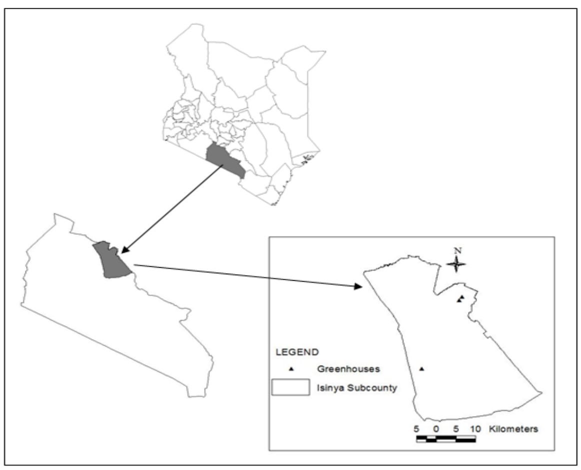

Figure 1: Map of Study Area

2.2. The Experiment

The rainwater harvesting experiment was set up in three farms that had installed green houses. Rainwater was collected from the greenhouse roof tops using gutters established on the sides of the green house and directed to a ditch that had the capacity to store a maximum of 16, 000 litres of water. Each green house had different surface area. The rooftop served as the rain water catchment surface with total surface areas as shown below on Table 1.

Table 1: Greenhouse Rooftop Rainwater Catchment Area

Green House	GPS Location	Surface area	Total surface area
1 (Kitengela)	**S01.49002° E036.94198°**	(4m x 3.142)* 15m	**188.52m²**
2 (Kitengela)	**S01.49857° E036.93623°**	(4m x 3.142) * 43m	**540.424m²**
3 (Isinya)	**S01.67727° E036.85070°**	(4m x 3.142) * 15m	**188.52m²**

To calculate the size of the roof, the following formula was used;

Roof surface = ½(Diameter x π) * Length π (Pi) is estimated at 3.142

Greenhouse 1 had a total of 188.52m2 surface area similar to Greenhouse 3, while Greenhouse 2 had a total surface area of 540.424m2. The rain water was collected and stored in a trapezoidal ditch of similar measurements in metres in each of the green house as follows:

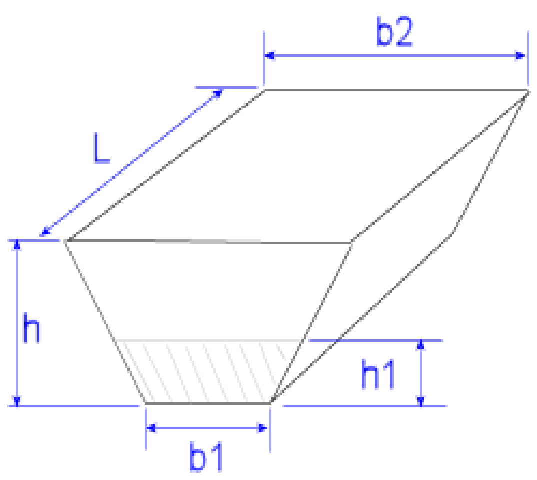

Figure 2: Diagram of Dug out Ditch

Volume = L * (b1 + (b2 - b1) * h1 / h + b1) * h1 / 2

Where b1=1; b2=3; h=2 and h1 stands for the ditch depth after every rainfall event.

When the ditch is full, then h1= h at 2m and a full ditch can store up to a maximum of 16m3 of rain water

Figure 3 Dug out Ditch covered with a Dam Liner

Figure 4: Greenhouse Rooftop Design for Rainwater Harvesting

Appropriate materials were bought to set up a water collection, conveyance and storage systems. Ditches were dug close to the green house in a trapezoid shape to prevent the side walls from collapsing. The measurement of the trapezoid was 4m in length, 3m top base and 1m bottom base and 2m height.

Materials for ditch construction were bought and its costs recorded. The ditch was lined with a polythene dam liner and reinforced on the side with timber as shown on the figure 3 below. The top of the ditch was covered with corrugated iron sheets to prevent evaporation and for security purposes. Rain water conveyance from greenhouse top to the ditch was constructed.

