Africa Journal of Physical Sciences 2 (1) (2015) 50-59

Domestic rainwater harvesting: a case study in Embu County, Kenya

GATERI Magdalene Wanjiku[*1 a], OPERE Alfred [1 b], GITAU Wilson[1 c], NGAINA Joshua Ndiwa[1 d]

[1] *Department of Meteorology, University of Nairobi, P. O. Box 30197 Nairobi, Kenya*

*[a]mgdki@yahoo.com, [b]aopere@uonbi.ac.ke, [c] wi.gitau@uonbi.ac.ke, [d] jngaina@gmail.com

ARTICLE INFO

Article History:
Available online 31 July 2015

Keywords:
Rainwater harvesting
Rainfall
Water demand

ABSTRACT

This study assessed probable water that could be harvested during rainy seasons over Embu County of Kenya. Monthly rainfall data was obtained from Kenya Meteorological Department while percentage distribution of household by household size, main roofing material, number of rooms in the main dwelling and per capita volume of water required was sourced from Kenya Integrated Household Budget of Survey (KIHBS). Minimum water demand per household was computed based on KIHBS. Kenya National Bureau of Statistics (KNBS) 2009 population census was used to determine population and number of occupants in the main dwelling. Embu County receives bimodal rainfall during March-April-May (MAM) and October-November-December (OND). Rainfall is highly variable with 8190 and 7490 litres of harvested water during MAM and OND season respectively expected to last for approximately 43 days (MAM) while 39 days (OND) and thus not sufficient to satisfy minimum water demand levels for Embu population. The total potential harvestable water during MAM and OND accounted for 45.4 % and would go a long way in meeting water demands in the region. Notably, harvestable water was being used to supplement natural sources of water. Therefore, enhanced water harvesting during rainy season could provide an alternate source of domestic water.

ISSN 2313-3317

1. Introduction

Water availability and its use form fundamental components for economic, social and cultural development in Kenya [1]. Water significantly influences the quality of human life [2,3]. Increasing population coupled with rapid urbanization and climate change puts tremendous pressure on available natural resources increasing the need for exploration of possible technology and adoption of integrated water resource approach in planning [4].

Rainwater harvesting (RWH) is defined as a method for inducing, collecting, storing, and conserving local surface runoff for agriculture in arid and semi -arid regions [5].

Rainwater harvesting may include micro -catchment (area less than 1000m^2) or macro -catchment runoff farming (area between $10^3 – 2\times10^6 m^2$ [6]. RWH is the process of intercepting and concentrating rainfall runoff water and its subsequent storage either in the soil for direct use by plants or in reservoirs for later application when needed to mitigate the effects of the dry spells [7]. Other reasons as to why we harvest rain water are: Arrest ground water decline and augment ground water table, beneficiate water quality in aquifers, conserve surface water during monsoon, inculcate a culture of water conservation and reduce soil erosion.

In this study, the nature of roofing material or surface was used to determine how much run off is generated. The most favourable roofing material for water harvesting is corrugated iron sheet with a runoff coefficient of 0.9 [8]. One of the considerations of harvestable water is roof size as a catchment area. Water is available during the rainy seasons and therefore RWH should be enhanced during this period . This will cater for water needs during the rest of the year which is usually dry in many parts of the country since little or no rainfall at all is experienced [9].

2. Materials and Methods

This study was carried out in Embu County, eastern Kenya [10]. Embu County lies between Latitude (0.90o– 0.20o) South and longitude (37.2o-38.00) East, covering an area of 281 square miles [11] as shown in Figure 1. The landscape is characterized by highlands ranging in altitude from (1,500 to 4,500 meters) and midlands ranging from 1,200 to 1,500 meters [12]. It has an annual mean temperature ranging from 17.4 to 24.5oC; average annual rainfall of 700 to 900 mm with a population density of 82 persons per km2 and an average farm size less than 5.0 ha per household [10]. The county has a population of 516,212 people.

