

Rainwater Harvesting Potential at the University of Eldoret, Kenya

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Abstract

Water is a vital resource in the environment and only 3% of all water on Earth is fresh water, all of which comes from rains. Water keeps the environment “alive”, and plays a key role in environmental sustainability. Proper harnessing of water has benefits which contribute to meeting our millennium development goals on water and environmental sanitation, promote sustainability, reduce annual expenditure on water and recharge underground aquifers. One of the ways to reduce dependence on municipal sources of water is through rainwater harvesting (RWH), defined as the collection, conveyance, and storage of rainwater for an intended use. The study was carried out to establish the potential of rainwater harvesting in the University of Eldoret, motivated by the need for rationalization of water supply in the university due to population growth, increased expenditure on water and the need to complement total dependence on municipal water supply. The investigation examined what happens to rain falling in the campus and included measurement of the area of available rooftops, roof top catchment calculations, reviewing the amount and rainfall pattern for 10 consecutive years and estimating the storage that may be required for the rainwater harvested. The study established that there is a substantial potential for RWH through rooftop water harvesting in the University as the rainfall is adequate, the rainfall pattern reliable and enough rooftop surfaces already in place. The amount of rainfall received in the area per annum is substantial and can satisfy a significant portion of the University water supply while also saving the university a substantial amount of money.

Key Words: Rainwater Harvesting, Rainwater Storage, Rooftop Catchment

INTRODUCTION

The phrase –Water is Life is a common quote; it stresses the fundamental role of water in biomass production. For humans, archeology has shown that human settlement has been dictated throughout history by availability of and/or proximity to a water source.

According to Chleg and Dupriez (1988), –Only 3% of all water on Earth is fresh water and 68% of the water is frozen ice on the North and South Poles. All humans and most animals as well as nearly all vegetation can only survive on fresh water free of salt and minerals. The other 97% of the water on planet Earth is saline seawater in which fish, whales, corals, plankton and other creatures flourish. Slightly salty water may be used for watering livestock and other animals, although fresh water is healthier.

Nearly half of all deep boreholes are dry or contain saline/brackish water with minerals harmful to humans, animals and plants (Agarwal and Narain (2003). Where fresh water is pumped up from very deep boreholes, it is called mining fossil water because the water withdrawn cannot be replaced by rains. Therefore, there are only two sustainable solutions to the world's increasing demand for water, namely rainwater harvesting and water conservationl.

Whereas it is known that clouds can be seeded with chemicals to produce rains, the practice is expensive and unsustainable. It is therefore recognized that rainfall varies from region to region and from one year to another beyond peoples' manipulation and interference. All fresh water comes from rains, including water in deep boreholes which originates from rains infiltrated into the underground thousands or millions of years ago. Fresh water can only be obtained from four main sources: rainwater harvesting, shallow ground water, deep ground water and desalination of seawater, and the two latter options are often too expensive for most users, leaving most of us with only two choices.

Rainwater harvesting (RWH) can be defined as the collection, conveyance, and storage of rainwater for an intended use (Gould, 1987). Most often, the intended uses are for biomass production, such as for crops, trees, or pasture, or for domestic needs (Malesu et al. 2007), including using it as piped water to flush toilets and for the garden watering, yard wash down, vehicle and car washing, instead of treated drinking (potable) water (Hydro International, 2009). Rainwater harvesting consists of 5 components (Fig 1):

1. *Rainfall*
2. *Catchment areas*, also called watersheds, onto which the rainwater falls
3. *Gutters*, or conveying channels, to bring rainwater from a catchment area to storage reservoir
4. *Storage reservoirs*, which can be tanks, ponds, dams and in situ storage in sand and soil, and
5. *Retrieval*, whereby water is extracted from *reservoirs* either by gravity or by pumps and lifts.

Thus, rainwater harvesting and utilization systems have been used since ancient times and evidence of roof catchment systems date back to early Roman times (Fig 1).

