An ACP-EU Technology-Transfer Network on Rainwater Harvesting Irrigation Management for Sustainable Dryland Agriculture, Food Security and Poverty Alleviation in sub-Saharan Africa

FOSTERING THE USE OF RAINWATER FOR SMALL-SCALE IRRIGATION IN SUB-SAHARAN AFRICA

A regional baseline study in Ethiopia, Kenya, Mozambique and Zimbabwe

LEAD PARTNER

Hochschule für Angewandte
Wissenschaften Hamburg
Hamburg University of Applied Sciences

Hamburg University of Applied Sciences
Josep de Trincheria, Prof. Dr. Walter Leal
Ulmenliet 20, 21033 Hamburg, Germany
Tel.: +49-40-42875-6107, Fax: +49-40-42875-6079
E-Mail: afrhinet@ls.haw-hamburg.de
Web: www.afrhinet.eu

Register to the AFRHINET network at:
www.afrhinet.eu/transnational-network.html
Visit the virtual AFRHINET Research and Technology Transfer Centres at:
www.rainwatertechcentres.net

ISBN 978-3-00-054353-1

FOSTERING THE USE OF RAINWATER FOR SMALL-SCALE IRRIGATION IN SUB-SAHARAN AFRICA

A regional baseline study in Ethiopia, Kenya, Mozambique and Zimbabwe

AFRHINET: A technology transfer network on rainwater harvesting irrigation management in rural arid and semi-arid areas of sub-Saharan Africa

Publisher

Hamburg University of Applied Sciences, Hamburg, Germany
Financed by ACP-EU Cooperation Programme in Science and Technology (ACP-S&T II). A programme implemented by the ACP Group of States, with the financial assistance of the European Union.

Authors

J. Trincheria*, N. Adhiambo, S. Bila, B. Cuamba, D. Dawit, W. Leal, A. Leão, B.M. Magonziwa, M. Malesu, S. Ngigi, E. Nissen-Petersen, G. Nyamadzawo, J. Nyamangara, A. Oduor, S. Sisenando, J. Pereira, N. Oguge, F. Oremo, B. Simane, T. Tulu, M. Wuta.

* The AFRHINET project is coordinated by Josep de Trincheria and Prof. Walter Leal (Hamburg University of Applied Sciences).
Email: josepmaria.detrincheriagomez@haw-hamburg.de.

Citation:

De Trincheria et al. (2016). Fostering the Use of Rainwater for Small-Scale Irrigation in Sub-Saharan Africa. AFRHINET Project. Hamburg University Applied Sciences, Hamburg, Germany.

CONTENTS

PROJECT BACKGROUND 1

EXECUTIVE SUMMARY 2

1. INTRODUCTION 3

1.1 Background 3

1.2 Goals and Objectives 3

1.3 Methodology 3

2. RAINWATER HARVESTING MANAGEMENT FOR FOOD SECURITY 5

2.1 Rainwater harvesting management for small-scale irrigation (RWHI) 5

2.2 Macro-catchment RWHI systems 6

2.2.1 Selected RWHI Storage technologies in Ethiopia, Kenya, Mozambique and Zimbabwe 7

2.2.2 On-farm pond systems 7

2.2.3 Earth dams and community pond systems 8

2.2.4 Groundwater dam systems: subsurface dams and sand storage dams 8

2.2.5 Rock outcrop catchment systems 8

2.2.6 Roadwater catchment systems 8

2.2.7 Rooftop catchment systems 9

2.2.8 Tanks 9

2.2.9 Surface dam systems 9

2.3 Micro-catchment and in-situ RWHI systems 9

2.3.1 Micro-catchment systems 10

2.3.2 In-situ systems 10

2.4 Small-scale irrigation systems 11

2.4.1 Selected small-scale irrigation systems in Ethiopia, Kenya, Mozambique and Zimbabwe 11

2.4.2 Manual irrigation systems 12

2.4.3 Sprinkler irrigation systems 13

2.4.4 Low-cost drip irrigation systems 13

2.4.5 Surface irrigation systems 14

2.4.6 Pumping systems 14

3. TECHNOLOGY-TRANSFER POTENTIAL 15

3.1 Technology transfer and rainwater harvesting irrigation management 15

3.2 Rainwater harvesting irrigation technologies with technology transfer potential 16

3.3 Selected examples of technology transfer strategies in the African partner countries 17

3.4 Regional similarities and differences 18

4. RESEARCH, INNOVATION AND CAPACITY-BUILDING NEEDS 19

4.1 Introduction 19

4.2 Needs in the 4 AFRHINET African partner countries 19

4.3 Barriers 20

5. COMPARATIVE ANALYSIS OF POLITICAL AND INSTITUTIONAL FRAMEWORKS 21

5.1 Introduction 21

5.2 Relevant policies in the 4 AFRHINET African partner countries 22

5.3 Regional similarities and differences 22

6. APPLICABILITY TO OTHER ARID AND SEMI-ARID REGIONS 23

7. RECOMMENDATIONS 25

8. REFERENCES 27

PROJECT BACKGROUND

AFRHINET is a three-year project which focuses on fostering the knowledge and use of rainwater harvesting technologies for supplemental irrigation in rural drylands of sub-Saharan Africa. The project focuses on the implementation of integrated capacity building activities, the development of research and technology transfer activities, namely technology transfer centres and demonstration trials, and the setting-up of a transnational network of multivariate relevant actors. The AFRHINET project is funded by the ACP Science and Technology Programme, an EU cooperation programme which is funded by the European Union and implemented by the ACP Secretariat. The action of the project takes place in Ethiopia, Kenya, Mozambique and Zimbabwe. The African partners are Addis Ababa University and WaterAid-Ethiopia in Ethiopia, University of Nairobi and ICRAF-Searnet in Kenya, Eduardo Mondlane University in Mozambique, and University of Zimbabwe and ICRISAT-Zimbabwe in Zimbabwe. The AFRHINET project envisages close involvement and participation of relevant stakeholders and target groups, i.e. NGOs, businesses / micro-enterprises, consultancies, ministries and local communities.

The main 4 core activities of the AFRHINET project are as it follows:

- **Development of endogenous and self-replicable capacities on RWHI management:**
  A two-phase capacity-building programme focusing on the scientific basis and the practical implementation of RWHI management coupled with the development of advanced training materials complemented by practical experiences and lessons learnt.
- **Establishment of research and technology transfer centres:**
  To serve as hubs of knowledge and expertise in the field of RWHI management and dryland agriculture in rural areas of sub-Saharan Africa, and foster capitalisation and dissemination of innovative and effective RWHI management practices.
- **Demonstration of innovative RWHI management**:
  Effective demonstrations relative to RWHI will not only support, but also reinforce, the idea of alternative concepts to local community groups, academic and scientific institutions, businesses/micro-enterprises, and non-governmental and public organisations. Thereby, showcasing that implementing cost-effective RWHI projects for improved food security and poverty alleviation is substantially feasible.
- **Networking activities**:
  To enhance the networking capacity of academic and scientific institutions with other relevant stakeholders at national and international level.

EXECUTIVE SUMMARY

This report is part of the AFRHINET project under the ACP-EU Cooperation Programme in Science and Technology (S&T II). The overall aims of the project are to enhance options for sustainable integration of rainwater harvesting for irrigation through understanding adoption constraints and developing networks for capacity building and technology transfer. The African partners are Addis Ababa University and WaterAid-Ethiopia in Ethiopia, University of Nairobi and ICRAF-Searnet in Kenya, Eduardo Mondlane University in Mozambique, and University of Zimbabwe and ICRISAT-Zimbabwe in Zimbabwe. Hamburg University of Applied Sciences (Germany) is the coordinator of the project.

The report is a summary of the most relevant information which was compiled in the frame of the baseline studies in the 4 AFRHINET African countries. The main goal of the baseline study was to conduct a capacity and technology transfer assessment in the field of rainwater harvesting for irrigation management. The national baseline studies were conducted through an extensive literature review, in-depth key informant interviews with representatives of stakeholder institutions and experts in the field of rainwater harvesting management and small-scale irrigation. Relevant information was also collected in the field and during national multi-stakeholder workshops, where information and experiences of relevant stakeholders was shared.

The use of rainwater harvesting for small-scale irrigation during the dry season has been practiced in all the four countries with significant success in terms of high crop productivity. In all the participating countries, rainwater harvesting for irrigation (RWHI) included collecting surface runoff from external catchments and using storage structures such as earth dams, water pans, farm ponds, underground tanks and groundwater dams. The water was used to irrigate crops during the dry season or to supplement rainwater during dry spells. In some cases, surface runoff was redirected into the fields to irrigate crops (flood irrigation) and to increase infiltration and recharge groundwater resources. Low-head low-cost drip irrigation systems were identified as the most efficient irrigation system, usually using rainwater harvested from rooftops. In Ethiopia, Kenya, Mozambique and Zimbabwe, several mechanisms and technologies have been developed to reduce evaporation and percolation losses, which include, among others, greenhouses, roof covers, pond lining with geomembrane and groundwater dams. The appropriateness of RWHI technologies in each country was strongly determined by biophysical factors and the avaialability of financial resources.

The national surveys in the four countries indicated that RWHI interventions have been implemented by national associations, Non-Governmental Organisations (NGOs) and private organisations. In most cases, NGOs significantly contributed to the implementation of these interventions. However, there is also an increasing interest for research and innovation in the field of RWHI among governmental and scientific institutions, private sector and civil society.

Studies and experiences in all countries indicated that RWHI can be replicated and scaled up through self-replicable capacity building activities, better coordinated research, improved communication and dissemination of cost-efficient and/or innovative technologies, transnational networking activities, and effective policy-making.

Ethiopia and Kenya have made some progress in the implementation of RWHI systems. However, Mozambique and Zimbabwe face major challenges, like the stigmatisation of RWHI as a technology for the poor, lack of technical standards, fragmented efforts in the implementation of RWHI systems, and lack of specific policies on RWHI. For an effective implementation of RWHI management, there is a need in all countries to review policy, legal and institutional arrangements that negatively affect adoption and scaling up of rainwater harvesting and irrigation technologies.

1. INTRODUCTION

1.1 Background

Food and water scarcity have negative economic impacts and exacerbate poverty, especially in rural communities that are located in arid and semi-arid areas of sub-Saharan Africa (UN, 2015). Water scarcity is often related to high intensity and short duration of rainfall, with large spatial and temporal variability, rather than to cumulative annual and seasonal rainfall (Falkenmark and Rockström, 2004; Rockström and Falkenmark, 2015; IWMI, 2015; Nicol et al., 2015). Such irregular patterns result in high risk of drought and intra-seasonal dry spells. This in turn leads to unpredictable and depressed crop yields, perennial food shortages and disruptive conflicts over use and access to existing water supplies (Ngigi, 2003). The situation is being aggravated by the ensuing climate change and variability (Pachauri et al., 2014).

Climate change models have projected a decrease in rainfall in sub-Saharan Africa (New et al., 2006; Musiyiwa, 2014) and empirical literature has already shown similar trends (Nyagumbo et al., 2009). Therefore, meeting current and future food demands would require upgrading of agriculture by adopting climate- and water-smart technologies such as rainwater harvesting and management (Rockström and Falkenmark, 2015). Smallholder farmers in semi-arid areas of sub-Saharan Africa often experience total crop failure once every ten years and drastically reduced yields two to four times within similar period (Fischer et al., 2009). Agricultural droughts, which occur during the crop growing season, often have dire consequences on food and economic security of poor rural households (Malesu et al., 2012).

The potential of rainfed farming can be unlocked significantly in regions subject to dry spells through rainwater harvesting and storage for small-scale irrigation during the dry season (Awulachew et al., 2005; Mutabazi et al., 2005; Mati et al., 2006; Mati, 2007; Malesu et al., 2012). When surface runoff is collected and stored in reservoirs, it can be used for growing crops during periods of low or no rainfall. Surface runoff can also be used for recharging soil storage and groundwater replenishment that impacts positively on springs and shallow wells, which in turn, can also be used for small-scale irrigation.

