CONTRIBUTION OF ROOFTOP RAINWATER HARVESTING IN RELATION TO TOTAL WATER SUPPLY IN HOUSEHOLDS-A CASE STUDY, NAIROBI COUNTY, KENYA

Student: Ombuna Christine
P.O Box 30650-00100, Nairobi, **KENYA**

Prof. Mochoge Benson
Department of Agricultural Resource Management Kenyatta University P.O Box 43844 -00100, Nairobi **KENYA**. Email: bensonmochoge@gmail.com / mochoge.benson@ku.ac.ke

Dr .Mwetu Kennedy
Department of Engineering, Kenyatta University, P.O Box 43844 – 00100, Nairobi, **KENYA**

Abstract

Water supply deficit for Nairobi City is estimated at 170, 000 m^3/day which is 23% of the total water requirement. Aim of the study was to assess the amount of rainwater harvested from various roof catchments, storage capacities, water quality and adoption rate of water harvesting from rooftops. A total of 150 samples were collected, namely 50 from maisonettes, 50 from multi-story buildings, and 25 samples each from industry and institution buildings. Data collected included rainfall depths, roof surface areas, size of tanks, water quality of the rainwater harvested from roof catchments and socio-economic data affecting urban water harvesting. Results obtained showed that rain water harvested could meet the deficit encountered with most households and Institutions in the city. Institutions like schools were found to lead in rainwater harvesting (44%) followed by maisonettes (20%), multi-story buildings (6%) and industry (4%) in that order. Nearly 93% of the residents interviewed were found to depend on piped water, 7% depended on private owned boreholes while 16% of the residents had fully adopted roof rainwater harvest system to supplement other sources. The quality of rainwater harvested indicted presence of Lead (Pd) and Turbidity close to 1 NTU. Rainwater from roof tops was found to be suitable for non-potable purposes.

Keywords: Adoption Rate, Contribution, Rainwater harvesting, Rooftop catchment.

INTRODUCTION

The demand for water in urban areas worldwide exceeds its supply as most urban areas depend to a large extent on water from distant sources conveyed by large infrastructures that are encumbered by leakage and vandalism (Jeremy et al., 2012). Urban centers require large amounts of water to sustain their ever growing populations and services. For example, the population growth rate of Nairobi county is currently 4.1% and its population is estimated to reach 5million by 2025 from the current 3.6million. The water supply deficit for Nairobi City is estimated at 170,000 m^3/day which is 23% of the current demands, and is predicated to rise to 970,000 m^3/day by 2035, if no water supply alternatives are sourced (Athi Water Services Board, 2012). Nairobi city obtains its water supply from Rivers Athi and Tana, and from over 3000 boreholes dug within the County (Ledant et al.,2010).

Rain water harvesting from rooftops has for a long time been ignored by policy makers to be included in the master plan of water sources especially in urban centres (Kenya Rain Water

Association,2012;Athi Water Services Board Report,2012 and Awiti,2013). Nairobi County is heavily flooded during rainy seasons and if this water could be captured through roof catchments before forming surface runoffs, it could be a solution to water crisis in the City. The current snag is the lack of policies and laws enacted by the County to enforce roof water catchment and storage.

The quality of rainwater from roof tops has been considered as suitable for non-potable purposes (Mendes *et al*., 2010; Gakungu, 2013; World Health Organization, 2012). However, this resource is disposed as urban storm water using centralized drainage systems which quickly turn rainwater from a valuable resource into a menace in form of flooding, soil erosion and toxic loading on rivers and treatment plants (Jackson, 2001).

Rainwater harvesting is defined as the practice of collecting water from surfaces on which rain falls and stored for later use (Chanan *et al*., 2007). Roof-top rainwater harvesting system basically consists of the rooftop as the catchment area, gutters for collecting water and storage tank. The size of the tank depends on the available rooftop area, precipitation size and user's capacity of water consumption (Colorado Water Conservation Board, 2010). The volume of rainwater from rooftops could meet water demands of the occupants of that building, especially to the City residents if the consumption rate would be less than 40 litres per person per day (lpcd). World health organization suggests that 40 lpcd is fit for a very simple life, but even that is beyond reach of many consumers in Nairobi (Ledant *et al.,2010;* Moraa *et a*l.,2012).

The objective of this study was to assess the Volume, Storage capacity, Quality of water, rainwater harvesting adoption rate and challenges facing inhabitants in roof top rainwater harvesting in Nairobi County

MATERIALS AND METHODS

Area of study

The study was conducted in Nairobi County which has an area of 684 km^2. Nairobi County is the Capital City of Kenya lying at an altitude of 1798 m above the sea level. It has an average annual rainfall of about 900 mm, while the actual amounts range between500 and 1500 mm in any one year. There are two rainy seasons; mid-March to the end of May (Long Rains), and mid-October to mid-December (Short Rains).The County has five meteorological weather stations situated at Kabete, Jomo Kenyatta International Airport (JKIA), Moi Airbase, Wilson and Dagoretti Corner (Fig.1).