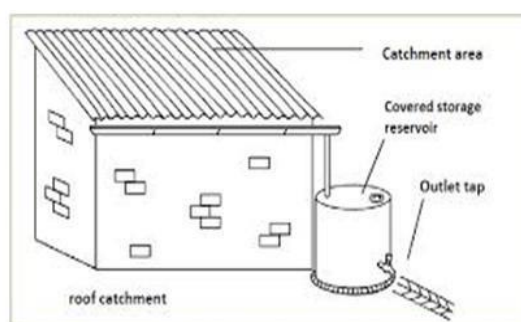


Fig. 1. Schematic of a typical rainwater catchment system

Source: UNEPIETC, 1998

There is evidence in the Mediterranean region of a sophisticated rainwater collection and storage system at the Palace of Knossos which is believed to have been in use as early as 1700 BC (Hasse, 1989). In Sardinia, from the 6th century BC onwards, many settlements collected and used roof runoff as their main source of water (Crasta *et al*, 1982). Many Roman villas and cities are known to have used rainwater as the primary source of drinking water and for domestic purposes (Kovacs, 1979). Rain water harvesting has been practiced for more than 4000 years throughout the world (Norma Khoury-Nolde, 2001).

Currently, in the United Kingdom water butts are often found in domestic gardens to collect rainwater, which is then used to water the garden, and the British government's "*Code For Sustainable Homes*" encourages fitting large underground tanks to newly-built homes to collect rainwater for flushing toilets, washing clothes, watering the garden, and washing cars, and is estimated to reduce by 50% the amount of mains water used by the home (Gov. UK, 2008). In the U.S. Virgin Islands, the law requires that provision be made in the construction of all new buildings for the capture and storage of rainfall coming into contact with their roofs. The law requires that roofs be guttered and that cisterns be constructed having a volume that depends on the size of the roof, the intended use of the structure, and the number of floors (UNEP, 2005).

Elsewhere, the Organization of American States (OAS, 2005) has recognized that rainwater harvesting (RWH) technology has proved to be very effective throughout several Latin American countries and most of the Caribbean islands, where cisterns are the principal source of water for residences; and in some Caribbean islands, governments regulate the design of rainwater harvesting systems. OAS (2005) lists the following advantages of RWH:

1. Rainwater harvesting provides a source of water at the point where it is needed. It is owner operated and managed.
2. It provides an essential reserve in times of emergency and/or breakdown of public water supply systems, particularly during natural disasters.
3. The construction of a rooftop rainwater catchment system is simple, and local people can easily be trained to build one, minimizing its cost.
4. The technology is flexible. The systems can be built to meet almost any requirements. Poor households can start with a single small tank and add more when they can afford them.
5. It can improve the engineering of building foundations when cisterns are built as part of the substructure of the buildings, as in the case of mandatory cisterns.
6. The physical and chemical properties of rainwater may be superior to those of groundwater or surface waters that may have been subjected to pollution, sometimes from unknown sources.
7. Running costs are low.
8. Construction, operation, and maintenance are not labor-intensive.

Traditionally, Kenyans have harvested rainwater for domestic use by whatever means was available to them, most often using earthen containers/tools to collect and store it for use. This has always included harvesting rainwater from roofs. In recent times, however, interest in rainwater harvesting has rapidly grown in Kenya over the last thirty years.

Kenya is among the water scarce countries of Africa (GOK, 2008) and has also seen her water storage per capita deteriorate to critical levels with time. It is for this reason that Kenya Rainwater Association (KRA) is promoting rainwater harvesting and utilization. Throughout the country, RWH projects have been carried out in an effort to provide long-term solutions to water resource problems. The key players in RWH include the following: government ministries and many NGOs and other Community-Based Organizations at national and local levels who have played a major role in putting rainwater harvesting in the limelight; and at the local levels, church organizations and Women Groups have been very active in this field. Through SEAR-Net (Southern and Eastern Africa Rainwater Network) established with the assistance of International Rainwater Catchment System Association and the support of the Regional Land Management Unit of UNEP, Kenya has been able to exchange information on rainwater harvesting with other countries in the east and southern Africa sub-regions (IWRM, 2010). Priscoli and Wolf (2004) in highlighting the importance of water security and water management to the growth of a community said: –Control of water is control of life. How we exercise this control reveals what we value, who we are, and what type of society we seek to become. Water management and its civil infrastructure is closely linked to our civic culture. Participation is central to such linkages.†

The population of the University of Eldoret (UOE), has increased rapidly in recent years thereby increasing pressure on existing infrastructural facilities: it currently has a student population of 17,000, all of whom cannot be simultaneously hosted by the institution at any one time. Of the 12,000 it can host in a semester, approximately only 53% live within the institution's hostels (both within UOE campus and outside hostels owned and rented by the institution). The University expects to have a student population of 30,000 by 2020 (UOE Administration, 2014, personal communication).

