Revisiting dominant practices in floodwater harvesting systems: making flood events worth their occurrence in flood-prone areas

Article · January 2020

DOI: 10.1007/s13201-019-1096-4

2 authors:

Mphatso Malota
Mzuzu University

Joshua Mchenga
Mzuzu University

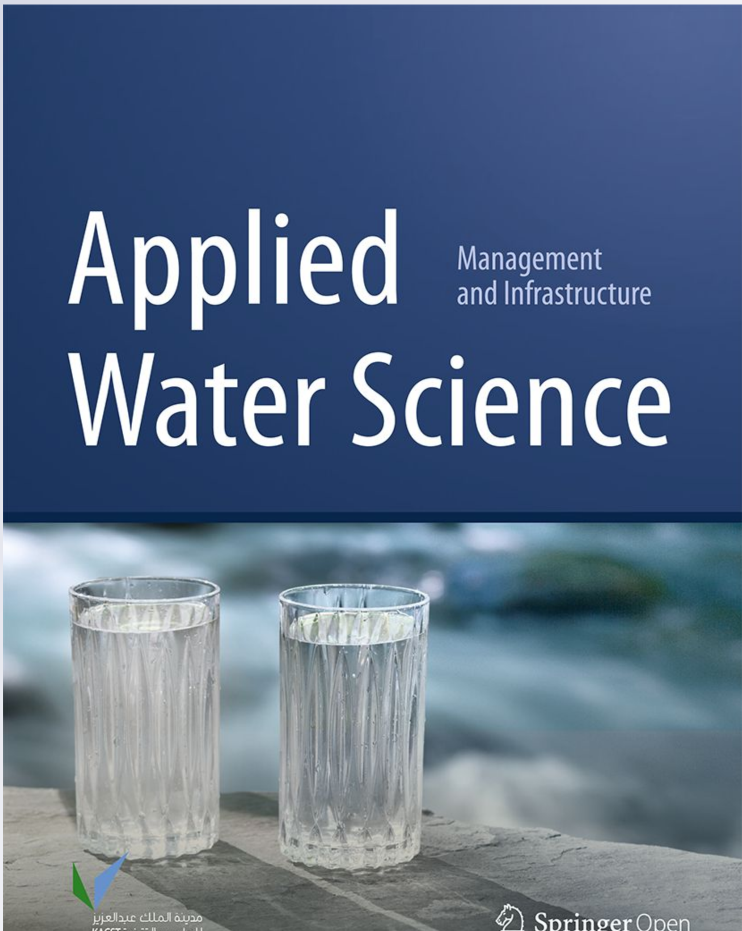
Revisiting dominant practices in floodwater harvesting systems: making flood events worth their occurrence in flood-prone areas

Mphatso Malota & Joshua Mchenga

Applied Water Science

ISSN 2190-5487
Volume 10
Number 1

Appl Water Sci (2020) 10:1-7
DOI 10.1007/s13201-019-1096-4



Springer

Applied Water Science (2020) 10:6
https://doi.org/10.1007/s13201-019-1096-4

ORIGINAL ARTICLE

Revisiting dominant practices in floodwater harvesting systems: making flood events worth their occurrence in flood-prone areas

Mphatso Malota[1] · **Joshua Mchenga**[1]

Received: 7 January 2018 / Accepted: 30 October 2019

Abstract

The lower Shire valley region in Malawi has long been characterized by floods which have accounted for many fatalities and disaster-related economic losses in the region. Rain-fed crop production has also been adversely affected by such floods, subsequently leading to the region registering the highest levels of poverty in the country due to low agricultural crop production. This study employed both qualitative and quantitative methods and based on what is practiced in the region and elsewhere, recommended strategies that would lower the risk of engaging in crop production under floodwater harvesting. Study results revealed that farmers in the region have sought to dig networks of water ponds and shallow wells as coping strategies to future water scarcity at a scheme level. The absence of well-designed networks of field waterways in the irrigation schemes results in an unequal distribution of floodwaters among field plots. The study concluded that in addition to digging a network of shallow wells and small water ponds to enhance infiltration of floodwaters and increasing groundwater recharge, a resilient and low-risk package of the floodwater harvesting system in the region must also include (1) construction of floodwater diversion structures to increase the chances of flooding even from relatively small rainfall storms, (2) construction of floodwater field distribution channel networks to facilitate field to field distribution of floodwaters, and (3) formulating water distribution rules to enhance equal floodwater distribution among field plots.