Rainfall Thiessen polygons were created using ArcGIS Version 9.2 software as indicated in Figure 1 which shows the Thiessens that classified the County into five sections based on meteorological stations. The buildings were grouped into Multi-story residential buildings, Bungalows/Maisonettes residential buildings, institutions and industries. A random sampling method was used to select 10 samples of maisonettes, 10 multi-story buildings, five institutions in each polygon, and twenty five buildings from industrial area which predominantly fall in J.K.I.A meteorological polygon. A total of one hundred and fifty samples were obtained. A Germin GPS was used for locating sampling positions.

The amount of monthly rainfall averages for 31 years computed for all stations were used to predict monthly and annual volumes of rainwater available for harvesting from different meteorological stations in Nairobi County.

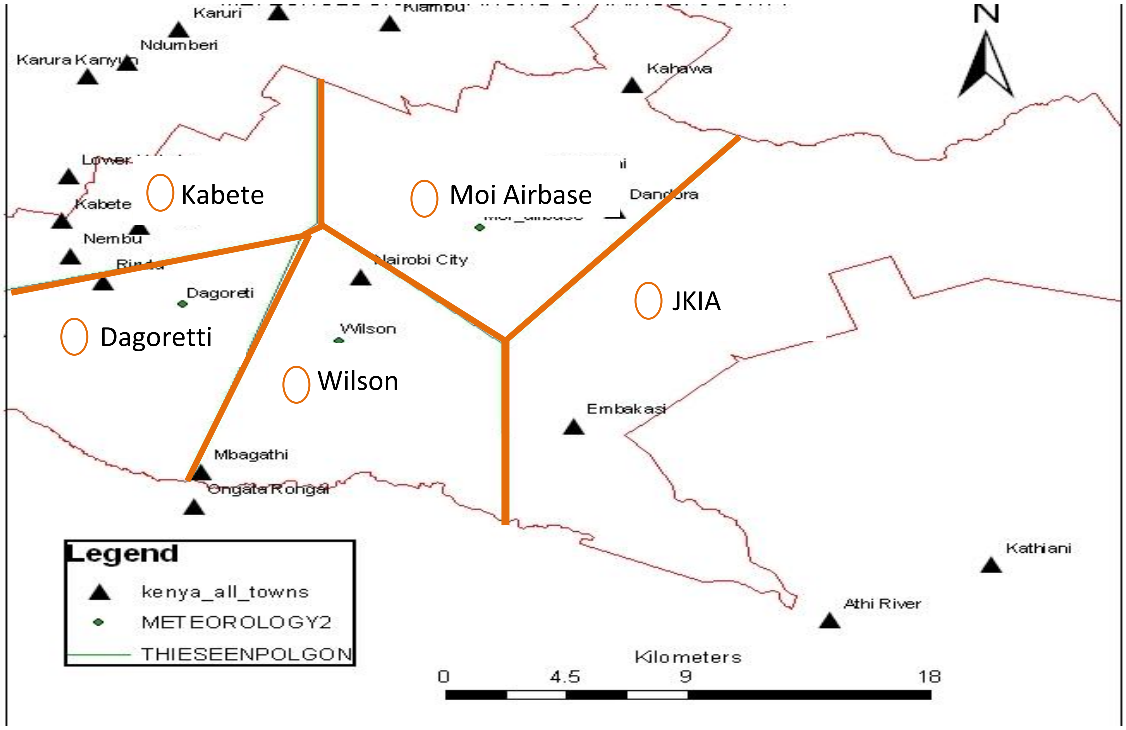

Figure 1: Meteorological Thiessen Polygons for Nairobi County

Volume of rainwater available for harvesting

The formulas used for calculation of rainwater for storage are indicated in equations *i* to *vi*

$$Q = PxAxC \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (i)$$

Q is volume of rainwater available for storage in litres per year
P is Annual rainfall in mm
A is roof area in square metres
C is coefficient of roofing materials

Volume demanded per building

a) Residential buildings

$$D = Nx80\frac{l}{p}x365days \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (ii)$$

N is (2 x Number of bedrooms) +1, as per buildings design requirements. According to Pader (2002); buildings codes allows a maximum of two persons per bedroom and one extra. A one bed roomed house is allowed to have a maximum of three occupants.

b) Churches

$$D = Nx20\frac{l}{p}x104days \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (iii)$$

Assuming two days of church functions per week

c) Day Schools

$$D = Nx20\frac{l}{p}x280days...(iv)$$

Boarding schools schools

$$D = Nx40\frac{l}{d}x280days...(v)$$

Assuming 40 weeks /year school attendance

d) Industries

$$D = (Nx20\frac{l}{p}x365days) + v...(vi)$$

Where N is Number of occupants in the building
D is Annual water demand
in litres per person(l/p)
v is volume used in industrial processes per year.

