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Research Application Summary

Rainwater Harvesting Technology: An Adaptation Approach to Climate Change Among Farmers in Africa: a Systematic Review

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Abstract

Water scarcity and drought accumulating from erratic rainfall patterns are responsible for significant losses in agricultural productivity across Africa and beyond. This has overtime contributed to significant decline in economic growth and development. Growing body of knowledge have revealed that rainwater harvesting has the potential to significantly increase farmers' income and to drive a significant number of people out of the poverty trap. However, little is known about the significance of integrating rainwater harvesting systems in crop production practices in Africa. As a result, the level of adoption remains relatively low across the continent (<20%). The aim of this study was to explore the different approaches of rainwater harvest technology as a basis for improving extension services delivery in arid and semi-arid zones of Africa. The use of thematic content analysis revealed that the use of rooftop rainwater harvesting can increase crop yield from 10-20%. The authors recommend the need to significantly adopt and cascade rooftop rainwater harvesting technology in arid and semiarid regions of Africa.

Key words: Africa, agricultural production,climate change, irrigation, rainwater harvesting technology

Résumé

La rareté de l'eau et la sécheresse qui s'accumulent à cause de l'irrégularité des précipitations sont responsables de pertes significatives de la productivité agricole en Afrique et ailleurs. Cela a contribué à un déclin significatif de la croissance économique et du développement. Un ensemble croissant de connaissances a révélé que la collecte des eaux de pluie a le potentiel d'augmenter de manière significative les revenus des agriculteurs et de sortir un nombre important de personnes du piège de la pauvreté. Cependant, on sait peu de choses sur l'importance de l'intégration des systèmes de collecte des eaux de pluie dans les pratiques de production agricole en Afrique. En conséquence, le niveau d'adoption reste relativement faible sur le continent (<20%). L'objectif de cette étude était d'explorer les différentes approches de la technologie de collecte des eaux de pluie comme base pour améliorer la prestation des services de vulgarisation dans les zones arides et semi-arides d'Afrique. L'utilisation de l'analyse de contenu thématique a révélé que l'utilisation de la collecte des eaux de pluie sur les toits peut augmenter le rendement des cultures de 10 à 20 %. Les auteurs recommandent la nécessité d'adopter de manière significative et en cascade la technologie de collecte des eaux de pluie sur les toits dans les régions arides et semi-arides d'Afrique.

Mots clés : Afrique, production agricole, changement climatique, irrigation, technologie de collecte des eaux de pluie.

Introduction

The intensity and occurrence of water scarcity and drought due to climate change have remained a bottleneck in arid and semi-arid countries. Given that Africa's agricultural production system is rainfed, this often leads to losses in agricultural production thereby undermining progress toward attaining zero hunger (Peprah, 2014; Rahman *et al*., 2017). The vast majority of farmers affected by this include cereal, vegetables and fruits and of pastoralists. Statistic show that 821.6 million people are hungry globally with Africa and Asia accounting for the largest proportion – 19.9 and 11.3%, respectively (FAO, 2019). The increase in the pool of hungry people in Africa is to a large extent due to water scarcity, drought and conflict in some parts of the continent.

Changing this narrative requires multifaceted approaches in agricultural production, one that integrate new method of increasing stock water for domestic use, fodder and crop production such as rainwater harvest technology (Rensburg *et al*., 2012). Rainwater harvesting is the practice of redirecting, collecting and storing water to increase water availability (Recha *et al*., 2015; Melville-shreeve *et al*., 2016). Literature reveals that it is a feasible, affordable, efficient, and an effective solution to supplement rain-fed farming in Europe and other continents. However, little is known about the significance of integrating rainwater harvesting systems in crop production practices in Africa. As a result, the level of adoption remains relatively low across the continent (<20%). The aim of this study was to explore the different approaches of rainwater harvest technology as a basis for improving extension services delivery in arid and semi-arid zones of Africa.

Rainwater Harvest Technology: Origins and Description

Rainwater harvesting technology (RWHT) is a practice of collecting and storing rain water obtained from rooftops, ground, and from channel flow for use in domestic, agriculture production, livestock fodder, and environmental management (Recha *et al*., 2015; Yannopoulos *et al*., 2017). It is used in many rural settings around the globe especially in developing countries. The technology dates back to the Minoan era (3200-1100 BC) in Hellas, now Greece, where people that lived in arid and semi-arid regions relied mainly on rain for water (Antoniou *et al*., 2014). This technology was also adopted in China and India in the third millennium BC in which rain falling on the roof, yards and open areas were collected and transferred into cisterns (Angelakis, 2016; Yannopoulos *et al*., 2017). Rainwater harvesting consist of four mechanisms/components; (1) rainfall, (2) a roof, a yard, a surface area from which water is harvested known as a catchment, (3) a gutter/ flowing channel that transports water from the catchment, and (4) a tank, dam, or reservoir - the storage facility (van Rensburg *et al*., 2012 Antoniou *et al*., 2014).