Water level readings in the ditch were done daily from June to December 2013 at 8 am from one point using a long straight wooden stick and measurements recorded in meters and centimetres. Rain gauge readings were recorded after every rainy day in the morning at 8 am. Farm assistants were trained and employed to take and record daily ditch and rain gauge reading. At the end of this period the total volume of rainwater collected was calculated using the formula below:

To derive the formula for the above collection ditch the following calculations were undertaken:

TanØ= x/h=1/2(b2-b1)/h.

Therefore the Cross Sectional Area= ½(b1+2x+b1)*h...............(a)

But TanØ= x/h=1/2(b2-b1)/h.

Therefore solving for x in the above equation:

X=h1*1/2(b2-b1)/h..(b)

Substituting in Equation (a) above:

CSA=1/2{b1+[h1*1/2(b2-b1)]/h+b1}*h1

The Volume for Water collected in the above ditch is given as:

Volume= 1/2{b1+[h1*1/2(b2-b1)]/h+b1}*h1*L...............................(c)

Total volume of rain water collected and stored in the ditches was calculated for each greenhouse. The three greenhouses were considered as replicates to reduce errors and increase precision of data analysis. The daily rain water collected from the green houses was correlated with one another to increase precision of the harvested rain water

2.3.Costs of Constructing the Rain Water Harvesting System

All the costs incurred for each green house in the construction of the rainwater harvesting and storage system were carefully recorded and analyzed to arrive at the final cost for each green house. Total amount of water collected was calculated. A comparison was done between the cost of storing one litre of water using traditional storage systems of plastic tanks and the customized design of a dug out ditch covered with anti-seepage and anti-evaporation materials. The calculation of the above costs is based on the assumption that there must be an existing greenhouse whose cost is separate from the cost of setting up a rainwater storage system.

2.4. Water Storage Costs

ISSN: 2456-8643

The total costs incurred in the construction of the rainwater harvesting and storage system was recorded. A comparison was done between the cost of storing one litre of water using traditional storage systems of plastic tanks and the customized design of a dug out ditch covered with anti-seepage and anti-evaporation materials. The results were used to test the hypothesis on the cost effectiveness of rain water storage to store one litre of harvested water in a customized ditch than in a traditional plastic tank.

3. RESULTS AND DISCUSSIONS:

3.1. Determination of Volume of Rainwater Harvested

Collection surface area for each greenhouse were calculated and recorded as given in Table 1 above where Greenhouse 1and 3 each had 188.52m2 surface and Greenhouse 2 had 540.424m2 surface.

The amount actually collected for each rainfall event was recorded as shown in Table 2 below:

Table 2: Total Daily Volume of Rainwater Harvested

	Greenhouse 1		Greenhouse 2		Greenhouse 3	
Day	Volume in m^3	Rainfall in mm	Volume in m^3	Rainfall in mm	Volume in m^3	Rainfall in mm
1	1.075	8.00	2.500	7.00	0.691	6.10
2	0.150	1.00	3.420	6.00	0.434	2.40
3	2.088	12.00	1.325	10.00	0.439	5.80
4	0.853	5.20	2.275	5.50	0.554	2.80
5	0.356	2.00	1.485	4.00	1.234	8.20
6	2.432	12.00	2.120	7.00	1.477	10.10
7	0.342	2.10	0.555	2.00	1.129	1.50
8	0.383	1.55	0.565	1.50	0.502	4.20
9	0.863	9.00	4.235	12.00	0.877	6.00
10	0.129	7.80	2.369	6.00	0.077	0.50
11	0.562	4.60	1.651	4.50	0.797	6.00
12	0.286	2.60	6.705	19.00	2.586	13.60
13	9.217	9.10	4.075	9.00	2.389	18.10
14	15.300	17.78	7.040	18.00	5.289	33.80
15	13.560	28.99	11.760	30.00	5.801	35.80

16	11.561	12.00	4.240	13.00	1.470	15.50
17	7.400	12.20	11.300	23.00	13.250	88.00
Total Volume	**66.562**	**147.92**	**67.620**	**177.50**	**39.005**	**258.40**

In Greenhouse 1 it was possible to harvest a total of 66.562m3 of water while in Greenhouse 2, a total of 67.62m3 were harvested, and Greenhouse 3 yielded a total of 39.005m3.