Size of storage tanks (Reservoir)

The size of storage tank required is a function of roof area, rainfall amounts in the region and household demand. In determining the size of storage tank required both rainfall supply and household demand were considered (International Relief Development, 2013). If percentage annual demand is less than 100%, the size of reservoir has to harvest 90% of rainfall (Assuming a rainfall efficiency of 90%). In this case, Equation (vii) was used to determine size of reservoir.

$$Q = \{0.9(April + May)xAxC\} - z...vii$$

Q is the size of reservoir in litres, A is roof area in square metres, C is coefficient of roofing material and z is a monthly water demand in litres.

Water samples for quality analysis

Rainwater samples were collected from rooftops of corrugated iron sheets, clay tiles and concrete tiles. The samples were collected during the month of October, November, April and May (short and long rainy seasons).They were kept in plastic containers that were thoroughly washed. The samples were analyzed for physical, chemical and bacteriological content using standard methods for water analysis at Kenya Industrial Research and Development Institute water laboratories.

Interview Schedule

An interview using an open structured questionnaire was administered to gather information about type of roof materials, sources of water, adoption rate of rainwater harvesting, storage capacities and challenges facing rainwater harvesting in the County.

Statistical analysis

The data were analyzed using SPSS version 22 and Microsoft Excel 2007 to obtain regression models, means, standard deviations, and maximum and minimum.

RESULTS

According to the monthly rainfall averages for 31 years computed for all stations as shown in Table 1, Kabete polygon was found to be the wettest area with an annual average of 1085 mm of rainfall, followed by Dagoretti (1031 mm), Eastleigh Moi Airbase (926 mm), Wilson(912 mm) and J.K.I.A station with 818mm,the driest polygon in Nairobi County. In terms of months averages, April receives highest amount (189.2mm) of rainfall across all five meteorological stations followed by May (153.4) and November (145.6) while July (16.2), September (21.2), August(23.2) and June(34.2) receive the lowest amounts as shown in Table 1.

Table 1: Monthly average rainfall (mm) for 31 (1980-2012) years for Meteorological Stations in Nairobi County

Month	MoiAB	Wilson	Dagoretti	J.K.l.A	Kabete	Monthly Averages
J	**63**	69	66	55	63	63.2
F	41	37	51	38	50	43.4
M	89	93	91	72	97	88.4
A	186	180	213	129	238	189.2
M	148	142	175	123	179	153.4
J	35	37	38	23	38	34.2
J	16	21	16	10	18	16.2
A	38	18	23	13	24	23.2
S	19	19	24	15	29	21.2
O	62	66	78	55	83	68.8
N	136	136	154	140	162	145.6
D	93	94	102	82	104	95
Maximum	186	180	213	140	238	
Minimum	16	18	16	10	18	
Annual Average	926	912	1031	818	1085	

(Source: Kenya Meteorological Services and Authors' calculations)

The quantities of rainwater from rooftops per category of buildings and from different meteorological stations are shown in Table 2. A 10% of rain was deducted from annual rainfall assumed to be the first flush that is recommended for cleaning, roofing and piping surfaces (Carolina et al., 2010). The 90% of average volume of rainwater available for harvesting from different stations was then used to calculate rainwater to be harvested.

Table 2. Percentage Water Demand Satisfied from rainwater harvesting from different-roof catchments of buildings.

			PERCENTAGES				
Meteorological Station	**Building**	**f**	**No. above 23%**	**Max**	**Min**	**Mean**	**Std dev**
Kabete	Maisonettes	10	10	132	84	130	67.4
	Multi-story	10	6	48	13	28	12.4
Wilson	Maisonettes	10	10	126	61	86.3	22.2
	Multi-story	10	5	71	12	25.9	16.9
Dagoretti	Maisonettes	10	10	155	69	114.5	52.4
	Multi-story	10	8	54	18	29	10.7
Eastleigh	Maisonettes	10	10	135	61	78.8	19.2
Moi Airbase	Multi-story	10	5	53	18	27	12.9
J.K.I.A	Maisonettes	10	10	85	51	60.3	11.7
	Multi-story	10	7	37	11	30.5	16.6
	Industries	25	25	842	30	215.5	186.7
	Institutions	25	25	327	30	122.5	75.9

(f= Frequency).

Rainwater supply of the occupants' demand in household buildings was expressed on the basis of 23% water supply deficit for Nairobi city. About 30.7% of the maisonettes rainwater supply lay between 80 % – 99 %, while, 18.8% lay between 70% - 79%, 11.5% between 60 % - 69 % and 15.4 % which were all within J.K.I.A meteorological station lay between 50 % – 59 % of total demand met by roof top rainwater supply. All maisonettes within Kabete Meteorological station were above 84% of demand met by roof top rainwater supply. Majority of industries (76%) meet their water demand by rooftop rainwater harvesting. These industries have large size of roofs that capture more water than their demands. The other, 8% has between 90% - 99% which is impressive. A small percentage (16%) lies below 90% of water demand that would be satisfied by rooftop rainwater harvesting.

