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Prospective of Roof Rain Water Harvesting (RRWH) in Kesses Constituency, Uasin Gishu County, Kenya

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Abstract
As a water scarce country, Kenya has witness an increased investment in Rain Water Harvesting (RWH) projects. Most of Roof RWH research is centred on the potential and implementation of RWH systems, however not much focus has been placed on examining the demand satisfaction of these systems. The main goal of this study was to demonstrate in spatial domains, the large potential for RRWH in Kesses Constituency and thereby provide a tool for advocacy and decision support, for RRWH in Kenya. This research was based on literature revision, statistical analysis of precipitation data set (January, 1994 to December, 2013), rainwater laboratory tests (Hardness, pH, turbidity, Chlorine, e-coli, suspended matter and colour) and concise field study using key informant interviews and structured questionnaires. The results were analyzed by Descriptive statistical methods. In addition analysis of variance ANOVA, Statgraphics Centurion XVI and Microsoft Excel were used. The study concluded that each of the study wards received a high RRWH reliability based on the amount of water available in storage and secondly, that RRWH can satisfy the minimum demand requirement throughout a year, given sufficient guttered roof area. Numerous recommendations were also made on correlated issues.
Keywords: Harvesting, Kesses, Precipitation, Rainwater, Roof.

1. Introduction

The UN General Assembly in late 2003 adopted a resolution that proclaimed the period 2005-2015 as the International Decade for Action-Water for Life. The resolution emphasized that water is critical for sustainable development, including environmental integrity and eradication of poverty and hunger, and is indispensable for human health and well-being. At the Pan-African Conference on Water in Addis Ababa, 2003, and at the African MDGs on Hunger meeting in 2004, rainwater harvesting was identified as among the important interventions necessary towards meeting the MDGs in Africa (WWAP, 2009).

Water flow in Kenya originates from the country's five "water towers": Mount Kenya, Aberdare range forests, Mount Elgon, Cherangani hills and the Mau forest complex. Since the 1980s, increasing immigration and changing land use practices have interrupted these fragile ecosystems. Extensive logging, disappearing mountain top glaciers and deteriorating forest conditions are some of the identified issues affecting sources of water supply (UNEP, 2009). Increasing rates of illegal abstractions have caused low flows in many of the rivers (Mungai et al., 2004) while the supply of piped water has deteriorated over the years with some areas receiving less than 12 hours of service per day (Thompson et. al., 2000). Kenya faces water scarcity currently having an annual renewable fresh water supply of 650 cubic meters per capita (UNEP, 2004), well below the 1000 cubic meters benchmark developed by Dr. M. Falkenmark. Kenya has to deal with water stress which is expected to increase in the near future (Boko et al., 2007). As a result, there has been an increasing interest in the adoption of rainwater harvesting as an alternative source of water to compensate for variable rainfall, water pollution and decreasing availability of traditional water supply sources.

The capture and utilization of rainwater is an ancient tradition which dates back to similar techniques used in today's Iraq around 5000 years ago. Modern methods usually represent improvements with respect to technical variations (Mbilinyi, 2005). The term 'Rainfall harvesting' is broadly defined as the collection of any form of precipitation from a catchment (Babu& Simon, 2006). Roof Rainwater harvesting (RRWH) is the process of collecting and storing rainwater from rooftops using simple components (pots, tanks, cisterns) or more complex methods.(Zhu et. al., 2004). Components of a typical RRWH system are the catchment (roof area), down pipe and gutters, and storage tank. RRWH, yields harvested waters with contaminants in levels acceptable by international drinking water standards (Kahinda et. al.; 2007; Zhu et. al., 2004) and is thus thought to be a superior option when considering domestic water supply, in particular potable water. A major advantage of rainwater collected from roofs is that it is usually free and much cleaner than water from streams, burst pipes and dams.

For years, NGOs, faith-based groups and networks have been advocating the use of RWH with slow progress. One of the problems has been lack of tangible scientifically verified information which can be used to demonstrate the areas where RWH can be applied. This information is required for awareness creation and as a decision support tool for targeting RWH plans and investments at sub-regional scales (Web article 1).

Research shows that there is still a considerable amount of untapped rainwater potential in Africa, including Kenya that can be used to supply adequate water to an immense portion of the population (UNEP, 2008). However, before adopting RRWH systems, it is important to verify the RWH potential of the area of interest and conclude whether the conditional parameters produce a satisfactory reliability for water supply.

As a water scarce country, Kenya has seen an increased investment in RWH projects to harness the vastly untapped rainwater resource, particularly in rural areas. Most of RRWH research is centered on the potential and implementation of RWH systems, however not much focus has been placed on examining the demand satisfaction of these systems.

The purpose of this study was to determine the level of intensity of RRWH at Kesses Constituency. An additional inquest was on whether the RRWH reliability of the region would be sufficient in providing for a minimum water demand in the area. The main goal of this study was to demonstrate in spatial domains, the large potential for RRWH in Kesses Constituency, and thereby provide a tool for advocacy and decision support, for RRWH in Kenya.