1.2 Goals and Objectives

The report is a summary of 4 national baseline studies conducted in Ethiopia, Kenya, Mozambique and Zimbabwe in the frame of the AFRHINET project. The main goal of the national baseline studies was to carry out both a capacity and technology transfer assessment in the field of RWHI in these countries. The results of the baseline study provided the conceptual basis for the implementation of key AFRHINET project activities, particularly the development of capacity building programmes, the establishment of research and technology transfer centres (RTTCs), and the implementation of demonstration trials. Extensive baseline information focusing on each of the 4 AFRHINET countries can be found at http://www.afrhinet.eu/materials/viewcategory/11-baseline-studies.html.

The specific objectives of the baseline studies were:

1. To assess relevant and currently available know-how and map best practices in the field of RWHI
2. To identify the national capacity and training needs in the field of RWHI
3. To analyse the policy and institutional framework in the field of RWHI
4. To analyse the research and innovation needs in the field of RWHI
5. To assess the technology transfer and market-oriented needs of RWHI

1.3 Methodology

The baseline studies consisted on an extensive literature review coupled with in-depth key informant interviews with relevant institutions and experts in the field of RWHI. In addition, the baseline studies were further complemented during the implementation of national multi-stakeholder workshops, where relevant information and experiences of relevant stakeholders were shared. Finally, the baseline studies collected on-the-ground data and experiences during study visits and field activities in regions of Ethiopia, Kenya, Mozambique and Zimbabwe where RWHI systems had been implemented.

2. RAINWATER HARVESTING MANAGEMENT FOR FOOD SECURITY

Local communities in arid and semi-arid areas have since ancient times under widely varying ecological conditions attempted to harvest water to secure or increase agricultural production (Prinz, 2002). Recently, a wide variety of techniques for collecting, storing, and using natural precipitation for agricultural purposes have gained worldwide momentum (Biazin et al., 2012). Agricultural uses include irrigation, livestock watering, fodder and tree production and, less frequently, water supply for fish and duck ponds (Biazin et al., 2012). In-situ techniques and appropriate land management practices, which enhance infiltration and reduce surface runoff and soil evaporation, are also included as rainwater harvesting management techniques (Rockstrom et al., 2002). In this study, the term rainwater harvesting and management (RWHM) for food security has been used to encompass all practices of rainwater collection, storage and efficient utilisation for crop production (Rockstrom et al., 2002; Ngigi et al., 2005; Biazin et al., 2012). As it is shown in Figure 1, RWH management for food security can be further classified in three main categories (Biazin et al., 2012):

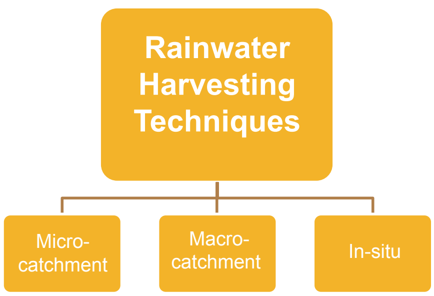

Figure 1: Classification of RWH systems for food security

- Micro-Catchment RWH Systems: Collection of surface runoff from micro-catchment systems with water storage in the soil for dry-spell mitigation
- Macro-Catchment RWH Systems: Collection of surface runoff from macro-catchment systems with water storage for supplementary irrigation
- In-situ RWH Systems: Techniques for maximising infiltration, reducing surface runoff and soil evaporation, and improving soil and water availability

2.1 Rainwater harvesting management for small-scale irrigation (RWHI)

RWHI is defined as a system that allows concentrating and storing rainwater from a larger catchment area to be used in a smaller target area. The collected rainwater is stored in a storage facility for irrigation of high-value crops during the dry season. RWHI differs from the use of rainwater for supplemental irrigation because it is specifically meant to conduct small-scale agricultural activities during the dry season, especially kitchen gardens, trees, and high-value horticultural crops along riverbanks, by means of the use of mainly macro-catchment RWH technologies connected to a low-cost irrigation system.

RWHI is predominantly designed to sustain subsistence agricultural activities at the smallholder level. RWHI is suited to be practiced in arid and semiarid regions, where rainwater often has an intermittent character. Due to the irregular distribution of rainfall, storage is an integral part of a RWHI system. Water will therefore be stored directly in on/off-farm small reservoirs, tanks and shallow groundwater aquifers.

Thus, a RWHI system has three main components:

1. Rainwater/runoff collection catchment
2. Rainwater/runoff storage facility by means of a man-made surface or sub-surface reservoir
3. Crop area involving the application of water during dry spells by means of a low-cost irrigation system

Thus, two elements are key in order to apply a RWHI system: a macro-catchment RWH system to collect water coupled with a storage system (section 2.2) and a low-cost irrigation system to provide water to the crop area during dry spells (section 2.4). Figure 2 and 3 show specific examples of a RWHI system. Some specific micro-catchment and in-situ RWH systems can complementary be used to increase the volume of water collected and stored. In these cases, the main objective would be to increase the level of shallow groundwater in order to use it for small-scale irrigation by means of a shallow well (section 2.4). Figure 4 shows the combination of a micro-catchment and in-situ RWHI system.

To optimise the natural biophysical capacity of arid and semi-arid areas by means of the collection, storage and reuse of rainfall has an immense transformative potential. Thus, Malesu et al. (2006) have stated that if only 15% of the rainwater in sub-Saharan Africa were harvested, it would be enough to meet all water-related food security needs of the continent.

In addition, supplemental and off-season irrigation during dry spells can trigger important positive production shifts (Oweis et al., 1999; Biazin et al., 2012) (see section 2.4). Thus, improved irrigation could halve the world's food gap that it is necessary to eradicate hunger worldwide by 2050 as well as increase production by an average of more than 55% in sub-Saharan Africa, which would be possible without expanding the area of land being farmed (Bacha et al., 2011).

To use rainwater for small-scale irrigation in arid and semi-arid areas can double smallholder yields in drought-prone regions while at the same time improving resilience to climate risks (Oweis et al., 1999; Dile et al., 2013). It could also contribute increasing global production by 41% and close the water-related yield gap by 62% (Jägermeyr et al., 2016; Park, 2016). This would be coupled with a diversification of the income-generation activities which would improve the livelihood potential in rural areas and alleviate poverty. Therefore, RWHI management has a very significant potential for food security, poverty alleviation and rural development. However, despite the direct proportionality among RWHI, food security, poverty alleviation and climate resilience, the full potential has not yet been exploited in terms of agricultural and livelihood improvements on one hand, and technological development and market/institutional adoption on the other (Payen et al., 2012).

Figure 2: A sand storage dam connected to a small-scale irrigation system in Kenya. Source: (AFRHINET project)

Figure 3: A low-cost drip irrigation system uses the water stored in a small earth dam to water high-value crops in Kenya. Source: (AFRHINET project)

Figure 4: A RWHI system based on a farm pond is complemented by other micro-catchment and in-situ RWH management technologies in Kenya. Source: (Oduor and Malesu, 2015)

2.2 Macro-catchment RWHI systems

This type of technologies collect surface runoff from external catchments and store it for further use during the dry season (Hatibu and Mahoo, 2000; Biazin et al., 2012). Rainwater/runoff is collected from existing paved surfaces and natural slopes, and at a lower extent from purpose-built structures (Biazin et al., 2012). The components of the system, the storage volume, and the catchment type and area, depend on the local rainfall pattern and soil types (Studer and Liniger, 2013). Several of the widely applied macro-catchment rainwater harvesting techniques are indigenous or modified from indigenous practices (Biazin et al., 2012). Rainwater harvesting irrigation from macro-catchment systems have eventually achieved recognisition as an alternative to conventional irrigation schemes (Rosegrant, 1997). Figure 5 shows the basic structure and components of a macro-catchment RWHI system.

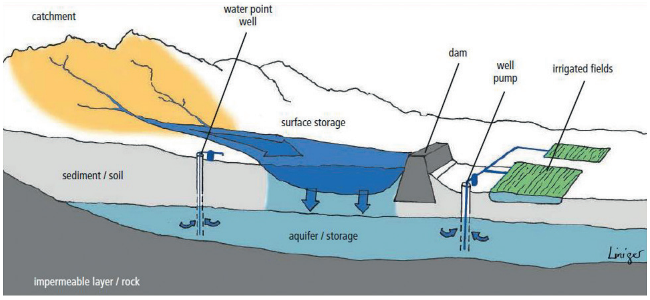

Figure 5: Basic structure and components of a macro-catchment RWHI system: A catchment area, storage and application area are clearly separated and connected by conveyance systems to an irrigated crop area. Source: (Studer and Liniger, 2013)

2.2.1 Selected RWHI Storage technologies in Ethiopia, Kenya, Mozambique and Zimbabwe

Most configurations for RWHI storage technologies are relatively common in the four countries participating in the study (Table 1). These include traditional and improved surface dams being promoted by local communities, governments, private sector and NGOs. Rainwater harvesting from tanks, ponds and earth dams are also common in all the countries. In some cases, water ponds in Ethiopia and Kenya and are covered by a roof to reduce evaporation losses. However, such configurations are not common in Mozambique and Zimbabwe.

Another important system used in Kenya, and at a lower extent in Ethiopia, Zimbabwe and Mozambique, are groundwater dams. However, their link to small-scale irrigation is generally untapped, with some exceptions in Kenya and Zimbabwe, where a small number of groundwater dams are being used to irrigate community-based vegetable gardens.

In all the countries, in-situ and micro-catchment technologies, especially terraces, infiltration pits, fanya juus and dead level contours are widely implemented (section 2.3).

In Ethiopia, trenches and terraces are common in steep slopes. Only in Mozambique the use of pots has been reported for irrigating horticultural crops. Widespread adoption of tied ridges has been reported in Zimbabwe. Although micro-basins have been widely promoted in Zimbabwe by NGOs, their adoption appears to be hampered by high labour requirements.

Table 1 shows a selection of relevant macro-catchment RWH collection technologies coupled with a storage system that are currently implemented in Ethiopia, Kenya, Mozambique and Zimbabwe. These technologies, at a lower or larger extent, show the potential to be efficiently linked with small-scale irrigation systems to irrigate crops during dry spells.

2.2.2 On-farm pond systems

These structures are constructed by excavating a depression for the water reservoir and depositing the excavated soil on the lower side of the water reservoir as an embankment that will increase the storage volume of the excavated water reservoir (Nissen-Petersen, 2006a). A geo-membrane can be placed inside the depression to prevent percolation. The dam wall is often 2-5m high and has a clay core and spillway to discharge excess runoff (Ngigi, 2003). Water pans and ponds usually range in size from 50-1,500 m^3 and can store water for 4-16 weeks after rains depending on the soil type (Ngigi, 2003). Due to their size, these structures are predominantly used at household level. Figure 6 shows an on-farm pond in Kenya.

Figure 6: Lined farm ponds formed by excavating soil in Kenya. Source: (AFRHINET project)

Table 1: Macro-catchment RWHI systems with the potential to be used for small-scale irrigation. Source: adapted from Simane et al. (2014), Oguge and Oremo (2014), Cuamba et al. (2015) and Wuta et al. (2014)

RWH Storage Technology	Ethiopia	Kenya	Mozambique	Zimbabwe
Water pans and ponds	+++	+++	+++	+++
Earth dams and Community ponds	+++	+++	+++	+++
Groundwater dams: sand dams, sub-surface dams and weirs	+	++	+	+
Rock outcrops	+	++	++	+
Rooftop Catchments	+	+	+	+
Road Catchments	+++	+++	+	+
Surface dams and perennial riverbeds	+	+	++	+
Micro-catchment and In-situ RWHI systems for shallow groundwater recharge	+++	+++	+	++

2.2.3 Earth dams and community pond systems

Earth dams and community ponds are also excavated water reservoirs as water pans and ponds. Figure 7 shows an example of an earth dam. However, their storage capacity is significantly higher, and therefore, are built to be used at community level. According to Nissen-Petersen (2006a), these dams present storage capacities up to 10,000 m^3 and have embankments up to a height of 5 metres. Earth dams can be built manually, using animal draught, a farm tractor, a crawler or bulldozer. There are three main types of earth dams:

1. Charco dams for predominantly flat lands
2. Hillside dams for rolling and hilly lands
3. Valley dams for seasonal water courses and valleys

Figure 7: An earth dam in southern Kenya. Source: (AFRHINET Project)

2.2.4 Groundwater dam systems: Subsurface dams and sand storage dams

There are two main types of groundwater dams: subsurface dams and sand storage dams. A subsurface dam is a small-scale hydraulic retention structure which is built across seasonal sandy riverbeds (Nissen-Petersen, 2006b; 2013). To construct a subsurface dam, a trench is dug across a valley at a suitable site, reaching down the bedrock or impervious layer. In the trench, an impermeable wall or barrier is constructed, which is refilled with clayey soil, rubble stone masonry or concrete (Nissen-Petersen, 2013). Subsurface dams block the flow of shallow groundwater and raise its level minimizing evaporation as long as the crest of the spillway is kept under at least 1 m (Nissen-Petersen, 2013). Subsurface dams do not present any vulnerability to siltation or flood erosion due to their underground position (Nissen-Petersen, 2013, De Trincheria et al., 2015). Therefore, subsurface dams show an inherent higher cost-efficiency than sand storage dams (Nissen-Petersen, 2013, De Trincheria et al., 2015).