Table 3: Total Volume per 1mm Rainfall on 1m2 Surface Areas

	Greenhouse 1	Greenhouse 2	Greenhouse 3
Total Harvest in m^3	66.562	67.620	39.005
Total Surface Area in m^2	188.52	540.424	188.52
Total Rainfall (mm)	147.92	177.5	258.4
Volume in m^3 per 1mm rainfall per $1m^2$ surface area	0.002387[1]	0.000705	0.000801
Average volume per 1mm rainfall on 1m2 surface area of greenhouse top			0.000753

The volume harvested from 1m2 surface area when it rained 1mm of rainfall were therefore 0.002387m3 for greenhouse 1, 0.000705m3 for greenhouse 2 and 0.000801m3 for greenhouse 3 as shown in Table 3 above. The average collection for 1mm of rainfall on 1m2 surface area of the three Greenhouse top was therefore 0.001297m3. However in view of the big difference between Greenhouse1 mean and the other means, it became imperative to ignore the data from Greenhouse 1. Therefore based on Greenhouse 2 and 3 averages, it can be concluded that it is possible to harvest an average of 0.000753m3 of water when it rained 1mm of rainfall falling on 1m2 of Greenhouse rooftop.

A correlation analysis was done for the three greenhouses. In each Greenhouse the amount harvested daily was correlated with daily amount of rainfall. The results were as shown in the following scatter plot graphs on Fig.5, 6 and 7 below

[1] This mean is markedly different from the mean for Greenhouse 2 and 3, thus suggesting errors in data collection

ISSN: 2456-8643

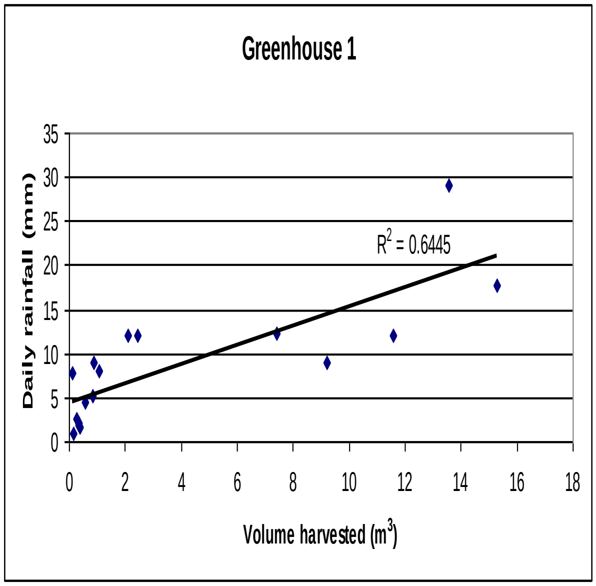

Figure 5: Greenhouse 1 Volume harvest and Rainfall Correlation

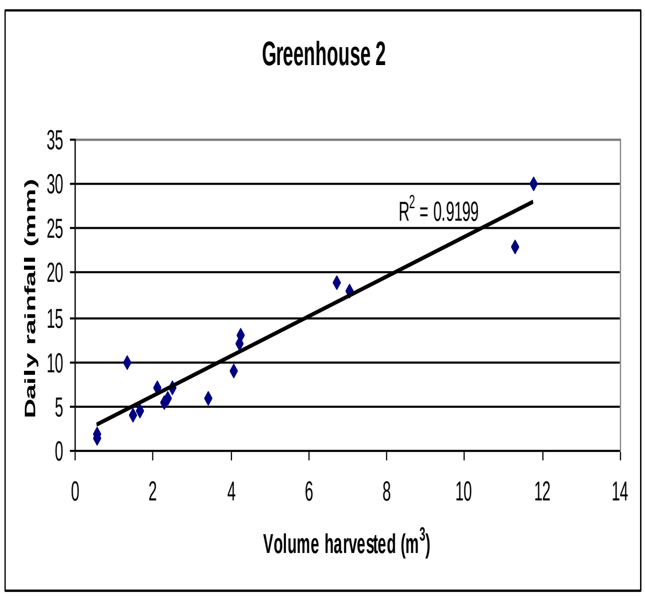

Figure 6: Greenhouse 2 Volume Harvest Rainfall Correlation 22

The amount of water harvested from each greenhouse daily was correlated with each of its own rainfall recording. Greenhouse 1 Correlation Factor was 0.6445, Greenhouse 2 was 0.9199 and Greenhouse3 was 0.9855. These results demonstrated a positive correlation between daily amount of rain harvested and daily rainfall measurements.

