POTENTIAL OF RAINWATER HARVESTING FOR ENHANCED WATER SECURITY IN KAHAWA SUKARI PERI-URBAN ECOSYSTEM IN KIAMBU COUNTY, KENYA

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ABSTRACT

Water is a critical ecosystem service, whose scarcity is increasing in urban and peri-urban areas commensurate with population growth. This paper reports on the potential of roof-based rainwater harvesting as an option in mitigating this challenge and complementing metered water supplies. Roof footprints were mapped and computed using standard GIS procedures. A social survey using questionnaires was used to collect data from homeowners in the estate. The social data were subjected to descriptive statistics to yield general trends on water availability, use, and management. Rainfall data covering the period 2005-2017 was obtained from the Kenyatta University Field Meteorological Station. Results showed that at least 90% of households depend on Nairobi Water and Sewerage Company for water. Despite the prevailing water shortages, about 80% of homes lack complete and functioning rainwater harvesting infrastructure. Potential harvests based on a standard roof area of 350 m^2 per residence range from 5250 to 63,350 litres per month, with a mean of 26,000 litres. The two rainy seasons can in particular yield significant quantities of water and greatly enhance water security in the area. Scaling-up of rainwater harvesting can however benefit from appropriate policy incentives such as lowering the cost of plastic tanks to make them more affordable, and including rainwater harvesting infrastructure as a requirement for construction approvals.

Keywords: Rainwater Harvesting, Water Security, Peri-urban Residences, Kenya

1.0 INTRODUCTION

1.1 Background

The importance of water as a basic human need and a key driver for agricultural and industrial development cannot be overemphasised. The public's access to water is however diminishing with time due to a myriad of reasons such as population pressure, pollution, and climate change (Haque, et al., 2016). Sustainable access to safe drinking water and water for other uses continues to be a big challenge in Africa. For instance, sub-Saharan Africa accounts for 40% of people in the world without access to potable water (Sojobi et al., 2016). According to UNEP vital water statistics, about 75-250 million people will be exposed to water stress in Africa by 2020. Further, it is estimated that by 2025, water stress countries would have risen to 18, which will affect about 600 million people. According to the

United Nations World Water Development Report (UN, 2018), global demand for water has been increasing at a rate of about 1% per year due to a combination of factors such as population growth and changing consumption patterns. The World Health Organization reported that 783 million people lack enough water to simply meet their basic needs (WHO/UNICEF, 2013). Further, it is estimated that by 2025, water-stressed countries would have increased to 18, effectively affecting up to about 600 million people. Sustainable access to safe drinking water will, in particular, continue to be a big challenge in Sub-Saharan Africa, which accounts for 40% of people in the world without access to potable water (Sojobi et al., 2016). Safe water is particularly a challenge in Kenya's urban and peri-urban ecosystems where population growth and proliferation of slums remain key drivers of environmental and socio-economic changes. According to UNEP (2018), two-thirds of people are expected to live in cities by 2050. This presents a real challenge of re-imagining and re-constructing urban and peri-urban ecosystems in terms of water availability and nature conservation. The limited supply of water is also associated with deaths from waterborne diseases like diarrhoea, dysentery, and cholera (Sobel et al., 2004).

Conventional and centralized water supply is also facing many challenges such as limited water resources, high operation costs and salinization among others (Semra et al. 2011; Agusa et al., 2014 and Wilbers et al., 2014). Alternative ways of meeting water demand are therefore critical development agenda in water stressed and scarcity countries. Despite its potential in this regard, rainwater harvesting has not received the attention it deserves, both in rural and peri-urban areas of low-income countries (Opare, 2012; Ndiritu et al., 2011; Aladenola and Adeboye, 2010). Rainwater harvesting is also often ignored in places where rainfall is perceived as being abundant (Ghis and Schondermark, 2013). Scaling-out of rainwater harvesting has also been slow due to various challenges faced such as erratic and unreliable rainfall, non-existence or ineffective nationwide agencies to facilitate rainwater harvesting, poor roofing materials that compromise water quality, high expenses associated with requisite infrastructure, and various legal, institutional and political bottlenecks, which vary across different countries (Mwenge et al., 2011; Kahinda and Taigbenu, 2011; Sample and Liu., 2014; Kohlitz and Smith, 2015; Oke and Oyebola, 2015). There is no doubt that water sources and management issues will evolve over the decades and the sector will face multiple uncertainties due to increasing competing demands (Tarhule (2017). This explains why for instance sustainable development goal six emphasises the need to ensure availability and sustainable management of water and sanitation for all. Transformative leadership in the water sector should thus play a leading role in integrated water resources management in countries at risk of water insecurity. An opportunity in this regard exists through rainwater harvesting. Leveraging on this strategy, however, calls for integrated approaches involving key stakeholders in the water sector. The role of government is particularly important from policy, legislation and political leadership dimensions (Republic of Kenya, 2010, 2016; Water Resource Management Authority, 2013).