Keywords Floodwater · Irrigation · Water management · Sediments · Water harvesting

Introduction

Water scarcity in predominantly rain-fed crop production systems is largely influenced by rainfall variability and substantial unproductive water losses in form of runoff (Biazin et al. 2011; Araya and Stroosnijder 2010; Welderufael et al. 2008). The high rainfall intensities of short duration being experienced worldwide (Helmreich and Horn 2009; Ngigi 2003) have not only resulted in the generation of high runoff discharges and flood-related agricultural crop damage, but also loss of lives through such floods (van Steenbergen et al. 1997). According to Kowsar (2005), subsequent to a flood event, farming calendars in flood-prone environments are affected as it takes nearly 3 to 4 weeks before the fields naturally drain and become accessible. Arguably, this trend has rendered rain-fed crop production almost impossible in many flood-prone environments, as crop production calendars fail to match with the rainfall season.

In common with most developing countries in the sub-Saharan Africa (SSA), Malawi faces numerous challenges, which often preclude the investments required to enhance rural livelihood through crop production. For example, in the past decade alone, the country registered an annual average of 12% maize yield production losses due to flood-related crop damage (Pauw et al. 2010). Although flooding affects most parts of the country, the rural lower Shire valley region has historically borne the brunt of such events. For the past 10 years, floods in the region registered almost three-quarters of the total flood disaster-related economic losses in the country (Coulibaly et al. 2015; Mwale et al. 2015). According to Pauw et al. (2010), the high poverty levels in the region are largely attributed to the flood disaster-related economic losses, which are normally experienced annually.

The projected increase in flood events in the lower Shire valley region, both in magnitude and frequency (Joshua et al. 2016; Coulibaly et al. 2015; Pauw et al. 2010),

✉ Mphatso Malota
mphatsomalota@yahoo.com

1 Department of Water Resources Management and Development, Mzuzu University, P/Bag 201, Luwinga, Mzuzu 2, Malawi

Published online: 12 November 2019

provides an excellent opportunity to enhance crop production through floodwater harvesting system (FWHS) in the region. Gould (1999) defines FWHS as a generalized term that describes all deliberate efforts aimed at concentrating, collecting, and storing floodwaters for agricultural or domestic use. Unlike spate irrigation, where rivers and streams are deliberately made to flood and flow through dry wadis and conveyed to croplands (Mehari et al. 2010; van Steenbergen et al. 2010, 2011; Mehari et al. 2007), FWHS depends on natural flooding of cultivated lands (van Steenbergen et al. 2010). On the other hand, Mehari et al. (2010) report that flood occurrence is uncertain, which renders production under FWHS an even more risk-prone investment. In the lower Shire valley region of Malawi, the system has for the past fifteen years been a source of rural livelihood to more than 300 households. However, apart from ad hoc farmer experience-based suggestions and improvements (e.g., planting early maturing crop varieties), no thorough research has been conducted to suggest evidence-based improvements which need to be adopted for the FWHS in the region to be resilient and lower the risks associated with the crop production system. The objective of this study was to formulate a resilient and low-risk package of a crop production system in collocation with floodwater harvesting system in the lower Shire valley region of Malawi.

Materials and methods

Description of the study site

This study was conducted in three irrigation schemes: Nyangalande (250 beneficiaries), Nkholovuwa (156 beneficiaries), and Nyamula (132 beneficiaries) located in the area of Traditional Authority Tengani in Nsanje District (Fig. 1). Farmers at all the three schemes practice nonconventional irrigation, where crop production is dependent on soil moisture brought by floodwaters that spread through croplands. Normally, planting is done after the soil system has naturally drained. In this paper, the study sites are referred to as irrigation schemes because crop production under FWHS in the area resembles that of subirrigation.