Among other things, water demand is steadily rising beyond what the university can comfortably provide with its current budget. This study therefore aimed to demonstrate the potential for (rooftop) rainwater harvesting in the University of Eldoret in the hope that it can assist the university to address issues such as the Millennium development goals regarding water use and total dependence on municipal water supply. The general objective of the study was to demonstrate the potential feasibility of rainwater harvesting by the university based on its own current infrastructure. Two objectives were identified as necessary to pursue to achieve the aims of the study; these were to estimate the area of roof surfaces and estimate the amount of rainwater they can harvest in an average year based on the mean annual rainfall in the area, and to examine the current water usage in the university and derive from it the storage facilities that may be required. It was recognized that the university is a growing institution and will continue to continuously grow its infrastructure, including those related to its water usage.

METHODOLOGY

The area of study, University of Eldoret, is located within Eldoret Municipality, Uasin Gishu County, Kenya, about 10km North of Eldoret town CBD along the C48 Ziwa-Kitale road. Eldoret is one of the areas in Kenya known for its cool and temperate climate favoring high agricultural productivity due to its friable reddish-brown loam soils and the heavy rainfall it experiences, ranging between 900 to more than 1200mm. It has two

rainy seasons with diurnal mean temperature range from 8.4°C to 27°C. Local elevation of Eldoret varies from about 2100 to more than 2700 meters above sea level. The predominant land use in the area surrounding Eldoret town is subsistence and semi-commercial agriculture mainly of food crops and dairy farming; however urban sprawl is steadily spreading into these agricultural lands (GoK, 2013). The underlying geology is a tertiary phonolite/trachyte plateau, sloping westwards to Lake Victoria.

The study covered the part of the main campus where there is a high concentration of buildings. A total of 61 main buildings were included in the study (Fig 2): the Administration Block, the New Library, New Space, Mtello B, Mtello A, Academia, Lavi buildings, Academic block, Annex hall, Dean of students building, 6 hostels, Clinic, Blocks (1-5), Kerio hall, Labs (L1), Building (L1), Hostels B, Laboratories (L4 and L5), Tana hostels, and four Farm buildings. A number of outlying buildings which are part of the main campus were not included.

The data for this research were gathered through a number of avenues: measurement of building dimensions (in particular roof areas), retrieval of meteorological data, in particular rainfall, observation and examination of water installations and utilization in various buildings, retrieval of university expenses on water with the help of university officials, photography, and one-to-one discussions with university officials and student colleagues. The following procedures were followed to address the two objectives:

Objective 1: To estimate the area of roof surfaces and estimate the volume of rainwater that can be harvested (monthly and yearly) based on the mean monthly and mean annual rainfall in the area:

- (i) Building roof dimensions were measured (in M) and the results obtained cross-checked with university building plans where these were available. Total roof areas (in M²) were calculated; and their yield capacity also calculated using the length and horizontal width of the roof of each building (Nissen-Petersen, 2007,). The individual roof areas were then summed up.
- (ii) Historical rainfall data was obtained from the UOE meteorological station. The rainfall data collected covered the period 2004 – 2013 (see Fig 3) as well as data for 2013 (the latest complete year prior to the study). These data showed months when rain is high, medium and those with no rainfall at all. Additional data was acquired from internet sources on rain averages, rainfall reliability, temperature averages and the number of rainy days per annum.