1.2 Problem Statement

Kenya is classified as a water scarcity nation. With 41% of the population lacking improved water sources and 69% without access to improved sanitation, the World Health Organisation ranks Kenya among the 25 countries globally with the least access to safe water. Kandji (2006) observed that 80% of Kenyans continue to have inadequate access to water, drink unsafe water, and spend much time and money trying to acquire water. In urban areas, such as the greater Nairobi, only about 40% of the inhabitants have direct access to piped water (Herrero, et al., 2010). About 40% of those with access to piped water receive it 24 hours per day (Nyangeri and Ombongi, 2007). In other places, residents get water on average once per week. Nationally, 9 out of 55 public water service providers in Kenya attempt a continuous water supply regime. The rest leave peoples to find water in their own way. This supply gap especially in urban and peri-urban areas is often filled by private water vendors, whose water sources and quality remain unreliable and untrustworthy. Unless pro-active measures are taken to reduce water, footprints and tap into alternative water supply sources, water scarcity will increase and negatively impact households, agriculture, industry, and the environment. According to Kandji, (2006), 80% of Kenyans do not have access to clean water and end up drinking unsafe water from unreliable sources. In urban areas, such as Nairobi, Thika, Ruiru, and Kahawa Sukari, only about 40% of the inhabitants have direct access to piped water (Herrero, et al., 2010). The rest obtain water from vendors and boreholes. Only about 40 % of those with access to piped water receive water 24 hours per day (Nyangeri and Ombongi, 2007).

The scarcity of portable water in Kahawa Sukari residential estate is as old as the estate. Residents are dependent on metered water supplied by the Nairobi Water and Sewerage Company once or twice Scarcity of water is evidenced by frequent complaints posted on welfare portals and also the presence of increasing private water vendors plying the estate. The existence of intact roof catchments in the estate, however, offers an opportunity to mitigate this shortage through rainwater harvesting and saving technologies. This approach has helped many households in developing nations cope with water shortages (Rahman et al., 2014). Similarly, investing in sustainable water supply systems is not an option for Kenya if it has to fulfil its development agenda as envisaged in the social pillar of vision 2030, the principles of land and environmental management in the national constitution, and the big four agenda especially the aspects of food security and affordable housing. As such the overall objective of this research was to assess the potential of rainwater harvesting and management implications with the view of addressing challenges that limit water security in this residential ecosystem.

2.0 METHODOLOGY

2.1 Study Area Characteristics

This study was done in Kahawa Sukari Ward in Ruiru Sub-County, Kiambu County. In comparison to other sub-counties, Ruiru has currently the highest population estimated at 371,111 people (Republic of Kenya, 2019). The households at the time of this research were about 3800. Land use is mainly residential, under controlled development model. Water demand will keep rising as more people settle in the estate. For not being able to meet the water demand today, Nairobi Water and Sewerage Company will find it more difficult to fulfil this public service in the future. Interviews with key respondents during the reconnaissance survey indicated the existence of simmering dissatisfactions over water supply and management practices by the service provider. As an emerging land use, urban and peri-urban agriculture will exacerbate demand for water, thus putting more strain on available quantities for domestic use.

