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Rainwater harvesting technologies: Adoption, maintenance, and limitations among smallholder farmers in drought prone areas of Uganda

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ABSTRACT

Despite the devastating effects of drought on agriculture-dependent lives and livelihoods, there is a very low level of understanding and use of available water stress management technologies such as rainwater harvesting (RWH). This study characterized RWH technologies used by smallholder farmers in drought-prone areas of Uganda to establish the limitations to their optimal use. A cross-sectional household survey involving a mixture of stratified random and purposive sampling was carried out. A total of 480 smallholder farmers utilizing RWH technologies were selected and interviewed using a semi-structured questionnaire. Data were analysed using descriptive statistics, signed-rank sum test, and a logistic regression model. Results show that plastic containers, metallic drums, metallic tanks, concrete ferrocement tanks, ponds, clay pots, valley tanks, and valley dams are the most used technologies. Most RWH technologies used roof surfaces at the catchment stage with gutters and pipes conveying water into the collection facilities. The RWH technologies are largely used for domestic and production purposes. The use is mainly influenced by livelihood dependence on livestock, farmer's age, and household size. Decisions for use of RWH systems largely (60%) depend on indigenous knowledge and experiences. Farmers perceived the low capacity of RWH systems, contamination of water sources, leaks, high cleaning intensity, seepage, and siltation as the major limitations to the utilization of RWH technologies. Therefore, innovations in knowledge, practice, and policy to enhance RWH technologies' capacity are needed. Such efforts should integrate scientific information with locally existing RWH management systems amongst the farmers.

Keywords: Climate change, livelihood, rain-fed agriculture, sub-Saharan Africa

RÉSUMÉ

Malgré les effets dévastateurs de la sécheresse sur les vies et les moyens de subsistance qui dépendent de l'agriculture, le niveau de compréhension et d'utilisation des technologies disponibles de gestion du stress hydrique telles que la collecte des eaux de pluie (CEP) est très faible. Cette étude a caractérisé les technologies « CEP » utilisées par les petits exploitants agricoles dans les zones vulnérables à la sécheresse de l'Ouganda pour établir les limites de leur utilisation optimale. Une enquête transversale auprès des ménages impliquant un mélange d'échantillonnage stratifié aléatoire et raisonné a été réalisée. Au total, 480 petits exploitants

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agricoles utilisant des technologies de de CEP ont été sélectionnés et interrogés à l'aide d'un questionnaire semi-structuré. Les données ont été analysées à l'aide de statistiques descriptives, d'un test de somme des rangs signés et d'un modèle de régression logistique. Les résultats montrent que les conteneurs en plastique, les fûts métalliques, les réservoirs métalliques, les réservoirs en béton de ferrociment, les étangs, les pots en argile, les réservoirs de vallée et les barrages de vallée sont les technologies les plus utilisées. La plupart des technologies de CEP utilisaient des surfaces de toit au niveau du captage avec des gouttières et des tuyaux acheminant l'eau vers les installations de collecte. Les technologies de CEP sont largement utilisées à des fins domestiques et de production. L'utilisation est principalement influencée par la dépendance des moyens de subsistance à l'égard du bétail, l'âge de l'agriculteur et la taille du ménage. Les décisions d'utilisation des systèmes de CEP dépendent en grande partie (60 %) des connaissances et expériences indigènes. Les agriculteurs ont perçu la faible capacité des systèmes RWH, la contamination des sources d'eau, les fuites, la forte intensité de nettoyage, les infiltrations et l'envasement comme les principales limites à l'utilisation des technologies de CEP. Par conséquent, des innovations dans les connaissances, les pratiques et les politiques pour améliorer la capacité des technologies de CEP sont nécessaires. De tels efforts devraient intégrer les informations scientifiques aux systèmes de gestion de CEP existants localement parmi les agriculteurs.

Mots-clés: Changement Climatique, Moyens de subsistance, Agriculture pluviale, Afrique Subsaharienne

INTRODUCTION

Agriculture is a source of livelihood for more than 70% of the world's population (Muyanga and Jayne, 2014). Most of this population are smallholder farmers (Samberg *et al.,* 2016). Globally, about 500 million people directly depend on smallholder farming systems, representing 85% of the world's farms (Harvey *et al*., 2014). On average, the farmers operate on two hectares (Graeub *et al.,* 2016; Lowder *et al*., 2016). In Africa, smallholder farming contributes 20-60% of each country's GDP and employs two-thirds of the actively working population (Kilimani *et al.,* 2016). Similarly, Smallholder agriculture is vital to development in Uganda, with about 75% of the population directly depending on it (Wiggins and Sharada, 2013; AGRA, 2017).

Changes in climatic conditions including increased frequency and intensity of droughts have continued to negatively impact smallholder farming systems in Africa (Eakin *et al.,* 2014; Antwi-Agyei *et al.,* 2015; Giordano and Bassini, 2019). Drought incidences have resulted in increased water scarcity hence affecting agricultural production, mainly because of farmers' constrained preventive and adaptive capacity (Niang *et al.,* 2014; Ayanlade *et al.,* 2018). Smallholder farming is mostly carried out under rain-fed conditions with very limited use of irrigation (Mwangi and Kariuki, 2015; Moswetsi *et al.,* 2017).

Studies show that dependency on rain-fed agriculture for food and income is the major constraint to coping with drought-induced water stress among rural communities in Africa (Rankoana, 2016; Ubisi *et al.,* 2017). Less than 6% of the total area in Africa is under irrigation making the remaining cultivable land under rain-fed farming (Harris and Orr, 2014). As a result, the farmers continue to be susceptible to the impacts of dry spells and droughts, most especially in arid and semi-arid areas.

The complex dynamics of water stress associated with temperature and rainfall variability require innovative strategies to sustain smallholder agricultural production and livelihoods (Chivenge *et al.,* 2015). Numerous water management practices including; dam construction, desalination of salty water, installation of water-saving irrigation technologies and drainage networks, wastewater recycling and rainwater harvesting have been used to counter the problem of water stress in Africa (Kharraz *et al.,* 2012;

Brauman e*t al.,* 2013; Kummu *et al.,* 2016). It is, nevertheless, not known why there is still an extremely low level of use of such technologies and practices.

Although boosting agricultural production requires major water investments, the high yield gaps in the arid and semi-arid areas are not absolutely due to a lack of water but rather due to insufficient management (Rockström *et al.,* 2010; Foley *et al.,* 2011). For arid and semi-arid areas, a key strategy is to minimise the dry spell-induced livestock and crop failures, which requires, among others, emphasis on water harvesting systems for supplemental irrigation (Kimera, 2018; Kumar *et al.,* 2019). There is, however, inadequate research to inform practice on water harvesting for agricultural production among smallholder farmers. This inadequacy poses a limitation to options for managing the ever-increasing water stress problems in areas experiencing erratic rainfall patterns, but with potential for rainwater harvesting.