Crop production under floodwater harvesting in the area was first adopted by farmers at Nyangalande irrigation scheme, followed by farmers at Nkholovuwa and Nyamula irrigation schemes. All the three schemes started as informal wetland cultivation, commonly known as dimbas in the

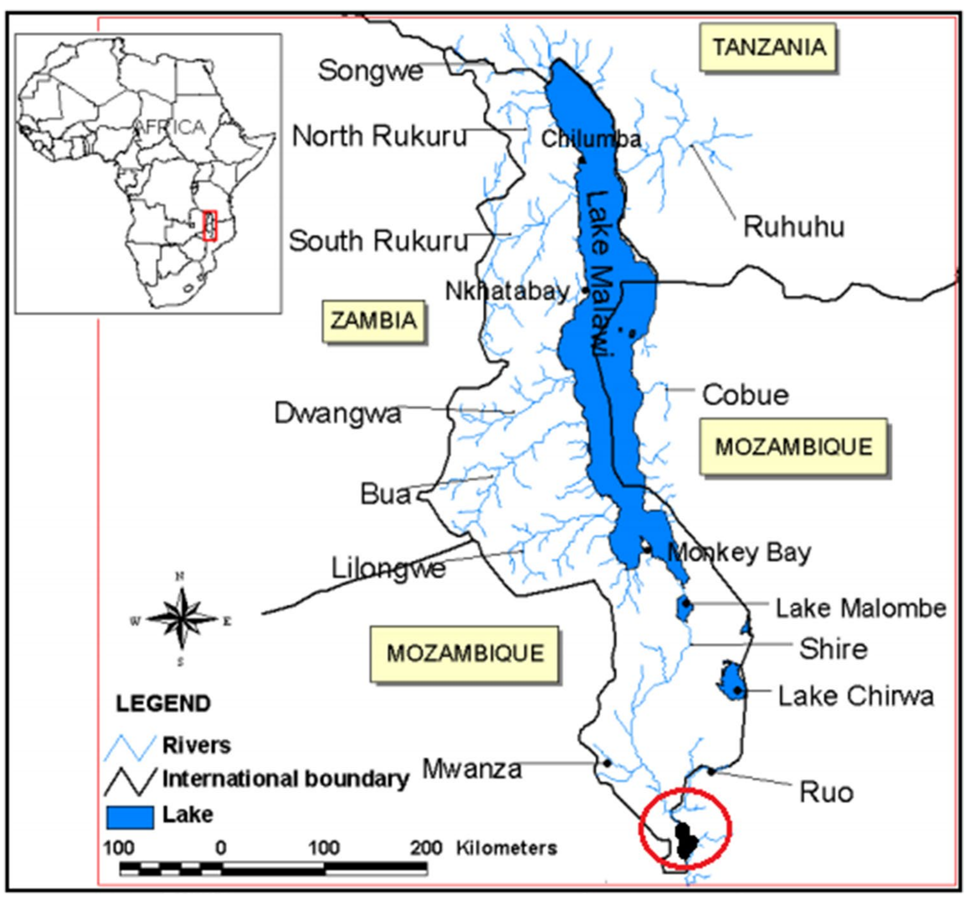


Fig. 1 Location of the study site (encircled are where the three irrigation schemes are located)

Malawian local language. The main source of water for crop production in all the three irrigation schemes is the floodwaters from the Shire River, which also forms the only outlet of Lake Malawi. The dominant soil type at the three irrigation schemes is clay-sandy soil. Table 1 presents the details of the three irrigation schemes.