The main purpose of RWHT is to increase the quantity of water for domestic use and for agricultural purposes (Baiphethi *et al*. 2006; Recha *et al*. 2015; Adham *et al*. 2016; Mahinda *et al*. 2018). In dry areas such as in the case of Western Sudan RWHT is used to reduce the growing water scarcity, and misuse of water resources. It is also seen as a viable solution to desertification, erosion hazards as well as groundwater recharge resulting in increased agricultural production and environmental restoration (Biazin *et al*., 2012; Ali *et al*., 2015). Given its efficacy and the high rate of food insecurity due to poverty aggravated by weather extremes, the technology should be practiced in all sectors and by all individuals especially small-scale farmers, subsistence farmers and urban dwellers in countries/ regions that are water-stressed

Table 1. Rainwater Harvesting Methods

Major harvesting method	Description	References
Micro-catchment	This is a technique that has a distinct separate catchment area and a cropped basin. They are designed to collect runoff from a relatively small catchment area, ranging between 10– 500 m² in size, within the farm boundary. The runoff water is usually steered into a type of infiltration enhancement structure (a hole) and it is used to grow plants. Types of micro-catchment techniques are: pitting (Zai pits, Ngoro pits, trenches, tassa pits, etc.), Contouring (stone/soil bunds, hedge-rows, vegetation barriers), Terracing (Fanya Juu, Semi- circular and hillside terraces), Micro-basins (Negarims, half-moons, and eye- brows).	(Biazin *et al*., 2012; Kimani *et al*. 2015)
Macro-catchment	This technique includes traditional open ponds; cisterns, earthen dams (microdams), sand dams, ephemeral stream diversions and spate irrigation. This technique usually consists of a rainwater collection chamber, the storage unit and the targeted area. The runoff is collected from external catchments and diverted into well-designed storage structures. Although most of the macro-catchment rainwater harvesting techniques have a catchment area of less than 2 ha, in some cases runoff is being collected from catchments as large as 50 km².	(Hatibu and Mahoo, 1999; Biazin *et al*., 2012; Ali *et al*., 2015; Recha *et al*., 2015)
In situ rainwater harvesting	This technique harvests water by trapping rainwater the water in one area usually at a cropped area also allowing infiltration, this process conserves water. The method is more effective in soils that have a high holding capacity and where rainfall is equal. Examples of this method are deep tillage, contour farming and ridging, and agronomic practices such as weeding and mulching. Notice that all these methods create roughness which reduces runoff, soil evaporation and increases infiltration.	(Hatibu & Mahoo, 1999; Vohland and Barry, 2009; Biazin *et al*., 2012)
Rooftop harvesting	A traditional method of rainwater harvesting, common in many households and schools globally. It uses gutter-to-tank technology. As the rain falls on the roof, it flows through a gutter which transfers to the tank. It yields good quality water which is primarily for domestic use such as drinking, washing and other household chores,	(Medina, 2011; Kimani *et al*., 2015)

Types of Rainwater Harvesting Technologies

Apart from the indigenous means of capturing rainwater, new and improved methods have been developed depending on the location, the handlers and the targeted use of water harvesting. These methods can be divided into Micro/Macro catchments, In-situ, and rooftops as explained in Table 1 (Mahoo, 1999; Vohland and Barry, 2009; Biazin *et al*., 2012; Hatibu; Recha *et al*., 2015; Angelakis, 2016; Duguna and Januszkiewicz, 2019) Some of the experiences are listed in Tables 2 and 3.

Relevance to Africa

Africa is faced with enormous glitches from political instability, diseases, conflicts, natural disasters poverty, and food insecurity. However, water scarcity is the most threatening. Currently, between 75 and 250 million people in Africa are estimated to suffer from water stress. More so, harvests from rain-fed agriculture is expected to reduce by 50% in some regions, which will severely curtail agricultural production, including access to food, thus, worsening food insecurity (Ammar *et al*, 2016). In view of this, rainwater harvesting (specifically rooftop rainwater harvesting) is proposed as a solution to persistent drought and solution to water scarcity in most regions of the world, a lesson that Africa can adopt. According to Kumar (2019) adopting rooftop rainwater harvesting in urban areas can go a long way in redeeming the worsening situation of shortage of groundwater as rainwater is not only for domestic use but it can also be used to reduce strain/dependency on natural water resources,