Objective 2: To examine the current water usage in the university and derive from it the storage facilities that may be required the following were undertaken:

- (i) Identification of the water uses and the existing storage facilities and their designs (see Plates 1-6 below) were done through observation and photography.
- (ii) Estimation of the volume of rainwater that can be collected through RWH was calculated using the Texas A&M AgriLife Extension Service Formula: - Rain Fall Harvest = Area x Amount of Rain x Efficiency . The rooftop harvest efficiency was taken to be 0.75 (75%) of the actual rainfall on the catchment area after accounting for losses due to evaporation during periods when short, light showers

are interspersed with periods of prolonged sunshine (Nissen-Petersen, 2007, Texas A&M 2006, UNEP 2005, OAS 2005,).

- (iii) The university water consumption amount: this was estimated using the university's records on daily and monthly water usage.
- (iv) From these calculations, the capacities of the tanks that may be required was then estimated.

The data was analysed using SPSS and results presented in graphs and tables.

RESULTS AND DISCUSSIONS

Total Roof Area

The 61 main buildings as measured and calculated as described above were found to have a total area of 31,553.52 square meters (rounded to 31,554m²). It was clear that these rooftops are thus large enough to yield a substantial amount of rainwater considering that it has been estimated that 1 cm of rain on 100 m² of roof yields 10 000 liters (or 10m³) with a yield efficiency of 75% (UNEP 2005).

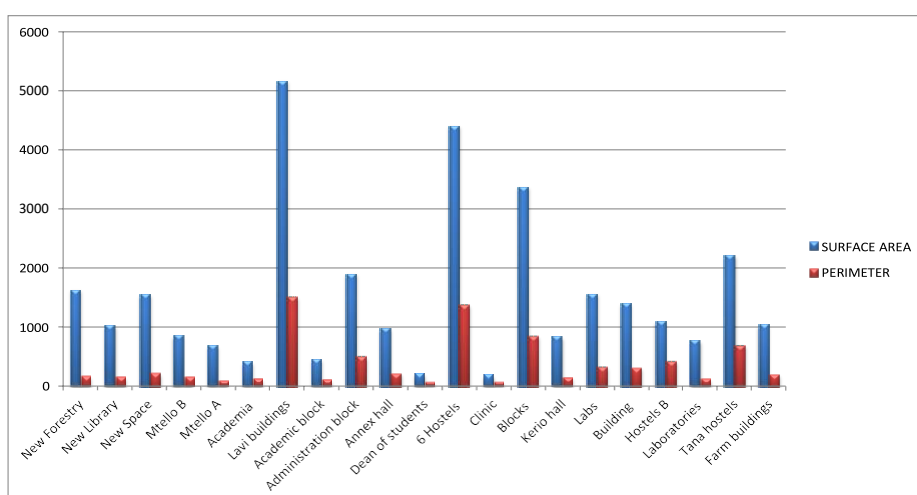


Figure 2. Surface area (m²) and perimeter (m) of the university's roof tops

Rainfall received in UOE per annum

From the decadal data (2004-2013) plotted in Fig 3 below obtained from the university meteorological station it was observed that: The driest year for the subject period was 2009 with the annual rainfall of 791.3mm and monthly mean rainfall of 65.3mm; and the wettest year was 2006 with monthly mean of 141.1mm and an annual total of 1692.7mm.

The rainfall received in UOE for this decade (10yrs) show an annual rainfall range of nearly 800mm to 1700mm.