2. Material and Methods

The Kesses Constituency, Uasin Gishu County of Kenya is not only the focus of this research; it is also the spatial category that defines the boundaries of this study's empirical analysis. This research was based on literature revision, statistical analysis of precipitation data, rainwater laboratory tests and concise field study. The methods chosen were interdisciplinary from both social and natural sciences, in order to describe countryside conditions and the impact of RWH systems as holistically as possible within the scope of this paper.

2.1. Area of research and Sample size

Kesses Constituency has a Population of 135,979 and an area of 299.00 Sq. Kms (GoK, 2009). It consists of the following County Assembly Wards: (1) Racecourse-Langas, (2) Cheptiret/Kipchamo-Saruiyot, Lengut, Mugundoi, Kaptumo, Cheptiret and Emekwen, (3) Tulwet/Chuiyat-Kesses, Tulwet, Koisagat and Lingwai and (4) Tarakwa-Tarakwa, Leinguse, Kipkurere and Chagaio (Timboroa) (Web article 2). Figure1 shows the consolidated map of Kesses constituency (indicating the geographical position of the County Assembly Wards from where the data was collected).

Published literature on RRWH i.e. books, scientific studies, publications and reports of NGOs and journal articles were used in justification and also in the actual research to provide guidelines of achieving the set objectives. A precipitation dataset of monthly rainfall (mm) records for the period (January, 1994 to December, 2013) was obtained from the School of Environmental Studies, University of Eldoret. Rainfall data was examined for homogeneity and consistency. Rainfall probability was estimated by Weibull formula. Descriptive analysis was first carried out in order to explore the distribution of rainfall in the region. The arithmetic mean was used for numerical summary measure, whereas line graphs and trend lines of rainfall against time were generated for graphical presentation of the data. For the purpose of determining possible changes or significant trends in the amount of rainfall overtime, the reference period (1994-2013) was split into two 10 year time periods: 1994-2003 and 2004-2014. For both numerical and graphical measures, the analysis was done separately for the two time periods and overall (1994 - 2013). In order to have a complete understanding of the changes in the amount of rainfall over the last 20 years, the monthly amount of rainfall for each year were reduced to a single (mean) value. The rainfall probability was found graphically according to RELMA, 1998. Rainfall probability (%) is a crossing point of plotted calculated probability for every rank of rainfall value and the line corresponding to the mean annual rainfall (for the subject period). The following formula (KRA, 2010) is applicable:

$$P = m / (n+1)$$

Where: P- rainfall probability, m - rank of rainfall value, n - total number of subject years.

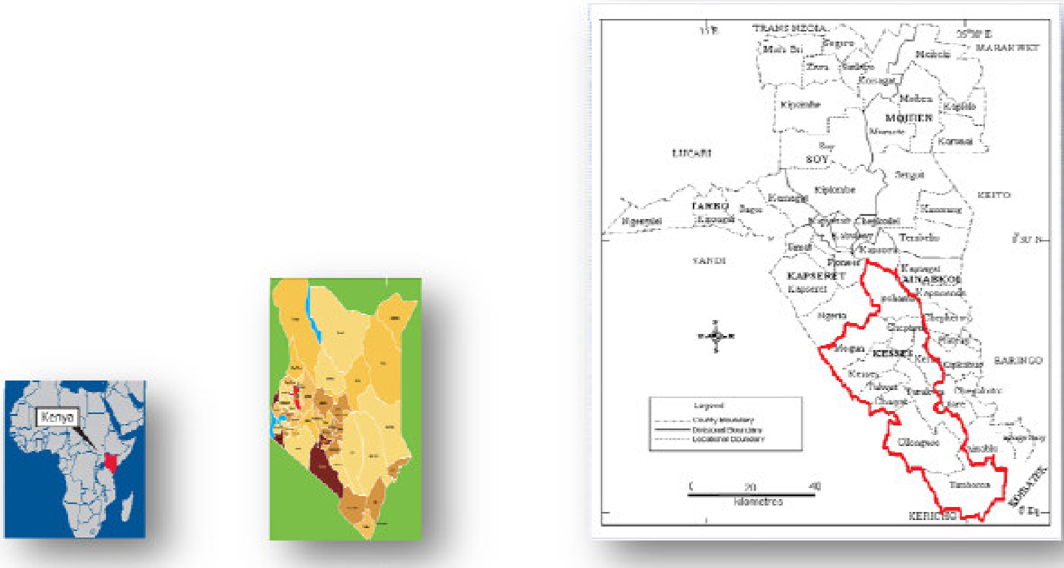

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Figure1: Concolidated map (from web article 3)
Key: 1- Position of Kenya in African continent (in red)
2- Position of Uasin Gishu County in Kenya (in red)
3- Position of Kesses Constituency in Uasin Gishu County (with County Assembly Wards)

The results were analyzed by Descriptive statistical methods. In addition analysis of Variance ANOVA, Statgraphics Centurion XVI and Microsoft Excel were used.

A descriptive field survey method using key informant interviews and structured questionnaires were utilised in the study. To evaluate the RRWH potential a total of 20 households and 8 institutions were selected at random (for each Ward a sample size of 5 households and 2 institutions was taken). Regular field visits were carried out for a period of four months, so as to collect relevant data. From the survey carried, 28 questionnaires were administered to the adult occupants of the households and management of institutions of the sample population. During face to face interviews, the questionnaires were filled by the authors from the words of the respondents as majority of residents were not proficient in English. The major aim of the questioners was to determine the methods used to store the collected rainwater (if any) and how the rain water is used among other relevant issues. Examinations of the type of rooftops common in the region were done by observations. Measurements of the roof size parameters were done manually with the consent and assistance of owners of the sampled houses.