Rainwater supply above institution's water demand was 48%. On the other hand, 24% of these institutions had a rainwater supply lying between 70% - 100%; a 20% between 50% - 69% and the other 52% between 30% - 49%. Rainwater supply for multi-story buildings was mostly below 50% of water demand. Multi-story buildings that were above 50% of rainwater supply are only 7.5%, while 11.3 % lie between 40% - 50%, 15.2% between 30% – 39%, 37.7 % between 20 % - 29 % and the remaining 28.3% between 10% -19%. Water demand to be satisfied by rainwater harvesting in multi-story buildings is less compared to maisonettes, Institutions and Industries. This is due to large size of occupants whose water demand is high and the roof catchments of buildings are small in size. However, rooftop rainwater catchment can contribute substantial water supply if implemented on large scale.

Size of Reservoirs

Maisonettes have an annual rainwater supply that would meet a demand of between 51% and 307% while multi story buildings had between 11 % and 71 % assuming 80 l/p/d. The storage tank required for maisonettes ranged from 5126 litres to 60840 litres while multi-story buildings, the range was between 32400 and 344250 litres. Pearson product moment of correlation coefficient and regression equations for storage reservoirs are shown in Table3**.**

Table 3. Pearson product moment of correlation coefficient and regression equations for storage reservoirs.

Stations	r	Regression Equations Maisonettes	r	Multi-story Buildings
Kabete	0.97	$y = 293x - 5081$	0.98	$y = 349.7x - 14.41$
Wilson	0.97	$y = 253.5x - 4870$	0.99	$y = 180.6x + 33779$
Dagoretti	0.99	$y = 326x - 10835$	0.96	$y = 278.2x + 13329$
Moi Airbase	0.97	$y = 224.8x - 5428$	0.91	$y = 122.6x + 53918$
J.K.I.A	0.97	$y = 211x - 12644$	0.96	$y = 144.6x + 20726$

Using regression equations in Table 3, the size of storage tanks were determined after measuring roof area of the buildings. The regression models are intended to assist building designers, government, donors, private agencies and users in determination of size of storage facilities per class of building.

The Quality of Rainwater from Roof Catchments

The water samples were analyzed for physical, chemical and bacteriological content (Tables 4a and 4b). E coli and coliform bacteria were not detected in any of the samples (Table4b). The pH levels of water harvested from corrugated Iron sheets and clay tiles, sampled in high density residential areas were 5.8 and 6.1, respectively. The slightly acidic behavior of this water could be probably because of carbon dioxide generated from this high density populated area, which reacts with rain water to form carbonic acid, which is a weak acid. However, the pH levels of water sampled from industrial areas and low density residential areas were 7.30 and 7.10, respectively, a slightly alkaline behavior. This pH levels lies within tolerable World Health Organization (WHO) standards for drinking water. Turbidity was close to 1 NTU in samples from industrial area roofs but within WHO standards for samples from residential area roofs. Of concern is that lead (Pb) was detected in rainwater from industrial areas and nearby residential buildings. This might have originated from emissions from industries or corrosion of rainwater piping (United States Environmental Protection Agency, 2007). Nevertheless, all water samples were suitable for non- potable purposes such as laundry, toilet flushing, general cleaning, industrial cooling and irrigation. Table 4 and 5 shows chemical, physical and bacteriological analysis, respectively.

Table 4a: Chemical analysis of harvested rainwater

PARAMETER	Units	RESULTS Industrial Area iron Sheets	High density residential areas, Iron Sheets	Low density residential area, Concrete tiles	High density residential areas clay tiles	WHO Guidelines
Chloride Cl^-	mg/l	ND	ND	ND	6.99	250
Fluorides	mg/l	0.6	0.4	0.45	0.45	1.5
Total Hardness	mg/l	6	14	16	32	
Sulphates	mg/l	2.3	0.55	2.15	5.45	250
Copper	mg/l	ND	ND	ND	0.14	2.0
Iron Fe	mg/l	0.53	2.65	0.61	0.18	0.3
Lead Pb	mg/l	0.27	ND	0.57	ND	0.01
Zinc Zn	mg/l	0.25	0.89	0.65	ND	5.0
Magnesium	mg/l	11.94	1.80	15.75	2.54	0.4
Nitrates No^{3+}	mg/l	1.7	2.45	1.1	0.15	50
pH	mg/l	7.30@ 22^0c	5.8 @ 24^0c	7.10@ 22^0c	6.01@ 25^0c	