Data used include rainfall, population and household survey. Monthly rainfall data for the period 1980 to 2010 was sourced from the Kenya Meteorological Department. Table 1 shows the list of stations used in the study. Population data was sourced from the Kenya National Bureau of Statistics (KNBS) and included; Kenya Integrated Household Budget Survey (KIHBS) Basic Report of the year 2005/2006, where information on percentage distribution of household by household size, percentage distribution by main roofing material and also percentage distribution by number of rooms in the main dwelling was obtained [13].

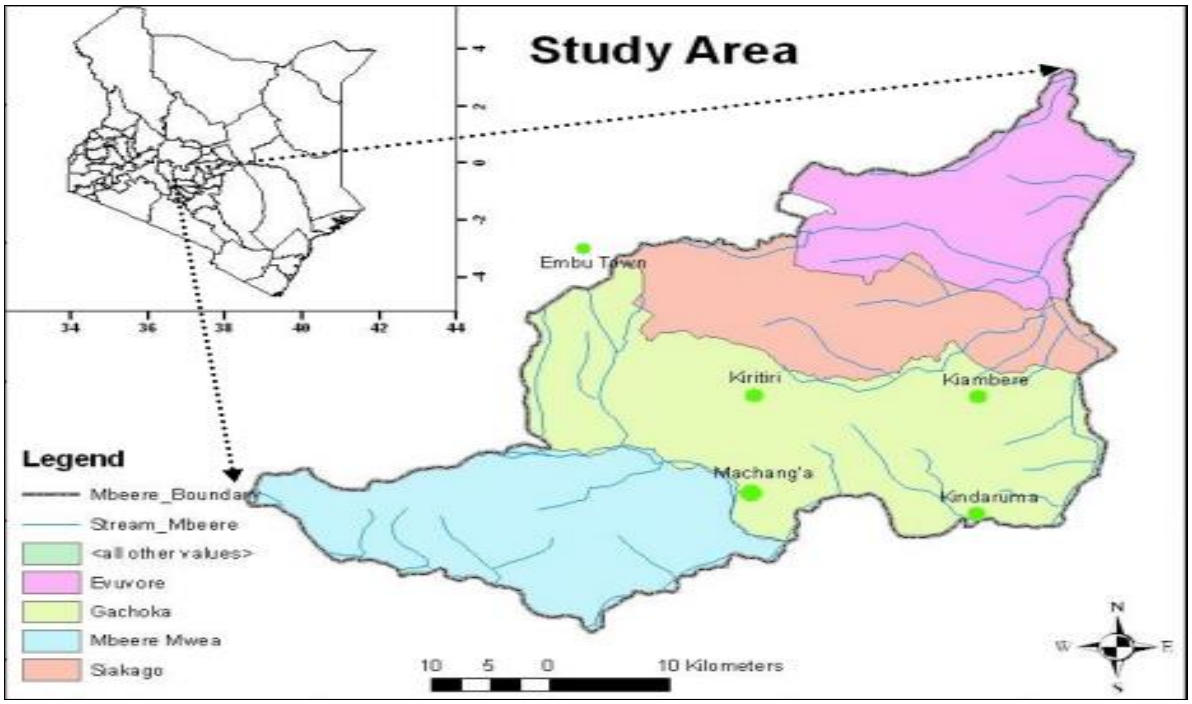

Figure 1: Map showing the location study area [12]

Table 1: Rainfall records used in the study

Station Name	Lon	Lat	Period of record
Embu Met	37.4	-0.50	1980-2010
Weru dispensary	37.7	-0.30	1984-2010
Murinduko farm	37.4	-0.57	1980-1995
Kiamuriuki FGP	37.2	-0.13	1980-1994
Siakago	37.6	-0.57	1984-1992

Graphical analysis was used to generate annual cycle based on computed monthly mean rainfall aimed at investigating the climatology of Embu County. The roof catchment area was then computed through determination of the nature of roofing material and the surface areas covered by the roofs. The surface area of the roofing surface determines how much water a particular structure is able to harvest. The total surface area of the roof within a homestead is a function of the number of rooms and the particular sizes of each room. This was estimated from the main house in a homestead. The roof catchment area for single story homes is usually greater than the floor area of the same building due to presence of eaves.