Rainwater harvesting (RWH) is one of the recognised practices to cope with and adapt to water stress in agricultural production (Assefa *et al.,* 2016). For example, harvesting 15% of rainwater in Africa would not only meet the continent's agricultural water needs but also provide water for other uses (Critchley and Gowing 2012). Rainwater harvesting (RWH) involves practices that aid the collection and storage of rainwater/ runoffs for domestic, agricultural, industrial and environmental uses (Rockstrom and Baron, 2003; Recha *et al.,* 2015).

Rainwater harvesting (RWH) catchment systems can be categorized as ex-situ or in-situ with four basic components including catchment or collection area, runoff conveyance, storage and an application area. Ex-situ systems collect water from rooftops, land surfaces, steep slopes, road surfaces, and rock catchments and are stored in tanks. In-situ technologies involve strategies undertaken through soil management practices to improve rainfall infiltration and reduction of surface runoff (Kiggundu *et al.,* 2018). These systems involve rainwater harvesting methods such as direct runoff concentration in the soil profile for direct crop uptake or approaches that support the collection and storage of rainwater in structures such as sub-surface, surface, small dams and ponds for future uses (Pachpute *et al.,* 2009). The use of a particular system and method is dependent on a combination of factors prevailing in a given location. In-situ RWH systems, for example, are more likely to be used by smallholder farmers because they require small investment capital since most systems are implemented on small scale (Kiggundu *et al.,* 2018). It is critical, therefore, that rainwater management efforts are well supported by context-specific studies to continuously ascertain the provision of actionable information to enhance decision-making for use of particular methods and technologies.

The importance of RWH technologies for smallholder farming livelihoods is well acknowledged (Yosef and Asmamaw, 2015; Taffere *et al.,* 2016; Londra *et al.,* 2018). For example, it has been reported that the collection and storage of rainwater in structures such as dams and ponds in combination with soil nutrient and crop management practices improve crop productivity (Pachpute *et al.,* 2009). Despite the recognised importance and potential of RWH in improving agriculture dependant lives and livelihoods, the rate of use of associated technologies is very low in the developing world (Bandiera and Rasul, 2006).

Some studies show that the low level of use of technology for agriculture-dependent communities is associated with factors such as farmer and farm household characteristics, biophysical conditions, financial and management practices as well as other exogenous factors beyond the control of the farmer (Yigezu *et al.,* 2018). Nevertheless, several aspects of technology use in agriculture, especially in Africa remain poorly understood (Worku, 2019). This is particularly so for smallholder farming systems in communities and countries where livelihood is predominantly dependent on agriculture.

Overall, there has been very minimal attention given to the location-specific understanding of RWH and associated technologies among smallholder farmers in drought-prone areas (Nnaji, 2019; Oremo *et al.,* 2019). There is particularly very limited understanding of location contextualised features of RWH technologies, their experiences and perceptions amongst smallholder farmers (Brauman *et al.,* 2013). Such understanding is needed to foster targeted decision-making processes aimed at alleviating the cost of drought both at micro and macro levels (Brauman *et al*., 2013; Kilimani *et al.,* 2016). Towards this end, this study seeks to characterize the various RWH technologies used in drought-prone areas of Uganda and establish the factors promoting and/or limiting their use among smallholder farmers. The study addresses the following questions in particular: i) What are the characteristics of the RWH technologies used by smallholder farmers as a coping response to drought? ii) What are the household level determinants for the adoption of RWH technologies? and iii) What are the limitations for optimal use of RWH technologies by farmers to cope with drought?

METHODOLOGY

Study area description. The study was conducted in southwestern, central and mid-western Uganda, covering nine districts: Hoima, Isingiro, Kiboga, Luweero, Masaka, Mubende, Nakaseke, Nakasongola and Sembabule (Figure 1). The main consideration for selecting the districts was their proneness to drought and their characteristic erratic rainfall distribution in space and time (Zziwa *et al.,* 2012; Nimusiima *et al*., 2013; Twongyirwe *et al*., 2019; Kakeeto *et al.,* 2019; Nakabugo *et al*., 2019). Rainfall in the study area is highly variable and sporadic with mean annual rainfall ranging between 500 mm and 1600 mm (Makuma-Massa *et al.,* 2017; Turyagyenda *et al.,* 2013). Generally, rains are usually expected from March to April (Long rains) and September to November (Short rains) of each seasonal calendar year. However, this has changed in the recent past where variability has increased significantly characterised by a shift in and shortening of growing seasons associated with more prolonged dry spells and droughts. The average temperatures range from 25 °C to 30 °C.

The area comprises an undulating landscape with a continuum of plains, hills and valleys associated with seasonal streams that often dry up once the rains have ceased hence leading to water scarcity (Mugerwa *et al.,* 2014). During water shortages associated with droughts and erratic rainfall, some households resort to migration with animal herds in search of water as well as engaging in off-farm activities. Water resources in the area include boreholes, multi-purpose valley tanks, dams and ponds that are non-uniformly distributed and under different ownership arrangements (Mugerwa *et al.,* 2014). The uneven distribution of water resources in the area undermines the livelihoods of the agro-pastoral households that predominate the area (Nsubuga *et al.,* 2014). Moreover, some of the land used and/or owned by the smallholder farmers in the area is under land tenures such as the customary system, which constrains equitably and gender-inclusive ownership and use (Vanlauwe *et al.,* 2014).

Agriculture is the main economic activity for most of the households in the study area. The subsistence of rain-fed crop growing and livestock rearing characterize most of the landscape. The key crops grown include maize, bananas, coffee, beans, cassava, etc. Livestock includes cattle, goats, sheep, pigs and poultry, among others. The secondary sources of income include fishing, formal employment, and small-scale businesses.

Data collection. The rainwater harvesting technologies considered in this study included jars, plastic tanks, metallic tanks, clay pots, industrial drums (metallic), concrete ferrocement tanks, 'jerrycans', valley tanks, valley dams and ponds. A detailed description of the RWH technologies is provided in Table 1.

[1]Customary tenure system is where the clan and other chiefs exercise control over land under family ownership as well as over land subject to collective rights (Van Leeuwen, 2014).