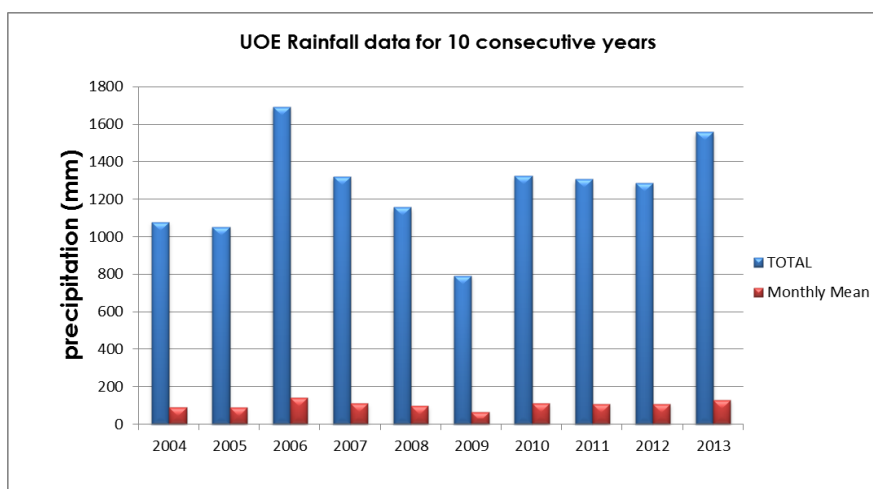


Figure 3. Annual total and monthly mean rainfall (mm) (2004-2013), UOE

Also from the data of this decade it was observed that the driest months were February, March, June and November, with corresponding monthly mean rainfall of 0.3mm, 2.5mm 10mm and 12.8mm respectively; and the wettest months were April, July and August with corresponding monthly mean rainfall of 284.6mm, 223.5mm and 169.7mm respectively. According to Kenya Rainwater Association, RWH in Kenya is generally feasible if the amount of annual rainfall is at least 600mm. Thus, the study area is a good candidate for rainwater harvesting.

Rainfall in 2013

The data on rainfall in 2013 (Fig 4) was obtained principally to assist in demonstrating how much rainwater the university would have harvested in the latest full year. These data gave an average monthly rainfall of 64mm with a range of 29mm to 280mm during the year, and appears to be a typical year compared to the 10year data.

Thus, these figures show that during 2013 the average monthly 64mm and 31,554m² roof area available would have yielded the following average amounts of rainwater per month, given that 1 cm of rain on 100 m² of roof yields 10,000 liters with a yield efficiency of 75% (UNEP 2005, Texas A&M 2006):

$(64/10) \times (31,554/100) \times 0.75 \times 10,000 \text{ L} = 6.4 \times 315.54 \times 0.75 \times 10,000 \text{ L} = 15,145,920\text{L}$ or $15,145.92\text{m}^3$ of water per month; or $15,145.92 \times 12 = 181,751.04\text{m}^3$ of water for the year 2013.

Looked at another way, the 180mm of rainfall in August 2013 would have yielded $18.0 \times 315.54 \times 0.75 \times 10 \text{ m}^3 = 42,597.9\text{m}^3$ of water, *almost three times the monthly average*.

This is significant as August is the month when the university opens for the academic year, experiencing its highest population and possibly highest monthly water use.