Table 2. Achievements and Lessons learned in Europe, America and the Caribbean

Author	Parameters studied	Key results	Key Recommendations
Food and Agriculture Organization (2014) Liang and Dijk (2016)	Continual drought and depletion of groundwater stocks accounts for around 60% of losses in agriculture. RWHs is not operating as expected, as such, the author assessed the contribution of non-technological factors through determining decisive factors involved in the use of RWHs for agriculture irrigation	Non-technological factors (financial, knowledge, attitude and practice) are critical for sustainable water management. These considerations are necessary to assure reliability of the system to support crop production and to achieve optimum returns in the use of the technology.	Continuous operation of RWH depends on the confidence of users in the water quality and their motivation to use the rainwater, a need to accelerate awareness and instill motivations
Boers and Ben-Asher, 1982	To determine the potentials of rainwater harvesting in crop production practices..	RWH is practiced in the USA, Australia, and Mexico but with limited research potential and use in South Sahara Africa and the Middle East	170 articles published were found (three quarters from USA), all of them revealing an awareness of the increasing need for rainwater harvesting(rooftop) and a recognition of its potential.
Abdulla, 2009	To evaluate the potential use and efficiency of RWH in Jordan	RWH contributes to 5.6% of domestic water supply in 2005 and is a very important and effective water management strategy which suits household's needs. RWH reduces government spending (subsidy) by 5% in Jordan	Government supports are essential mechanisms to encourage widespread rainwater harvesting (rooftop) in Jordan. There is a need for further development of the rainwater-harvesting program in Jordan as well as for other arid and semi-arid areas of the world.
X. Li, 2016	Occurrence and frequency of water stress accounts for 90% of yield reduction, one that requires immediate action.	RWH irrigation system significantly increase crop yields by 10-20% and spur farmers incentives to maximize profit. RWH contributes to economic profit of vegetables about 65-240RMB which is significantly higher than economic profit of wheat and corn (2.9 – 6.3 RMB)	Investment in the use of the technology must be encouraged at all levels as it guarantees stable food supply and increase income.
Lupia, *et al.*, 2017	Dry spells affect fruits and vegetable production, a need to investigate rainwater harvesting potential and irrigation water requirement of residential gardens (RGs) located in the urban area of the city of Rome.	19% and 33% of gardens could be water self-sufficient for the low and high irrigation efficiency scenario, respectively if rooftop RHT are priorotised. The remaining gardens, by using the available rainwater, could satisfy 22% (low efficiency) and 44% (high efficiency) of the water needs resulting in a reduction in the use of conventional water sources Findings suggest that collecting and storing rainwater from roofs can potentially provide an alternative irrigation source to be used by the Residential Gardens located in the urban area, reducing water costs and providing an additional resource during dry periods.	Urban water management and sustainable water use require further attention due to the increased in water scarcity globally
Cook, *et al.*, 2000; Li, *et al.*, 2009	Each year nearly 1600 mill. Tones (Mt) of topsoil are lost from Gansu China through water and wind erosion, with associated loss of about 8 Mt of organic matter, 2.4 Mt of nitrogen, 3.2 Mt of potassium and 0.02 Mt of available phosphorus making the soil infertile for production	140,000 ha of rain-fed lands have been irrigated using rainwater harvesting (Yang, 1998). RWH has the potential to improve performance in rain-fed farming systems and to address environmental problems.	Research scientists and extension agents should provide long- term training and technical services to local farmers, thereby, increasing their ability to apply the technology and to ensure adequate maintenance of rainwater harvesting facilities. Also, a need to design and develop alternative policy instruments and implementing strategies that facilitate the spread of rooftop RWHT.
Kim, *et al.*, 2013	Drought in spring season that follows the long dry season of autumn and winter becomes a serious problem in Korean agriculture, even though the annual total precipitation depth is increasing. The study assessed the possibility of water harvesting implementation for Korean field irrigation on field farming condition	Rainwater catchment from about 60% area covered can harvest sufficient water for irrigation. Therefore, the implementation of water harvesting in Korea is necessary for field farming condition	Integration of traditional perspective of agricultural society must be promoted to ensure the success of RWHT