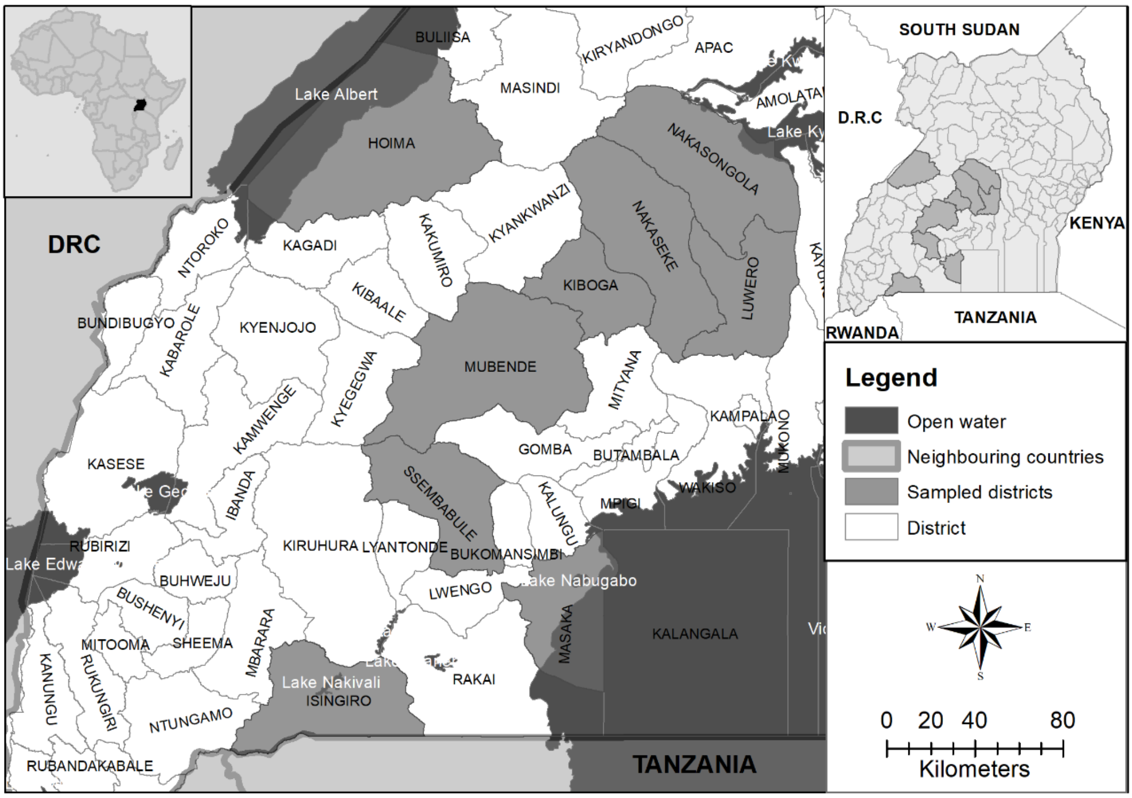

Figure 1. Location of the study area

Table 1. Description of rainwater harvesting technologies used in Uganda

RWH technology types	Description of technology
Jars	Water jars are relatively small capacity harvesting and storage vessels shaped like pots or bottles with volumes usually ranging from less than 100 litres to 2000 litres. The sizes commonly used in Uganda range from about 300 to 2000 litres. They are made from different materials including metal sheets, earthenware, and ferrocement. The common types used in Uganda are made from ferrocement but with much lighter wire reinforcement.
Plastic tanks	Plastic tanks are factory-made and are mainly used for storage. Tanks are produced in various capacities ranging from 100 litres to 24000 litres. The larger tanks, suitable for rainwater harvesting are usually cylindrical. Plastic tanks are lightweight and easy to transport, install, and maintain.
Metallic tanks	Metallic tanks are widely used in Uganda. They are fabricated using galvanized or pre-painted corrugated iron sheets manufactured locally or imported. Depending on the materials used, the tanks can be affected by rusting which creates weaknesses and eventually leaks. Capacities range from 1000 to 15000 litres. They are easy to install and maintain. Initial corrosion when used normally creates a thin adherent film that coats the interior surface of the tank and provides protection against further corrosion.
Clay Pots	Clay pots have been used for millennia in Uganda as a part of the traditional RWH practice. While they have been largely phased out in favour of more durable plastic products, there are rural areas where knowledge and use of clay pots of various storage capacities have been preserved.

'Jerrycans' (plastic containers in range of 20-50 Litres)	Used to collect and store rainwater from underneath edges of house roofs. They are also used to transport water from other water sources. The storage capacity is certainly low.
Valley tanks	These are constructed by the excavation of soil to create a large storage pit or chamber in the ground. After the soil excavation, the sides and base of the pit are usually lined and compacted with clay to reduce the seepage of water. When it rains, surface runoff collects into the chamber for storage.
Valley dams	These are formed essentially by the construction of an earth dam across a valley by joining points along the same contour line or altitude above sea level, thereby impounding the surface runoff and creating a large storage reservoir.
Ponds	Runoff collected from hill slopes, natural watercourses, footpaths or animal tracks is stored in pits of various sizes. Most of the stored water is lost due to seepage and evaporation.
Concrete Ferrocement tanks	Ferrocement is essentially an extension of conventional reinforced cement concrete technology. It is a thin-walled construction consisting of rich cement mortar with uniformly distributed and closely spaced layers of continuous and relatively small diameter mesh (metallic or other suitable material). Compared to other cement concrete structures, those made of ferrocement are lightweight, tough, durable, crack-resistant and can be made into virtually any shape. It is a low-cost and easy-to-repair technology.
Metallic Drums	Common re-use of the standard oil drum, once empty, is used for RWH and storage. It is not uncommon to see even the smallest house erect just a meter of guttering directed into a re-used oil drum. These drums could be categorized as 'traditional' since they seem to have been used in Uganda longer than the other manufactured products.

Source: Adapted from Uganda Ministry of Water and Environment, MWE, 2015

Sampling and data collection. This study is based on a cross-sectional household survey involving a mixture of stratified random and purposive sampling. Sampling considered only smallholder farmer households that were using RWH technologies. The representative sample of the households was determined using a selection procedure by Krejcie and Morgan (1970). Accordingly, 480 respondent households were randomly and proportionally (based on population size) selected from the purposively selected districts. Stratified random sampling was used to select parish and village locations of respondent households. A semi-structured questionnaire, mainly comprised of predetermined response options, was used and directly administered to the heads of the selected households between July and September 2018. In a few cases, the questionnaire was administered to the most senior and knowledgeable of the adults available at a selected homestead. The themes of the used questionnaire included types of technologies used, household socio-economic characteristics, technology utilisation at different stages of RWH (catchment, conveyance, abstraction and maintenance), factors for use of technologies and constraints.