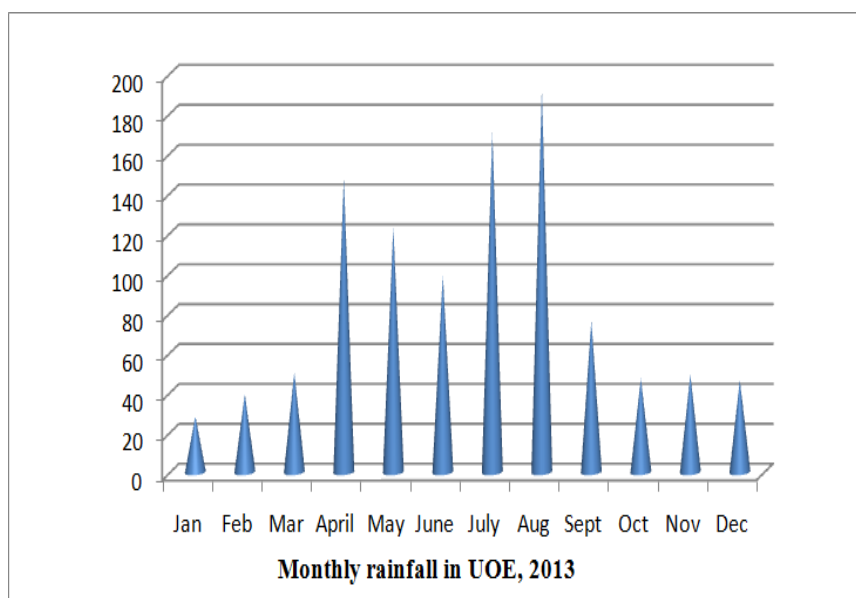


Figure 4. Monthly rainfall in UOE, 2013

Water Usage and Expenditure by UOE

The main area of the University considered in this study has a total number of 61 buildings. The major water usages are: cooking, drinking, bathing, laboratories, cleaning rooms, toilet flushing, and washing, both clothes and utensils. Other areas water is required include livestock watering, tree/flower nursery watering, watering flower beds and monuments and for crop growing (in green houses) – not for general irrigation (Plates 1-6) below. All of these uses, except cooking, drinking and laboratories could be satisfactorily met using rainwater.

The water expenditure figures obtained from the university finance department indicated that water usage for selected months (the university record was incomplete) ranged from 15,000m³ to 22,000m³ in the four recent years, 2010 – 2013 (Fig 5). There was a general increase from 2010 to 2013 reflecting the growth in student population, which is set to steadily grow in the university development plan to a student population of 30,000 by 2020. The university ceased to be a college of Moi university (and became University of Eldoret) in February 2013 and this is reflected in the rise in monthly water bills as shown in Figure 6. Total expenditure in 2013 was KShs 21,116,253.60 (University Finance Officer -Personal communication, April 2014).



Plate 1. Watering nursery plants



Plate 2. Watering flower beds and monuments



Plate 3. Crop growing in green house



Plate 4. Dish washers



Plate 5. Water use in bathrooms



Plate 6. Place for brushing teeth and hand washing

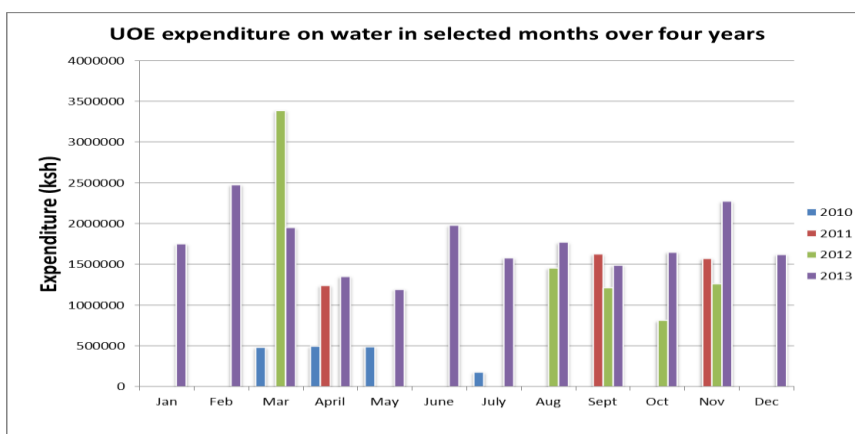


Figure 5. Expenditure on water of selected months in four years, 2010 – 2013 (KShs)

University's Monthly Water Bills, 2013

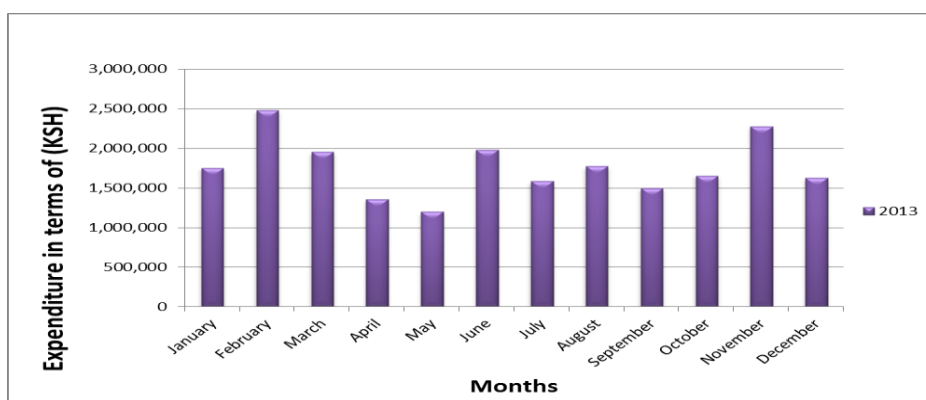


Figure 6. Expenditure on water bills in the year 2013 in (KShs), UOE

Information on consumer categorization, consumption block classification (in M³) and approved tariff was obtained from Eldoret Water and Sanitation Company (ELDOWAS), which supplies processed water to Eldoret Municipality, including UOE. This is presented in Table 2 below. It was found that while educational institutions are billed in the category of schools, the UOE is billed at the commercial/industrial category (Table 1), which thereby contributes substantially to the large sum of money paid by the institution for water bills.