2.2. Research Design, Data Collection, and Analysis Methods

A GIS-based spatial survey was used to map and estimate roof footprints in the study area. Actual roof areas were calculated by multiplying the roof footprints by a factor of 1.15 and divided by cosine 250 being the average roof gradient. Data on water governance at the household levels were obtained by the use of a survey questionnaire. The respondent's confidentiality was guaranteed by not providing for names or telephone contact in the questionnaire. The design sample size of 346 from a household population of about 3800 was arrived at using guidelines provided by Krejcie and Morgan (1970). Up to 159 completed questionnaires were obtained. These data were cleaned, coded, and subjected to descriptive statistics to obtain general trends on water use and management. The total amount of water supplied to the estate by the Nairobi Company was out of the scope for this study. The focus was on the perceived scarcity of water at household levels and what could be done to remedy the situation. Being largely a social survey, this study was limited by among other factors the unwillingness of some residents to complete the questionnaires and allow the researcher access into their compounds for ground verification of GIS output. The possibility of a few biased responses can also not be ruled out. Nevertheless, the near homogeneity of residents (at least 70% had a university degree) guarantee reliability of data obtained for generalization and planning purposes.

3.0 RESULTS AND DISCUSSION

3.1 Roof Footprints of Residential Houses in Kahawa Sukari

Up to 7742 rooftops were digitized from Google Earth in an area of about 944.35 acres (3.82 km^2) Details of spatial data from this total area are summarised in table 1.

Table 1: Summary of GIS-based spatially estimated items

Spatial Item	**Area (m^2)**	**Area (km^2)**
Estimated estate area (to the nearest whole number)	3,821,644	3.82
Surface area of the rooftops from the total number of digitized polygons	2,047,347	2.05
Smallest roof footprint	19.39	0.000019
Largest roof footprint	1,655.00	0.0017
Average roof footprint	264.00	0.000264
Actual roof area (after correcting for a gable roof pitch of 25$^{o)}$	335.56	0.000336

The distribution of rooftops in the estate is shown in figure 1. Houses are built in a linear pattern per avenue. The undeveloped (unsettled) area was estimated at 1.77 km^2. The average roof footprint in Kahawa Sukari was estimated at 264.45 m^2. The actual mean roof catchment area was 335.56 m^2 bearing in mind the adjustment occasioned by the roof ridge gradient. For purposes of estimating potential harvests in this area, a rounded roof catchment area of 350 m^2 (0.035 ha) was used.

3.2 Socio-economic Information of Respondents

At least 60% of respondents affirmed private land ownership. In terms of education, 70% indicated having a university degree. This provides a glimpse into the attitude of the middle class on rainwater harvesting. The mean family size of can serve as the benchmark when planning for water supply either through metered water, rainwater harvesting, or both.