In addition to household-level data collection, key informant interviews and focus group discussions were held. The key informant interviews were conducted at the district level. Interviewees included officials from natural resources, agricultural production, water, planning, administration departments, and political and opinion leaders. Seven key informants were interviewed in each district. Eight focus group discussions comprising 10-12 equal numbers of males and females including youth farmers were also conducted.

Data analysis. The data collected were subjected to descriptive and inferential statistics. Descriptive statistics were used for aggregation into frequencies and summaries. A signed rank-sum test was used to analyse the characteristics and stages of utilised technologies. A binary logistic regression model was performed to examine the factors that influenced the adoption of rainwater harvesting technologies. The model was run in Statisgraphics software. The model took one of the two possible values: the factors (x-independent variables) influencing the use by the households; and the results (y-dependent variables) measured. Before running the model, multicollinearity and Chi-Square tests were performed to select appropriate independent variables. There was no multicollinearity.

The dependent variable was assigned a score of 1 'when a respondent adopted and used RWH' and a score of 0 'for no use'.
The equation of the fitted model is:

RWH = exp(eta)/(1+exp(eta))………… (Eq. 1)

Where:
eta = -98.978 - 0.873905*Age of household - 0.0153945*Altitude + 24.6163*Household size + 50.7766*Number of iron sheet roofed structures + 29.552*Grass thatched + 119.515*Iron sheets +33.7489*Clay tiles -11.99*Crop production + 18.4978*Livestock production + 0.919586*Household owned land size - 7.64797* Land tenure system - 2.39262*Sources of water (rain) - 43.4369*Education=Masters -33.5988*Education=Certificate +19.34*Education=Degree-34.4419*Education=Diploma+ 42.158*Education=Never went to school +10.6656*Education=Primaryschool-9.89449*Gender

Table 2. Independent variables used in the study

Variables	Description	Category
Respondent Factors		
Age of household head	Age (years)	Continuous
Household location altitude	Elevation (slope)	Continuous
Household size	Number of household members	Continuous
Number of Iron sheets of roofed structures	Number of iron sheets used on building used to harvest water	Continuous
Household land size	Size of land owned by a farmer	Continuous
Land tenure system	1=customary, 2=leasehold, 3= Mailoland, 4= Freeland, 5=Public land,	Categorical
Sources of water	1=Harvests rainwater, 2= Does not harvest rainwater	Categorical
Gender	1=Male, 2=Female	Categorical
Type of residential dwelling by roof material		
Grass thatched	1=Grass thatched, 2=Not thatched	Categorical
Iron sheets	1=Iron roofed, 2= Not iron roofed	Categorical
Clay tiles	1=Clay roofed, 2= Not clay roofed	Categorical
Main source livelihood		
Crop production	1=Crop is the main source of income, 2= Crop is not the main source of income	Categorical
Livestock production	1=Livestock is the main source of income, 2= Livestock is not the main source of income	Categorical
Education levels		
Education=Masters	1=Attained master's degree, 2=Not attained a master's degree	Categorical
Education=Certificate	1=Attained certificate, 2=Not attained certificate	Categorical
Education=Degree	1=Attained undergraduate degree,	

	2=Not attained an undergraduate degree	Categorical
Education=Diploma	1=Attained diploma, 2=Not diploma	Categorical
Education=Never went to school	1=Attained formal education, 2=Not attained formal education	Categorical
Education=Primary school	1=Attained primary education, 2=Not attained primary education	Categorical

RESULTS

Socio-economic characteristics of smallholder farmers. The socio-economic characteristics of smallholder farmers using RWH technologies are presented in Table 3. The results of this study show that the harvested rainwater is majorly used for domestic purposes, livestock and crop production. The farmers using RWH technologies indicated that freehold[2] and mailo[3] tenure systems were the main forms of land ownership. On average, each household owned about 1-5 acres of land. Most of the RWH technologies were implemented within the homestead's vicinity (0-1km).

Table 3. Household socio-economic characteristics of farmers (N= 480, %)

Category	Characteristics		%
Gender	Females		60
	Males		40
Main use and type of RWH system	Domestic (RWH water jars, plastic tanks, metallic tanks, clay pots, Jerrycans, concrete ferro tanks)		50
	Livestock production (metallic tanks, plastic tanks, valley tanks, valley dams, ponds)		30
	Crop production (valley tanks, valley dams, ponds,)		20
Overall average size of land owned	1-5 acres		
Land tenure	Freehold		48
	Mailo		26
	Leasehold[5]		12
	Public		8
	Customary land		6
Average distance to RWH facility	Residential RWH systems	0-1Km	70
	Non-residential	1-4km	30
Source of information on RWH	Indigenous knowledge and experience		60
	Agricultural extension		12
	Neighbours and friends		11
	Local leaders		9
	Radio/Television		6
	Internet and social media		2

[2]Individualized type of land tenure.
[3]Mailo land tenure is a landlord-tenant tenure system unique to Uganda introduced in the colonial era (Van Leeuwen, 2014). The tenure guarantees the secu rity of occupancy of tenants and other lawful occupants, who have used or developed land un challenged by the owner for at least 12 years (Munk et al., 2013).
[4]Leasehold tenure system provides for access to land through a time-bound contract (Munk et al., 2013).

RWH technologies adopted by the farmers. The RWH technologies used by farmers can be broadly characterised as residential and non-residential (Table 4). Results of the signed-rank sum test show that Jerrycans, metallic drums, metallic tanks, plastic tanks, concrete ferrocement tanks, and ponds are relatively the most important residential RWH technologies. The rainwater harvesting jars are the least used by smallholder farmers. During the focus group discussions and informant interviews, participants indicated that the majority of the technologies are individually (household) owned.

Characterisation of rainwater harvesting technologies. At catchment level, roof surfaces (iron sheets, grass) and vegetation cover were the most important modes of collecting rainwater. The various catchment modes, conveyance and abstraction methods and materials for the different RWH technologies are presented in Table 5. Water is predominantly conveyed for collection and/or storage using gutters and pipes. At the abstraction stage, the most used means were: metallic taps on concrete ferrocement tanks, electric pumping systems to light-handled withdrawal containers such as cups, and jars especially where metallic drums are used.

Maintenance practices of rainwater harvesting technologies. The most predominant maintenance practices employed to clean technologies (Jerrycans, metallic drums, metallic tanks, plastic tanks, concrete ferrocement tanks, ponds) by smallholder farmers include cleaning, desilting and fencing (Figure 2).