Table 1. Approved tariff structure for the year 2010/2011 by ELDOWAS

Customer category	Consumption block (M ³)	Approved Tariff (Kshs./M ³)
Domestic/Residential	0-6	18.87
	7-20	37.52
	21-50	48.12
	51-100	75.09
	101-300	93.96
	≥ 300	93.96
Commercial/ Industrial (University is charged at this category)	0-6	18.87
	7-20	37.52
	21-50	48.12
	51-100	75.09
	101-300	93.96
	≥ 300	93.96
Schools (instead of this category)	0-600	16.98
	601-1200	16.98
	>1200	16.98
Water kiosks/Community Water providers	Flat rate	15.00

Source: Gazette Notice no. 5317

Storage Facilities Required

The characteristics of the catchment area determine the storage conditions, for example water harvested from buildings which are close to one another can be consolidated and directed to one storage facility while this may be uneconomical when buildings are widely dispersed. Thus for this study the number of storage facilities and capacities were determined through characterization of the development pattern within the institution. It was found to be a cluster form of development, and the location of tanks within a cluster was determined by the topography of the buildings within that particular cluster. The result is given in Table 2 below. It is emphasized that a more detailed assessment would be necessary to inform final decision on the most appropriate locations for storage tanks.

Table 2. Suggested number of storage facilities required and their locations

Clustered Areas	Roof Area (M ²)	Expected rainfall yield (M ³)/month	Suggested tank capacity (M ³)#*	Suggested tank location
Cluster 1: The 22 Lavi buildings, academia and new space	7,312	3,510	120	Adjacent to Lavi hostels
Cluster 2: New Forestry, New Library, Academic block 1 and 2	5,075	2,436	81	Area between Administration block and transport offices
Cluster 3: Mtello, Hostels A-F, Block 1-5, and Clinic	11,215	5,383	180	Behind Block D
Cluster 4: Area around	6,857	3,291	110	Within the farm

Hostel G to Kerio Hall, Labs and Farm				area
Cluster 5: Tana Hostels area	1,095	525	18	Next to the hostels
TOTAL	31,554	15,145	509	-

= Expected rainwater harvest divided by 30 days in a month

* = It is assumed water will be continuously under use therefore capacity suggested is mainly to avoid overflow for each day and thereby wastage**

** = During detailed assessment the actual rate of usage at each point (the drawdown) should be determined more accurately to assist in determining tank capacity necessary

Possible Savings by University

Figures obtained from the UOE administration indicated that the university used an average of $18,728\text{M}^3$ of water per month in the year 2013 (or a total of $18,728 \times 12 = 221,136\text{M}^3$ of water in the year 2013). This cost UOE a total of 21,116,253.60 as mentioned above. The total of $221,136\text{M}^3$ of water used compared to the possible total roof catchment yield of $181,751\text{m}^3$ in the same year as calculated above means that $39,385\text{M}^3$ ($221,136\text{M}^3 - 181,751\text{m}^3$) of water would have been all the UOE required from ELDOWAS in that year. Put another way, the university had the potential to harvest as much as $181,751/221,136 \times 100\%$, i.e. 82% of its water requirements from its own roofs in 2013, and make a correspondingly substantial saving in its water budget!

Situational Analysis

Overall, rainwater harvesting presents a great opportunity that can help the university address some of its day to day management challenges and well as positioning itself to address strategic university needs that come with increasing university population. Down the line, if RWH can be integrated in building designs for future development it can greatly expand this opportunity. Table 3 is a summary of the strengths, weakness, opportunities and threats of RWH that the university should consider going forward so as to maximize its RWH potential (modified from UNEP 2005, 2007, OAS 2005, Nissen-Petersen 2007, IWRM 2010, and Texas A&M 2006).