Table4b: Physical and bacteriological contents analysis of harvested rainwater

Parameter	Units	Results Industrial Area Corrugated Iron Sheets	High density residential areas Corrugated Iron Sheets	Low density residential areas, Concrete tiles	High density residential areas clay tiles	WHO Guideline for drinking water
Turbidity	NTU	0.98	0.43	0.72	0.32	1.0
Total Suspended solids	mg/l	176.25	66	27.5	35	
Total Dissolved solid	mg/l	153.75	40	20	210	500
E. coli	MPN/ 100ml	ND	ND	ND	ND	0
Coliforms	MPN/ 100ml	ND	ND	ND	ND	0

(ND: Not detected) (NTU: Nephlometric Turbidity Unit)

Interview schedule

An interview schedule was conducted to institutions, industry, maisonettes and multi-story buildings. The schedule gathered information on roofing materials, water sources, adoption rate and challenges facing roof top rainwater harvesting.

Institutions

These were mainly schools and churches. Roofing materials were corrugated iron sheets that were 72%, followed by clay tiles 24% and others were 4%. Sources of water varied, about

48% of the institution relied on city council piped water and only 44% had roof top rainwater catchment.

The uses of water for institutions was mostly for non-portable purposes such as cleaning floors, flushing toilets, watering plants and recharging swimming pools; rarely was it used for food preparation or drinking. Majority of institution considered the source of water as reliable. In case of shortages they used stored water from their reservoirs, skipped regular chores that used water such as cleaning, bought water from nearby boreholes, tankers or handcarts.

The ones that harvested rainwater from roof tops, 82% used above ground plastic tanks for storage while, 18% used underground concrete tanks. The size of these storage tanks were in the range of 20000, 24000, 30000, 40000, 48000 and 100000 litres. In all of the samples, the tanks would serve the users for one week, one month or two months. The uses of rainwater from roof catchment was mainly for cleaning floors, flushing toilets, watering plants, washing cloths and bathing. A 66% of these institutions were satisfied with their rainwater harvesting system, 34% were not satisfied. Majority of the institutions used their own money to finance rainwater harvesting system, the others used donations. There were no reported diseases associated with water usage in any of the institutions.

Figure 3 shows a satisfying water harvesting structure with a harvesting tank and elevated supply tank for a toilet facility in a public school while Figure 4 indicates unsatisfying system. The two figures give a preview of technology requirements for roof top rainwater harvesting.

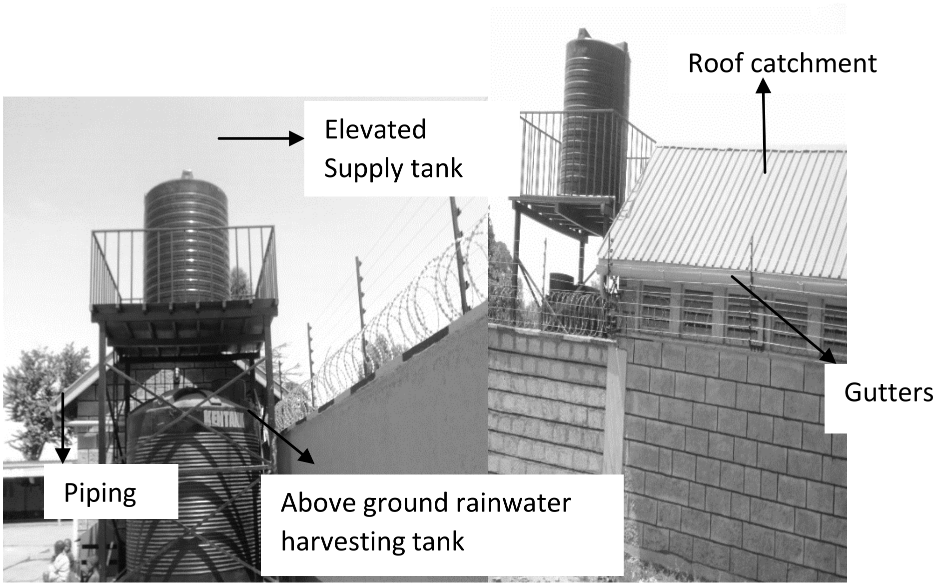

Figure 3: Above ground rainwater reservoirs in a public swimming pool/school in Nairobi County.

Figure 4: Improvised mechanism for harvesting rain water by a church in Embakasi; from left is the piping system followed by an underground concrete storage reservoir.

Industries

The industries studied were metal products manufacturing, Agro chemical and food processing, warehouses/dispatch and transport structures. The type of roofing materials were corrugated iron sheets (84%), clay tiles (12%) and others. The major sources of water were city council piped water 76%, and only 4% was from roof top rainwater harvesting. About 88% of these industries had reliable sources of water was reliable while 12% had unreliable sources. The major uses of water were for boiler operation, cleaning floors and equipment, chemical and food processing, cooling and irrigating flowers. All the industries had a reservoir for storing water for use in times of water cut off from the main supplies.