Intercropping has consistently been the cropping system adopted at all the three irrigation schemes, where maize as the main crop is either intercropped with beans, pigeon peas, or both. On average, every farmer holds about 0.3 ha of an irrigation plot. The Agricultural Extension Officer working in the area indicated that intercropping maize, which is the main food crop in the area, with other crops increases land productivity by increasing crop yields per unit land. Largely, beans and pigeon peas are grown as cash crops, whose sales are used to purchase agricultural inputs and other items as may be required by the farmer.

Weather data records (2005–2015) obtained from Makanga meteorological station (located on latitude − 16.51° and longitude 35.5° west) categorizes the area as a dry-humid (aridity index = 1.3), depicting that the area receives highly intense rainfalls of short duration (UNESCO 1979). Analysis of the 10-year weather data shows that high monthly average rainfall of more than 150 mm was recorded in the months of December, January, February, and March. Although we intended to use a weather data record of more than 30 years, weather data records for the previous years contained a lot of gaps and were, therefore, unreliable particularly when computing monthly weather data averages.

Data collection and processing

The study employed both primary and secondary data. Largely, the primary data consisted of field plot sizes, preferred crop types, crop yield history, and challenges to the crop production system at each of the three irrigation schemes. The secondary data included crop productivity estimates obtained from Nsanje District Agricultural Office, general crop type preferences in the district, and history of floodwater harvesting in the district. The primary data were obtained through a structured questionnaire administered to individual farmers who were engaged in farming activities at each of the three irrigation schemes. The questionnaires were administered to 50% of farmers at each of the three irrigation schemes, i.e., 125 respondents for Nyangalande, 78 respondents for Nkholovuwa, and 66 respondents for Nyamula irrigation scheme. A checklist was also used to gather as much information as possible from Water Users Associations (WUAs) at each of the irrigation schemes.

On the other hand, field observations were made at each scheme in order to provide necessary information on the presence of artificial hydraulic structures, e.g., field waterways, water ponds, diversion structures, field bunds, and floodwater energy dissipaters. Secondary information from the literature on floodwater harvesting crop production systems was used to complement findings of the study, particularly when formulating a FWHS resilience and risk reduction package for the area.

Table 1 Details of the floodwater irrigation schemes focused on the study

Name of irrigation scheme	Area under cultivation (ha)	Year of development	Crops grown
Nyangalande	60.0	1993	Maize, beans, pigeon peas
Nkholovuwa	38.6	2002	
Nyamula	18.0	2006	

Results and discussion

Adoption of FWHS in the area

Prior to Nyangalande irrigation scheme establishment in 1993, only 13% ($n = 125$) of respondents received a start-up training in irrigation operation and management of floodwater harvesting systems. The training was provided by Agricultural Extension Officers (AEOs) from the Ministry of Agriculture, Irrigation, and Water Development. On the other hand, nearly 35% ($n = 78$) of respondents at Nkholovuwa irrigation scheme got their start-up training on irrigation scheme operation and management from farmers at Nyangalande irrigation scheme. Similarly, 43% ($n = 66$) of respondents at Nyamula irrigation scheme also reported having received a start-up training on irrigation management and operation from farmers at Nyangalande irrigation scheme.

The success of the farmer to farmer training that was adopted during the establishment of the Nkholovuwa and Nyamula irrigation schemes clearly indicates that this form of agricultural extension approach is still relevant in advancing the adoption of agricultural technologies among farmers. The possible explanation to the success of the farmer to farmer training approach could be that farmers are likely to adopt a technology introduced to them by one who has ever taken a risk in adopting the same technology they are advancing. These findings corroborate very well with those of Kuehne et al. (2017), who argue that farmers' interest to adopt a new technology is dependent on how the farmer perceives the trainer to be knowledgeable enough on the use of the technology in question. Further to that, Kuehne et al. (2017) mention that farmer trainers with high practical experience in the technology which they are advancing to farmers are more likely to yield a high adoption rate of the technology among farmers, as opposed to trainers who are not fully conversant on the usage of a given technology. These results suggest that while the Ministry of Agriculture relies more on Agricultural Extension Officers to advance various agricultural technologies, farmers with an experience in a given agricultural technology must also be targeted to promote adoption of new agricultural technologies among their fellow farmers.