Figure 8: A sand storage dam built by stages in Zimbabwe (left) and in one-stage in Kenya (right). Source: (AFRHINET project)

As it is shown in Figure 8, a sand storage dam is a subsurface dam whose spillway has been raised several meters on the surface of the riverbed. The main working principle is to accumulate the coarsest sediments of the runoff in order to build an artificial aquifer made of coarse sand. Under the precautionary principle, in order to assure a maximum accumulation of the coarsest materials and a systematic minimisation of siltation, the spillway should be built by stages of reduced height (De Trincheria et al., 2015; De Trincheria et al., 2016). The minimum optimal water yield of a sand dam is 1,000 m^3/dry season (De Trincheria et al., 2016).

2.2.5 Rock outcrop catchment systems

Rock outcrops generate significant volumes of water that can be collected and stored for small-scale irrigation purposes. The major requirement is a rock outcrop with a large surface area. Therefore, the option is suitable for areas with rocky outcrops, as it is shown in Figure 9. It is estimated that rock catchments can collect 90% of total rainfall in the catchment area, providing a valuable water supply even when rains are below normal levels (Hauser, 2012). Rocks lined near the bottom of the rock outcrop can trap solid debri. The water is usually stored in tanks which are built near the rock catchment. Also, a dam built on the surface of the rock can be built to store the water.

Figure 9: A rock catchment rainwater harvesting system in Kenya. Source: AFRHINET project..

2.2.6 Roadwater catchment systems

This group of practices focuses on accumulating and storing the rainwater from roads for further reuse for small-scale irrigation. Road runoff water harvesting systems vary from simple diversion structures directing surface water into crop fields, to deep trenches with check dams in order to enable both flood and subsurface irrigation (Masila et al., 2015). Figure 10 shows one example of road that can be used as a catchment to collect and diver rainwater. In order to use road water harvesting for small-scale irrigation, the runoff collected must be stored either in a tank (section 2.2.8) or in permeable soil connected to a shallow groundwater reservoir.

Figure 10: Roads can be used as a catchment to collect and divert rainwater, as it is shown in this example in Kenya. Source: (AFRHINET Project)

2.2.7 Rooftop catchment systems

These type of technologies revolve around the collection of rainwater by means of roof catchments and the storage through gutters in a tank (section 2.2.8) for their prospective use for small-scale irrigation purposes, as it is shown in Figure 11. Typically, a rooftop RWH system consists of a catchment area, filter, storage tank and a supply facility (Mun and Han, 2012). Roofs, particularly those with tiles, metal or asbestos sheets, can be used to collect and redirect rainwater into collection tanks. Gutters are usually placed at the lower roof to concentrate and redirect rainwater to a collection tank. In rural areas, rooftop RWH systems are mainly used for household use (Gur and Spuhler, 2010).

Figure 11: Building roof with gutters that direct water to an underground storage tank in Zimbabwe (left) or to a surface tank in Kenya (middle and right). Source: (Wuta et al., 2015 and AFRHINET Project).

2.2.8 Tanks

These are large containers which are used to store water. Tanks greatly vary in sizes, forms and materials (metal, wood, plastic, fibreglass, brick, interlocking blocks, compressed soil or rubble-stone blocks, ferro-cement and reinforced concrete). However, they usually store $1m^3$-$30m^3$ of water and are made from galvanized iron or plastic. Due to their size, tanks are used at the household level, both above or below the ground (Gur and Spuhler, 2010). Figure 12 shows a specific example of a plastic tank.

Fgure 12: Plastic storage tanks in Kenya. Source: (AFRHINET project)

2.2.9 Surface dam systems

Surface dams are runoff storage structures that are built across perennial and seasonal rivers. The dam wall is usually made of reinforced steel, concrete, rubble stone or soil. The capacity of dams varies from site to site. Figure 13 shows an example of a small-scale surface dam across a gulley.

Figure 13: A small surface dam is used to store harvested water for irrigation. Source: (Simane et al., 2014)

2.3 Micro-catchment and in-situ RWHI systems

Throughout human history, societies have developed various traditional water harvesting techniques such as terraces, earth and stone bunds (Critchley et al., 1991; Beckers et al., 2013; Josef and Asmamaw, 2015). These were relatively inexpensive and moderately successful in intensifying agricultural productivity in environments where crop productivity was significantly reduced by inadequate or poorly distributed rainfall (Beckers et al., 2013). Over the years, these traditional water harvesting techniques have been upgraded, and several other modern techniques introduced (Nyamadzawo et al., 2013). The main working principle of these technologies is maximising infiltration and minimising surface runoff in order to achieve better yields where soil moisture is a constraint. Some of the water captured by these technologies, especially in high rainfall events, can recharge shallow groundwater where it may become available for small-scale irrigation during the dry season, if the water is connected to a shallow well. Figure 14 shows a specific example of this RWHI system in Zimbabwe.

Figure 14:A combination of a rock catchment and different micro-catchment (terraces, trenches) and in-situ RWH systems (furrows and conservation tillage) allowed sufficient shallow groundwater recharge to use a shallow well for small-scale irrigation during the dry season in semi-arid Zimbabwe. Source: (AFRHINET project)

2.3.1 Micro-catchment systems

According to Biazin et al. (2012), a micro-catchment rainwater harvesting system collects runoff from relatively small catchment areas from 10 to 500 m² within the farm boundary. Figure 15 shows a technical diagram of a micro-catchment RWH system. The most commonly applied micro-catchment rainwater harvesting techniques in sub-Saharan Africa include pitting, contouring, terracing and micro-basins (Motsi et al., 2004; Nyamangara and Nyagumbo, 2010; Biazin et al., 2012; Malesu et al., 2012; Nyamadzawo et al., 2013). These type of technologies are more widely implemented in Ethiopia and Kenya as compared to Zimbabwe and Mozambique. Table 2 shows the distribution of relevant micro-catchment technologies for RWH in Ethiopia, Kenya, Mozambique and Zimbabwe. Figure 16 shows different examples of this type of RWH systems.

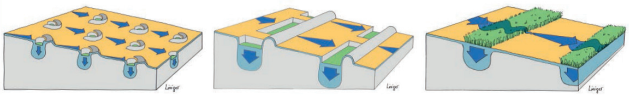

Figure 15: Basic structure of several micro-catchment RWH systems: planting pits (left), contour bunds (middle) and vegetative barriers (right). Source: (Studer and Liniger, 2013)

Figure 16: Micro-catchment RWH systems (terraces -below- and trenches -above-) that are facilitating infiltration of rainwater; reduced runoff and higher shallow groundwater levels in Ethiopia. Source: (Simane et al., 2014)

2.3.2 In-situ systems

In-situ systems involve the use of practices that increase infiltration, reducing runoff and evaporation, and improving soil moisture in the crop rooting zone by trapping and holding the rain where it falls (Hatibu and Mahoo, 2000; Ngigi, 2003; Gebreegziabhert et al., 2009; Nyamangara and Nyagumbo, 2010). These techniques generally do not need a runoff-inducing catchment area; rather, they are aimed at enhancing rainfall infiltration and reducing soil evaporation. The most commonly applied in-situ rainwater harvesting and management practices in sub-Saharan Africa include ridging, mulching, various types of furrowing and hoeing, and conservation tillage (Biazin et al., 2012).

Various studies suggest that in-situ rainwater harvesting in combination with improved soil fertility and good agronomic practices has the potential to unlock rainfed crop production systems (Ngigi, 2003; Gichangi et al., 2007; Mati, 2007; Kathuli et al., 2010; Nyamangara and Nyagumbo, 2010; Nyagumbo et al., 2011; Malesu et al., 2012; Nyamangara et al., 2013). Table 3 shows the distribution of relevant in-situ RWH catchment systems in Ethiopia, Kenya, Mozambique and Zimbabwe. Figure 17 shows specific examples of this RWH system.

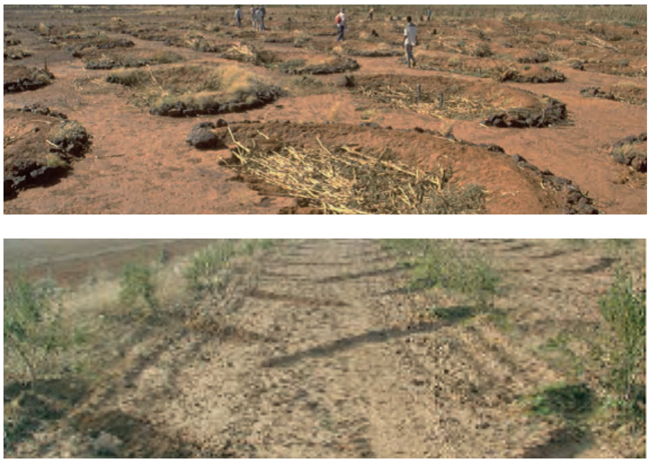

Figure 17: Mulching (top) and runoff collection with furrows (bottom). Source: (Studer and Liniger, 2013)

Table 2: Relevant micro-catchment technologies for RWHI in Ethiopia, Kenya, Mozambique and Zimbabwe. Source: adapted from Biazin et al. (2012), Simane et al. (2014), Oguge and Oremo (2014), Cuamba et al. (2015) and Wuta et al. (2014)

Micro-catchment RWH	Description	Ethiopia	Kenya	Mozambique	Zimbabwe
Pitting: Different types of planting pits and trenches	Grid of planting pits are dug across plots or along the contours with or without bunds downslope	+++	+++	+	+++
Contouring: Stone and soil bunds, hedge rows and vegetation barriers	Stones or earthen bank is piled on a foundation along the contour in a cultivated hill-slope, sometimes stabilized with vegetation.	+++	+++	+	+
Terracing: Fanya juu, semi-circular and hillside terraces	Bunds in association with a ditch, along the contour or on the lateral of a gradient which are constructed in different forms	+++	+++	+	++
Micro-basins	Different shapes of basins surrounded by low earth bunds	+++	+++	+	+

Table 3: Overview of the most relevant in-situ RWH systems practices in Ethiopia, Kenya, Mozambique and Zimbabwe. Source: adapted from Biazin et al. (2012), Simane et al. (2014), Oguge and Oremo (2014), Cuamba et al. (2015) and Wuta et al. (2014)

In-situ RWH	Description	Ethiopia	Kenya	Mozambique	Zimbabwe
Furrowing	Different furrowing techniques are used before or after planting in order to conserve soil and water. Fertilisers are usually used in conjunction	+++	+++	+	+
Ridging	Basins wider than traditional furrows are implemented using a modified ploughing instrument	+++	+++	++	+++
Mulching	The use of crop residues and other materials like stones which are aimed at covering the soil and improve water infiltration	++	++	+	+
Conservation tillage	A wide range of tillage techniques meant to increase soil moisture and enhance crop production	+++	+++	++	+++

2.4 Small-scale irrigation systems

Small-scale irrigation is emerging in sub-Saharan Africa as there is an increasing number of smallholder farmers that engage in small-scale irrigation and in many countries the area under privately managed and owned irrigation is larger than under public irrigation schemes (De Fraiture and Giordano, 2014). In fact, much of the investment in small-scale water extraction devices and irrigation equipment in sub-Saharan Africa has been made by individual farmers, without involving a formal irrigation scheme or a water user association (Wichelns 2013, De Fraiture and Giordano, 2014). In this study, small-scale irrigation is understood as a group of simple technologies/practices operated and managed by individuals or in small self-initiated groups, which usually have been initiated and funded by the farmers themselves in areas lower than 2 ha, and that use low-cost and easy-to-maintain technologies in order to grow high-value crops during the dry season for direct consumption and/or the local market (De Fraiture and Giordano, 2014).