2.2. Roof sites survey

The amount of RRWH depends on the annual rainfall in the area, type of roof and the availability of gutters on those roofs. With the calculated rooftop area (from measurements taken during field visits from the sample buildings with gutters), the quantity (Q) of water that runs off a roof into gutters in litres per year was determined by the following formula (Tripathy &Pandey, 2005)

$$Q = f \times R \times A$$

Where: R - annual rainfall (m) (lowest value in 10 years was considered) *A* - the guttered roof area (m^2)
f - 'run-off coefficient'. It takes into account evaporation from the roof and losses between the roof and any storage tank. Values of this coefficient for various roof types as determined by Kumar (2004) are shown in Table 1.

Table 1: Coefficient of runoff for common roof types (Kumar, 2004)

Roof type	Runoff coefficient
Galvanized iron sheet	0.90
Asbestos sheet	0.80
Tiled roof	0.75
Concrete roof	0.70

Depending on climate and workload, a human needs about 3-10 litres of water per day. Cultural habits, pattern and standard of living, methods of withdrawal, cost and quality of water will greatly influence the use of rainwater for domestic purposes. It can be noted that water for drinking and cooking purposes range from 3-10 litres per day while for general domestic uses it varies between 5-250 litres depending on distance and type of source or mode of withdrawal (Wanyonyi, 2013). For this study 20 litres per day per person was used according to web article 4.The number of residents in each of the sampled houses was recorded during interviews. The annual water demand for a household was determined by multiplying the average water demand per person by the number of occupants and by the number of days in a year.

Rainwater samples were obtained with the help of improvised sample container. Figure 2 shows an example of such improvised container.

Figure 2: Set up for rainwater sample collection

The rainwater samples from the sample containers were poured into 0.5 liter glass bottles that had been soaked in nitric and sulphuric acid solution 1:1 volume ratios, washed, rinsed and then dried prior to field work. The laboratory tests on rainwater quality were limited to six major water quality parameters to determine if the harvested rainwater meets the WHO requirements. The selected tested parameters were: Hardness, pH, turbidity, Chlorine, e-coli, suspended matter and color.

Ten rainwater samples from each (galvanized iron sheets, asbestos and tiled) roofing were collected at different precipitation incidents during rainy season. The rainwater samples were collected at random from households across the constituency and the tests were carried out at the public health laboratory (Prof. L. Huissman Lab) in Civil &Structural Engineering Department, School of Engineering, Moi University. The samples were tested within 28 hours of collection or were preserved in a refrigerator at 4^0C until the test is due. Standard testing methods, collection and preservation of rainwater samples were followed according to procedures stipulated in APHA, 1997.

3. Results

Figure 3 illustrates seasonal graph showing two rainfall seasons.

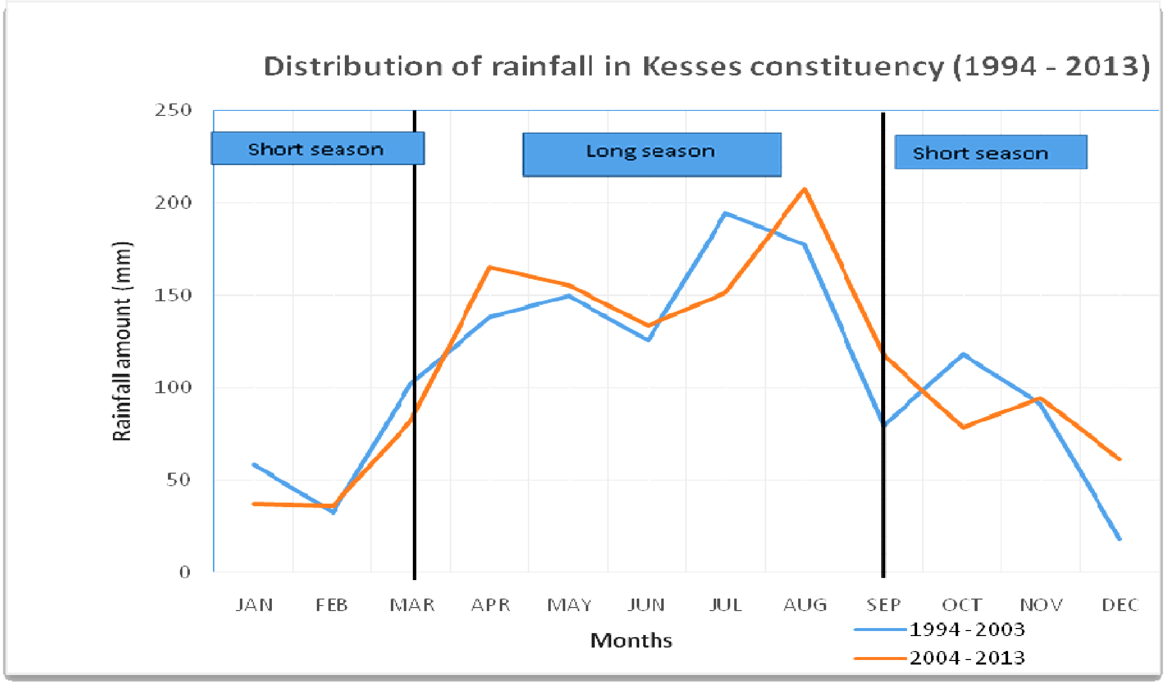

Figure 3: Seasonal graph showing two rainfall seasons

Figure 4 gives mean monthly distribution of rainfall during the years 1994-2003, 2004-2013; while Table2 shows analysis of Variance ANOVA.