On-site FWHS and water management strategies

Apart from small square-shaped (of nearly 40 cm × 40 cm) water ponds in the ranges of 25–30 cm depth, and a series of hand-dug wells (about 4 wells per ha) which were observed at all the three irrigation schemes, there were no any other artificially made hydraulic structures observed on any of the three schemes. The WUAs indicated that the water ponds were dug to collect and store floodwaters during flood events and facilitate infiltration. When asked to give more detail on why the WUAs encourage farmers to construct networks of small water ponds in the schemes, the WUAs further reported that in addition to enhancing infiltration, inclusion of the water ponds in their fields further serve two main purposes: (i) acting as energy dissipaters in slowing down the advance of the floodwaters and (ii) reducing soil erosion by trapping eroded soil particles and increasing surface roughness. There were no deliberate efforts made to distribute the floodwaters to specific field plots through artificially made waterways. Further to that, there were no floodwater diversion structures constructed at floodwater intake points to enhance flooding of the river even from relatively small rainfall events. The advance of floodwaters to low lying croplands followed the natural terrain of the land, which implied that field plots close to the flooding rivers were always the first to receive the floodwaters. This indicates that irrigation fields located in the low lying areas were at a disadvantage of getting little or no floodwaters for crop production.

Although the presence of water ponds and the shallow wells in the fields corroborated very well with those reported by Mati (2005), their adoption in combination with bunding of field plots as recommended by Mehari et al. (2010) can further improve soil water storage for crop production. The high susceptibility of field bunds to get damaged by floods could, however, explain the farmers' preference for constructing water ponds and hand-dug wells alone, as opposed to constructing field bunds.

On-site FWHS challenges

Results summarizing challenges that farmers are facing at the three irrigation schemes are presented in Fig. 2. The majority of farmers (87%; $n = 269$) indicated water scarcity to be a major challenge. The WUAs stressed that irrigation

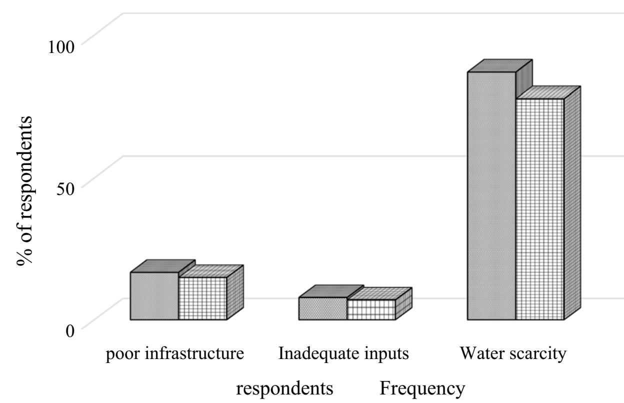


Fig. 2 Challenges to irrigation at the three irrigation schemes

plots in the lower sections of the irrigation schemes are the ones which commonly face the water scarcity problem. As a solution to this challenge, lower sections of the schemes are left to the farmers who generally grow leafy vegetables that take nearly 1 to 2 months to mature, e.g., Lettuce and Chinese cabbage. The water scarcity problem, particularly in field plots located in the low lying areas, could be attributed to the lack of an artificial floodwater distribution system in the three irrigation schemes. Construction of artificial waterways would possibly result in an improved and equal floodwater distribution system at each scheme. While an artificial floodwater distribution would facilitate field to field floodwater distribution on a rotational basis, Mehari et al. (2010) argue that its success is dependent on good cooperation among farmers. It is, therefore, apparent that an artificial floodwater distribution system must also be supported by rules which govern the distribution of floodwaters among filed plots.