Maisonettes Residential buildings

The type of roofing materials for these buildings was majorly clay tiles (72%), corrugated iron sheets (12%), concrete tiles (12%) and others were 6%. The source of water differed with city council piped water leading (56%) and only 20% harvested rainwater. However, 72% indicated that water sources were reliable, while 28 % said that it was not reliable at all. In times of shortages, 55% of the residents bought water from vendors such as water tankers or handcarts while 36% used water from their own reservoirs that had been stored for water shortage sessions. The others either recycled or minimized usage. A number of residents, (30%) used water for irrigating kitchen gardens, green houses or flowers.

The ones who harvested rainwater (20%) from roof catchments, 44% used above ground plastic storage tanks while 56% used underground concrete tanks. The capacity range were; 1000, 1200, 5000, 10000, 20000 and 24000 litres. The uses of rainwater from roof catchment was mainly for laundry, flushing toilets, irrigating plants (non-potable uses) and some used it for all domestic chores. A 77% were satisfied with their rainwater harvesting system, the others were not satisfied. Majority of them (88%) used their own money, while 12% used money from loans to finance storage reservoirs. There were no diseases associated with water usage in any of the Maisonettes buildings.

Multi-story residential buildings

The type of roofing materials in this type of buildings was corrugated iron sheets (50%), clay tiles (36%), Aluminum sheets (6%), concrete tiles (2%) and others 6%. The sources of water used were from different sources with city council piped water leading (50%) and only 6% harvested rainwater.

Most buildings in this category indicated that water sources were not reliable at all (46%) a higher rate than any type of building highlighted. On the other hand, 54% had a reliable water source throughout the year. Majority of those who experienced water shortages bought water from water tankers or handcart vendors (60%), the others used water from their reservoirs. The rate of rainwater harvesting from roof catchments were very low, (6%). The kind of storage reservoir used was underground concrete tank of capacities 1000, 1500 and 5000 litres, having been financed by owner's money. Water from these reservoirs would serve residents within a week. The harvesting systems were satisfactory and there were no diseases associated with rainwater usage although, some used it for all domestic chores. Table one show the different sources of water per class of building where f is the frequency.

When asked the need of roof top rainwater harvesting, the respondents recommended rainwater to be harvested in Nairobi City County in order to supplement borehole and surface water supplies, reduce the cost of operations, reduce flooding, mitigate water theft along the pipelines and reduce competition for surface and underground water resources.

Table 5: Sources of water for different classes of buildings

	Source of water	**Institutions**		**Industry**		**Maisonettes**		**Multi-story**	
		f	%	f	%	F	%	f	%
1	City council	12	**48**	19	**76**	28	**56**	25	**50**
2	Private borehole, city council, and roof top rain catchment	3	**12**	0	**0**	1	**2**	0	**0**
3	City council and Roof top rain catchment	8	**32**	1	**4**	8	**16**	3	**6**
4	Private borehole and city council	2	**8**	5	**20**	9	**18**	15	**30**
5	Private borehole and roof top rain catchment	0	**0**	0	**0**	1	**2**	0	**0**
6	Private borehole only	0	**0**	0	**0**	3	**6**	7	**14**
	Total	25	**100**	25	**100**	50	**100**	50	**100**

(f: frequency) *(%: Percentage)*

Perceptions and challenges facing rooftop rainwater harvesting in Nairobi County

Assessment of perception, and challenges of roof –top rainwater harvesting in Nairobi County was conducted where responses to the questions were: 1 – strongly disagree 2 – Disagree 3 – Neutral 4 - agree and 5 – Strongly agree. The results are as shown in table 2 in terms of frequency (F), Maximum, Minimum, Mean and Standard deviation.

Table 7: Perception and challenges of rooftop rainwater harvesting in Nairobi County

7.1	**Reasons for not harvesting rainwater**	**f**	**Max**	**Min**	**Mean**	**Std dev**
i	No storage tank	122	5	1	3.24	1.28
ii	Pipe water is reliable	124	4	1	1.94	0.877
iii	There is no space to install a tank	121	4	1	1.83	0.69
iv	It is costly to install a rainwater harvesting system	123	5	1	1.97	0.71
v	The city council does not allow rainwater harvesting	121	5	1	2.21	0.92
vi	Rainwater harvesting system was not	120	5	1	3.97	1.04

	included in the initial planning or design					
7.2	**The following might be causes of flooding in Nairobi City**					
i	No drainage system	92	5	1	3.1	1.11
ii	The drainage system is there but it blocks during heavy rains	128	5	1	4.0	0.95
7.3	**Perception of Roof top Rainwater Harvesting in Nairobi**					
i	Rainwater harvesting in Nairobi will increase water quantity and sanitation	142	5	1	4.23	0.76
ii	Rainwater harvesting in urban areas will reduce flooding and the associated damages	140	5	1	4.13	0.77
iii	Rain water quality is suitable for industrial and domestic consumption	138	5	1	4.17	0.78
iv	Rain water harvesting will reduce the cost of pumping water from NWSC, constructing and maintaining drainage systems	142	5	1	4.15	0.79