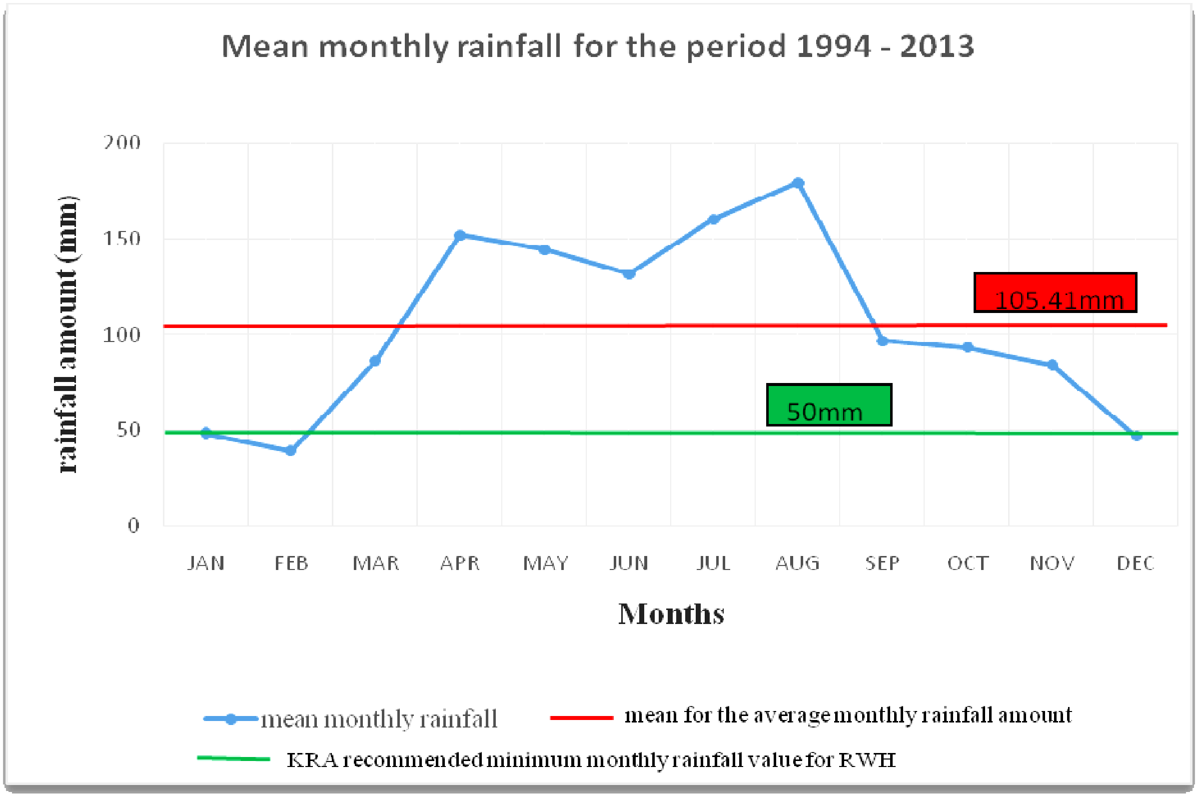

Figure 4: The mean monthly rainfall against time for the 20 year period

Table 2: ANOVA test results

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	155066.	19	8161.35	1.40	0.1265
Within groups	1.2788E6	220	5812.71		
Total (Corr.)	1.43386E6	239			

Figure 5 is a graph showing the total annual rainfall against time for the 20 years period while Figure 6 illustrates the rainfall probability at Kesses Constituency.