Greenhouse 1 demonstrated a weaker positive correlation while 2and 3 demonstrated very strong positive correlation. Greenhouse 1 mean was also markedly different from the rest. This indicate that there may have been errors in recording either the daily amount of rainfall of the daily volume of rainwater harvested.

Accordingly, in Isinya sub-county, smallholder farmers have the potential to harvest an average of 0.75 litres of rainwater whenever it rained 1mm rainfall falling on 1m2 of a greenhouse top and collected into a customized dug out ditch lined with a Dam Liner

3.2. Cost of Storing Harvested Rain Water.

The total cost of constructing, maintaining and storing rain water was calculated and it was a total of Kenya Shillings 157,904 for the three greenhouses. These included labour costs for designing and digging the ditch, materials costs such as gutters, dam liner and iron sheets, and monthly wages for maintaining the ditches in good working order. The average for each Greenhouse was therefore Kenya shillings 52,634.67 as shown in Table III below. To get the cost per litre of storing rainwater, the cost for each Greenhouse was compared with the total volume harvested in each Greenhouse. Therefore the total cost for storing one litre of water was an average of Kenya shillings 0.97.

Table 4: Cost of Rainwater Storage per Greenhouse

	Volume Harvested in m3	Costs Kshs per greenhouse	Cost per m3 per greenhouse
Green House 1	66.562	52634.67	790.76
Green House 2	67.620	52634.67	778.39
Green House 3	39.005	52634.67	1349.41
Average Storage Cost per litre			972.85

The cost for each greenhouse ditch was an average of Kenya shillings 52,635.00. A comparative study was done for all three green houses and the findings were that the average cost for storing one litre of water in the ditch was Kenya shilling 0.97. This cost was compared with the cost of purchasing a traditional plastic tank whose capacity was 5000 litres as shown on the Table IV below**:**

Table 5: Cost of Key Water Storage Tanks

Storage Device	Storage Capacity in m^3	Total Cost of Storage	Storage Cost per m^3 in Kes.
Toptank	5,000	40500	8.1
Zentank	5,000	38300	7.66
Polytank	5,000	34200	6.84
Roto Tank	5,000	45000	9
Average per Tank			7.9
Customized Ditch	5,000	4850	0.97

The findings indicate that it costs on average Kenya shillings 0.97per litres to store rainwater in a customised dug out ditch lined with a damliner compared to storage using plastic tanks whose average cost was Kenya shillings 7.9 per litre. Storing rain water in a plastic tank is likely to cost a smallholder farmer 8 times more than a dug out ditch.. The cost of storing 5000 litres of water in plastic tanks range from Kenya shillings 6.84 per litre being the lowest and Kenya shillings 9.00 being the highest as shown on Table VI above, Therefore it is much cheaper per litre to store water in a customized ditch than to buy traditional plastic water storage tanks assuming the greenhouses are already installed. The comparative analysis indicates that it is much cheaper for a small scale farmer to dig a rain water storage ditch compared to buying plastic tanks. The above cost of the plastic tanks does not include transport and installation costs, while the ditch costs is all inclusive.

The findings of this study were consistent with the work of Patel et al. (2014) in Sanlkalchand Patel College of Engineering (SPCE), Visnagar India who found that 0.999 litres of water could be harvested from 1m2 of surface rooftop when it rained 1mm of rainfall. Similarly Olowoiya and Adeboye (2009) could harvest 0.800 litres of water harvested from 1m2 of rooftop when it rained 1mm of rainfall which relates closely to the findings of this current study.

Likewise the findings of this study was consistent with the work of Kumar and Mandal (2014) who set up a rain water harvesting system in a remote village in Bangladesh and could harvest

ISSN: 2456-8643

0.261 litres of water from 1m2 surface area raining 1mm of rainfall. The current findings were also in agreement with the work of Patil-Pawar and Mali (2013) who attempted to evaluate the potential for harvesting rain water from a roof top in a village in India, and could harvest 0.755 litres of rainwater from 1m2 surface area when it rained 1mm rainfall.