Table 4. Utilisation of existing rainwater harvesting technologies (N=480)

District	Jars	Plastic tanks	Metallic tanks	Clay pots	Jerrycans	Valley tanks	Valley dams	Ponds	Concrete ferro cement tanks	Metallic drums
Hoima	0	2	2	1	36	2	0	2	14	32
Isingiro	0	10	2	1	43	3	1	6	36	8
Kiboga	5	31	7	0	17	9	12	3	3	12
Luweero	0	3	4	5	4	7	7	1	13	29
Masaka	0	0	0	0	1	0	0	0	0	1
Mubende	0	4	4	0	8	0	1	1	3	27
Nakaseke	0	8	2	0	10	1	1	5	10	43
Nakasongola	0	7	1	3	13	14	20	2	1	38
Sembabule	1	5	3	2	44	36	5	33	3	43
Signed rank sum test										
P-value	0.57	0.0076*	0.0070*	0.06	0.003*	0.0155*	0.015*	0.009*	0.0078*	0.0039*

[5]Typically small volume systems (200-400 m3) that capture rooftop runoff, generally for domestic consumption purposes (Kiggundu et al. 2018).

Table 5. Characterisation of rainwater harvesting technologies at various stages (N=480, n (%); Mean)

Stage of RWH	Plastic tanks	Metallic tanks	Jerry cans	Valley tanks	Valley dams	Ponds	Concrete ferrocement tanks	Metallic drums	P-Value
Catchment									
Roof surface	62(13.5)	24(5.2)	180(39.1)	14(30)	0(0)	3(0.7)	86(18.7)	240(52.2)	0.02*
Vegetation	1(0.2)	0(0)	1(0.2)	31(6.8)	5(1.1)	14(3)	0(0)	1(0.2)	0.04*
Bare soil	0(0)	0(0)	0(0)	26(5.7)	30(6.5)	15(3.3)	0(0)	0(0)	0.74
Impervious structures	0(0)	0(0)	0(0)	1(0.2)	2(0.4)	1(0.2)	0(0)	0(0)	0.72
Conveyance method									
Gutters	63(13.7)	42(9.1)	141(30.7)	12(2.6)	1(0.2)	2(0.4)	90(19.6)	251(54.6)	0.001*
Pipes	14(3)	8(1.7)	3(0.7)	2(0.4)	0(0)	0(0)	18(3.9)	3(0.7)	0.04*
Sticks/reeds	0(0)	0(0)	42(9.1)	0(0)	1(0.2)	0(0)	1(0.2)	14(3)	0.31
Bare canals	0(0)	0(0)	0(0)	38(8.2)	32(7)	22(4.8)	0(0)	3(0.7)	0.33
Vegetated canals	0(0)	0(0)	0(0)	25(5.4)	5(1.1)	10(2.2)	0(0)	0(0)	0.74
Galvanized iron sheets	0(0)	0(0)	4(0.9)	1(0.2)	0(0)	0(0)	1(0.2)	1(0.2)	0.31
Conveyance material									
PVC pipe	22(4.8)	17(3.7)	10(2.2)	6(1.3)	0(0)	0(0)	30(6.5)	20(4.3)	0.039*
Galvanized steel sheet	7(1.5)	7(1.5)	14(3)	2(0.4)	0(0)	1(0.2)	21(4.5)	55(11.7)	0.015*

Roofing sheet	46(10)	21(4.6)	109(23.7)	8(1.7)	0(0)	3(0.7)	38(8.3)	170(37)	0.01*
wood/plant system	0(0)	1(0.2)	38(8.3)	0(0)	0(0)	0(0)	1(0.2)	12(2.6)	0.30
Vegetation	0(0)	0(0)	1(0.2)	39(8.5)	38(8.2)	25(5.4)	1(0.2)	3(0.7)	0.04*
Abstraction method									
Taps	58(12.6)	45(9.8)	1(0.2)	1(0.2)	0(0)	0(0)	82(17.8)	3(0.7)	0.04*
jars/cups	18(3.9)	5(1.1)	84(18.3)	67(14.6)	27(5.9)	33(7.2)	25(5.4)	272(59.1)	0.01*
Pumping systems	1(0.2)	0(0)	5(1.1)	10(2.2)	14(3)	1(0.2)	2(0.4)	3(0.7)	0.012*

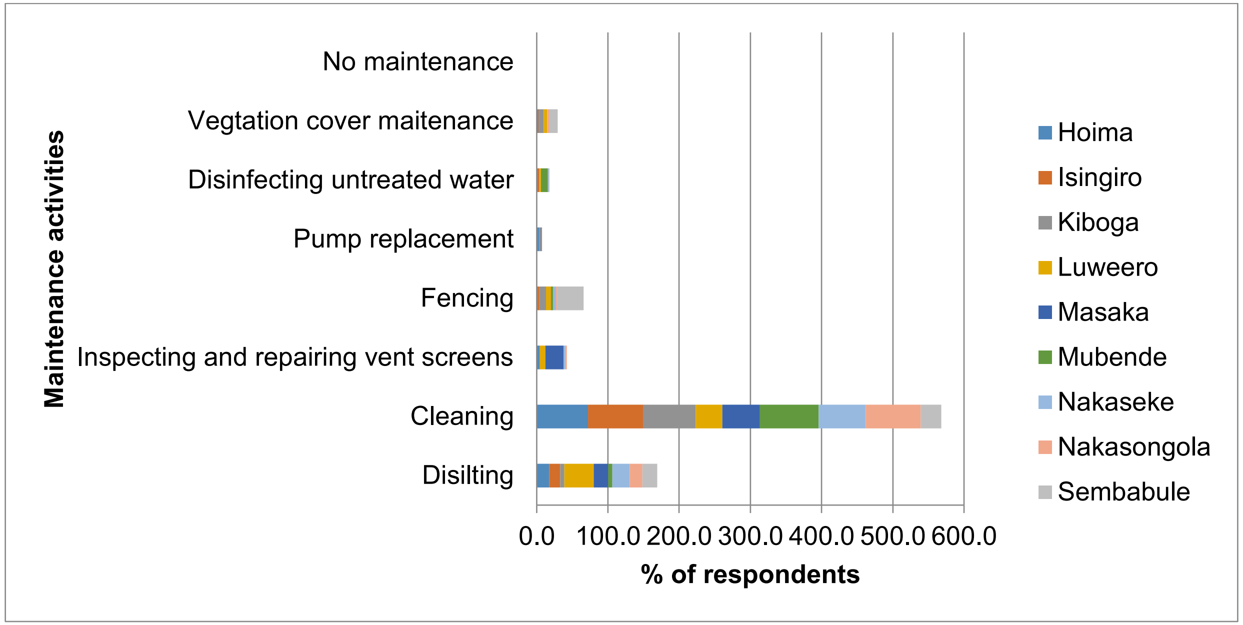

Figure 2. Maintenance practices undertaken in rainwater harvesting technologies (Jerrycans, metallic drums, metallic tanks, plastic tanks, concrete ferrocement tanks, ponds)

[6]Polyvinyl chloride (PVC) is a solid plastic made from vinyl chloride.