The WUAs reported that farmers at the three irrigation schemes were aware of the possibility of short water supply especially toward the middle and mature crop stages. In this regard, a WUA at each irrigation scheme is mandated to ensure that all shallow wells at each irrigation scheme are cleaned at the beginning of the rainfall season. According to the WUAs, as with the water ponds, the hand-dug wells function both as groundwater recharging ponds and emergency water storage reservoirs for crop production. These results clearly demonstrate that the farmers are aware of the water scarcity risk associated with the existing crop production system. With respect to spate and other floodwater harvesting systems, van Steenbergen et al. (2010) and Mehari et al. (2008) recommend proper coordination among groundwater-use authorization bodies and farmers. This according to the authors prevents exploitation of the groundwater resources especially during water scarce periods.

Table 2 Mean annual maize yields at the three irrigation schemes (converted to ton/ha)

Irrigation scheme	Mean annual maize yields (ton./ha)	Coefficient of variation (CV) (%)
Nyamula	2.10*	37
Nyangalande	1.90*	40
Nkholovuwa	2.13*	35

*No significant differences ($p \leq 0.05$) at 95% confidence interval

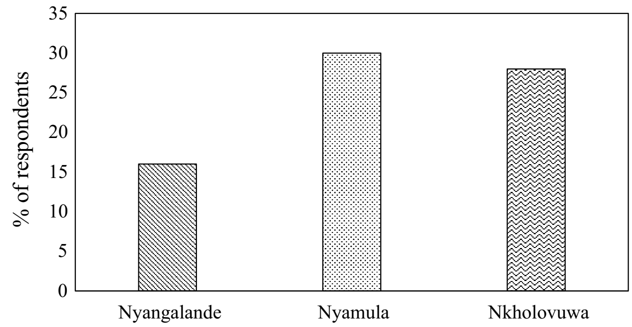


Fig. 3 Farmers' perceptions of the need to construct on-scheme artificial hydraulic structures

Crop yield variations at scheme level

Assessment of the success of the existing FWHS was based on crop yield history as provided by farmers from the three irrigation scheme. Table 2 presents the mean annual maize yield at each of the three schemes for the past decade. No significant yield differences were observed at all the schemes ($P \leq 0.05$). On the other hand, there were greater variations in maize yields among farmers in all the three irrigation schemes (CV ≥ 35%). Countrywide, Malawi has recorded a great variation in annual maize grain yields in the past years. For instance, very low average annual maize yields in the range of 1.050 to 1.4 ton/ha have been reported by Kihara et al. (2016), Snapp et al. (2010), and Phiri et al. (2010). On the other hand, in soils with high soil organic carbon, relatively high average maize yields of 2.0 to 2.2 ton/ha have been reported (Sirrine et al. 2010). Liu and Basso (2017) attribute the great annual average maize yield variation in Malawi to a number of factors that include rainfall variation, differences in the levels of soil fertility and soil organic carbon across the country, and poor and inconsistent crop management practices.

Farmers' willingness to construct artificial hydraulic structures

Results of farmer's perception of the need to construct hydraulic structures at each of the irrigation schemes are shown in Fig. 3. A majority of farmers at all the three schemes felt no need to construct artificial hydraulic structures in their schemes. Only 16% ($n = 125$) of respondents at Nyangalande irrigation scheme felt a need to construct artificial hydraulic structures in their fields. On the other hand, only 28% ($n = 78$) of respondents at Nkholovuwa irrigation scheme and 30% ($n = 66$) of respondents at Nyamula irrigation scheme felt a need for construction of artificial hydraulic structures in the schemes. Reasons given for opting for not to construct artificial waterways and diversion structures at the water source, included (i) a high likelihood of the hydraulic structures to get damaged by floods, (ii) high sediment deposits that would fill field waterways and render such structures unusable following flood events, and (iii) high maintenance cost of hydraulic structures after flood events. On the contrary, for a successful crop production systems under FWHS, van Steenbergen et al. (2010) stress on the need for a better understanding of the entire hydrological system within which a floodwater harvesting system exists. Mehari et al. (2010) stress that the success of FHWS crop production system is rooted in good floodwater management practices that farmers in flood-prone areas are willing to adopt in their fields. For example, Mehari et al. (2010) attribute the success of flood-based crop production system in Yemen and Ethiopia to water management practices such as bunding of field plots and the existence of an improved field to field flood water distribution system.