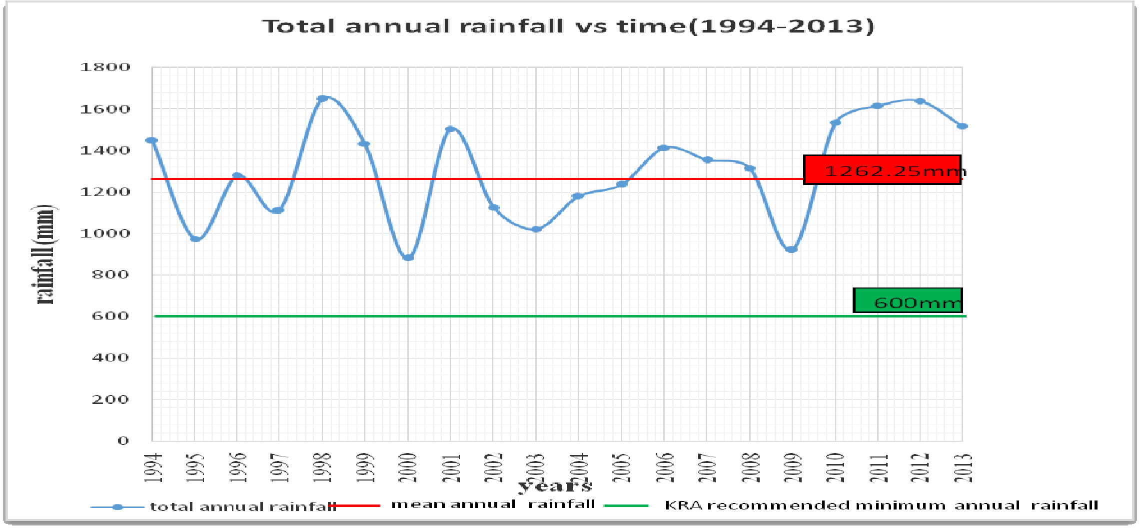

Figure.5: The total annual rainfall against time for the 20 year period

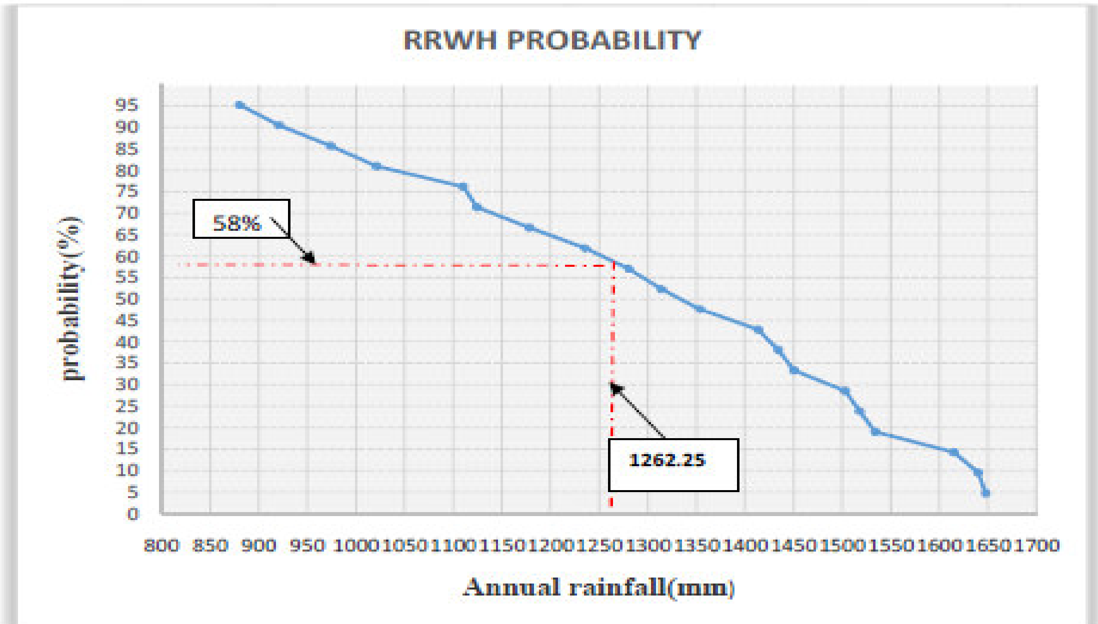

Figure 6: Rainfall probability.

3.1. Data interpretation of interviews/questioners

45% of the sampled populations were male while 55% were female. An equal representation (25% each) of the sample population across the four County Assemblies was taken. All the respondents collect rain water. Majority of the population, 82.1%, use PVC tanks to store collected water, 7.1% use concrete while 3.7% use Jerry-cans, buckets and drums for storage. 88.89% of the population use rain water as a wet season source of water while 11.11% use it as the main source throughout the year. 85.18% of the population use galvanized iron sheet, tiles and asbestos are at 7.14% each while no one in the sample population thatched their roof. 85.18% of the roofs were in good condition where as 14.82% were fair. 77.78% of the tanks had clean interiors while those with fair interiors were 22.22%. None of the sampled tanks were found to have poor interiors. 51.85% of the sampled gutters where in good condition while 48.15% were fair. None of the gutters in the population was in poor condition. 74.07% of the tanks were maintained in good condition where as 25.93% where in fair conditions. None was in poor condition. 92.59% of the systems had taps for water withdrawal while 7.41% did not use taps to withdraw water. 37.03% of the harvesting systems had first flush mechanism while 62.97% did not hold a first flush mechanism. 100% of the sample population did not have vegetation overhanging roof catchment areas.

3.2. RWH potential vs. water demand

The collected data was rationally organized into systematic patterns and themes and from which the average annual demand and annual RRWH potential for each selected household and institution was determined. Each household was assigned a code (1-20) and similarly for institutions (1-7). In Racecourse-Langas County Assembly Ward, only one institution practicing RWH was identified, despite visiting about three (Hill school, Wareng high school and an AIC dispensary). This could be attributed to the availability of piped water supply from ELDOWAS as well as time and financial constraints that limited the researches' efforts in trying to locate such an institution. Figure 61 is a graph showing annual potential of RRWH against annual demand for households, while Figure 7 showing the same for institutions. Table 3 shows the rainwater quality laboratory test results against WHO standards.