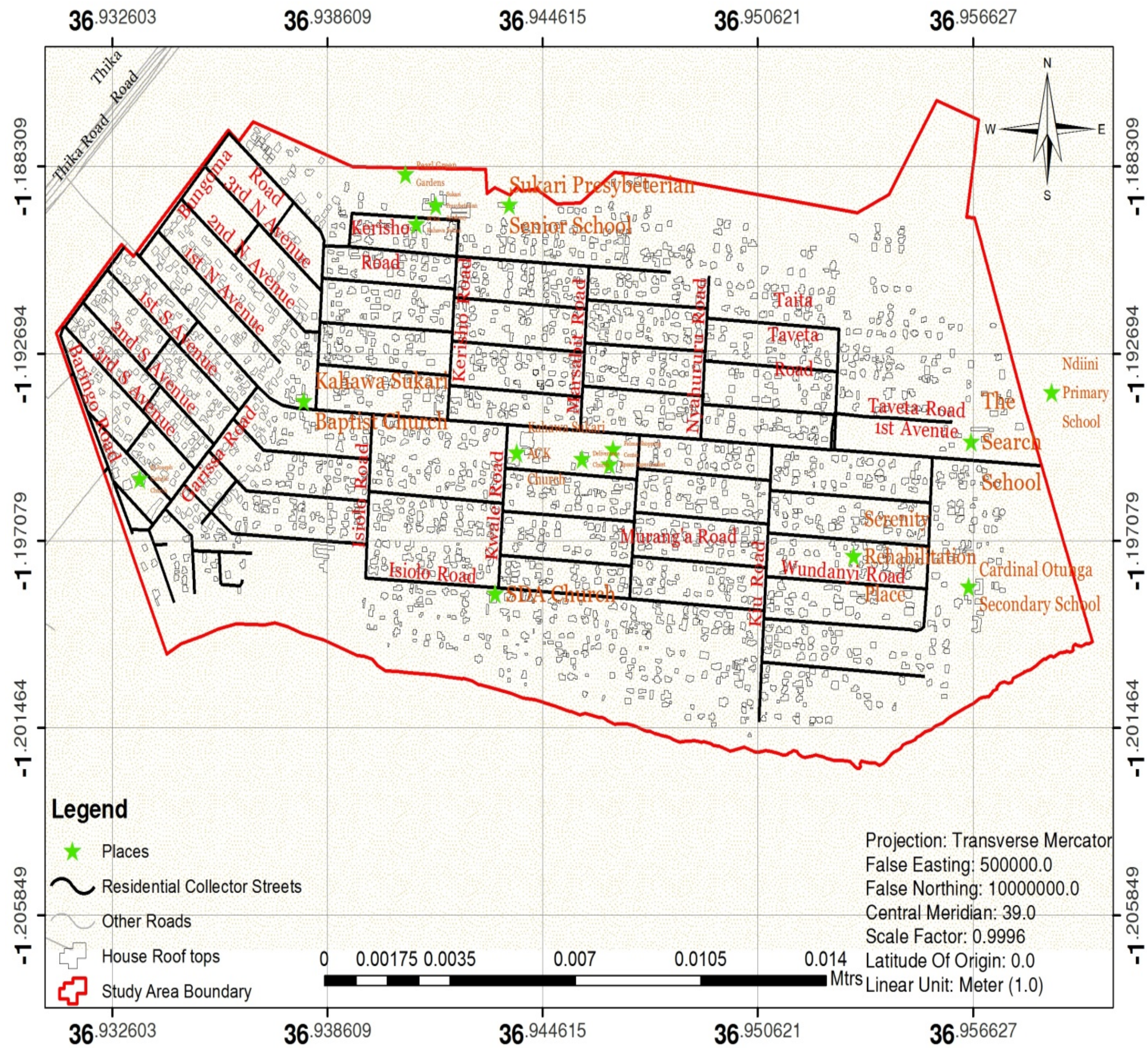

Figure 1: Distribution of rooftops in study area

3.3. Seasonal Potential of Roof-based Rainwater Harvesting

Monthly rainfall data from 2005 to 2017 suggests that the study area has a bimodal rainfall pattern with long rains occurring from March to May and short rains from October to December. April has the highest mean monthly rainfall of 180 mm and November 167 mm (Tables 1 and 2). Besides being erratic, the mean monthly rainfall days showed a decline with time while the trend of yearly rainfall totals remained generally flat (Figures 2 and 3). With appropriate rainwater harvesting and storage infrastructure, these two seasons can increase the longevity of available water.

Table 1: Number of rain days for greater Kahawa its surrounding area (2005-2017)

Month	Year												
	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	Mean
Jan	3	5	5	6	4	4	2	0	7	1	1	6	1	3.5
Feb	2	2	2	4	4	7	4	3	0	7	1	6	2	3.4
Mar	6	12	6	14	3	18	8	1	10	8	3	3	4	7.4
Apr	11	20	11	14	11	12	10	18	22	8	12	13	10	13.2
May	14	10	6	3	11	15	14	14	5	4	13	10	14	10.2
Jun	6	4	4	2	3	5	5	3	3	9	5	5	1	4.2
Jul	6	4	6	12	1	4	0	1	1	3	3	0	1	3.2
Aug	2	4	5	3	4	6	3	3	3	5	2	1	3	3.4
Sep	4	5	9	5	1	1	6	2	3	4	0	1	5	3.5
Oct	6	6	8	11	12	4	15	8	0	5	9	4	10	7.5
Nov	14	23	14	14	12	7	17	11	16	12	18	15	15	14.5
Dec	2	14	7	1	13	9	8	15	8	6	8	7	3	7.9
Total	76	109	83	89	79	92	92	79	78	72	75	71	69	6.8