RWH – Rain Water Harvesting, RWHT – Rain Water Harvesting Technology

Table 3. Perspective of achievements and lessons learned in Africa

Author	Parameters Studies	Key Results	Key Recommendations
Hatibu and Mahoo, 1999; Kibassa, 2013	Drought have become major constrained, thereby making the achievement of no poverty and zero hunger questionable. The authors investigated RWHT against production and income levels.	Adoption of RWH improved crop production leading to increased income and reduce poverty in Dodoma and Bahi, Tanzania.	There is a need to formulate a coherent policy or strategy towards strengthening extension and technical support of rain water harvesting for crop production
Alamerew *et al*., 2002; Keesstra *et al*., 2013; Wubetu, 2016	95% of the total land area in Ayub and Jarota (Ethiopia) respectively is used for rain-fed production of cereal crop with 60-90% contributing to household income. With water scarcity, yield becomes difficult to quantify	RWHT enhances production of cereals and other vegetables. It improves savings by reducing potential cost of production	Little has been done to understand traditionally practiced RWH technologies in many parts of Ethiopia. Local learning/training and research institutions should support applied research initiatives aimed at understanding existing RWH technologies and improving on their performance
Ali and Shuang-en, 2015	Sorghum is essential for an improved livelihood grown on approximately 15 million ha in different parts of Sudan. However, growing scarcity and misuse of water resources contribute to decrease yield.	RWH and storage enhance infiltration rate and moisture content, improve growth and yield of sorghum. Therefore, it plays a significant role in terms of sustainable agricultural and socio-economic development in western Sudan and beyond	Increasing farmers motivation toward the use of RWHT is essential for increased productivity
Berger, 2011; Black, 2012	Erratic rainfalls and high vulnerability of drought suppress human wellbeing and productivity in Kenya (Kimani *et al*., 2015) despite advances made in recent times. The author investigated whether policies and institutions promote or hinder RWHT	Adoption of RWHT in Kenya is hindered by legal framework rendering communities to have no legal base for the provision of water use rights.	A need to promote the interaction of policies and institutions (rural institutions and NGOs) that combine economic incentives with active support on a national, regional and local level as well as in the field of education and raising awareness.
Carden, 2017	South Africa experience water stress, which affect significant number of households and farmers. The author assess the validity of RWH in urban settings as metric to advert the situation	RWH was only economically viable for minor property owners (affluent) when considering large catchment and that climate change has little impact on the performance of RWH systems	Further research is needed in better understanding the viability of RWH systems under different climatic conditions, and the socio-econonic drivers on the uptake of RWH systems
Ibraimo and Munguambe, 2007; Wachira, 2013	Increased dry season river abstraction by farmers upstream caused periodic water shortages in Laikipia Central District. The author documented rainwater harvesting practices, cropping systems and crop productivity by smallholder farmers in Laikipia Central District	The average maize yield in farms with RWH (259 kg/ha) was 14 times more than farms not having RWH which was 18 kg/ha. For vegetable crops, the average yields increased from 4.6 to 9.9 t/ha for spinach, 4.8 to 12.5 t/ha for kales and 4.2 to 10.5 t/ha for garden peas	Development agencies should mobilize and support households to ensure that they invested in improved RWH storage systems.

relieving pressure on often-overused water resources. While Rojas-Torres. (2014) reported that water harvesting can provide more than 20 % of the water demands, given that agriculture is mostly rain-fed in Africa this water can be used to support agricultural production. Biazin *et al*. (2012) and Duguna and Januszkiewicz (2019) reported that the implementation of rainwater harvest and energy resources development projects can successfully ensure food security, as vegetables and other cash crops will be produced to increase incomes, improve nutrition, and enhance and sustain livelihoods. Currently, women and children walk long distances to fetch water. As such, adoption of rainwater harvest can reduce the burden on women in collecting water from far distances which will improve their health. Thus, rainwater harvesting can improve resilience and adaptability especially to extreme weather conditions and climate change (Hatibu and Mahoo, 1999; Vohland and Barry, 2009) thereby increasing production, income and reduce poverty.

Conclusion

Currently, the RWHT methods often used in Africa and in other parts of the world include macro/ micro catchments, in-situ, and rooftops. It is important to note that the area of implementation of these types of RWHT is based on location, the handlers and the targeted use of the water harvested. However, rooftops have been the commonest traditional water harvesting technology practiced in rural areas of developing countries, especially in Africa (<20%). Rooftop has the potential to increase agricultural productivity, increase household income and reduce poverty.

Recommendations

Recognizing the potentials of rainwater harvesting technology as a metric for increased production and accelerating households and national income, the authors recommend a need to cascade the technology across Africa, and beyond. This entails the establishment of a knowledge hub led by research scientists and extension agents that provide adequate training and technical services to local farmers to enable them to apply and maintain the technology. The knowledge should also reach out to rural areas who are most vulnerable and need to adopt the technology to address their water needs. Moreover, the national governments need to promote the interaction of policies and institutions (rural institutions and NGOs) that combine economic incentives with active support at a national, regional and local level as well as in the field of education. Furthermore, the need for community- driven innovations built around indigenous knowledge should be adopted. This will further ensure the long-term sustainability of these innovations by ensuring easy maintenance.

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