The surface area of the roof that was used to harvest the rainwater was calculated by using the extract from the KIHBS and also using guides from architectural association of Kenya where eave length is taken to be 0.6 m and elevation angle taken to be 22.5 degrees. This was based on the assumption that a pitched/hipped roof was considered and also rainf water would only be harvested in the main house. Therefore, using a minimum standard size of a single room to be (3 x 3) m^2, surface area of the roof used for rainwater harvesting was computed using equation 1.

$$\text{Sin } \theta = \frac{Pt}{X} \qquad (1)$$

Where θ is the elevation angle, taken to be 22.5°, Pt is the height of the pitch (Roof), in this case 1.5 metres and X is the length of the roof.

Using the main type of roofing material which was corrugated iron sheet and the number of rooms in the main dwelling, data was collected by multiplying the number of rooms in the main dwelling by the roof surface area for a single room. Roof surface area for a single room ranged from 25 m^2 to 35 m^2 for a typical house. The average surface area was taken as 30 m^2 [14]. Based on household demand and surface preferences in Kenya and by use of per capita water requirement where the amount of water that each household needs on a daily basis was estimated as an average of 40 litres per person. From KIHBS, the mean household size for Embu County was 4.8 persons. Considering per household and using the available harvestable water, minimum volume of water required was computed using statistical analysis. The number of households in a homestead was determined and this helped to establish per capita water requirement for each person per day and also per month. The minimum water demand was computed using equation 2.

$$W_{min} = \frac{D_v \text{ x } D_m}{1000} \text{ litres} \qquad (2)$$

Where $W_{min}$is the minimum water demand, D_v is the daily volume of water in cubic meters and D_m is the number of days per month. The amount of water available for harvesting was computed using equation 3:

$$\text{RWHpot} = \frac{P}{1000} \text{ x Cd x Ad x } \eta \qquad (3)$$

Where $RWHpot$ is the Rain water harvesting potential, which gives the amount of harvestable rainwater per roof area for a specific location, P is the average monthly rainfall (mm), Cd is the runoff coefficient dependent on the common roof material used, Ad is the total roof surface in m^2 and η is the rainfall reliability, assumed as 0.67 for the East Africa region dependent on the monsoons [15].

The study noted that the size of storage tank needed for a particular application is mainly determined by the amount of water available for storage (a function of roof size and local average rainfall), the amount of water likely to be used (a function of occupancy and use purpose) and the projected length of time without rain (drought period). The amount of storage needed to store the harvested water is determined by the amount of water harvestable in a month and the per capita water needs for the area of study. The harvestable water is given as the excess water above the minimum water demand. The capacity of storage was computed using equation 4.

$$V = \text{HRW} - M \qquad (4)$$

Where V is the capacity of the storage system, HRW is the harvestable rainwater for a given month and M is the minimum water demand for that particular month. Satisfaction level was computed based on satisfaction index as shown in equation 5.

$$\text{Satisfaction index} = \frac{\mathbf{V}}{\text{Wminimum}} \text{ x } 100 \qquad (5)$$

Where V is the capacity of the storage system and Wminimum is the minimum water demand for that particular month.

3. Results and Discussion

3.1 Annual rainfall cycle

The rainfall climatology for Embu County (Figure 2) indicats a bimodal rainfall pattern with long rains during March-April-May (MAM) and short rains during October-November-December (OND). Notably, the amount of rainfall during MAM season was observed to be higher than that of OND season for Embu and Murinduko stations while for Weru station, rainfall amount for OND season was higher than that of MAM season. The wettest month for Embu and Murinduko was April with 295.0 mm and 273.6 mm of rainfall respectively, while for Weru station the wettest month was November with a value of 314.58 mm. All the months out of season showed depressed rainfall amount of less than 60 mm each month.