As agriculture is the most important source of rural livelihoods in Africa, improvements in agriculture will not only help secure food supply but also will contribute to the growth of household incomes in rural areas (Rosegrant et al., 2006). In addition, smallholder irrigation may considerably contribute to agricultural productivity growth in sub-Saharan Africa with a large potential for profitable smallholder irrigation expansion in sub-Saharan Africa (Xie et al., 2014). Small-scale irrigation during the dry season has the specific advantage of obtaining additional income during a period when other agricultural incomes are low (Wichelns, 2013; De Fraiture and Giordano, 2014; Nicol et al., 2015). Therefore, small-scale irrigation has a very significant potential for poverty alleviation and rural development (Wichelns, 2013; De Fraiture and Giordano, 2014; Xi et al., 2014). Thus, Bacha et al. (2009) found that the incidence, depth, and severity of poverty were significantly lower among those farm households with access to irrigation. Nicol et al. (2015) found that small-scale irrigators in Kenya gives good profits: compared with farm incomes from rainfed land, which average less than USD 750/ha, irrigated land can produce two-three crops a year worth USD 1,400 (snow peas, French beans), USD 450 (kale) or USD 600 (onions). The investment costs of private irrigation are usually low and affordable to individual farmers and the operational costs of these manual technologies are low because family labour is typically not priced in the market (De Fraiture and Giordano, 2014).

2.4.1 Selected small-scale irrigation systems in Ethiopia, Kenya, Mozambique and Zimbabwe

Wichelns (2013) found that in sub-Saharan Africa, smallholders mainly invest in buckets, watering cans, drip irrigation kits, pipes, manual pumps or small motorized pumps. The predominant water sources are nearby rivers, canals, reservoirs or shallow wells.

The most common small-scale irrigation method in all the four countries is manual irrigation by means of the use of a watering can, bucket or jerry can (Fraiture and Giordano, 2014; Simane et al., 2014; Oguge and Oremo, 2014; Cuamba et al., 2015; Wuta et al., 2014). Water is directly applied to a plant through a spout fitted with a shower rose. This method is widely practiced in the production of garden vegetables and where the water source is near the garden. In addition, most smallholder irrigation schemes in sub-Saharan Africa usually apply surface irrigation (De Fraiture and Giordano, 2014). These methods involve the diversion of water from streams and dams by gravity or mechanised pumping. The water is then conveyed by means of mainly open channels or pipes to the cropped area. Canals, which are lined or unlined, are also used to direct water into the fields. Unlined canals are popular among the resource-poor farmers because of low initial costs. Water can also be conveyed to the fields by using pipes fitted with or without sprinklers. The pipes vary in different sizes and can be moved from one position in the field to another (Simane et al., 2014; Oguge and Oremo, 2014; Wuta et al., 2015).

A specific type of small-scale irrigation system with high potential revolves around the use of micro-irrigation systems (Simane et al., 2014; Oguge and Oremo, 2014; Wuta et al., 2014). These mainly involve low-head, low-cost drip (LHLCD) irrigation kits for smallholder farmers. LHLCD kits range from 20-litre bucket kits to 200-litre mini-tank systems that operate at 0.5 to 1 metre water head and irrigate up to 2000 m^2 (Ngigi, 2009). De Fraiture and Giordano (2014) found that LHLCD kits that irrigate up to 500 m^2 are marketed for around USD 250. With drip systems, plants receive water through emitters that produce droplets of water, thereby, wetting the soil around the plant root zone (Ngigi, 2003). The simplest is a "bucket drip kit", which is made up of a bucket, a filter, connectors and a drip tape. Farmers commonly use the system in home/kitchen gardens (Kaluli et al., 2005). Other types of micro-irrigation systems are based on vegetable gardens that are manually irrigated and/or use simple manual pumps to lift water from a small reservoir usually located nearby the farm (Simane et al., 2014; Oguge and Oremo, 2014; Cuamba et al., 2015; Wuta et al., 2014).

Manually operated pumps such as treadle pumps have not been adopted at large scale, despite social marketing efforts by international NGOs (De Fraiture and Giordano, 2014). These authors also found that the adoption of water pumps which are coupled to diesel- and petrol-powered engines in sub-Saharan Africa has only recently started to take off, but the technology is spreading steadily. In Ethiopia, a conservative estimate of 400,000 pumps were imported from 2002 to 2012 (De Fraiture and Giordano, 2014).

In some places, foot-pumps are used to pump water for horticultural irrigation by the communities. In such cases, water conveyed to the fields by means of the use of pipes (e.g. HDPE, hoses, etc.) on which sprinklers can be connected. Solar-powered pumps are also increasingly being promoted by some NGOs (Simane et al., 2014; Oguge and Oremo, 2014; Cuamba et al., 2015; Wuta et al., 2014). Ox-drawn bowsers mounted on wheels are also used for small-scale irrigation. The water bowsers are fitted with a tap on which a flexible pipe can be fitted. Water is conveyed to the fields by use of the pipes. Such technologies usually apply water only at the planting station (Wuta et al., 2014).

Xie et al. (2014) found that the area expansion potential in sub-Saharan Africa is 30 million ha for motor pumps, 24 million ha for treadle pumps, 22 million ha for small reservoirs and 20 million ha for communal river diversions. These systems can benefit between 113 and 369 million rural people in the region generating net revenues of USD 14–22 billion per year, depending on the specific type of system (Xi et al., 2014).

The most widely practiced methods of irrigation in Ethiopia, Kenya, Mozambique and Zimbabwe are summarised in Table 4. The link between small-scale irrigation and RWH comes when the rainwater stored during the rainy season is used for irrigation during the dry season. An example of best practice is incorporating low-cost drip irrigation technology to a rainwater harvesting system, which can enhance rainwater management for agricultural production during the dry season.

2.4.2 Manual irrigation systems

Table 5 provides an overview of key factors relevant to the implementation of small-scale manual irrigation technologies. Figure 18 shows a specific example of manual irrigation in Kenya.

Figure 18: A bucket irrigation system connected to a sub-surface dam in Kenya. Source: (AFRHINET Project)

Table 4: Small-scale irrigation technologies commonly practiced in the countries under study. Source: adapted from Simane et al. (2014), Oguge and Oremo (2014), Cuamba et al. (2015) and Wuta et al. (2014)

Small scale RWHI Technology	Ethiopia	Kenya	Mozambique	Zimbabwe
Watering can/bucket	+++	+++	+++	+++
Sprinkler system (single drag hose)	+	+	+	+
Drag hose irrigation (no sprinklers)	+	+	+	+
Low-cost drip irrigation kits	+	+	+	+
Ox-drawn/tractor-drawn bowsers	-	-	-	++
Surface irrigation	++	+	+	++
Manual pumping	++	++	++	++
Mechanised pumping	+	+	+	+

Table 5: Key factors relevant for the implementation of small-scale manual irrigation systems. Source: adapted from Staufer and Spuhler (2010a)

System	Description	Advantages	Disadvantages	Costs	Suitability
Manual irrigation: Bucket/can irrigation	Water is delivered to the cropping area manually	Simple Effective No need of technical equipment Self-replicable Reduction of evaporation	High labour and time requirements	Low initial capital costs	Arid and semi-arid areas: Higher suitability for small-scale farming at household level or riparian communities

2.4.3 Sprinkler irrigation systems

Table 6 provides an overview of key factors relevant to the implementation of small-scale sprinkler irrigation systems. Figure 19 shows a specific example of this system in Zimbabwe.

Figure 19: A sprinkler irrigation system in Zimbabwe. Source: (Nyamangara, 2015)

2.4.4 Low-cost drip irrigation systems

Table 7 provides an overview of key factors relevant for the implementation of small-scale low-cost drip irrigation systems. Figure 20 shows specific examples of this system in Kenya and Zimbabwe.

Figure 20: A low-cost drip irrigation system in Kenya and Zimbabwe. Source: (AFRHINET Project; Nyamangara, 2015)

Table 6: Key factors relevant for the implementation of small-scale sprinkler irrigation systems. Source: adapted from Staufer and Spuhler (2010b)

System	Description	Advantages	Disadvantages	Costs	Suitability
Sprinkler irrigation	Rainfall-like irrigation to the crops through a system of pipes usually by pumping	Suitable for all types of crops and irrigable soils	Clogging High evaporation losses Sensitivity to crop diseases	For small sprinkler equipment for gardening the initial capital costs are relatively low. High operation costs due to expenses for pumping, labour and sprinklers and pipes	Low suitability to arid and semi-arid areas and resource poor farmers but it is appropriate for small-scale irrigation

Table 7: Key factors relevant for the implementation of small-scale drip irrigation systems. Source: adapted from Staufer (2010)

System	Description	Advantages	Disadvantages	Costs	Suitability
Low-cost drip irrigation	Water flows through a filter into special drip pipes. Water is distributed through the emitters directly into the soil near the roots	Effectivity Water conservation Reduction evaporation Reduction deep drainage High performance Small-scale drip systems can be operated by trained farmers	Maintenance requirements	Simple self-made systems are cheap (US$15 to $85) or construct it with local available material (buckets, bamboo or plastic pips)	Arid and semi-arid areas: Higher suitability for small-scale farming at community-based level

2.4.5 Surface irrigation systems

Table 8 provides an overview of key factors relevant for the implementation of small-scale surface irrigation systems. Figure 21 shows different examples of this type of systems in Kenya and Zimbabwe.

Figure 21: Water is gravitated from a 50 year old sand dam to fields situated at lower elevations (left) and surface irrigation in Zimbabwe (right). Source: (Nissen-Petersen, 2015 and Nyamangara, 2015)

2.4.6 Pumping systems

Table 9 provides an overview of key factors relevant for the implementation of small-scale manual and mechanised pumping systems. Figure 22 shows specific examples of manual and mechanised pumping in Kenya and Zimbabwe.

Figure 22: Manual pumping using a hand-pump in Kenya (top left and right), solar pumping in Zimbabwe (bottom left) and a portable petrol-powered water pump suitable in Kenya (bottom right). Source: (AFRHINET Project; Gumbo, 2015 and Nissen-Petersen, 2015)

Table 8: Key factors relevant for the implementation of small-scale surface irrigation systems. Source: adapted from Staufer and Spuhler (2010c)

System	Description	Advantages	Disadvantages	Costs	Suitability
Gravity surface irrigation	Water is distributed by gravity over the surface of the field	Simple High performance No pumping requirements High acceptability Low salinity risk	Levelling requirements High labour input Pounding risk Evaporation risk	If topography is uneven, capita costs are high	Moderate suitability to arid and semi-arid areas. Appropriate for small-scale irrigation at household level

Table 9: Key factors relevant for the implementation of small-scale surface pumping systems. Source: adapted from Bruni and Spuhler (2010a,b)

System	Description	Advantages	Disadvantages	Costs	Suitability
Manual pumping	Water-lifting devices that can be operated manually	Simple to install and operate Effective: depths up to 80 metres Versitability Suitable to wide local condition	High maintenance requirements, especially at community level Low cultural acceptance	Low-cost options exist making use of locally available material and labour	Arid and semi-arid areas for small-scale irrigation at household level Highly suitable for places where access to power sources is limited and where financial resources for investment are constrained
Mechanised pumping	Water-lifting is driven by various power sources: electricity, fuels, animals, wind power, solar power, and gravity. ‘motorised pumps’ are associated with diesel- and electro pumps	Very high performance if correctly maintained and operated	High level of technical skills Regular needs for spare parts	High capital, operation and maintenance costs. Low-cost options for mechanised pumps hardly exist	Arid and semi-arid areas for small-scale irrigation at community level. Low suitability for small-holders

3. TECHNOLOGY-TRANSFER POTENTIAL

3.1 Technology transfer and rainwater harvesting irrigation management

Technology transfer is the process of transferring skills, knowledge, technologies and facilities in order to ensure that scientific and technological developments are accessible to a wider range of users, who can then further develop and exploit the technology into new products, processes, applications, materials or services. It is closely related to knowledge transfer. Horizontal transfer is the movement of technologies from one area to another. Vertical transfer occurs when technologies are moved from applied research centres to research and development departments. The development and effective diffusion of new agricultural practices and technologies will largely shape how and how well farmers, especially in sub-Saharan Africa, mitigate and adapt to the effects of climate change (e.g. water scarcity) (Lybbert and Sumner, 2012).