A similar but somewhat different in methodology was done by Sharma et al. (2013) who carried out a study in an horticultural farm in Athi River outside Nairobi, Kenya. The area experienced sodicity problems which necessitated identification of a clean source of water and rain water was considered a better option. In this study rainwater harvesting provided 60% of its annual irrigation water requirement of an average about 300,000 m3. The study concluded that harvesting rain water and storing them for future use offers a viable solution for both commercial and smallholder farmers.

Kimiti (2007) carried out a similar study in Machakos to investigate the characteristics of rainfall and to quantify the probable amount of water that could be collected from rainfall inputs but the study differed markedly from the current study in terms of methodology because secondary rainfall data from The Kenya Meteorological Department was used. Missing data was estimated using the linear interpolation formula. Similarly, roof catchments areas were determined through exploratory survey of the area of study. The findings indicated high variability of temporal distribution of rainfall over the years in all stations.

In Sri Lanka and Uganda a DFID funded research project was carried out by Martinson et al., (2002) to facilitate the design of a low cost system to harvest rain water from rooftops among rural communities who experienced challenges in storing rain water. The results of this research were used to help guide the design of low cost rainwater storage facilities. Some of the recommendations include the tarpaulin tank as an example of a successful low cost design that is being replicated in southern Uganda. This design is closely related to the dugout ditch lined with a polythene material. In Bangladesh Islam et al., (2014) carried out a research to investigate rainwater harvesting and storage as a low cost option compared to the portable water. The findings were related to the present research and recommended that the roof top harvesting of rain water was viable and affordable at $171 which was assumed to be affordable in the region. This is roughly equivalent to Kenya shillings 17100 by current rates. The current design cost Kenya shillings 157, 904.00 is even lower

In Bangladesh India extensive rain water harvesting projects have been carried out in various regions. Two examples stand out. These are the Panscheel Cooperative Group housing Society Source (http://www.rainwaterharvesting.org/Urban/panchsheel.htm) who set up the system on their rooftops of their housings whose total surface collection area was 357,150m2 located in an area receiving 611mm rainfall annually. They collected a total of 174,575,000 litres of water at a total cost of Rs. 800,000.00. This is equivalent to Rs 0.0046 per litre or Kenya shillings 0.00687 per litre using the current exchange rate. The rooftop collection efficiency was 80%. In another of their project, Mother Dairy F & V Unit located in the same region they collected a total of 322, 249, 802 litres of water from 89,370m2 at a total cost of Rs. 435,000 equivalent of Rs. 0.0135 per litre or Kenya shillings 0.02 per litre. In this project the collection efficiency was 59%.

Babu (2010) set up a rain water harvesting project on the roof top to harvest safe drinking water in India. The study revealed that in addition to costing Rs. 1.30 equivalent to Kenya shillings 1.95 per litre it required that the community could positively embrace and maintain the project to ensure that water is delivered to their door step.

Contrary to current study one study carried out in the USA indicated that it was not cost effective to harvest rain water in comparison with municipal water. Hicks (2008) carried out an economic analysis from the perspective of a private developer that incorporates rainwater harvesting in rooftop designs in Arlington area of Virginia USA. The results were that it was uneconomical to incorporate rainwater harvesting system for a private developer but he found it economical when incorporated to be paid by the tenant by charging a modest premium of less than 1% for the privilege of occupying a “green” building.

Generally therefore except for a few isolated researches the findings of the current study agree with most researches done in the field of rain water harvesting. A lot of this work has been done extensively in many Asian countries and few in Africa and particularly Kenya. The results of these studies show marked differences in parameters such as volume harvested per 1mm of rainfall from one location to another. These differences arises mostly from the methodology. For example the current study relied on daily rainfall measurements while most of the others relied on annual rainfall measurements. The time frame for these studies also differed markedly with most doing several months and years. Further studies need therefore to be done for longer periods in order to establish key parameters that may be critical to the success of rain water harvesting as an alternative technology for water stressed ecological zones in Kenya.