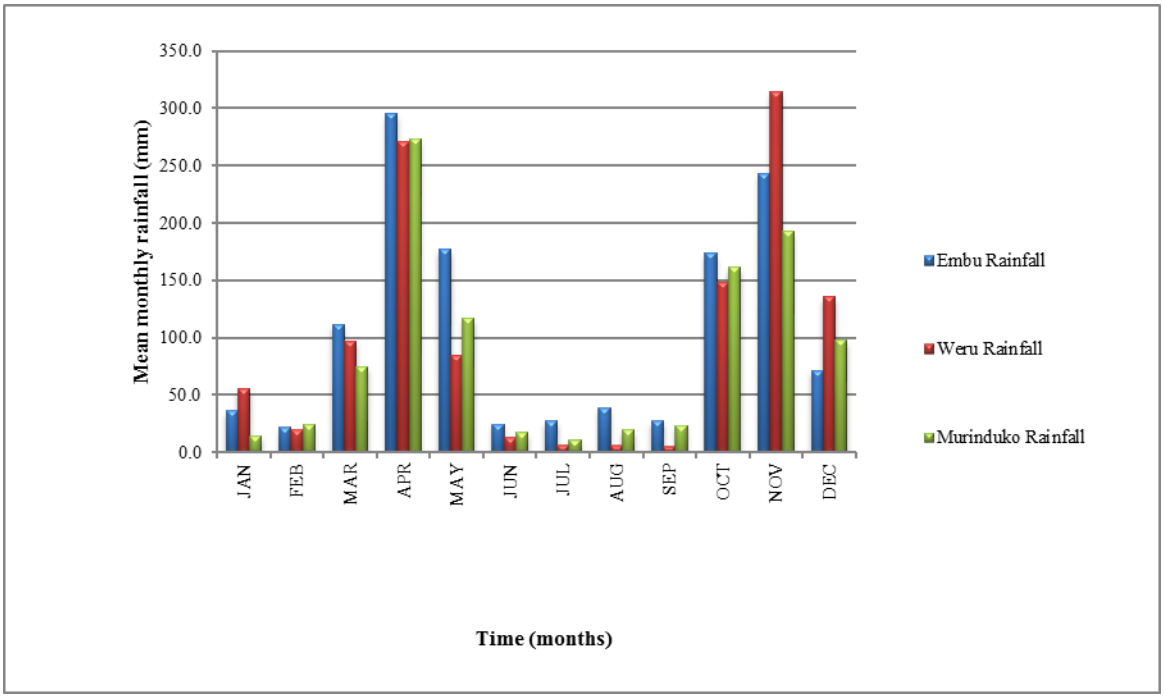

Figure 2: Mean monthly rainfall for the three rainfall station

3.2 Assessment of roof catchment area

The nature of roofing material and the surface areas covered by the roofs were determined and results presented in Table 2 and Figure 3.

Table 2: Percentage distribution of main roofing material in Embu County of Kenya

Roofing Material	Distribution (%)
Corrugated Iron Sheets	98.7
Tiles	0.2
Concrete	0
Asbetos	0.2
Grass	0
Tin	0
Makuti	0.9

Table 3: Representative average surface area per household

No. of Rooms	Surface Area per Room	Total surface area	Percentage	Representative average Surface area
1	30	30	19	5.7
2	30	60	33	19.8
3	30	90	32	28.8
4	30	120	16	19.2
Total Roof Surface Area				73.5