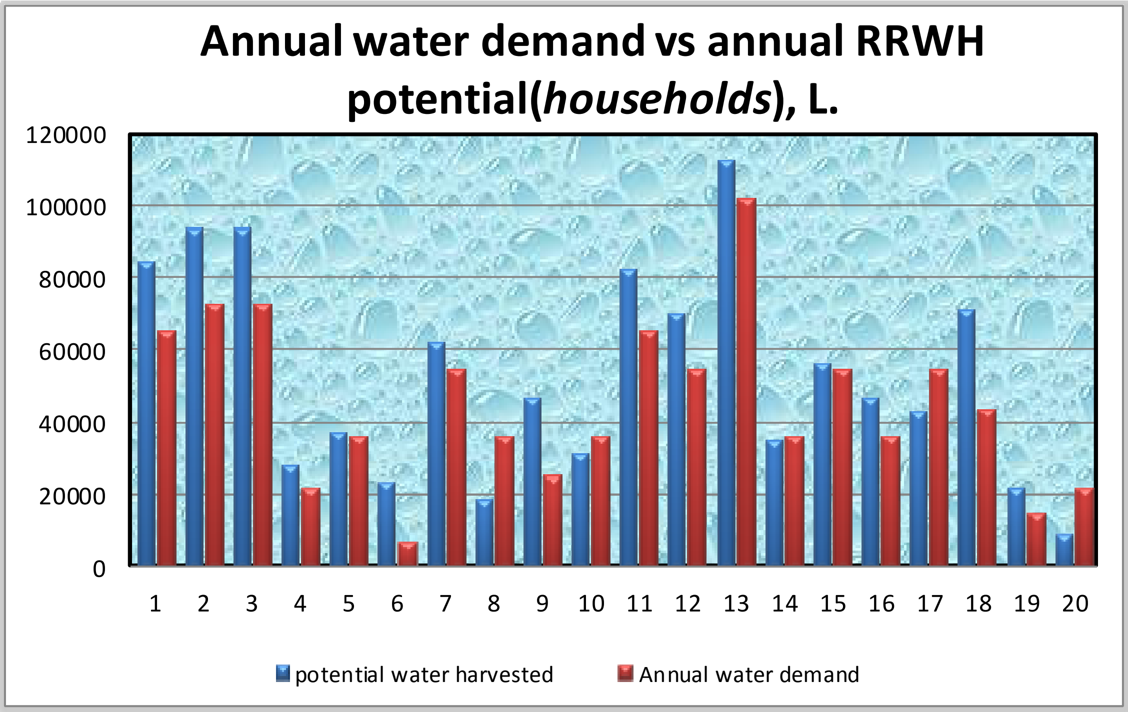

Figure 7: Annual water demand against annual RRWH potential (for households).

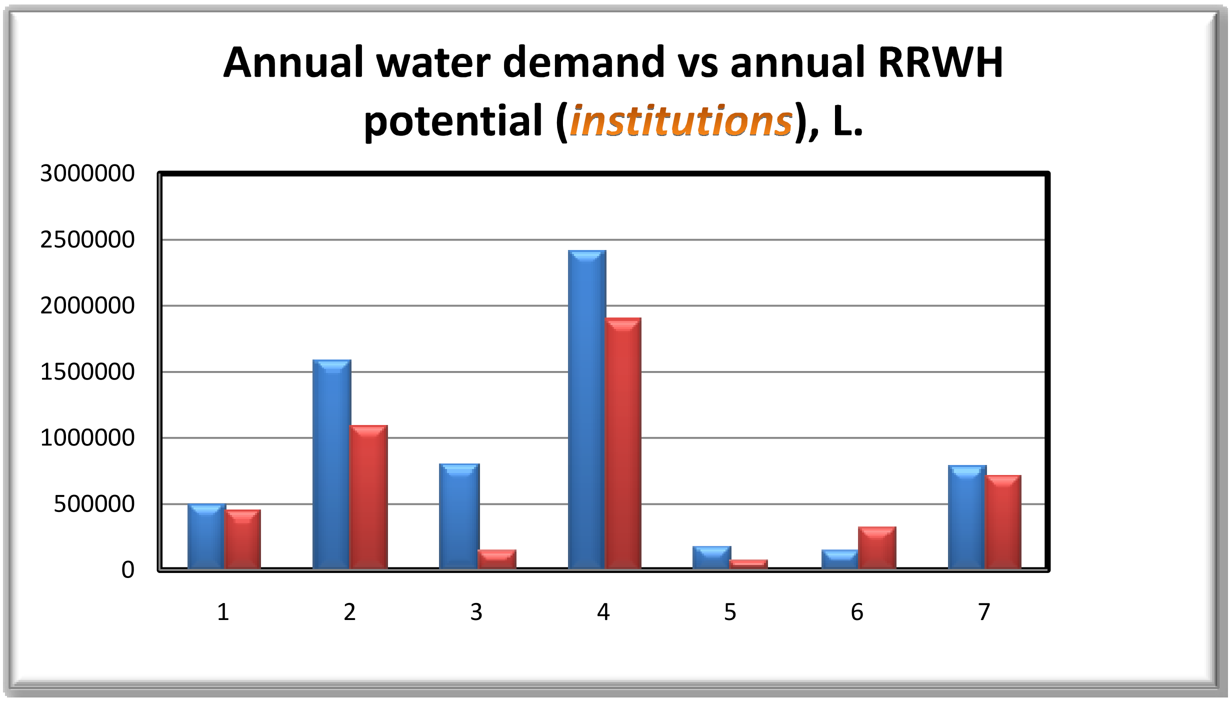

Figure 8: Annual water demand against annual RRWH potential (for institutions).