Most of the farmers indicated that they were not covering their RWH facilities unless the technology had been designed or fitted with the original cover to protect the water from contamination (Figure 3). A few of the farmers indicated to have used small pieces of iron sheets, saucepans and planting of cover grass to protect water facilities. Pieces of iron sheets used to protect water were commonly observed during field visits, especially in the districts of Luweero and Masaka.

Determinants for the adoption of rainwater harvesting technologies by the smallholder farmers. The age of a farmer, household membership size, and engagement in livestock production were the most important determinants of the use of RWH technologies (Tables 6 and 7). The coefficient of the age of the farmer was negatively associated with the use of RWH technologies, which means a low likelihood of use by older farmers. Households with bigger family sizes were more likely to adopt and use RWH technologies, in comparison with the households with smaller membership sizes. With a unit increase in the number of family members (an additional member), the results show that such farmers were (odds ratio=4.9) more likely to adopt and use RWH technologies. Ownership of more iron sheets roof surface positively influenced the use of RWH technologies. An increase in the number of house units in any homestead was more likely to lead to the use of RWH technologies (odds ratio=1.2).

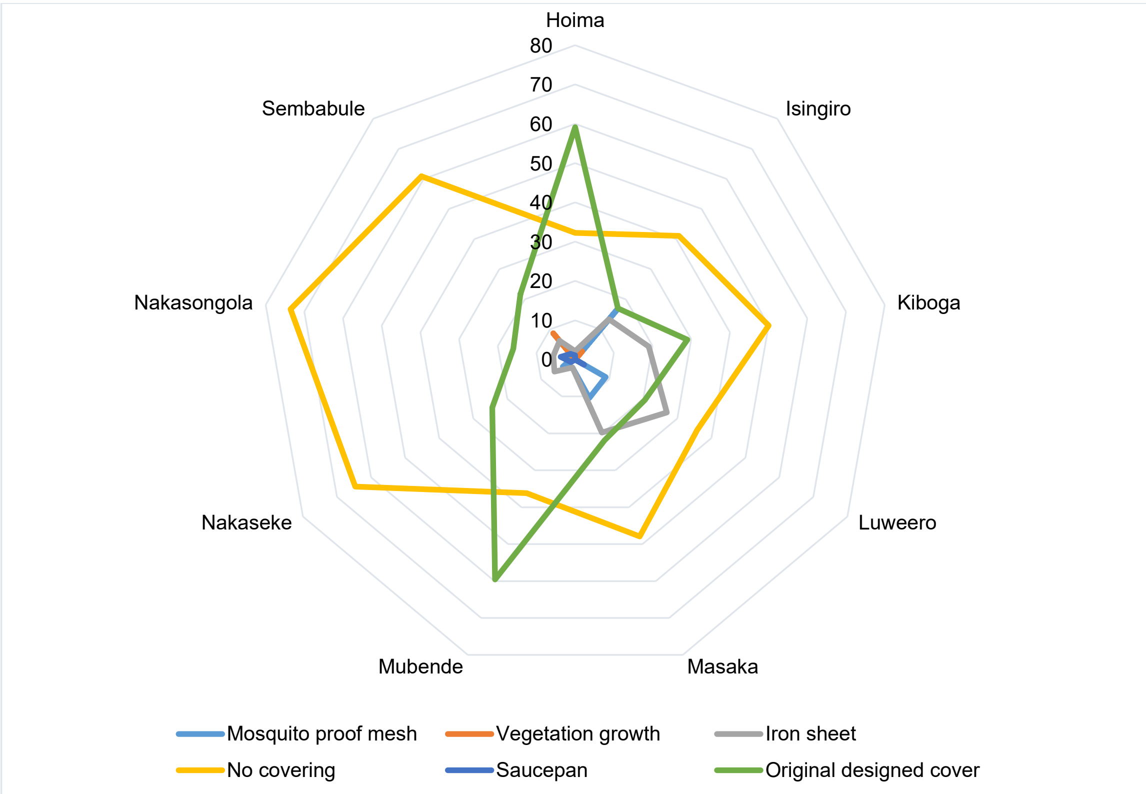

Figure 3. Characteristics of water source protection practices

Table 6. Estimated regression model (maximum likelihood) for factors that influenced the adoption of rainwater harvesting technologies (n= 480)

Parameter	Estimate	Standard Error	Estimated Odds Ratio
CONSTANT		-98.978	330.385
Household Factors			
Age of household	-0.873905	0.317837	0.417319
Household location altitude	-0.0153945	0.0375725	0.984723
Household size	24.6163	8.96957	
4.90604E10			
Number of iron sheet roofed structures	50.7766	13.3988	
1.12717E22			
Household land size	0.919586	9.43671	2.50825
Land tenure system	-7.64797	4.22453	
0.000477011			
Sources of water (rain)	-2.39262	6.45703	0.0913897
Gender	-9.89449	23.631	0.0000504519
Type of roof material of residential dwelling			
Grass	29.552	30.143	6.82749E12
Iron sheets	119.515	318.339	8.03101E51
Clay tiles	33.7489	50.8107	4.53922E14
Main source livelihood			
Crop production	-11.99	72.2631	0.000006206
Livestock production	18.4978	18.4535	1.08022E8
Education levels			
Education=Masters	-43.4369	317.613	1.3664E-19
Education=Certificate	-33.5988	66.0606	2.55993E-15
Education=Degree	19.34	82.0964	2.5076E8
Education=Diploma	-34.4419	56.7827	1.10168E-15
Education=Never went to school	42.158	29.9826	2.03688E18
Education=Primary school	10.6656	9.13549	42857.1

Table 7. Determinants for the adoption of RWH technologies by the smallholder farmers