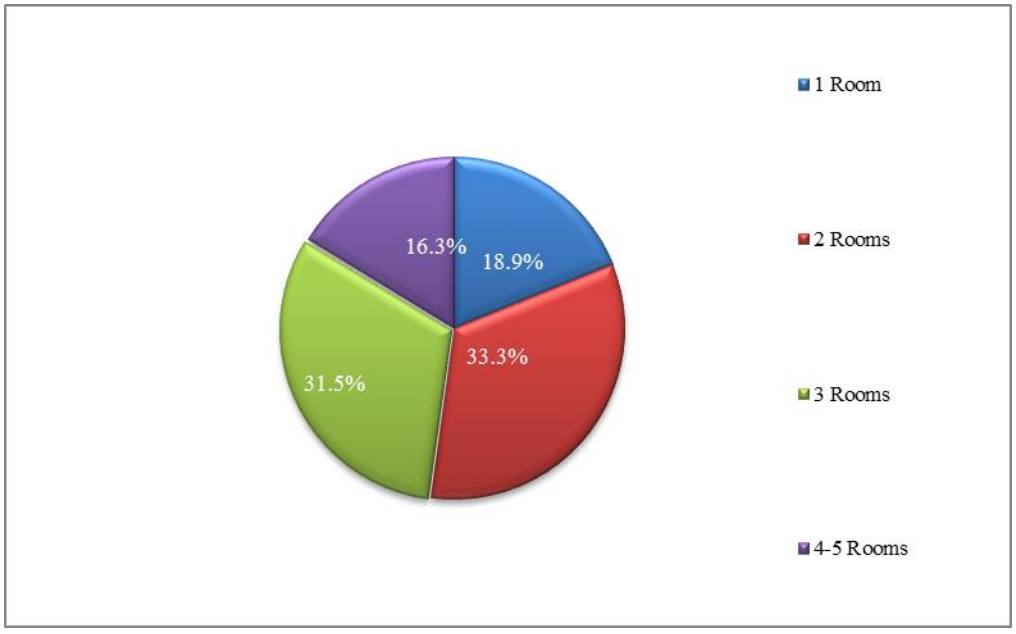

Figure 3: Percentage distribution of number of rooms in the main house.

Table 2 shows that approximately 99% of the houses were roofed with Iron sheets, hence the most preferable. Tiles, Concrete, Asbestos, Grass, Makuti, Tin and Tiles shared the 1.3%. Based on architectural association of Kenya requirements, computed surface area of the roof used for rainwater harvesting was found to have the standard length of 3.9 m.

The study assumed that the standard size of a single room was 3 m in length and it found that the surface area of the roof for water harvesting was 32.76 m^2.

The percentage distribution of number of rooms in the main house was 18.9%, 33.3%, 31.5% and 16.3% for one, two, three and four respectively (Figure 3). Table 3 shows that there was no preference occupancy of number of rooms in the main dwelling. Since those people occupying between two and three rooms showed almost same percentage of occupancy. This means that by using the average roof surface area of a single room, which is 30 m2, most homesteads would have a total surface area of 75 m^2. However, this is an average value and the actual surface area will vary from home to home.

3.3 Minimum Water Demand

The minimum water demand of households by number of rooms in a homestead was computed and results presented in Figure 4.