Technology transfer must be recognized as a broad and complex process in order to avoid dependency of the recipient and contribute to sustained and equitable development. The end-result for the recipient must be the ability to use, replicate, improve, and ideally resell the technology. Transfer of technology is more than the transfer of technologies from North-South, South-South or South-North. It also encompasses the transfer of know-how, goods and services, and organizational and managerial procedures. Thus, technology transfer is the suite of processes encompassing all dimensions of the origins, flows and uptake of know-how, experience across and within countries, stakeholder organizations and institutions. A further stage of technology transfer involves commercialization, where technology moves from research and development stage to become a product or service (Mc Inerney, 2014).

If the transfer of inadequate, unsustainable, or unsafe technologies is to be avoided, technology recipients should be able to identify and select technologies that are appropriate to their actual needs, circumstances and capacities. Therefore, a key element of this wider view of technology transfer is choice (Boithi et al., 2014). There is no single strategy for successful transfer that is appropriate to all situations. Desirably, a technology recipient will choose a technology, which at least meets the definition of being environmentally sound (Morelli, 2011). Environmentally sound technologies (ESTs) are technologies that have the potential for significantly improved environmental performance, relative to other technologies. Such technologies contribute to the three pillars of sustainable development.

Farmers and other resource users are naturally more willing to adopt technologies that provide significant and sustained returns in terms of increased food production and farm income. Water harvesting technologies recommended for up-scaling must be profitable for users and local communities. In this regard, cost efficiency, including short and long-term benefits are fundamental to the adoption of such technologies. Farmers who have insecure land tenure and limited access to market information are less likely to adopt rainwater harvesting technologies (Merrey, 2013). On the other hand, yield increase ranks as the most important driver for adoption of water harvesting technologies across sub-Saharan Africa (Dile et al., 2013) but farmers are reluctant to invest in water harvesting if the yield potential and returns on investment are low (Bouma et al., 2016). Rainwater harvesting irrigation systems should focus on overcoming the bottlenecks and maximizing opportunities along the market value chain. Besides contributing to household food security, rainwater harvesting should promote better linkages and access to markets by supporting transition of smallholder agriculture from subsistence to small-scale commercial enterprise in local markets, especially under semi-arid environments. Moreover, rainwater harvesting systems, such as earth dams, enhance diversification of income activities, including tree nurseries, brick making, fish farming, and poultry (ducks and geese), and therefore, contribute to poverty reduction. Improved access to markets is crucial to support such activities and enhancing realization of benefits.

While rainwater harvesting has been tried and tested often with significant success in terms of high crop yields (Dile et al., 2013; Karpouzoglou and Barron, 2014), such successes can be suppressed by high labour requirements and low market prices (Medhin and Teklehaimanot, 2013). With improving market prices and increased knowledge about innovative rainwater harvesting technologies, drylands have the potential to become self-sufficient and even net food producers. However, without secure land tenure, water rights and access to markets, farmers will remain reluctant to invest time and money in rainwater harvesting technologies. Access to land, inputs and market is a prerequisite for the successful adoption of rainwater harvesting innovations (Medhin and Teklehaimanot, 2013).

While a large number of rainwater harvesting projects have been carried out, the adoption and replication of such technologies remains low due to the following challenges.

- Firstly, promoting rainwater harvesting and increasing investments, both at community and donor levels, would require showcasing its potential through successful and sustainable projects (Malesu et al., 2012). This would serve to build confidence in rainwater harvesting as a viable and sustainable source of water for multiple uses -domestic, livestock and crop production, and hence, improved livelihoods, and food security. The main indicators of a successful project that will attract interest and investment, will be how rapidly and to what extent crop yields and income can be improved through rainwater harvesting irrigation systems (Dile et al., 2013; Bouma et al., 2016). Analysis of the potential of scaling up rainwater harvesting from farm to watershed scale is a challenge that must be addressed to convince policy-makers and development partners about the cost-effectiveness and sustainability. Success should first be demonstrated at farm and watershed levels before scaling up to river basin and national levels.

- Secondly, targeted practical training and establishment of technology promotion and demonstration centres should be promoted. In addition, more emphasis should be given to publicity and awareness creation on the effects of climate change on smallholder farming systems, and the potential of rainwater harvesting as a key adaptive strategy.

- Thirdly, establishment and strengthening of rainwater harvesting networks has the potential to accelerate investments and adoption of rainwater harvesting and irrigation systems (Karpouzoglou and Barron, 2014). An improved rainwater harvesting network will enhance, not only the communication and collaboration among relevant stakeholders, but will also lobby for government and donor support. Moreover, strengthening regional rainwater harvesting networks in countries at the forefront of innovative research and promotion of affordable rainwater harvesting systems, such as India, China, Brazil, the Netherlands, Ethiopia and Kenya, will enhance adoption of best practices. The AFRHINET project represents an excellent opportunity to kick-start this process of strengthening cooperation and enhancing networking among academic and research communities with businesses/micro-enterprises, NGOs and public sectors, and policy-making actors and local communities.

Furthermore, an improved rainwater harvesting network could also help facilitate the introduction of a certification process for rainwater harvesting products. A standardized framework for various products, such as water tanks or farm ponds, and the development of technical capacity building programmes is required in order to enhance quality control in design and production of rainwater harvesting products and services. Such a network would also develop guidelines, standards and criteria for site selection, provide basic data for design and socio-economic analysis, and linkage with service providers (e.g. trainers and spare parts) for various components of rainwater harvesting systems. The analysis of potential sites for rainwater harvesting in terms of topography, soils, and climate; and socio-economic data is very essential (Jha et al., 2014). The technology required should be appropriate to the local needs (Boithi et al., 2014; Mc Inerney, 2014). For example, the use of electric pumps for rainwater harvesting tanks or ponds in rural areas may not be prudent because they will be rendered useless if spare parts or technical knowledge is not locally available or affordable or if electricity is unreliable or non-existent.

3.2 Rainwater harvesting irrigation technologies with technology transfer potential

As the appropriateness of RWHI technologies in each country is determined by the biophysical conditions of the area, access and availability of resources, there is a need to conduct region-specific research on RWHI. At the smallholder scale, availability of labour is critical for sustainable implementation of rainwater harvesting technologies. Runoff collection and storage may present a better opportunity for implementation in all the partner countries due to their lower labour requirements. It is also easier to divert rainwater/runoff into different storage systems, like farm ponds, and use any excess water to water the fields during the rainy season. This technology can be attractive to farmers because of the often high intensity rainfall that are received within the tropical areas.

In the drier regions of the countries under study, there is also potential for implementing groundwater dams. This technology has the advantage of increasing infiltration and reducing evaporation. It is estimated that evaporation can account up to 60-97% of the water loss from open water sources (Mugabe, 2003; Fowe et al., 2015). However, the link of groundwater dams with small-scale irrigation is limited to the immediate nearby area of the riverbed. This means that usually the water stored in the reservoir is used to grow horticultural crops along the riverbeds.

The link of groundwater dams with small-scale irrigation at household level requires a conveyance and pumping system, which may be too expensive for smallholders. At household level, the use of ponds, rooftops and bare rocks has also potential. However, rooftop RWHI normally requires special water collecting structures such as gutters which can be expensive for the smallholder farmers. Table 10 shows the transfer potential of the rainwater harvesting storage technologies that can be used for small-scale irrigation.

RWH Storage Technology	Replicability and Transfer potential
Earth dams and Community ponds	+++
Farm ponds	+++
Road Catchments + Storage System	++
In-situ RWH for shallow groundwater recharge	++
Roof Catchments + Storage System	+
Rock Catchments + Storage System	+
Groundwater dams: sand dams, subsurface dams and weirs	+

Table 10: Transfer potential of the rainwater harvesting storage technologies that can be used for small-scale irrigation. Source: adapted from Simane et al. (2014), Oguge and Oremo (2014), Cuamba et al. (2015) and Wuta et al. (2014)

Earth dams and community ponds, and farm ponds, are considered the technologies with the highest replication and transfer potential. This is due to the fact that these technologies are suitable to a wider range of biophysical conditions as compared to the other selected technologies. Even though the capital investment and the labour requirements are significant and should be taken into account, there are many examples of spontaneous adoption and replication of these technologies, which necessarily indicates the replicability potential of these technologies. The link with small-scale irrigation comes inherently to the implementation of these structures, especially for farm ponds. In the case of earth dams and community ponds, the use for small-scale irrigation is necessarily related to community-based groups in nearby areas of the structures. Strictly focusing on technology transfer, there are still many innovations that these technologies could adapt in order to improve their replication and transfer potential. A good example of this is the selection of appropriate lining systems that avoid seepage in farm ponds, as well as the link of these ponds with affordable greenhouses in order to reduce evaporation.

Road catchments (coupled with a suitable storage system) and in-situ/groundwater recharge techniques specifically meant to recharge shallow groundwater (for its prospective use for small-scale irrigation during the dry season) are considered to have medium technology transfer potential. Even though roads are ubiquitous, the necessity to add a storage system in order to use it for small-scale irrigation limits the replicability and transfer potential. This necessarily increases the costs of this option and limits the adoption from local communities, and therefore, its suitability as a rainwater harvesting irrigation technology. It is necessary to take into account the limited storage capacity of the storage system, which will be proportional to the costs of the system. However, the link between harvesting water from roads and their prospective use for small-scale irrigation shows high potential for research and innovation, as there is still the need to identify different systems that could cost-efficiently carry out this function. With regard to the use of in-situ/groundwater recharge techniques specifically meant to recharge shallow groundwater (for its prospective use for small-scale irrigation during the dry season), the replicability and transfer potential is also estimated to be medium because not all potential implementation sites will have the necessary biophysical conditions to allow this.

This is especially the case for reservoirs of shallow groundwater coupled with layers of highly permeable soil materials. In these cases, the investment costs would be considered to be low. However, the human labour requirements would be high, which would further limit their adoption. The innovation potential with regard to the use of these set of options is considered to be low. Roof and rock catchments are considered to have the relative lowest technology transfer potential. This is mainly caused because their implementation is limited where suitable catchment areas (i.e. roof or rocks) exist. In addition, there is the need to add a storage system, which further increases the costs and reduces the adoption potential for local communities. Another key point is the limited storage capacity of the storage system, which will be proportional to the costs. Groundwater dams are also considered to have a limited replicability potential due to the many biophysical conditions that limit their suitability, among them, seasonal sandy riverbeds with no seepage problems. In addition, the need to link the sand reservoir with a pumping and conveyance system is a barrier that needs to be taken into account in order to evaluate the adoption of this option for small-scale irrigation. In any case, groundwater dams present research and innovation potential in order to identify low-cost and cost-efficient ways to connect the sand reservoirs with small-scale irrigation at the household level.

3.3 Selected examples of technology transfer strategies in the African partner countries

In 1995, the regional government of Tigray, in Ethiopia, embarked on a water harvesting plan which consisted on building 500 micro-dams in 10 years, intended mainly for irrigation agriculture. However, the program was initiated without initial assessment, and stopped in 2001, achieving less than 10% of the target. An evaluation study in 1998 showed that the initial assumptions of potential water resources available were overly optimistic: the cost was significantly higher than estimated, and technical skills, human capacity and equipment were lacking.