4. CONCLUSION AND RECOMMENDATION

The study concluded that it is possible harvest an average of 0.75 litres of rainwater when it rained 1mm of rainfall falling on 1m2 of a typical greenhouse rooftop. The study also concluded that when compared to purchasing a 5000 litre plastic storage tank it costed only Kenya shillings 0.97 to store a litre of rainwater in a custom dug out ditched lined with a dam liner compared to an average of Kenya shillings 7.90per litre for a traditional plastic storage. Therefore it was concluded that rainwater harvesting from greenhouse roof tops is a viable and affordable technology for smallholder farmers in water scarce regions of Kenya.

Each season has the capacity to produce adequate amount of water that can irrigate a crop. Adequate amount of rainfall can be harvested in the drylands for irrigation agriculture. Further harvesting and storing the rain water in a customized dug out ditch was far more affordable than traditional storage plastic tanks and therefore affordable to small scale farmers.

It is recommended therefore that smallholder farmers could harvest rainwater using rooftops such as households or greenhouses within the farm; and the harvested rain can be stored in ditches constructed using locally available materials at an affordable cost.

The recommendation therefore is that smallholder farmers could be encouraged through awareness campaigns and training to adopt this affordable rain water harvesting and storage technology for sustainable agriculture in dry lands of Kenya which will result in food security.

This study also recommends more similar studies to be done in the Kenya context to allow for more custom made technologies more relevant and applicable to the Kenyan smallholder farmer. A lot of this kind of work has been done extensively in many Asian countries and few in Africa and particularly Kenya. This study then will provide a base for building research on the potential offered by rooftops to harvest rainwater to be used by smallholder farmers in water stressed agro-ecological zones and in addition to options for storing the same water in a manner affordable and easily accessible to a smallholder farmer in dry lands.

REFERENCES

Babu, R. A. (2010) Roof top rain water harvesting system in Deccan plateau region, Andhra Pradesh, India. International rainwater catchment systems conference

Barron, J. Noel, S. Malesu M, Oduor A, Shone G, and Rockström J. (2008) Agricultural water management in smallholder farming systems: The value of soft components in meso-scale interventions. Stockholm Environment Institute

Bill Hicks, P.E. (2008) A Cost-Benefit Analysis of Rainwater Harvesting at Commercial Facilities in Arlington County, Virginia. Masters Project, Nicholas School of the Environment and Earth Sciences Duke University

Chanan, S. (2007) Harvesting Rainwater for environment, conservation and education: Some Australian case studies

Eruola, A. O., Ufoegwe G. C., Awomeso j. A., Adeofun C. O., Idowa O.A., and Sowunmi O. (2010) Quantilitative and Quantitative assessment of rainwater harvesting from rooftop catchment. Case study of Oke- lantoro community in Abeokuta Nigeria

Gichuki, F. N. (2002) Water Scarcity and Conflicts: A case study of the upper Ewaso Nyiro North basin. In Blank, Herbert, Mutero, C. M. and Rust, H.M, (eds.) (2002) The changing face of irrigation in Kenya: Opportunities for anticipating change in Eastern and Southern Africa: Colombo, Sri Lanka: International Water Management Institute Pp 113-134

Islam, K. Z., Islam, M. S., Lacoursière, J. O., & Dessborn, L. (2014). Low Cost Rainwater Harvesting: An Alternate Solution to Salinity Affected Coastal Region of Bangladesh. American Journal of Water Resources, 2(6), 141-148

Kahinda, J.M., Taigbenu, A.E., Boroto R.J. (2010) Domestic rainwater harvesting as an adaptation Water Research Group, School of Civil and Environmental Engineering, University of Witwatersrand, Private Bag 3, WITS 2050, South Africa.

Kimiti J.M. (2002) Rainwater Harvesting for Domestic Use: A case Study of Machakos District. College of Biological and Physical Science. University of Nairobi Library

Source: http://erepository.uonbi.ac.ke:8080/xmlui/handle/123456789/56864

Kubbinga, B. (2013) Road runoff harvesting in the dry lands of Sub-Saharan Africa: its potential for assisting smallholder farmers in coping with water scarcity and climate change, based on case studies in eastern province, Kenya. Msc. Thesis. Free University / Vrije Universiteit, Amsterdam, Faculty of Earth and Life Sciences

Kumar, B. B. and Mandal B. H. (2014) Construction and Evaluation of Rainwater Harvesting System for Domestic Use in a Remote and Rural Area of Khulna, Bangladesh. International Scholarly Research Notices Vol. 2014

Kumar, M. (2000) Aqua Dholavira. Archeology: A publication of the Archeological Institute of America, vol 53. No 6 2000.