Construction of a network of water ponds and wells has already been upheld by other authors (e.g., Mati, 2005) as effective ways of harvesting surface runoff, both for future or immediate agricultural use. However, for the FWHS in the region to remain competitive and ensure that farmers are satisfied with crop yields from their individual plots, multiple flood water management strategies would also need to be adopted. Other than focusing on selected subcomponents of the hydrological system, van Steenbergen et al. (2010) argue that the success of a floodwater harvesting system lies on how the base flow, sub-surface flow, water distribution system, and management of sediments are all intertwined and treated as an overall determinant of the success of a crop production system. These results, therefore, suggest that other than isolating the aforementioned reasons as a basis for not constructing artificial hydraulic structures, WUAs at the three schemes must seek to improve the coordination among farmers and hydrological experts in the region to assist in a better understanding of the hydrology of existing floodwater harvesting systems.

Interventions at the three schemes concentrated on increasing infiltration and coping with future water scarcity as a way of reducing the risks associated with the crop production under floodwater harvesting system. However, with the absence of artificial waterways at all the three irrigation schemes, unequal floodwater distribution among field plots is also inevitable. Mehari et al. (2010) and Mehari et al. (2007) argue that considering that flood occurrence is very uncertain, both in terms of magnitude and frequency, efforts aimed at reducing the risks associated with inadequate water supply production systems must also need to be extended to improve the floodwater distribution system.

Concluding remarks

Flooding of the Shire River in the lower Shire valley region of Malawi offers a great opportunity to enhance crop production when combined with floodwater harvesting. This form of crop production is, however, very risky and its success is rooted in the proper management of floodwaters in irrigation schemes. Farmers practicing crop production under floodwater harvesting in the region are aware of the uncertainty of flood occurrence and how this affects the overall crop production system. Study results demonstrated that apart from constructing a network of field water ponds and shallow wells in the field to enhance infiltration and water availability for immediate and future crop use, the existing FWHS in the region needs to be improved further. The study concluded that further improvement efforts must also be extended to (i) construction of floodwater diversion structures to increase the chances of flooding, (ii) constructing a floodwater field distribution channel network to facilitate field to field distribution of floodwaters, and (iii) formulation of floodwater distribution rules to enhance equal floodwater distribution among field plots.

Acknowledgements This study was conducted with funding from the International Fund for Agricultural Development (IFAD) through the 'Twinning of Juniors to Senior Agricultural Management Project'. We are, therefore, very grateful for the financial support that IFAD provided to us. We are also very thankful to the Blantyre Irrigation Services Division (BSID) for covering all the transport costs during field visits. Special thanks must also be extended to all the farmers from the three irrigation schemes for providing all the necessary information and data we required.

References

Araya A, Stroosnijder L (2010) Effects of tied-ridges and mulch on barley (Hordeum vulgare) rainwater use efficiency and production in Northern Ethiopia. Agric Water Manag 97:841–847

Biazin B, Sterk G, Temesgend M, Abdulkedir A, Stroosnijder L (2011) Rainwater harvesting and management in rainfed agricultural systems in sub-Saharan Africa: a review. J Phys Chem Earth. https://doi.org/10.1016/j.pce.2011.08.015

Coulibaly JY, Mbow C, Sileshi GW, Beedy T, Kundhlande G, Musau J (2015) Mapping vulnerability to climate change in Malawi: spatial and social differentiation in the Shire River Basin. Am J Clim Change. https://doi.org/10.4236/ajcc.2015.43023

Gould JE (1999) Rainwater catchment systems for house-hold water supply, environmental sanitation reviews, no. 32, ENSIC, Asian Institute of Technology, Bang-Kok

Helmreich B, Horn H (2009) Opportunities in rainwater harvesting. J Desalin 248:118–124