Table 3: Test results summary

Parameters (units)	Corrugated iron sheet roof	Tiled roof	Asbestos roof	WHO Standards (WHO, 2006).	Comments
E-coli **(colonies per 100 ml of sample)**	0	6	5	**0**	**Not Acceptable** (*for tiled and asbestos roofs*)
pH	7.27	6.70	7.09	**6.5-7.5**	Acceptable
Chlorine (*mg/l*)	0.023	0.025	0.023	**250**	Acceptable
Turbidity(*NTU*)	3.5	2.12	2.13	**<5**	Acceptable
Suspended solids (*g/100ml*)	0.7875	0.7712	0.8920	**0**	**Not acceptable**
Hardness (*mg/l*)	10	13.3	18.3	**500**	Acceptable

Discussions

Major findings of the study show that majority of households in the study area use harvested rainwater as a wet season source of water supply as bulk of the residents do not have adequate finances to construct or purchase larger storage facilities. Mainstream of the respondents depend on hand dug wells, water vendors and streams particularly in the dry season. This simply implies that a large proportion of households in the study area getting their water from untreated and sometimes unhealthy sources. Main storage methods for the harvested rainwater in the study area include PVC tanks, concrete tanks, metallic tanks and small buckets and drums. Result of the findings also indicated that majority of the buildings, 85%, use galvanized iron sheets for roofing. Only about 7% use asbestos and tiles for roofing. This therefore makes the area quite feasible for RRWH as galvanized iron sheet roofing provides the best catchment for rain water (having the highest run-off coefficient).

The research also revealed that the Danish Refugee Council and the Kenya Red Cross were involved in the resettlement of Internally Displaced persons after 2007 post-election violence where the houses constructed in Kesses and other areas were equipped with a 500 litres PVC tank and a guttering system. Currently these organisations are inactive in the area. None of the houses constructed by the Danish Refugee Council and the Kenya Red Cross were included in the sample. Also, in the Racecourse-Langas County Assembly Ward, most of the respondents had access to the municipal's piped water system and thus relied on RRWH as an emergency source of water when the piped water system fails. However some of the institutions such as Public health facilities and schools have some form of government and NGOs support for RWH systems. Some of the NGOs involved in RWH programs in the area include churches, Ampath and Caritas.

From the annual rainfall series obtained, plots of departure from a long term mean during the period's

1994-2003 and 2004-2013 were constructed in order to determine years of anomaly in the total amount of rainfall. The twelve months were categorized according to major rainy and dry seasons in the study area. That is, March-September (long rain season), October-February (short rain season). Rainfall (mm/season) was calculated and profiles of rainfall for each season were created separately for each of the two time periods. Thus Kesses Constituency has two rainfall season; the short rainfall season and the long rainfall season as shown in Fig.3. As seen from the figure, there are divergent variations in the amount of rainfall across several months and years during the period. Comparison across several months reveals that in the period of 1994-2003 the highest mean monthly rainfall was 210mm in August and in the time period 2004-2013 it was 170mm in July. The lowest in the 1994-2003 was 35mm in February and in the years 2004-2013 it was 30mm in January. This shows that the rainfall patterns in Kesses Constituency are unpredictable, in respect to onset and cessation in 1994-2003 the long rainy season ended in October while in 2004-2013 it ended in September. These changes in the two time period can be attributed to climatic changes in the region.

During the two time periods the annual rainfall value of the highest negative departures from mean were recorded in 1995 (81.141 mm), 2009 (76.758 mm) and in 2000 (73.358 mm). On the other hand, the highest positive departures were recorded in the years 1998, 2010 and 2012 with corresponding annual rainfall values of 137.308 mm, 127.841 mm and 126.516 mm respectively. There appears to be an even distribution of annual rainfall; that is, about equal numbers of years lying in both sides of the mean.

Analysis of Fig.4 and Fig.5 revealed that RRWH in Kesses is highly feasible, as monthly mean for 1994-2013 of 105.41mm is way above the recommended by KRA (Kenya Rainwater Association) 50mm per month. Analogous, the annual mean for the same period of 1262.25mm is again well above the recommended by KRA 600mm.

Figure 6 illustrates an indirect relation between the amount of rainfall and the rainfall probability (the higher the amount of rainfall the lower the probability). The graphically erected rainfall probability of 58% (based on the retrospective data for 20 years and the mean annual rainfall value for the subject period) is therefore considered fairly expected and dependable.