At the end, 46 micro dams were constructed out of which 37 are still operational. Some have sedimentation problems or are seeping, while others were never filled because rainfall and catchment capacity were overestimated. Also in Ethiopia, RAIN Foundation established a Rainwater Harvesting Capacity Centre (RHCC) in 2005 within an existing organization called ERHA (Ethiopian Rainwater Harvesting Association). They built 11 tanks with a total storage capacity of 445,000 litres to supply water to more than 3,000 people. The collected rainwater is currently used at schools and health centres, mainly for drinking and hygiene purposes.

There has not been a clear or elaborated technology transfer strategy in Kenya. Different stakeholders usually implement their projects independently and without national monitoring, coordination, and standardization process. Stakeholders in Kenya are rarely aware of what their peers or other organizations are developing or promoting. Notwithstanding lack of a clear technology transfer strategy, relevant stakeholder in the field of rainwater harvesting, mainly from development organizations, have recorded some achievements in technology development and transfer. For instance, Kenya Rainwater Association (KRA) has designed, piloted and upgraded on-farm rainwater harvesting and management systems for smallholder farmers. Their integrated technological innovation package includes upgraded farm ponds, flexible designs of low head drip irrigation kits, and locally designed and assembled low-cost metallic greenhouses. These products are tailor-made to suit farmers' preference, land dimensions and economic capacity. In addition, KRA has developed an integrated technological package for pastoral communities (e.g. upgraded communal reservoirs) and primary schools (i.e. WASH and Nutrition components comprising roof catchment systems, farm ponds, and vegetable gardens under drip irrigation). The KRA technological packages have shown significant impacts in improving livelihoods of target communities and beneficiaries.

In Mozambique, there is no clear or elaborated technology transfer strategy on rainwater harvesting for irrigation and also for domestic use. In fact, RWHI is not part of the major policy documents in both water and agricultural sectors. Different stakeholders implement most activities for rainwater harvesting for irrigation in an independent way and without national monitoring, coordination, and standardization. A similar situation is found in Zimbabwe, where no clear technology transfer policy or strategy is available. However some NGOs in Zimbabwe have been promoting RWHI although on a project basis and therefore, not coordinated at national level. Africare, an international NGO, implemented a water harvesting and storage project "Farmer Innovations and Innovations" in Zvishavane district in the semi-arid region of Zimbabwe (Nyamangara, 2007). Farmers were encouraged to harvest runoff from rock outcrops, roads and rooftops and store it in ponds or direct it into dead level contours where it infiltrated into downslope fields (Nyamadzawo et al., 2013). Many households reported growing two crops in one season as compared to the previous one crop per season in good rainfall years. However, more frequent droughts and mid-season dry spells in most of southern Africa (Musiyiwa, 2014) call for RHWI policies in order to ensure food security, especially in smallholder areas where formal irrigation infrastructure is not available.

3.4 Regional similarities and differences

Rainwater harvesting interventions are being implemented in all project partner countries, as it is shown in Table 10. In most cases such projects are funded by international organizations and it is very common to see such projects becoming disfunctional after the end of the donor funding. However, Ethiopia and Kenya have made significant steps in implementing RWHI technologies. In all project partner countries, there are national associations, NGOs and private organisations dealing with rainwater harvesting. In Mozambique, there is a relatively lower implementation of RWHI technologies at all levels.

4. RESEARCH, INNOVATION AND CAPACITY-BUILDING NEEDS

4.1 Introduction

Agricultural water scarcity in the predominantly rainfed agricultural system of sub-Saharan Africa is more related to the variability of rainfall and excessive non-productive losses than the total annual precipitation in the growing season (Biazin et al., 2012). Although several RWHI innovations have been developed worldwide and some of them have been introduced in eastern and southern Africa, applied research and innovation is still required in order to fit them to local lifestyles, local institutional patterns and social systems (Mbilinyi et al., 2005; Ludi et al., 2013; Boithi et al., 2014; Mc Inerney, 2014). There is also need to build the capacity of smallholder farmers to enable them to operate the systems and where possible, introduce local innovations to fit their particular circumstances and preferences. This will enable wide adoption of RWHI technologies and ultimately increase the resilience of the farmers in the face of ever increasing climate change-induced droughts and dry spells because innovations that go through a participatory process of local adaptation have a greater chance of adoption by smallholder farmers (Rockström et al., 2004).

There is an increasing interest for research and innovation in the field of rainwater harvesting for food security in eastern and southern Africa (Ludi et al., 2013; Nyamadzawo et al., 2013). In an effort to increase food security in arid and semi-arid areas, the AFRHINET project seeks to introduce cost-effective innovations in the use of rainwater for small-scale irrigation during the dry season. It is recognized that linking rainwater with proper small-scale irrigation and agronomic services at watershed level will have a positive impact on sustained productivity (Awulachew et al., 2005; Gezahegn et al., 2006). However, while strengthened research systems may increase the supply of new knowledge and technology, it may not necessarily improve the capacity for innovation (Ngigi, 2009). Innovation goes beyond the creation of knowledge and encompasses factors affecting demand for and use of knowledge in novel ways. The form of agricultural innovations generated and adopted by farmers is a product of economic forces and the state of scientific knowledge.

4.2 Needs in the 4 AFRHINET African partner countries

Table 11 shows a summary of the key research, innovation and capacity-building needs in the field of RWHI in Ethiopia, Kenya, Mozambique and Zimbabwe. In addition, relevant stakeholders in the field of rainwater harvesting irrigation can be classified as it follows:

- Academic and scientific institutions
- Government: Decision- and policy-makers, and their technical staff (both national as well as regional or local governments)
- NGOs and civil society groups: At national and international level
- Private sector: Local and international consultancies and businesses/micro-enterprises. All working in the agriculture, irrigation and water sector
- Cooperatives and community interest groups: Involving small-scale farmers, women and youth groups, and small entrepreneurs and civil society

Table 11: Key research, innovation and capacity-building needs in the field of RWHI. Source: adapted from Simane et al. (2014), Oguge and Oremo (2014), Cuamba et al. (2015) and Wuta et al. (2014)

Research	Innovation	Capacity-Building
Better coordination of research in RWHI	Improved communication and dissemination of the results of research and innovation activities	Better training
More applied research to adapt recognized RWHI techniques	Increased forums for sharing findings	Regular contact and information exchange with communities
Assessing the impacts, benefits, and economic viability of different rainwater harvesting and irrigation technologies with the aim of convincing farmers and development partners to invest in the technology	Improvement of the awareness of decision makers	Institutionalization of RWHI guidelines, manuals and technical papers
Reviewing policy, legal and institutional issues that may affect adoption and scaling up of rainwater harvesting and irrigation technologies	Better documentation of projects detailing with best practices and lessons learnt	Enhancing sense of ownership for communal structures by the communities
Assessing the impacts of different financing mechanisms such as subsidies and credits on the adoption of rainwater harvesting and irrigation technologies	Integration of rainwater harvesting interventions with other activities	Linking of training institutions and government extension services
Promote farm-based demonstration trials and research on promising practices of rainwater harvesting at different hydrological scales and farming systems	Promoting sustainable projects, which do not stop when the funding ends	A longer-term commitment by donors and government to support RWHI
Determine factors that cause low adoption of rainwater harvesting technologies despite their demonstrated impacts on water and food security	Better cooperation between projects and RWHI interventions	Lack of capacity of partner/associate institutions to capitalize and disseminate their expertise and outputs
-	Missing market-oriented research and educational approaches in the field of RWHI	Lacking links and co-operations with research and teaching institutions from other countries
-	Weak links of partner/associate institutions with the private, public and non-governmental sector	-

4.3 Barriers

Major problems found in Ethiopia, Kenya, Mozambique and Zimbabwe concerning the implementation of rainwater harvesting irrigation are common and can be summarised as follows:

1. Efforts in RWHI are currently fragmented: NGOs, government departments and research institutions are each of them doing their own interventions with none or little cooperation among them
2. Policy in the countries on RWHI mainly focuses on large and complex infrastructure but does not provide guidelines for technologies applied at lower levels such as rainwater harvesting at household level and small-scale irrigation
3. Extension workers are often not adequately trained on RWHI
4. Curricula at universities does not incorporate RWHI
5. Imbalance between eastern and southern Africa: Ethiopia and Kenya are much more advanced in terms of implementation of RWHI techniques. They have a range of functional institutions at all categories mentioned above
6. Lack of technical standards for RWHI techniques is a major challenge and therefore, research should help in overcoming this challenge
7. Low self-adoption of rainwater harvesting irrigation ttechnologies: In some communities RWHI techniques are perceived to be for the poor and some stigma exits around the application of these techniques

5. COMPARATIVE ANALYSIS OF POLITICAL AND INSTITUTIONAL FRAMEWORKS

5.1 Introduction

The governments of sub-Saharan African countries have primarily been focused on promoting large-scale water storage projects for water supply and irrigation far beyond household and community level (Van Koppen. 2003). While rainwater harvesting could provide a viable solution to decrease water resource scarcity at a local level, existing national policies are not conducive to widespread uptake of such technologies (Rockström et al., 2010). Policy evaluation studies are geared towards assessing impacts and inclusion in agricultural, food security and poverty alleviation policies. However, in addition to reviewing strategies for promoting rainwater harvesting irrigation, policy research should also identify gaps and make recommendations for enhancing policy and institutional reforms. From some of these studies, advocacy has been conducted at several regional and international forums, such as the African Ministerial Conferences on Water (AMCOW) and the World Water Forum to facilitate lobbying for policy change (Carlow et al., 2013).

The management of water resources involves key activities that have to be undertaken as the core functions of dedicated water sector institutions. These functions generally include the categories highlighted in Table 12. Sector functions include monitoring of water resources and water usage, information management, and education, training and capacity development.

Table 12: Management of water resources by key stakeholders and smallholder farmers. Source: adapted from Simane et al. (2014), Oguge and Oremo (2014), Cuamba et al. (2015) and Wuta et al. (2014)

Water resource management	Allocation of water rights (or rights to use water), management and control of abstractions from water sources, management and control of water quality, overall responsibility for developing water resources, and catchment management roles and responsibilities
Water supply provision	Management of infrastructure for transmission, storage, and treatment; management of retail water and sanitation services (distribution); Setting of tariffs and standards for service delivery
Agriculture	Development of irrigation policy and infrastructure; Development of rainwater harvesting for irrigation policy. Assessment of efficiency of different irrigation and water harvesting techniques. Provision of extension support in irrigation, agronomy and produce marketing.
Self-supply	Establishment of water conveyance and temporary storage infrastructure. Managing the application of water to the crops.
Irrigation	Purchasing irrigation equipment and developing on-farm water conveyance infrastructure. Developing irrigation scheduling systems for efficient water application.

5.2 Relevant policies in the 4 AFRHINET African partner countries

The four countries have developed legislation on matters concerning the use of water and irrigation. The government ministries and departments responsible for water sector for each country are shown in Table 13.

The Ethiopian Water Resources Management Proclamation, issued in March 2000, is currently the basic legal instrument governing the management, planning, utilization and protection of water resources in Ethiopia. This document provides the fundamental principles that need to be taken into account for the management and administration of the water resources in the country.

In Kenya, the policy making process for integrated water resources management including RWHI, rests with the Ministries of Water and Agriculture (Table 13). The overall development of water storage infrastructure is under the Ministry of Water, while development of the agricultural sector and intervention in irrigation sub-sector policies is the docket of the Ministry of Agriculture. The reforms in the water sector through the Water Act 2005 can be summarized in four themes: (a) the separation of water resources management and development of water delivery services; (b) the separation of policy making from day to day administration and regulation; (c) the decentralization of functions to lower level state organs; and (d) the involvement of non-state actors/entities in the management of water resources and in the provision of water services.

The major institution dealing with water issues in Mozambique is the National Directorate of Water, which is integrated in the Ministry of Public Works, Housing and Hydro Resources. This body deals with water legislation for different purposes and for different users. The Ministry of Agriculture and Food Security addresses issues related with water for irrigation. This Ministry used to have a National Directorate for Hydraulic issues, which has been turned into the National Institute for Irrigation, with tasks to support irrigation development projects. Nevertheless, issues related with small-scale rainwater harvesting systems for irrigation have not been considered so far. Under the 1995 Water Law, the National Water Directorate is responsible for policy making and implementation, the overall planning and management of the country's water resources, and the provision of water supply and sanitation services. The National Institute for Irrigation, within the Ministry of Agriculture and Food Security, maintains responsibility for activities relating to irrigation and drainage.