Source: Field Weather Station, Department of Geography, Kenyatta University

Table 2. Rainfall amounts for greater Kahawa and its surrounding area (mm) (2005-2017)

Month	Year													
	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	Mean
Jan	19.0	9.6	29.4	70.9	63.9	149.9	6.3	0.0	49.2	8.0	8.0	180.2	87.5	52.5
Feb	21.1	33.9	29.4	21.2	38	151.7	71.0	4.5	0.0	128.5	40.8	12.4	15.5	43.7
Mar	50.9	96.9	43.6	204.9	84.6	257.9	92.6	4.2	69.4	167.6	22.8	9.6	36.0	87.8
Apr	163	323.6	252.5	178.3	63.1	112.7	73.4	250.7	375.9	52.1	234.4	182.9	79.6	180.2
May	241.8	68.3	66.2	15.6	96	230.7	102.0	186.7	30.4	45.4	143.6	238.6	140.1	123.5
Jun	22.1	11.7	47.2	1.5	7.1	23.5	39.1	59.3	16.3	85.4	77.1	18.0	4.0	31.7
Jul	13.5	3.1	43.3	74.0	6.2	7.0	0.0	5.3	8.8	12.0	8.2	0.0	11.6	14.8
Aug	1.7	22.1	26.1	8.4	3.9	14.5	12.3	31.2	22.5	71.2	8.3	32.3	20.2	21.1
Sept	6.4	34.1	31.5	45.6	1.2	1.0	64.3	38.5	11.7	0.0	0.0	0.3	15.8	19.3
Oct	22.7	24	73.1	150.1	97.7	65.8	96.6	135.6	0.0	44.4	125.9	4.8	153.7	76.5
Nov	85.8	404.6	128.7	197.4	49.7	57.1	237.2	126.5	89.3	137.7	429.2	83.8	143.9	167.0
Dec	1.1	114.6	36.8	2.8	93.2	71.1	51.7	220.5	78.3	40.3	231.7	18.4	45.6	77.4
Total	649.1	1146.5	807.8	970.7	604.6	1142.9	846.5	1063.0	751.8	792.6	1330.0	781.3	753.5	74.6

Source: Field Weather Station, Department of Geography, Kenyatta University

Figure 2. Time Series for Rainfall Frequency (2005-2017) (Derived from totals in table 1 above)