SWOT Analysis Matrix

Table 3. Matrix showing strengths weaknesses opportunities and threats (SWOT) for RWH

STRENGTHS	WEAKNESSES	OPPORTUNITIES	THREATS
1. Rainwater harvesting provides a source of water at the point where it is needed. 2. It is owner operated and managed. 3. The technology is flexible, the system can be built to meet almost any requirements. 4. It can improve the engineering of building foundations when cisterns are built as part of the substructure of the building as in the case of mandatory cisterns. 5. The physical and chemical properties of rainwater may be superior to those of groundwater or surface waters that may have been subjected to polluting agents. Running cost are lower 6. Construction, operation and maintenances are not labor intensive	1. Possible contamination of water may results from animal waste and vegetable matter 2. Low storage capacities will limit rain water harvesting so that the system may not be able to provide water in a low rainfall period. 3. Where treatment of the water prior to potable use is infrequent due to lack of knowledge, health risks may result; further cisterns can be a breeding ground for mosquitoes if not well managed 4. Leakage from cisterns can cause the deterioration of load bearing slopes 5. The success of RWH harvesting depends on the frequency and amount of rainfall; therefore, it may not a dependable water source in times of dry weather or prolonged drought	1. Improvement in the quality of ground water 2. Reduction in campus soil erosion as surface runoff is reduced 3. Decrease in the chocking of storm water drains and flooding of roads 4. Rise in the water levels in wells and bore wells that are drying up.	1. Increased water storage capacities add to construction and operating cost and may make technology economically unfeasible unless it is subsidized by the government. 2. Rainfall harvesting system may reduce revenue to public utilities.

CONCLUSIONS

Rainwater harvesting potential depends on the rainwater endowment of that area - the total amount of water that is received in the form of rainfall over an area. This study was designed to demonstrate that the potential exists for the university to harvest a substantial amount of water from its own roofs and thereby realize significant savings in its water budget in the long term. It was not designed as an assessment of that possibility, and therefore the figures generated are only good as indicators of the order of magnitude. It is however only logical to conclude that a substantial potential exists.

In encouraging the university to give RWH further consideration, a SWOT analysis is included below that can assist as a starting argument for further consideration. It is emphasized that with the growth of the university the roof area available for RWH is bound to increase substantially and, besides, if the consideration is given serious thought, roof building and roof designs can be proactively adopted to maximize future RWH, and RWH facilities incorporated into the building contracts to minimize construction costs. In addition, the university will increase the areas of paved surface in its development and these could also be incorporated in RWH designs. Above all, rainwater harvesting in education institutions is an unexploited resource in the country with massive potential that remains untapped and which needs to be explored.

RECOMMENDATIONS

RWH reinforced system is recommended for UOE as a supplementary source of water. By implementing RWH the institution will have an opportunity to save substantially in its water budget as demonstrated in this study. From the finding of this study, UOE should pay serious attention to the following recommendations if they have to tap the potential of RWH that this study has established:

1. UOE should adopt a parallel piping system for consumable water and that for other uses. Rainwater should be used for washing, flushing toilets, watering flowers/monuments, irrigating in nurseries and greenhouses, to reduce the amount of water supplied by ELDOWAS which should now be used for drinking, cooking scientific laboratory work, and other consumption purposes;
2. Tapping rooftop water at the green house and in the farm tap rainwater from roofs, unpaved areas and ponds;
3. For the existing water supply there should be proper maintenance for piping systems to avoid losses of water through constant leakage by instituting measures such as plugging leakages, checks on running taps and proper maintenance measures;
4. Storage for rainwater could be in the existing tanks used for toilet flushing;
5. Apply strict house-keeping by:
 - a. Training students during student orientation on environmental education and awareness;
 - b. Giving environmental awards to those observing guidelines drafted;
 - c. Training housekeepers to report any leakages or broken water facilities; and
 - d. Training students to assist in maintenance for a fee.

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