In Zimbabwe, the governing of the water sector rests with the Ministry of Environment, Water and Climate, within which there is the Zimbabwe National Water Authority (ZINWA), responsible for the costing, allocation and the distribution of water. It is also the regulator in the water sector, and is in charge of major dams and all water resources. The Department of Water Development (DWD) is in charge of the overall formulation of national policies and standards for the planning, management and development of the nation's water resources. The Environmental Management Agency (EMA) monitors and enforces water quality standards to prevent pollution of water bodies, wetlands and land.

5.3 Regional similarities and differences

The four project partner countries have both institutional frameworks and legislations, which accommodate rainwater harvesting activities. In Ethiopia, Kenya and Zimbabwe, rainwater harvesting irrigation activities are anchored in the legal framework. However, in Mozambique, rainwater harvesting irrigation does not feature in the water policy and irrigation policy. Mozambique has been giving more attention to the exploitation of groundwater for rural water supply, which is part of the water legal framework.

Table 13. Functions and responsibilities of Government Departments in the studied countries. Source: adapted from Simane et al. (2014), Oguge and Oremo (2014), Cuamba et al. (2015) and Wuta et al. (2014)

Country	Policy Formulation	Water Resources Development	Water Resources Management	Irrigation Water Management
Ethiopia	Ethiopian Water Resources Management	Ethiopian Water Resources Management	Ethiopian Water Resources Management	Ethiopian Water Resources Management
Kenya	Ministry of Water & Irrigation	Water Service Boards	Water Resources Management Authority	Water Resources Management Authority
Mozambique	Ministry of Public Works, Housing and Hydro Resources	Ministry of Public Works, Housing and Hydro Resources	Ministry of Public Works, Housing and Hydro Resources	Ministry of Agriculture and Food Security
Zimbabwe	Ministry of Environment, Water and Climate	Department of Water Resources	Zimbabwe National Water Authority and Environmental Management Agency	Department of Irrigation

6. APPLICABILITY TO OTHER ARID AND SEMI-ARID REGIONS

Arid and semi-arid areas are characterized by low erratic rainfall of up to 700 mm per annum, periodic droughts and different associations of vegetative cover and soils. Inter-annual rainfall varies from 50-100% with averages of up to 350 mm. Thus, rainfall in arid and semi-arid zones is characterised by high variability. This is coupled with high evaporative demand which creates severe constraints for crop growth. For example, Barron et al. (2003) reported at a semi-arid site in Kenya that maize was exposed to at least one dry spell of at least ten days in 74-80% of seasons, and yet crops only utilized 36-64% of the rainwater while the rest was lost through runoff and deep percolation. RWHI can therefore be crucial to optimise the collection of rainwater/runoff in arid and semi-arid areas, and subsequently use this water to improve crop productivity.

Although this study focused on four countries in eastern and southern Africa, the results can be applied to semi agro-ecological and geophysical conditions across sub-Saharan Africa, due to the inherent similarities in terms of rainfall variability in arid and semi-arid areas. (Rockström, 2000; Dile et al., 2013). RWHI can therefore contribute to transform crop production and food security across arid and semi-arid areas in sub-Saharan Africa, which are periodically ravaged by drought-related famine and conflicts (Deng and Minear, 1992; Haile, 2005; Schilling et al., 2014).

However, there is need to create legal and institutional policies that promote the development of arid and semi-arid regions. The roles and responsibilities of government departments and NGOs involved in the water sector should be clear. The implementation of RWHI technologies at small-scale is relatively affordable. Therefore, in the smallholder and communal farming sectors, such technologies show a high potential to be promoted, replicated and upscaled.

Notwithstanding, the responsability of replicating and upscaling RWHI interventions at local level, as well as regional and national level, should not exclusively fall on the shoulders of local communities. Instead, all other relevant stakeholders, especially governmental bodies, NGOs and the scientific community, each of them playing their respective part, should develop and implement all mechanisms to make possible the adoption, replication and upscaling of RWHI interventions.

7. RECOMMENDATIONS

Arid and semi-arid areas comprise a very wide area in sub-Saharan Africa, which is however, equally and greatly affected by the variability of rainfall, and its consequences on agriculture, landscape and livelihood. The use of rainwater for small-scale irrigation during the dry season has not been exploited sufficiently in despite of the scarcity of water resources in these areas. The absence of an enabling financial, policy and institutional environment coupled with capital investment costs which are usually out of reach for local communities, it is a major barrier for the replication of existing and emerging RWHI technologies.

From the different RWHI systems highlighted, it is clear that most of them are site specific, and hence, their adoption, applicability, and scalability are limited to biophysical and hydrological characteristics. This means, each technology is applicable under different circumstances based on topography, landscape characteristics, and community capacity and preferences. Therefore, the recommendations on each technology should be considered independently based on a multidimensional analysis of all relevant biophysical, technical, economic and social factors.

In Ethiopia, Kenya, Mozambique and Zimbabwe, there are institutional frameworks on both water and irrigation sectors which could be used more effectively to promote rainwater harvesting for irrigation. However, higher education and research institutions need reinforcing in order to tackle issues oriented to rainwater harvesting. In addition, the legislation needs to make a clear reference to not only rainwater harvesting but its specific use for small-scale irrigation purposes. In all countries studied, there is a need to promote policy and institutional developments in order to sustain a favourable economic environment by means of:

1. Securing and redirecting external and institutional funding in order to carry out long-term programmes at a local, regional and national level which specifically focus on replicating and transferring cost-efficient small-scale RWHI interventions for food security, poverty alleviation and climate resilience.
2. Raising the awareness of decision- and policy-makers in order that the inclusion of RWHI interventions into local, national and regional policies, as well as their financing, can be secured.
3. Implementing self-replicable and tailor-made capacity building activities to all relevant stakeholders, especially governmental bodies, scientists and practitioners, and local communities. It is strictly required to first make good use of the capacity already available in the region as a first basic step towards it.
4. Planning, designing, implementing, operating and maintaining RWHI schemes as agribusiness at different scale levels by ensuring profitability through access to information and markets for agro-inputs, farm products and credit facilities.
5. Providing economic incentives (prices, subsidies, tax exemptions) that recognise the opportunity costs of water and water services. In addition, capital, operation and maintenance costs require incentives to ensure development and sustainability.
6. Promoting and showcasing cost-effective and innovative activities on rainwater harvesting irrigation.
7. Fostering innovation through the strategic implementation of research and technology transfer activities and the establishment of research and technology transfer and/or excellence centres.

8. REFERENCES

A

Awulachew, S. B., Merrey, D. J., Kamara, A. B., Van Koppen, B., Penning de Vries, F., Boelee, E., Makombe, G. (2005). Experiences and opportunities for promoting small–scale/micro irrigation and rainwater harvesting for food security in Ethiopia. Colombo, Sri Lanka: IWMI. v. 86p. Working paper 98.

B

Bacha, D., Namara, R., Bogale, A., & Tesfaye, A. (2011). Impact of small□scale irrigation on household poverty: empirical evidence from the Ambo district in Ethiopia. *Irrigation and Drainage, 60*(1), 1-10.

Barron, J. and Okwachi, G. (2005). Run-off water harvesting for dry spell mitigation in maize (Zea mays L.): results from on-farm research in semi-arid Kenya. *Agricultural Water Management*, 74(1): 1-21.

Barron, J., Rockström, J., Gichuki, F. (2003). Dry spell analysis and maize yields for two semi-arid locations in east Africa. *Agricultural Water Management*, 117, 23-37.

Beckers, B., Berking, J. and Schutt, B. (2013). Ancient water harvesting methods in the drylands of the Mediterranean and Western Asia. *Journal for Ancient Studies*, 2, 145-164.

Biazin, B., Sterk, G., Temesgen, M., Abdulkedir, A., Stroosnijder, L. (2012). Rainwater harvesting and management in rainfed agricultural systems in sub-Saharan African – A review. *Physics and Chemistry of the Earth*, 47-48, 139-151.

Boithi, F.N, Muchiri, E., Birech, R., Mulu-Mutuku, M. (2014). Factors Influencing Smallholder Farmers' Adoption of Agricultural Water Technologies and Innovations in Lare and Elementaita Divisions of Nakuru County, Kenya. *Journal of Innovation and Applied Studies,* 7.4, 1338-1343.

Bouma, J.A., Hedge, S.S. and Kasage, R. (2016). Assessing the returns to water harvesting: a meta-analysis. *Agricultural water management,* 163, 100-109.

Bruni, M. and Spuhler, D. (2010a). Manual pumping. In the SSWM Toolbox. Basel: Seecon international gmbh. Accessed at http://www.sswm.info/category/implementation-tools/water-sources/hardware/groundwater-sources/manual-pumping. Retrieved on January 2015

Bruni, M. and Spuhler, D. (2010b). Mechanised pumping. In the SSWM Toolbox. Basel: Seecon international gmbh. Accessed at http://www.sswm.info/category/implementation-tools/water-sources/hardware/groundwater-sources/mechanised-pumping. Retrieved on January 2015

C

Calow, R., Ludi, E. and Tucker, J. (2013). Archiving water security: Lessons from research in water supply, sanitation and hygiene in Ethiopia. Practical Action Publishing, Rugby, UK.

Critchley, W. and Siegert, K. (1991). Water harvesting: A manual for the design and construction of water harvesting schemes for plant production. FAO, AGL/MISC/17/91.

Cuamba, B., Leão, A., Sisenando, S., Pereira, J., Bila, S. (2015). Baseline Study on Rainwater Harvesting for Irrigation in Mozambique. AFRHINET Project. Available at http://afrhinet.eu/materials/viewcategory/14-baseline-study-mozambique.html

D

De Fraiture, C., & Giordano, M. (2014). Small private irrigation: A thriving but overlooked sector. *Agricultural Water Management, 131*, 167-174.

De Trincheria, J., Nissen-Petersen, E., Leal Filho, W., Otterpohl, R. (2015). Factors affecting the performance and cost-efficiency of sand storage dams in south-eastern Kenya [conference paper]. E-proceedings of the 36th IAHR World Congress, The Hague, the Netherlands, 28 June – 3 July, 2015

De Trincheria, J., Leal Filho, W., Otterpohl, R. (2016). Towards achieving universal levels optimal performance by minimising siltation in sand storage dams. Manuscript under review submitted for publication.

Deng, F.M. and Minear, L. (1992). The challenges of famine relief emergency operation in The Sudan. Brookings Institution, Washington DC, pp 185.

Dile, Y.T, Karlberg, L., Temesgen, M., Rockstrom, .J. (2013). The role of water harvesting to achieve sustainable agricultural intensification and resilience against water related shocks in sub-Saharan Africa. *Agriculture Ecosystems and Environment*, 181, 69-79.

F

Falkenmark, M., and Rockström, J. (2004). Balancing water for man and nature: The new approach to ecohydrology, EarthScan, U.K.

Fischer, R.A., Byerlee, D. and Edmeades, G.O. (2009). Can technology deliver on the yield challenge to 2050? Paper presented at the FAO Expert Meeting: How to Feed the World in 2050, 24-26 June, Food and Agriculture Organization of the United Nations, Rome.

Fowe, T., Karambiri, H., Paturel, J.-E., Poussin, J.-C., Cecchi, P. (2015). Water balance of small reservoirs in the Volta basin: A case study of Boura reservoir in Burkina Faso. *Agricultural Water Management,* 152, 99-109.

G

Gebreegziabhert, T., Nyssen, T., Govaerts, B., Getnet, F., Behailu, M., Halle, M. and Deckers, J. (2009). Contour furrows for insitu soil and water conservation, Tigray, Northen Ethiopia. *Soil and Tillage Research*, 103, 257-264.

Gezahegn, A., Ayana, G., Gedefe, K., Bekele, M., Hordofa, T. and Georgis, K. (2006). Water Harvesting practices and impacts on livelihood outcomes in Ethiopia. EDRI, Addis Ababa, Ethiopia.