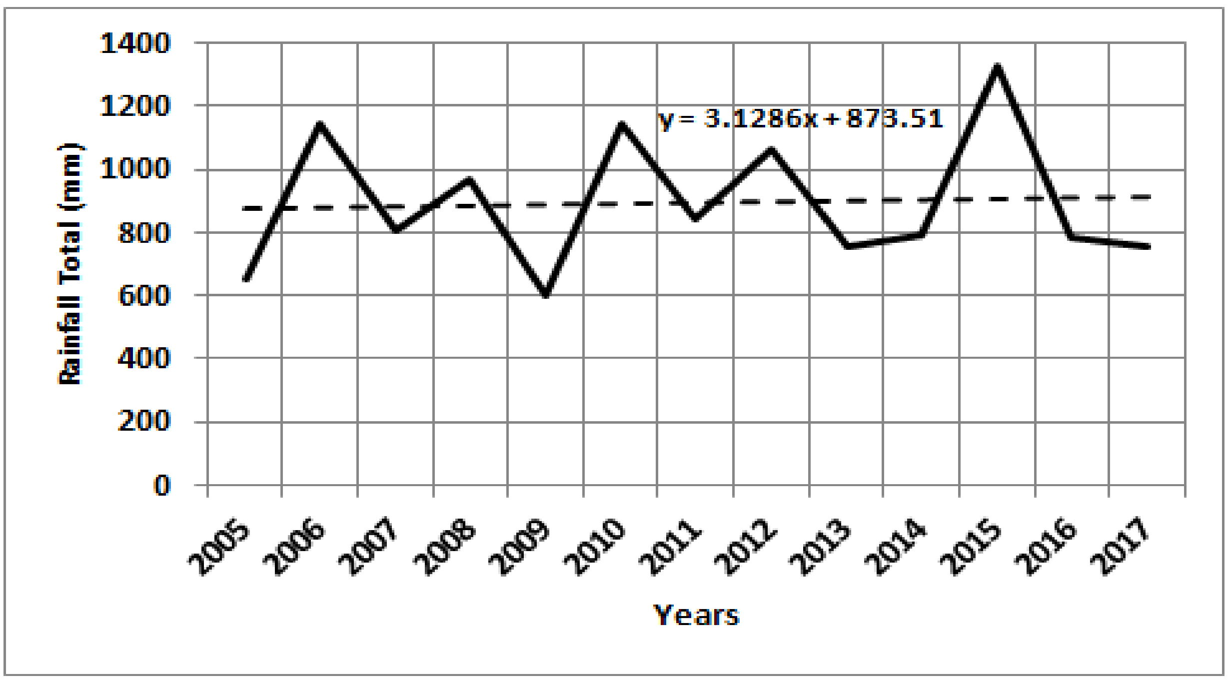

Figure 3. Rainfall Time Series: 2005 – 2017 (Derived from totals in table 2 above).

Reducing rainfall days is a pointer to future water scarcity and hence the need to pro-actively plan for alternative water sources and efficient uses of the little that is received. Potential harvests based on the mean monthly rainfall range from 5250 to 63350 litres (Table 3). As expected, households have the possibility of harvesting much water during the long and short rainy seasons of March-May and October - December respectively.

Table 3. Potential rainwater harvests based on a standard roof area of 350 m^2

	A	B	C	D
Month	**Mean rainfall (mm)**	**Mean rainfall (m)**	**Est Volume (C) = 350B (m^3)**	**Est volume (Litres)**
January	52.5	0.053	18.55	18,550
February	43.7	0.044	15.40	15,400
March	87.8	0.088	30.80	30,800
April	180.8	0.181	63.35	63,350
May	123.5	0.124	43.40	43,400
June	31.7	0.032	11.20	11,200
July	14.8	0.015	5.25	5250
August	21.1	0.021	7.35	7350
September	19.3	0.019	6.65	6650
October	76.5	0.077	26.95	26,950
November	167.0	0.167	58.45	58,450
December	77.4	0.077	26.95	26,950
Mean	74.68	0.075	26.192	**26,192**

NB: Rainfall data obtained from table 2 above

3.4. Causes of water shortages

In terms of the status of water availability within the estate, 13.8% of the residents indicated that availability was adequate, while 53.4% and 32.8% indicated that the supply was scarce and extremely scarce respectively. When asked about weekly water availability, the majority of respondents (45%) indicated receiving water only twice per week. About 21% and 10% received water once and thrice per week respectively. Overall, over 80% indicated that water availability was scarce. This is a pointer to the need for alternative water supplies to supplement metered water. At least 27% of the respondents attributed insufficiency of metered water to interference by water vendors, who were blamed for working with cartels to close supply gates and encourage inequitable rationing of water in order to cause artificial shortages that would allow them to sell their water. Although 21% of respondents attributed water shortages to insufficient supply by the water company, increasing demand as more people settle in Kahawa Sukari could be the root cause. Shortages and disparities in water access were also blamed on residents pumping directly from the main supply conduit. A management requirement in this regard would be participatory inspection and dismantling of all pumps directly abstracting water from the main supply line. Residents should only pump water that would have collected in their storage tanks.