Table 8: Checklist on Water structures

	Water structures	Yes	No
1.	Building is completely guttered	77%	12.4%
	Partially guttered	10.6%	
2.	Collection pipes are installed	86.6%	
3.	Water pump already installed	97%	
4.	Space availability (Approximate size 4 m^2 or more)	98%	
5.	Supply tank already installed	98%	

Most residents felt that they were not harvesting rainwater because rainwater harvesting system was not included in the initial planning or architectural design of the building (mean of 3.97 out of 5). However, a mean of 4.23 felt that rainwater harvesting in Nairobi would increase water quantity and sanitation, it would also reduce flooding and associated damages (4.13) and that rainwater quality is suitable for some domestic and industrial uses (4.17). Most buildings (77%) were completely guttered with collection pipes and 98% has an approximate space of 4 m^2.

DISCUSSION

Rainwater available for harvesting

Maisonettes residential buildings within Kabete and Dagoretti meteorological stations indicated mean of 130% and 114%, respectively of rain water available for storage. This means residents can solely depend on rainwater harvesting from rooftops as source of water. Maisonettes from Wilson, Eastleigh Moi Airbase and J.K.I.A indicated a mean of between 60% – 86%. Which means that they will require a small percentage of water supplements from other sources. However, multi-story buildings had a mean of between 25% - 30% which are above 23%, the deficit encountered from surface and borehole supplies (Athi Water Services Board, 2012).

Industries and Institutions had means of 215 % and 122 %, respectively which are above their demand indicating that Industries and institutions can harvest rainwater from roof tops and meet their demands wholly. This will reduce stress on critical water supplies and increase supply to the projected demand of 2.5 million cubic meters per day by 2030 (Caltlin and Yamim,2008), Jeremy et al.,(2012), and Noah et al., (2011).This extra water harvested could be used in small scale agricultural production, especially gardens around households. Large scale rainwater harvesting has been reported to decrease seasonal flooding in urban areas (Chanan. *et al*., 2007).

Storage capacities

According to Gabe *et al*., (2012) who did research in the largest city of New Zealand on perception of rainwater harvesting tank size, found out that most residents who installed above – ground rainwater tanks described them as inefficient use of land and it was good if the size of the tank would be reduced. According to an interview schedule conducted in this study, most residents were not harvesting rainwater because they lacked storage reservoirs and for the ones who harvested, their reservoir sizes were far below rainwater supply and/or household water demand.Constructing or buying a rainwater storage reservoir is a costly venture in rainwater harvesting system (International Relief and Development, 2013) and this is a major cause why many residents are not harvesting rainwater from their rooftops. The storage tank required for maisonette ranged from 5126 litres to 60840 litres while multi-story buildings, it ranged from 32400–344250 litres. The maisonettes buildings had an estimated cost of above ground plastic tanks ranging from Ksh 35000 – Ksh 595000. The benefits are water saving same as city water rates, surface water protection same as surface water treatment costs and flood risk reduction same as the cost of sizing an onsite detention/ drainage system (Caltlin Grant *et al.* ,2008). The class of people in this type of buildings is medium to high class and this would be an average cost on them. Models to be used for determining storage reservoirs and cost for harvesting rainwater from roof tops for different stations in Nairobi City County were generated. The purpose of the models is to assist engineers, designers, plumbers, builders, developers, government and users in determination of correct size and cost of tanks for a particular building.

Adoption of roof top rainwater harvesting in Nairobi County and major water sources

According to interview schedule conducted, major water sources across all building types was city council piped water (93%). Industries largely (78%) depended on city council piped water and only 4% harvested rainwater, despite having a potential of meeting their water demand (mean of 215%) from roof top rain catchment. Non potable indoor and outdoor water uses would be 86% and above for industries (Noah, 2011) and rainwater quality from roof tops is suitable for these purposes; unfortunately this resource is disposed as storm water. The industries in addition, largely depended on their private borehole (20%) followed by multi- story buildings (14%) and maisonettes (6%). It would be prudent if industries harvest rain water in order to allow some percentage of city council piped water (potable water) to residential (domestic) buildings because according to (Noah, 2011) their need of potable water is high than for industries (21.7% and 14%, respectively).

In the four types of buildings assessed, Institutions are leading in roof top rainwater catchment (44%) followed by maisonettes. These institutions are either public schools or

ISSN 2056-5879

churches and the source of money for acquiring tanks is majorly from donations and/or constituency development funds.