The ANOVA table decomposes the variance of the data into two components: a between-group component and a within-group component. The F-ratio, which in this case equals 1.40405, is a ratio of the between-group estimate to the within-group estimate. Since the P-value of the F-test is greater than or equal to 0.05, there is no statistically significant difference between the means of the 20 variables at the 95.0% confidence level.

When comparing annual water demand against RRWH potential, it was identified that in houses coded as # 8, 10, 17 and 20 the annual water demand exceeded the RRWH potential for the same period. For institutions, the same occur only for institution coded as # 6. This is majorly attributed to the fact that only a small area of the roofs were fitted with gutters and the calculations were done based on only the gutted roof areas. The potential amount of water harvested can be greatly improved if more gutters would be fitted thus increasing the catchment area. Additional reasons could be a high number of residents and a small roof area, as water demand for a household directly proportional to the number of people and the area of the roof is one of the most important determinants for establishment of RRWH potential.

Regarding quality of rainwater harvested from three different roof types (galvanized iron sheets, tiles and asbestos) - all parameters of rainwater samples were within stipulated by WHO standards, with exception of total suspended solids (for all three types of roofs) and E-coli (for tiled and asbestos roofs). This signifies that harvested rainwater must be treated prior to drinking. Thus, the study recommends the use of a First-flush diverter to prevent contaminants entering the storage facility. Additional water treatment may be required such as filtration, direct exposure to UV radiation or boiling water prior to its potable use.

Vision 2030 is a long-term strategic plan for the development of the entire nation of Kenya. One of its chapters addresses water and sanitation. The chapter explicitly mentions that "the country aims to conserve water sources and start new ways of harvesting and using rain and underground water" (GoK, 2007). Thus, RWH is also represented in this long-term national plan which can be seen as a reference point for the development of the entire country of Kenya. In its current Strategic Plan, the Kenya Rainwater Association (KRA) writes: *"In spite of its potential, rainwater harvesting and management (RHM) has not received* adequate interest among policy makers, planners and water project managers in Kenya [...]because it is considered competing rather than supplementary to the conventional and *motorised water supply systems."* (KRA, 2009)

In many parts of Kenya people cannot be expected to improve their current living conditions without adequate water supply. For any development, may it be industrial, commercial or agricultural; water is needed for it to succeed. The flexibility of rainwater harvesting gives room for innovation. From one rainwater harvesting storage structure a numerous interrelated activities can arise including kitchen gardens, poultry keeping, zero grazing, biogas digester installations, manure harvesting, drip irrigation for horticultural crops production and fish farming among other economic activities. All these activities have a projection on increased income generation, improved nutrition status, better sanitation and personal hygiene, creation of on-farm employment leading to poverty reduction and conservation of the environment (web article 4).

Observations in most of Kenya urban centres (Berger, 2011), including Kesses Constituency, show that RRWH structures are not integrated into the building but are added as an afterthought. This is due to the existing by-laws and lack of awareness by planners, policy makers, beneficiaries and many architects. Therefore RRWH should be introduced as a by-law in the building guidelines. Moreover, there is a need to develop training and educational materials on RRWH to help design appropriate systems and to realize the full potential of RRWH. Successful and widespread integration of RRWH systems with public water systems requires a commitment on the part of state and local County governments to develop professional programs and opportunities for education, training, and certification on RRWH systems.

4. Conclusions and Recommendations

Drawing from the above study, two inferences were made. First it was concluded that each of the study wards received a high RRWH reliability based on the amount of water available in storage. Secondly, it was concluded that RRWH can satisfy the minimum demand requirement through all days of the year for majority of the households and institutions sampled, it is also more than able to provide an alternative water supply for the domestic household in periods of long dry spells or when primary water source are inadequate. Exceptions were buildings with no gutters or with fragmented gutters coverage. Additional reasons for not satisfying a water demand could be: the small buildings with correspondingly undersized roof area and equally small storage facility and in some cases buildings with high number of residents. As a larger storage volume would be required to satisfy a water demand and because the storage component holds the bulk of the system's cost, implementing these systems can pose as a financial impediment to many of the qualifying households. County Government would need to provide subsidies and other incentives for the public to accommodate the increased cost. Future research directions should involve further examination and investigation of the RRWH factors, specifically roof area, runoff coefficient and storage volume, to determine the best combination of factors that can be assumed when implementing RRWH in areas that received highly inconsistent rainfall. Regarding the quality of rainwater, the study recommends examination of the extent of penetration, availability and design types of First flush off systems in the area.

The study also recommends that the Uasin Gishu County government carries out public awareness program on the benefits of RRWH and provide suitable assistance to the residents to enable them acquire storage systems big enough to satisfy their water demand throughout the year. The County government should also develop incentive programs to encourage the incorporation of RWH systems into the design and construction of new residential, educational, commercial, and industrial facilities in the County. Operation manuals and water quality guidelines should be developed for use as tools for replication.

Lastly, the authors believe that this study provides a very strong evidence to suggest that RRWH represents one of the most realistic and viable options to help widely satisfy the basic water needs of Kenya, especially in regions with similar conditions. Moreover, hopefully the study may potentially contribute to the promotion of the support of local County Government administration in RRWH investment.

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