Factors	Chi-Square	Df	P-Value
Age of a farmer	4.30298	1	0.0380*
Altitude/elevation	0.0192141	1	0.8898
Household membership size	8.8355	1	0.0030*
Number of iron sheet roofed structures	11.4543	1	0.0007
Grass thatched	1.11373	1	0.2913
Use of iron sheets	0.00102102	1	0.9745
Clay tiles	1.41653	1	0.2340
Involvement in crop production	-0.00102791	1	1.0000
Involvement in livestock production	5.66925	1	0.0173*
Household land size	0.00374038	1	0.9512
Land tenure system	0.187714	1	0.6648
Sources of water (rain)	0.0119388	1	0.9130
Education level	7.76484	6	0.2558
Gender	0.0834805	1	0.7727

Limitations to the adoption and utilization of rainwater harvesting technologies. The farmers indicated the major limitations of adopting and using RWH technologies to be the small capacity of available systems, contamination of water sources by people and animals, leaks, seepage, and siltation (Figure 4). The limited capacity of the utilized residential and non-residential RWH systems was a shared constraint across all the districts. The key informant interviews showed that for plastic tanks, the constraints include vandalism and limited financial resources to purchase them. Focus group discussions information showed that the use of pots is limited by damage and breakage caused by children, contamination from animals (rats fall and die in the water), and mosquito breeding. For the concrete ferrocement tanks, usage is limited by seepage, frequent breakage of taps, short durability, and shortage of some construction materials. The use of metallic drums was associated with accidents of children drowning, contamination, limited storage capacity, and theft. It was noticed from focus group discussions that the use of valley tanks is limited by the associated high labour expenses needed to establish them.

DISCUSSION

In the study area, most (74%) of the farmers who were using RWH technologies owned land under freehold and mailo tenure. These land tenure systems enable the permanent establishment of some of the RWH technologies (especially dams) among the farmers (Aberra, 2004; Mucheru-Muna *et al.*, 2017). The tenure systems legitimately give absolute rights to own and use RWH technologies (Bouma *et al.*, 2012; Nyamadzawo *et al.*, 2013). The security of land tenure, therefore, appears to be increasing the likelihood of farmers to invest in RWH assets for responding to drought effects and risks, hence an improvement of livelihood stands. Studies in Bangladesh and South Africa have shown that more secure tenure rights among farmers were more likely to positively influence their adaptation to water scarcity through RWH (Alam, 2015; Baiyegunhi, 2015). In addition, a review of trends and constraints of smallholder irrigation in East Africa highlights land tenure rights as a factor for adopting RWH among

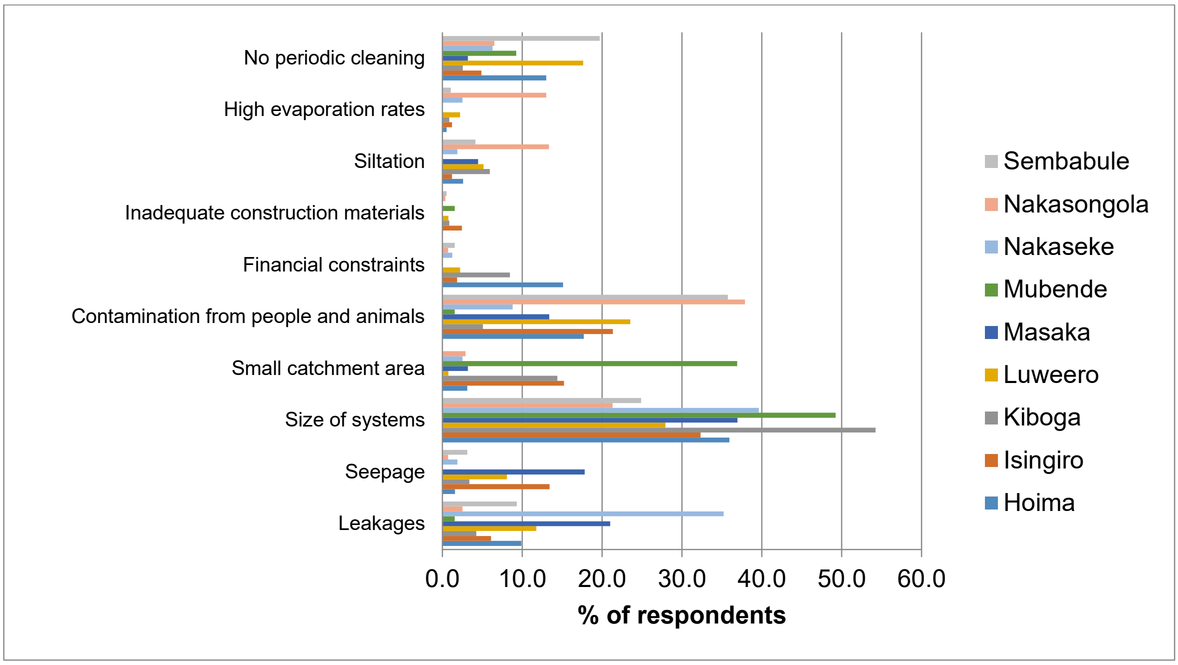

Figure 4. Limitations to the use of rainwater harvesting technologies

smallholder farmers (Nakawuka *et al.,* 2018).

On the other hand, having the smallest proportions of farmers under customary land using RWH technologies points to the likelihood that this tenure system could be limiting the level of use. Since the customary land tenure system is under traditional or cultural institutions, smallholder farmers who are squatters on such land are likely to feel insecure to invest in RWH systems. This is plausibly due to a lack of guarantee that such investments would translate into permanent use and benefits for their livelihood capacity and activities (Goldstein and Udry, 2008). Related studies have shown that the location of water sources on customary owned land presents threats of disputes over access and related payments for using the land between the users and traditional owners of the land (Quigley *et al.,* 2016).

In the study area, roof surfaces (iron sheets, grass) and vegetation cover were the most important modes of collecting rainwater. This could be attributed to the small sizes of land (between 1-5 acres) that constrain farmers' RWH catchment options. This result is related to other studies showing that small size land ownership in Sub-Saharan Africa is a key drawback to the implementation of both residential and non-residential RWH systems for domestic use and agricultural production (e.g. Drechsel *et al.,* 2005; Gurung and Sharma, 2014). It is apparent that amidst the land limitations, the capacity of the current RWH technology systems used was not likely to sustain domestic, livestock, and crop production water demands for drought response. Focus group discussions showed that there is overlapping demand for water that at times creates trade-offs in its use in relation to livelihood activities. In this case, most of the farmers were using residential RWH technologies, hence the reason most of the water was mainly limited to serving household consumption purposes (Kiggundu *et al.,* 2018). A related study in the semi-arid region of Kenya similarly reported that most of the harvested rainwater was mainly used for domestic needs (Kalungu *et al.,* 2015).