Joshua MK, Ngongondo C, Chipungu F, Monjerezi M, Liwenga E, Majule AE (2016) Climate change in semi-arid Malawi: perceptions, adaptation strategies and water governance. J Disaster Risk Stud. https://doi.org/10.4102/jamba.v8i3.255

Kihara J, Nziguheba G, Zingore S (2016) Understanding variability in crop response to fertilizer and amendments in sub-Saharan Africa. Agric Ecosyst Environ 229:1–12

Kowsar SA (2005) Abkhandari (aquifer management): a green path to the sustainable development of marginal lands. J Mt Sci 2(3):233–243

Kuehne G, Llewellyn R, Pannel DJ, Wilkinson R, Dolling P, Ouzman J, Ewing M (2017) Predicting farmer uptake of new agricultural practices: a tool for research, extension and policy. J Agric Syst 156:115–125

Liu L, Basso B (2017) Spatial evaluation of maize yield in Malawi. J Agric Syst 157:187–192

Mati BM (2005) Overview of water and soil nutrient management under smallholder rainfed agriculture in East Africa. Working Paper 105. Colombo, Sri Lanka: International Water Management Institute (IWMI)

Mehari A, van Steenbergen F, Schultz B (2007) Water rights and rules and management in spate irrigation systems in Eritrea, Yemen and Pakistan. In: Van Koppen B, Giordano M, Butterworth J (eds) Community-based water law and water resource management reform in developing countries: comprehensive assessment of water management in agriculture series. CAB International, Wallingford, p 5

Mehari A, Schultz B, Depeweg H, De Laat PJM (2008) Modelling soil moisture and assessing its impact on water sharing and crop yield for the Wadi Laba spate irrigation system, Eritrea. J Irrig Drain 57(1):1–16

Mehari A, van Steenbergen F, Shultz B (2010) Modernization of spate irrigated agriculture: a new approach. J Irrig Drain. https://doi.org/10.1002/ird.565

Mwale FD, Adeloye AJ, Beevers L (2015) Quantifying vulnerability of rural communities to flooding in SSA: a contemporary disaster management perspective applied to the Lower Shire Valley, Malawi. Int J Disast Risk Reduct 12:172–187. https://doi.org/10.1016/j.ijdrr.2015.01.003

Ngigi SN (2003) What is the limit of up-scaling rainwater harvesting in a river basin? J Phys Chem Earth 28:943–956

Pauw K, Thurlow J, van Seventer D (2010) Droughts and floods in Malawi: assessing the economy wide effects. IFPRI Discussion Paper 00962

Phiri AT, Njoloma JP, Kanyama-Phiri GY, Snapp S, Lowole MW (2010) Maize yield response to the combined application of Tundulu rock phosphate and pigeon peas residues in Kasungu, Central Malawi. Afr J Agric Res 5:1235–1242

Sirrine D, Shennan C, Sirrine JR (2010) Comparing agroforestry systems' ex ante adoption potential and ex post adoption: on-farm partcipatory research from southern Malawi. Agrofor Syst 79:253–266

Snapp SS, Blackie MJ, Gilbert RA, Bezner-Kerr R, Kanyama-Phiri GY (2010) Biodiversity can support a greener revolution in Africa. Proc Natl Acad Sci 107:20840–20845
UNESCO (1979) Map of the World distribution of arid regions. Accompanied by explanatory notes. UNESCO, Paris
van Steenbergen F (1997) Understanding the sociology of spate irrigation: cases from Balochistan. J Arid Environ 35:349–365
van Steenbergen F, Lawrence F, Mehari A, Salman M, Faures J (2010) Guidelines on spate irrigation. Food and Agriculture Organization, Rome
van Steenbergen F, Mehari A, Alemehayu T, Alamirew T, Geleta Y (2011) Status and potential of spate irrigation in Ethiopia. Water Resour Manag 25:1899–1913
Welderufael WA, Le Roux PAL, Hensley M (2008) Quantifying rainfall-runoff relationships on the Dera calcic fluvic Regosol ecotope in Ethiopia. Agric Water Manag 95:1223–1232

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.