3.5 Catchment Status and Water Use in Kahawa Sukari

The extent of roof catchments and storages however varied across the respondents with only about 14% having gutted their entire roofs. About 16% had partly gutted their main roof (Table 4). In principle, about 70% of the residences lacked rainwater harvesting infrastructure, which is a pointer to poor performance in terms of reducing the water footprint. In terms of storage type, those who preferred above-ground tanks pegged it on ease of abstraction and better safety of people in the compound. Under-ground tanks were, on the other hand, preferred where supply pressure was low and much storage capacity was needed. The latter option is however often constrained by limited land. That only 9% used harvested water for drinking and cooking; is perhaps a pointer to lack of trust in the water quality based on roof types used. But when asked whether they had done any water analysis for domestic use 79% responded in the negative with only 5% responding in the affirmative. This presents a knowledge gap that needs attention in order to enhance the adoption of rainwater harvesting technology. The relationship between water quality and the now popular decra roofing material deserves attention. That water harvesting from clay tiles is still relatively low could be indicative of water quality fears introduced through the production process. This also calls for water quality analysis from different roofing material and disseminating the outcome to the target population. This could reduce dependence on metered water, which currently stands at about 90% of households. Where residents indicated reliance on own water supply, boreholes were the main sources of water.

Table 4. Household responses on selected water issues

Water issue	Number of respondents (n)	Frequency (%)
Roof status		
1. Gutters on entire roof	19	14.4
2. Gutters on part of roof	21	15.9
Water storage system		
3. Above ground tank	25	18.9
4. Underground tank	15	11.4
Water source		
5. Partly harvest	20	15.2
6. Don’t use council water	6	4.5
Water use		
7. Use for drinking and cooking	12	9.1
8. Use for irrigation	8	6.1
9. Use for animal production	1	0.8
10. Other uses	5	3.8

That 6% and 1% of respondents used harvested water for irrigation and animal production respectively suggests the emerging importance of urban farming (kitchen gardens). It is also possible that much of this irrigation water is used for greening initiatives in the interest of aesthetically appealing compounds (lawns and flowers). That only 4.5% did not use council water suggests over-dependence on metered water, its unreliability notwithstanding. Despite the efforts made to invest in rainwater harvesting infrastructure, most respondents (82.8%) had not accessed prior training in the same. Where training had been done, the majority of the respondents did not specify the sources. In terms of constraints to rainwater harvesting, the majority of the respondents (39.7%) singled out limited access to rainwater harvesting infrastructure as most important. Since roof catchments were already in place, lack of infrastructure in this context implied difficulties to access water storage tanks and support accessories due to the cost factor. The low score attached to limited knowledge on rainwater harvesting (10%) is a reflection of the informed community that Kahawa Sukari represents. But why such a society of the "elite" appears not to invest in rainwater harvesting despite the unreliability of metered water, is a question whose answers can inform future policy for posterity. When asked how to improve water availability in the estate, respondents provided various interventions. Increasing supplied volumes by the Nairobi Water and Sewerage Company topped the list at 20.4%, thus confirming the attitude of dependence on external service providers and not own harvests (Figure 4).