Roof surface, gutters and taps were the most utilized RWH technologies for catchment, conveyance and abstraction respectively. This is not surprising because most of the systems for RWH are residential, requiring the use of these options over others at the household level. The prevalence of these is also most likely due to the low costs of the materials for the technologies that are within the incomes of the farmers. Regarding the conveyance stage, Polyvinyl chloride (PVC) pipes came out as the most used material to channel water from rooftops to the collection devices. A study by Kimani *et al*. (2015) in Kenya, also reported the predominant use of similar materials and devices for rooftop-based RWH technologies.

Most farmers depend on indigenous and experiential knowledge of drought and rainwater management as the main basis for using RWH technologies. Only 12% of the respondents were using knowledge from professional extension services. This is possible because of the long history of some of the RWH techniques used and passed on to different generations (Mercer *et al.,* 2010; Orlove *et al.,* 2010; Raymond *et al.,* 2010). On the other hand, it could be due to the low level of agro-advisories and limited availability of information tailored to the use of RWH technologies for drought management as was established during focus group discussions. As was indicated by Caswell *et al*. (2001), farmers will only adopt and use the technology they are aware of or have heard about. Access to information reduces the uncertainty about a technology's performance hence may change an individual's assessment from purely subjective to objective over time (Bonabana-Wabbi, 2002). Therefore, limited use of scientific information and lack of technical know-how about potentially better RWH technologies amongst smallholder farmers restricts the level of use of modern and possibly more capacity and efficient RWH technologies.

The dependency on indigenous knowledge by the farmers shows that it is still relevant and avails avenues for integration with scientific information while dealing with the present-day water-stressed conditions. Bhattacharya (2015) indicated that traditional water harvesting wisdom in India (including the use of bamboo pipes, and runoff impoundment ponds, among others) at all levels of society had enabled adequate availability of water for all, which in turn formed a basis for all-round development and prosperity. Other studies have also shown that traditions continue to serve as a basis for coping with drought, water stress and storm events. For example, in Nepal, traditional RWH for supplemental domestic and agriculture has been uninterrupted for nearly 15 centuries (Ghimire and Johnston, 2015).

The significant socio-economic determinants of RWH technology use in the study area are engagement in livestock production, age of a farmer and household membership size. Farmers whose livelihoods predominantly depend on livestock invest more in RWH technologies to meet the high and continuous demand for water by livestock, particularly during dry spells and droughts. Other studies (e.g., Vermeulen and Wynter, 2014) have also shown that livestock-dependent farmers are more likely to uptake information and technologies to adapt to changing conditions. The results also show that younger farmers are more likely to use RWH technologies than their older counterparts. The lower likelihood of older farmers adopting agriculture-related technologies has been attributed to their high level of risk aversion. Age is sometimes believed to increase risk aversion and decreased interest in long-term investment in farming. On the contrary, youthful farmers are less risk-averse and are more likely to venture into new technologies (Mauceri *et al.,* 2005; Mwangi and Kariuki 2015).

Households with bigger membership sizes were more likely to use RWH harvesting technologies than those with a smaller number of people. This could be related to the fact that most of the household labour, in the study area, is mainly provided by family members including activities such as establishing and maintaining RWH technologies. Therefore, household size can be looked at as a measure of labour availability and livelihood capacity for supporting the establishment of RWH systems and other drought response options. Studies have shown that household size determines the adoption process in that, a larger household can relax the labour constraints required especially during the introduction of new technology (Bonabana- Wabbi, 2002; Mignouna *et al.,* 2011).

The low capacity across all RWH systems was perceived by farmers as the principal setback to the optimal utilization of RWH. Small residential RWH systems were predominantly used leading to harvesting quantities of water that are far less than the water demands during dry spells and droughts. Looking at the socio-economic characteristic of the farmers, this could be due to a lack of affordability. Studies have shown low levels of income to be the most likely reason why most farmers are not able to establish higher capacity RWH systems (Biazin *et al.,* 2012; Jafari *et al.,* 2016). Domènech *et al* (2012) highlight that the inability of vulnerable households to invest in and maintain RWH technologies poses a risk to insufficient quantity of harvested and available water for use when needed.

CONCLUSIONS

In this paper, we have characterised the RWH technologies used by smallholder farmers in drought-prone areas of Uganda. The paper also analyses the determinants of the use of RWH technologies and sheds light on the limitations for optimal use of RWH technologies. RWH technologies, among farmers, in the study area, are characterised by the use for domestic purposes with limited use for agricultural production; small volume systems that capture rooftop runoff without further treatment; predominant use of indigenous and experiential knowledge, and use of basic catchment, conveyance, abstraction and storage techniques. Fewer farmers owning customary land (tenure system where clan and other chiefs exercise control over land) are using RWH technologies compared to those owning land on mailo (an individualized type of land tenure system in Uganda) and freehold tenure. The pattern of use is significantly influenced by the level of livelihood dependence on livestock, age of a farmer and household size. The optimal use of RWH by the farmers is limited by capacity and water quality maintenance constraints. The major constraint is the low quantity capacity of the technologies in place. Leaks, seepage, siltation and contamination are common issues associated with most of the water harvesting techniques used by farmers. Shortage of water dictates trade-offs that limit farmers to domestic use of harvested water and not for agricultural production.

The existing and predominant use of indigenous and experiential knowledge provides an opportunity that can be leveraged through integration with scientific information while dealing with the current water constraints in response to dry spells and drought. Knowledge and technical support systems to improve RWH should prioritise increasing harvesting capacity to extend the use beyond domestic use to crop and livestock production. The capacity improvements will need to take into consideration of water quality management limitations to deal with the current resource demands for cleaning, desilting and fencing of harvested water from land use and other sources of contamination. This will require technical capacity building including awareness-raising and training on both micro and macro rainwater harvesting systems management. The higher potential of interest in and use of the technologies by the younger farmers needs to be explored to catalyse improvements in the quantity of harvested water. A pilot strategy on appropriate size tanks to facilitate RWH in the area needs to be developed and investigated for community acceptance and use. In so doing, it is essential to develop policies and other mechanisms that can facilitate the establishment of RHW technologies in ways that will guarantee the security of ownership and use of land and technology systems and associated assets. This way, more farmers owning or using land on customary and leasehold tenure might be able to undertake more investments and use the technologies. This will most likely lead to livelihood diversification through, for example, more crop farmers adopting livestock farming due to increased availability and access to the required water.

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STATEMENT OF NO-CONFLICT OF INTEREST

The authors declare that there is no conflict of interest in this paper.

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