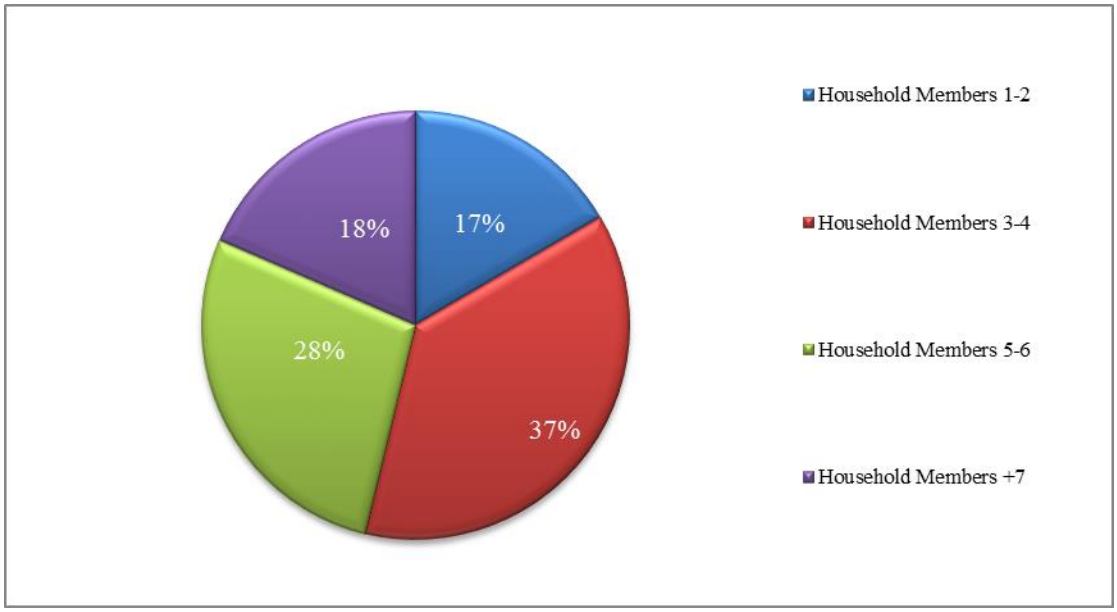

Figure 4: Percentage distribution of households by number of rooms in a homestead over Embu County

Figure 4 shows that most houses were occupied by 3-4 members. This averaged to 3.5 which translated to 3 or 4 occupants per room. From Household demand and surface preferences in Kenya and by use of per capita water requirement the amount of water that each household needs on a daily basis was estimated as an average of 40 litres. From Kenya Integrated Household Budget of Survey (KIHBS), the mean household size for Embu County is 4.8. So the minimum amount of water needed per person per day is (40×4.8= 192) litres per household per day.

3.4 Harvestable water

Harvestable water was assumed as a function of the total roof surface area, type of roofing material and runoff coefficient and the total amount of rainfall received in an area.

Figure 5 shows that in April, October and November were the months in which harvestable water exceeded minimum demand level by 8.14 m3, 1.85 m3 and 5.64 m3 respectively. Total excess water during MAM would be 8.19 m3 requiring a storage capacity of 8190 litres whereas during OND, total excess water would be 7.49 m3 requiring a storage capacity of 7490 litres. Total harvestable water in two seasons would be 15,680 litres. If all excess water was used exclusively to satisfy minimum water demand, then during MAM, amount of harvestable water being 8,190 litres would last for 43 days, and amount of water harvestable during (OND) season of 7490 litres would last for 39 days. This means that total harvestable water during MAM and OND would last for 82 days. Deficit obtained in comparing the minimum water demand for six months out of season being 34560 litres compared to total harvestable water during MAM and OND of 15,680litres. This meant that harvestable volume of water was not sufficient to satisfy minimum water demand levels of people in Embu during dry seasons.