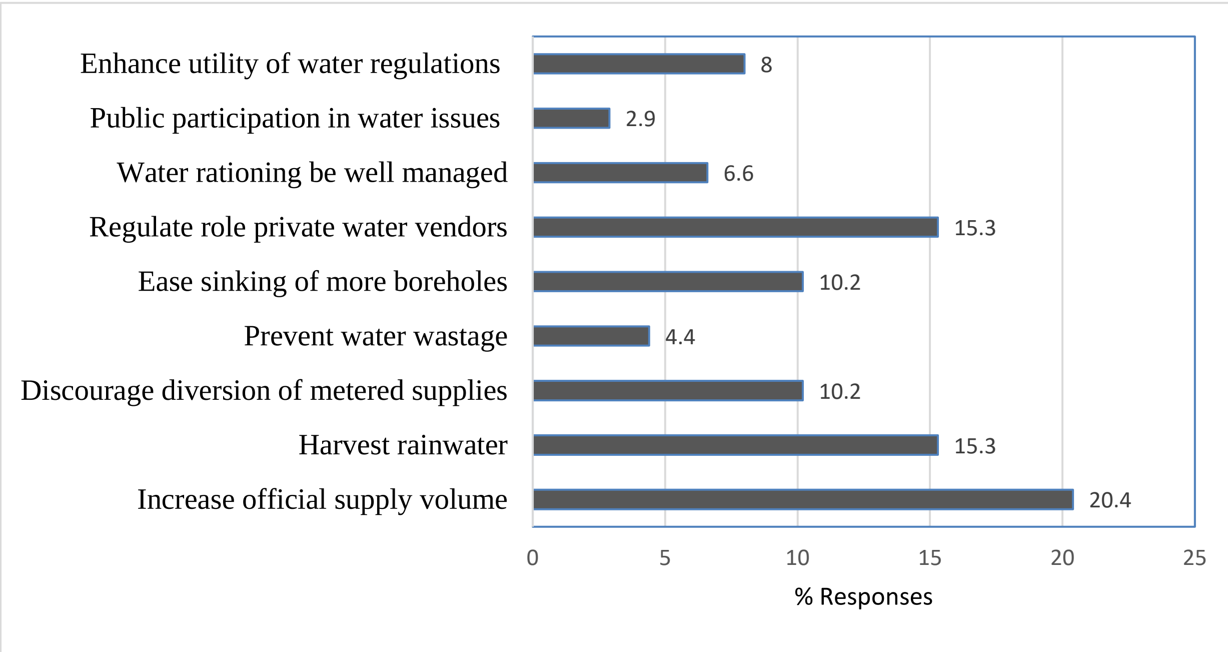

Figure 4. Measures for improving water security within Kahawa Sukari Ward

Dismantling cartels (water vendors) and water harvesting itself followed at 15.3% each. The perception of vendors being associated with water shortages is based on the perception that neighbouring estates are adequately supplied with water by the same supplier unlike the "income rich" Kahawa Sukari, which is then dominated with private water tankers. Discouraging diversion of Nairobi Company water was also an indirect pointer to the perceived artificial shortages meant to benefit private water vendors. Sinking of boreholes currently requires authorization by the relevant water agency in order to regulate abstraction. The salt levels may however limit its overall utility and thus fail to lessen impacts of water shortages. The need for sound regulations by authorities was a pointer to a participatory approach when planning for supply layout, rationing volumes and schedules, which at the moment are the preserve of the water company. Kahawa Sukari appears not to have a master plan on conduit layout. And if it exists, it is not followed when distributing water. This in part explains why the perception exists that some zones are over-supplied while others experience persistent scarcity.

More than 58% of the households pay at least KES 500 (about US $ 5) per month for metered water. Those who paid nothing were about 2% and had their supply from underground abstraction (Bore holes). Harvesting rainwater and implementing a management regime that strategically shifts from metered to rainwater supplies in tandem with seasonal changes has the potential of reducing this cost. Although the cost of rainwater harvesting infrastructure was identified as a key hindrance, respondents did not specifically mention the need to reduce the prices of plastic tanks as an incentive for water harvesting. Essentially, the culture of depending on Council water is deeply entrenched. Prices of plastic tanks of the same capacity varied across different brands. Most manufacturers did not have tanks of over 15,000 litres, which explains the popularity of tank capacities of 5,000 -10,000 litres in the estate. Their cost ranged from KES 27,560 to 49,700 (about US $ 275-497) and KES 60,000 to 181,000 (about US $ 600-1810) respectively. These costs are perceived as high and hence an intrinsic disincentive to rainwater harvesting.

4.0 CONCLUSIONS AND RECOMMENDATIONS

The perennial scarcity of water in Kahawa Sukari can be alleviated by maximising on rainwater harvesting and saving technologies because most homes already have intact roof catchments, which are completely or partially gutted. Most households do not practice rainwater harvesting. Instead they depend metered water supplies despites its insufficiency and unreliability. Water scarcity was blamed on several factors such as poor water management exemplified by artificial shortages that allow private vendors to do business with residents, and residents pumping water from the main supply line. Although limited investment in rainwater harvesting was attributed to the high cost of plastic storage tanks, the root cause could be more socio-cultural than technical. Scaling-up rainwater harvesting in Kahawa Sukari can be enhanced by among other factors including rainwater harvesting infrastructure in approval requirements for residential buildings, prohibiting roofing materials that compromise water quality for drinking, reducing the cost of plastic water storage tanks in order to make them more affordable and safeguarding metered supplies from interference from private vendors.

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Conflict of Interest:

The authors confirm that there is no conflict of interest on this publication.

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