CONCLUSIONS

The results of this study indicate that the volume of rainwater harvested from rooftops would not meet water demand of the occupants for most buildings but would serve as supplement to surface and ground water sources. Nevertheless, the water harvested from some maisonettes, institutions and industrial buildings could fully meet water demands of the occupants. The size of storage tanks required for rainwater storage differed widely with maisonette buildings requiring 5,126 to 60,840 litres while Multi-story buildings require an approximate of 32,400 to 344,250 litres. The quality of water from roof tops in most cases does not meet the required standards (WHO) for potable water use but it would be used for non-potable uses without subject to any treatment.Only 16% harvest rainwater from roof tops of institutions buildings are leading followed by those of maisonettes , Multi-story residential buildings and industries in that order as far as adoption of roof top rainwater harvesting is concerned. Most residents are not harvesting rainwater from rooftops because they do not have storage facilities. Moreover, rainwater harvesting facilities are not included in the initial designs and construction of buildings. Those who harvest water from rooftops, they use that water for non-potable purposes and they have not experienced diseases associated with rainwater usage.

Urban water management should shift from depending on centralized systems alone and encourage decentralized systems such as domestic rainwater harvesting. This will increase water quantity and sanitation. More importantly, rain water harvesting facilities should be included in building designs together with harvesting techniques, and if possible with affordable or subsidized prices for storage tanks. This indeed will encourage many inhabitants to adopt the water harvesting technology which will lead to water sufficiency in most households in urban areas.

ACKNOWLEDGEMENTS

This work was part of a Master's thesis degree at Kenyatta University, School of Agriculture and Enterprise Development. It was funded by Kenya Industrial Research and Development Institute. National Commission for Science, Technology and Innovation (NACOSTI) authorized the research and Kenya Meteorological Services availed rainfall data.

Reference

1. Athi Water Services Board (2012). The master plan for developing new water sources for Nairobi City and 13 satellite towns, http://www.afriwater.org
2. Awiti,J. (2013). Water use will define County development. The Star (Kenya daily paper) of March 19,2013.
3. Gabe,J., Sam, T. and Diveshkuman M. (2012). Mandatory urban rainwater harvesting, learning from experience, Water Science and Technology.
4. Caltlin Grant and Yamim Y. (2008). Analysis of water and energy conservation of rainwater captures system on a single family home. VWRRC special report on SR39 – 2008.

5. Carolina B., Brandon K., Bright R. (2010).Effect of roof Materials-water quality for rainwater harvesting systems,Texas water development Board. Available on http://www.harvesting rainwater..com
6. Chanan, A., Vigneswaran S. and Kandasamy J. (2007). Harvesting rainwater for Environmental, conservation and Education, Some Australians case Study, http://www.iwahq.org/contentsuite.
7. Colorado Water Conservation Board, (2010). Criteria and Guideline for rainwater Harvesting, Department of Irrigation and drainage Malaysia Vol 4, 5.
8. Gakungu J. (2013).Qualitative Assessment of rainwater harvesting from roof top catchments: Case study of Embakasi, Nairobi County. International Journal of soft computing and Engineering volume 3, Issue 4. www.ijsce.org.
9. International Relief and Development (2013). Roof–top rainwater harvesting best practices Guide, http://www.ird.org/uploads/IRD.
10. Jackson, R. B. (2001). Water in changing world, Journal of Eco. APPI, 11, 1027 – 1045.
11. Jeremy, G., Sam, T. and Diveshkuman M. (2012). Mandatory urban rainwater harvesting, learning from experience, 12th international Conference on urban Drainage, Brazil.
12. Kenya Rain Water Association (2012). Rainwater harvesting in Kenya, contribution to the Global Environment. Nairobi, Kenya
13. Ledant, M., et al. (2010). Access to water in Nairobi: Mapping the inequities beyond the statistics. A report by Global water operator's partnerships Alliance and the French Institute for Research in Africa.
14. Mendes, B.C. et al.(2010). Effect-of-Roof-Material-Water Quality for Rainwater Harvesting Systems, Texas water Development Board, Available on, http://www.harvestingrainwater.com
15. Moraa, H., Otieno, A.and Salim, A. (2012). Water Governance in Kenya: Ensuring accessibility, service delivery and citizen participation. Available on: http://research.ihub.co.ke.
16. Noah, G., Christopher, K and Robb, L. (2011). Capturing Rainwater from rooftops: An efficient water Resource management strategy that increase supply and reduce pollution. Natural Resource Defense Council. www.nrdc.org/water.
17. Pader, E.(2002).Housing occupancy standards: Inscribing Ethnicity and family relations on the land. Journal of Architectural and planning Research 19:4, 300-318.
18. United States Environmental Protection Agency (2007). Secondary drinking water regulations. Guidance for Nuisance chemicals water. www.water.epa.gov /drink
19. World health organization (2012). pH in drinking water – Guidelines for drinking water quality 2nd ed vol.2.