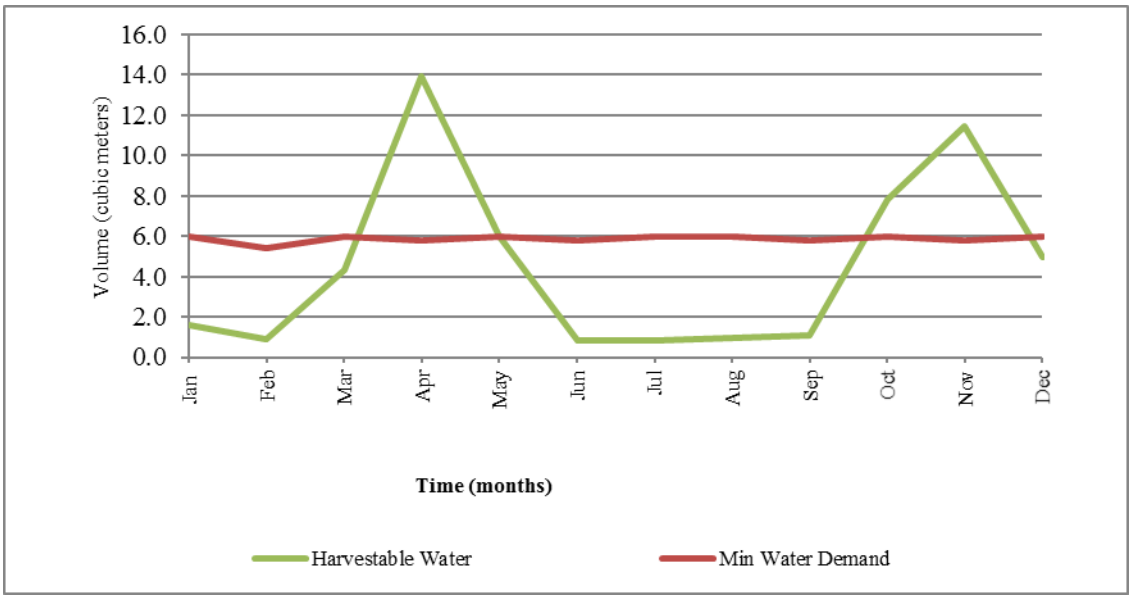

Figure 5: A plot of harvestable water versus minimum water demand

Embu County could be used to supplement the natural sources of water and if well enhanced can be used as an alternate source of the much needed water. The study notes that other RWH methods apart from rooftop method such as surface runoff and groundwater need to be implemented as it is essential for sustainability of the increasing population. Further, alternative sources of water such as streams, boreholes or precipitation enhancement through weather modification could be used to augment available water sources.

3.5 Storage capacity and satisfaction level

Maximum excesses were added together as storage volumes while the percentage level to which a reservoir could supply enough volume to satisfy a minimum water demand was computed as percentage level of satisfaction. These results are summarized and presented in Table 4.

Table 4: Summary of the comparison between Seasonal harvestable water and minimum water demand.

Month		Harvestable water (M^3)	Minimum water demand (M^3)	Water Deficit (M^3)	Satisfaction level (%)
MAM	Mar	4.3	1.65	27.7	5.95
	Apr	13.9	-8.14	-141.3	5.76
	May	6	-0.05	-0.8	5.95
OND	Oct	7.8	-1.85	-31.1	5.95
	Nov	11.4	-5.64	-97.9	5.76
	Dec	5	0.95	16	5.95
Total		48.4	35.32	-15.68	-227.4

In Table 4, negative values indicate that harvestable water was more than minimum water demand, an indication that water could be harvested when rainfall was in abundance and stored for use during water stress durations. Notably, Table 4 shows that RWH is enhanced during April, May, October and November where harvestable water was more than minimum water demand. Upon adding excess, a value of -8.19 m^3 was obtained equivalent to 8190 litres indicating capacity required to store harvestable rainwater during MAM while a value of -7.14 m^3 was obtained equivalent to 7140 litres indicating capacity required to store harvestable rainwater during OND in order to satisfy the minimum water demand for each home respectively. If all excess water was used exclusively to satisfy minimum water demand, then during MAM and OND, 15680 litres of harvestable water would last for approximately 82 days implying that harvestable volume of water was not sufficient to satisfy water demand levels of people in Embu County. However, deficit obtained in comparing minimum water demand for six months out of season was 34560 litres and total harvestable water during two seasons being 15680 litres was found to be 45.4%.

4. Conclusions

Rainfall in Embu is bimodal with peak in April and November while July and August were driest. There was no preference occupancy of number of rooms in the main dwelling because people occupying between two and three rooms showed almost same percentage of occupancy and thus using the average roof surface area of a single room indicated a total surface area of 75 m^2 in homesteads. The dominant roofing material was corrugated iron sheets. The satisfaction levels of minimum demand by harvestable rainwater showed great variations in different months ranging from 1% in July and August to over 100% in April and November.

During MAM and OND, amount of harvestable water would last for approximately 82 days. The deficit obtained in comparing the minimum water demand for the 6 months out of season and the total harvestable water during the two seasons was (45.4%). Therefore, the study noted that harvestable volume of water was not sufficient to satisfy the water demand levels of the people in Embu County.