Li Fengrui, Cook Seth, Gordon T. Geballe and William R. B Jr (2000) Rainwater Harvesting Agriculture: An Integrated System for Water Management on Rainfed Land in China's Semiarid Areas A Journal of the Human Environment 29(8):477-483.

Source:

http://dx.doi.org/10.1579/0044-7447-29.8.477

Martin, D.B. Ranatunga, N.K and Gunaratne A. M (2002) Reducing Eain Water Harvesting System Cost WEDC 28, Calcutta India

Ngigi, S.N. (2003). Rainwater Harvesting for Improved Food Security. GHARP 83-84pp.

Ngigi, S.N, Hubert H.G. Savenije, Johan Rockström, Gachene C.K.(2005) Hydro-economic evaluation of rainwater harvesting and management technologies: Farmers' investment options and risks in semi-arid Laikipia district of Kenya, Physics and Chemistry of the Earth, Parts A/B/C, Volume 30, Issues 11–16, Pages 772-782.

Source: http://www.sciencedirect.com/science/article/pii/S1474706505000914)

Nyuk Hien Wong, Su Fen Tay, Raymond Wong, Chui Leng Ong, Angelia Sia. (2003) Life cycle cost analysis of rooftop gardens in Singapore, Building and Environment, Volume 38, Issue 3, Pages 499-509.

Source: http://www.sciencedirect.com/science/article/pii/S0360132302001312

Olowoiya, O.A., and Adeboye O.B. (2010) Assessing the Potential for Rainwater Harvesting Water Resources Management Volume 24, Issue 10, pp 2129-2137

Panscheel Housing Cooperative Rainwater harvesting Project (2006) Centre for Science and Enviroment. New Delhi India

Source: http://www.rainwaterharvesting.org/urban/panchsheel.htm

Patel, R.U., Patel, V.A., Balya, M.I. and Rajgor H. (2014) Rooftop Rainwater Harvesting at SPSV Campus, Visnagar: Gujurat- A case Study. International Journal of Research in Engineering and Technolgy Vol 3 Issue 4

Pawar-Patil, V.S., and Mali S. P. (2013) Potential Roof Rain Water Harvesting In Pirwadi Village Of Kolhapur District, Maharashtra (India) - A Geospatial Approach Journal of Research in Humanities and Social Science Volume1 ~ Issue 4 pp: 19-24

Sharma, B., Madziva F., Tumbo S.D., Bouitfirass M., Boufaroua M., El Mourid M., Salem A. Rainwater harvesting in the management of agro-eco Systems in barron . (ed) (2009), rainwater harvesting: a lifeline for human well-being Stockholm Environment Institute, York, UK Stockholm Resilience Centre, Stockholm, Sweden

Vol. 2, No. 06; 2017

ISSN: 2456-8643

Thuo, J. K., Hide, J M., Kimani, J. (2001). Informal Irrigation in the Peri-Urban Zone of Nairobi, Kenya. An Analysis of Farmer Activity and Productivity. UK Department for International Development (DFID) Report OD/TN 104.

UNEP (2009) Rainwater Harvesting: A lifeline for Human Well-being. Stockholm Environment Institute, Sweden

Xue-Feng He, Huhua Cao, Feng-Min L. (2007) Econometric analysis of the determinants of adoption of rainwater harvesting and supplementary irrigation technology (RHSIT) in the semiarid Loess Plateau of China agricultural water management 8 9 2 4 3 – 2 5 0

Yuan, T. Fengmin, L. and Puhai, L. (2003) Economic analysis of rainwater harvesting and irrigation methods, with an example from China, Agricultural Water Management, Volume 60, Issue 3, Pages 217-226

Source: http://www.sciencedirect.com/science/article/pii/S0378377402001713