Embu County could be used to supplement the natural sources of water and if well enhanced can be used as an alternate source of the much needed water. The study notes that other RWH methods apart from rooftop method such as surface runoff and groundwater need to be implemented as it is essential for sustainability of the increasing population.

Acknowledgement

The authors would like to thank the Department of Meteorology, University of Nairobi for providing support during the study and Kenya Meteorological Department for provision of rainfall datasets used for the study.

References

[1] Ministry of Water and Irrigation (MoWI) (2009) Flood Mitigation Strategy.

[2] Karkee, M.B. (2005) Harvesting of atmospheric water: a promising low cost technology. Ninth International Water Technology Conference, IWTC9 2005, Sharm El-Sheikh, Egypt. 3: 3–14.

[3] Levin, Z, Cotton, W.R. (Eds.) (2009). Aerosol Pollution Impact on Precipitation: A Sci. Rev. Springer, Dordrecht, The Netherlands, 386p.

[4] Ngaina, J.N., Muthama, J.N., Opere, A.O., Ininda, J.M., Ng'etich, C.K., Ongoma, V. & Mutai, B.K. (2014) Potential of harvesting atmospheric water over urban cities in Kenya. *International Journal of Physical Sciences*, **2**(5): 069-075.

[5] Saleh Z, Nadhir A, Mohammad E and Sven K (2012) Rain Water Harvesting at Eastern Sinjar Mountain, Iraq. *Geoscience Research*, **3**(2): 100-108.

[6] Prinz, D. & Singh A. (2000). *Technological Potential for Improvements of Water Harvesting*. Study for the World Commission on Dams, Cape Town, South Africa. Report: Dams and Development: A New Framework for Decision-Making.

[7] Mzirai O. & Tumbo S. (2010) Macro-catchment rainwater harvesting systems: challenges and opportunities to access runoff. *J. Animal & Plant Sciences*, **7**(2): 789-800.

[8] Worm, J. and van Hattum, T. (2006) *Rainwater Harvesting for Domestic Use*. Agromisa Foundation/Digigrafi, Wageningen, Netherlands.

[9] Gould, J.E. (1999) Development of Rainwater Catchment Systems: Technology & Implementation Strategies in the (1980s). 95-105 Government of Kenya, July 2004.

[10] Jaetzold, R., Schmidt, H., Hornet, Z.B. & Shisanya, C.A. (2007) *Farm Management Handbook of Kenya*. *Natural Conditions and Farm Information*, Vol 11/C, 2nd ed. Ministry of agriculture/GTZ, Nairobi (Eastern Province).

[11] Njeru, E. H. N. and Ember, M. (2002) *The Embu People*. Encyclopedia of World Cultures Supplement, pp. 107-111. New York. In: Macmillan Reference USA, Gale Group. Human Relations Area Files. African Wildlife Foundation. Nairobi.

[12] Kisaka, O., Mucheru-Muna, M., Ngetich, F., Mugwe, J.N., Mugendi, D., & Mairura, F. (2014) Rainfall variability, drought characterization and efficacy of rainfall data reconstruction: case of Eastern, Kenya. *Advances in Meteorology*, Volume 2014 (2014), Article ID 380404, 16pp.

[13] KNBS (2010) Kenya Population Census, 2009. Ministry of State for Planning, National Evaluation of Urbanization Influences on Urban Winds of Kenyan Development and Vision 2030, Nairobi.

[14] Kimiti, M.J. (2007) Rainwater Harvesting for Domestic Use: A Case Study of Machakos District. MSc Thesis, Department of Meteorology, University of Nairobi, Kenya.

[15] Rockstrom, J., Barron, J., and Fox, P. (2002) Rainwater management for increased productivity among smallholder farmers in drought prone environment. *Physics and Chemistry of the Earth*, **27**: 949-959.