Gichangi E.M., Njiru, E.N., Itabari, J.K., Wambua, J.M., Maina, J.N. and Karuku, A. (2007). Assessment of improved soil fertility and water harvesting technologies through community based on-farm trials in the ASALs of Kenya. In: A. Bationo (ed.) Advances in Integrated Soil Fertility Management in Sub-Saharan Africa: Challenges and Opportunities. p759-765.

Gumbo, D. (2015). Raising awareness on rainwater harvesting technologies for small-scale irrigation: capacity-building, technology transfer and up-scaling. [Conference paper] 3rd AFRHINET Networking, Dissemination and Roundtable Event, Harare, Zimbabwe, 28th September 2015 Available at http://afrhinet.eu/materials/viewcategory/39-international-dissemination-event-in-zimbabwe.html

Gur, E. and Spuhler, D. (2010). Rainwater Harvesting Rural. In the SSWM Toolbox. Basel: Seecon international gmbh. Accessed at http://www.sswm.info/category/implementation-tools/water-sources/hardware/precipitation-harvesting/rainwater-harvesting-r. Retrieved on January 2015.

H

Haile M. (2005). Weather patterns, food security and humanitarian response in sub-Saharan Africa. *Philosophical Transaction of the Royal Society*. DOI: 10.1098/rstb.2005.1746.

Hatibu, N. and Mahoo, H.F. (2000). Rainwater Harvesting for Natural Resources Management for Tanzania. Technical Handbook No. 22 RELMA, Nairobi.

Hauser, K. (2012). Harvesting rain with rocks in Kenya. Accessed at http://www.one.org/us/2012/05/12/harvesting-rain-with-rocks-in-kenya/. Retrieved on June 2015

I

International Water Management Institute (IWMI). (2015). Improving water management in Myanmar's dry zone for food security, livelihoods and health. Colombo, Sri Lanka: International Water Management Institute (IWMI). 52p. doi: 10.5337/2015.213.

J

Jha, M.K, Chowdary, V.M, Kulkarni, Y., Mal, B.C. (2014). Rainwater harvesting planning using geospatial techniques and multicriteria decision analysis. *Resources, Conservation and Recycling*, 83, 96-111.

Josef, B.A. and Asmamaw, D.K. (2015). Rainwater harvesting: An option for dryland agriculture in arid and semi-arid Ethiopia. *International Journal of Water Resources and Environmental Engineering*, 7, 17-28.

K

Kahinda, J., Rockstrom, J., Taigbenn, A.E., and Dimes, J. (2007). Rainwater harvesting to enhance water productivity of rainfed agriculture in the semi-arid Zimbabwe. *Physics and Chemistry of the Earth A/B/C 32* (15-18):1068-1073.

Kaluli, J. W., Nganga, K., Home, P. G., Gathenya, J. M., Muriuki, A.W. and Kihurani, A. W. (2005). Effect of Rain Water Harvesting and Drip Irrigation on Crop Performance in an Arid and Semi-Arid Environment.

Karpouzoglou, T. and Barron, J. (2014). A global and regional perspective of rainwater harvesting in sub-Saharan Africa's rainfed farming systems. *Physics and Chemistry of the Earth,* 72-75, 43-53.

Kathuli, P., Itabari, P. K., Nguluu, S. N. and Gichangi, E.M. (2010). Farmers perception on subsoiling/ ripping technology for rain- water harvesting in mixed dryland farming areas in Eastern Kenya. In: Proceedings of the 12th KARI Biennial Scientific Conference, pp. 1235–1240, Nairobi, Kenya, 2010.

L

Lybbert, T.J. and Sumner, D.A. (2012). Agricultural technologies for climate change in developing countries: Policy options for innovation and technology diffusion. *Food Policy,* 37, 114-123.

Ludi, E., Belay, A., Duncan, A.J., Snyder, K., Tucker, J., Cullen, B., Belissa, M., Oljira, T., Teferi, A., Nigussie, Z., Deresse, A., Debela, M., Chanie, Y., Lule, D., Samuel, D., Lema, Z., Berhanu, A. and Merrey, D.J. (2013). Rhetoric vs. realities—An assessment of rainwater management planning and implementation modalities in Oromia and Amhara regions, Ethiopia. IN: Wolde, M. (ed). 2013, Rainwater management for resilient livelihoods in Ethiopia: Proceedings of the Nile Basin Development Challenge Science Meeting, Addis Ababa, 9–10 July 2013. NBDC Technical Report 5. Nairobi, Kenya: ILRI.

M

Mabeza, C. M., & Mawere, M. (2012). Dambo cultivation in Zimbabwe: Challenges faced by small-scale dambo farming communities in Seke-Chitungwiza communal area. *Journal of sustainable development in Africa, 14*(5), 39-53.

Malesu, M.M., Sang, J.K.; Odhiambo, J.O., Nyabenge, M. (2006). Rainwater Harvesting Innovations in Response to Water Scarcity: The Lare experience. Technical Manual No. 5, World Agroforestry Centre, Nairobi, Kenya

Malesu, M., Black J., Alex O., Cheregony, K. and Nyabenge, M. (2012). Rain Water Harvesting Inventory of Kenya. The World Agroforestry Centre.

Masila, T., Udoto, M.O. and Obara, J. (2015). Influence of rain water harvesting technologies on household food security among small-scale farmers in Kyuso sub-County, Kitui County, Kenya. *Journal of Agriculture and Veterinary Science,* 8. 80-86.

Mati, B.M. (2007). 100 ways to manage water for small holder agriculture in East and Southern Africa. SWMnet Working Paper 13.Improved Management in Eastern and Southern Africa (IMAWESA).

Mati, B., De Bock, T., Malesu, M., Khaka, E., Oduor, A., Nyabenge, M., and Oduor, V. (2006). Mapping the potentials for Rainwater Harvesting technologies in Africa: A GIS overview on development domains for the continent and ten selected countries. Technical Manual No. 6 Nairobi, Kenya: World Agroforestry Centre (ICRAF).

Mbulinyi, B.P, Tumbo, S.D., Mahoo, H.F., Senkondo, E.M., Hatibu, N. (2005). Indigenous knowledge as decision support tool in rainwater harvesting. *Physics and Chemistry of the Earth,* 30, 712-798.

Mc Inerney F. (2014). Experience involving technology transfer, capacity building, and information exchange for the International Treaty on Plant Genetic Resources for Agriculture. Research Study 5. Rome, FAO.

Medhin, A.G. and Tecklehaimanot A. (2013). Exploring Market Opportunities for Smallholder Vegetable Growers the Case of Maynugus Irrigation Scheme, Tigray Regional State, Ethiopia. Journal of *Community Mobilisation and Sustainable Development,* 8, 109-112.

Merrey D. (2013). Improving the sustainability of capacity of agricultural water management interventions in challenging contexts: Investment guideline for smallholder agricultural water management. IFAD/IWMI report.

Morelli, J. (2011). Environmental Sustainability: A Definition for Environmental Professionals. *Journal of Environmental Sustainability.* DOI: 10.14448/ jes.01.0002.

Motsi , K. E., Chuma, E. and Mukamuri, B.B. (2004). Rainwater harvesting for sustainable agriculture in communal lands of Zimbabwe. *Physics and Chemistry of the Earth, Parts A/B/C* Vol.29, Issues 15–18, 1069–1073.

Mun, J.S and Han, M.Y. (2012). Design and operational parameters of a rooftop rainwater harvesting system: Definition, sensitivity and verification. *Journal of Environmental Management,* 93, 147-153.

Musiyiwa, K. (2014). Climate change in rural Zimbabwe: An assessment of the influences of gender and smallholding and its contribution towards adaptation to climate change in rural Zimbabwe. [PhD thesis]. Faculty of Science and Engineering, Manchester Metropolitan University, UK.

Mutabazi, K., Hatibu, N., Senkondo, E., Mbilinyi, B., Tumbo, D. (2005). Economics of Rainwater Harvesting for Crop Enterprises in Semi-Arid Areas: The Case of Makanya Watershed in Pangani River Basin, Tanzania. Soil-Water Management Research Group.

N

New, M., Hewitson, B., Stephenson, D.B., Tsiga, A., Kruger, A., Manhique, A., Gomez, B., Coelho, C.A., Masisi, D.N., Kululanga, E. and Mbambalala, E. (2006). Evidence of trends in daily climate extremes over southern and west Africa. *Journal of Geophysical Research: Atmospheres,* 111(D14).

Ngigi, S.N. (2003). Rainwater harvesting for improved food security: Promising technologies in the Greater Horn of Africa. Greater Horn of Africa Rainwater Partnership (GHARP), Kenya Rainwater Association (KRA), Nairobi, Kenya. 266p.

Ngigi, S.N. (2009). Climate change adaptation strategies: Water resources management options for smallholder farming systems in sub-Saharan Africa. Publication on a water study commissioned by the Rockefeller Foundation. The MDG Centre East and Southern Africa, the Earth Institute at Columbia University, New York, USA.

Ngigi, S.N., Thome, J.N., Rockström, J., Penning de Vries, F., Savenije, H. (2005). Agro-hydrological Evaluation of on-Farm Rainwater Storage Systems for Supplemental Irrigation in Laikipia District, Kenya.Agricultural Water Management, 73(1): 21-41.

Nicol, A.; Langan, S.; Victor, M.; Gonsalves, J. (Eds.) (2015). Water-smart agriculture in East Africa. Colombo, Sri Lanka: International Water Management Institute (IWMI). CGIAR Research Program on Water, Land and Ecosystems (WLE); Kampala, Uganda: Global Water Initiative East Africa (GWI EA). 352p. doi: 10.5337/2015.203.

Nissen-Petersen, E. (2006a). Water from Small Dams: A handbook for technicians, farmers and others on site investigations, designs, cost estimates, construction and maintenance of small earth dams. ASAL Consultants Ltd., Nairobi, Kenya.

Nissen-Petersen, E. (2006b). Water from Dry Riverbeds - How Dry and Sandy Riverbeds Can be Turned into Water Sources by Hand-dug Wells, Subsurface Dams, Weirs and Sand Dams. ASAL Consultants Ltd., Nairobi, Kenya.

Nissen-Petersen, E. (2013). Subsurface dams for water storage in dry riverbeds. ASAL Consultants Ltd., Nairobi, Kenya.

Nissen-Petersen, E. (2015). Water delivery systems for irrigation. [Unpublished presentation]

Nyagumbo, I. (2015). Some experiences with developing rain water harvesting technologies in semi-arid Zimbabwe: challenges and possible solutions. Global Conservation Agriculture Program (CIMMYT). [Conference presentation] 3rd AFRHINET Networking, Dissemination and Roundtable Event, Harare, Zimbabwe, 28th September 2015. Available at http://afrhinet.eu/materials/viewcategory/39-international-dissemination-event-in-zimbabwe.html.

Nyagumbo, I., Mvumi, B.M., Mutsamba, E. (2009). CA in Zimbabwe: socioeconomic and biophysical studies. [Conference paper]. Regional Conference on Sustainable Land Management, Windhoek, Namibia, pp 7–11, September 2009.

Nyagumbo, I., Nyamangara, J., Rurinda, J. (2011). Scaling out integrated soil nutrient and water management technologies through farmer participatory research: Experiences from semi-arid central Zimbabwe. pp. 1257-1268. In: A. Batiano, B. Waswa, J. Okeyo and F. Maina (Eds.) Innovations as key to the green revolution in Africa. Springer Science Business Media B.V. Dordrecht, The Netherlands.

Nyamadzawo, G., Wuta, M., Nyamangara, J., & Gumbo, D. (2013). Opportunities for optimization of in-field water harvesting to cope with changing climate in semi-arid smallholder farming areas of Zimbabwe. *SpringerPlus*, 2(1), 100.

Nyamangara, E. (2015). Rain Water Harvesting and Irrigation Methods in use in Smallholder Farming Areas. What is the role of Department of Irrigation in facilitating scaling up? Department of Irrigation [Conference Presentation]. 3rd AFRHINET Networking, Dissemination and Roundtable Event, Harare, Zimbabwe, 28th September 2015. Available at http://afrhinet.eu/materials/viewcategory/39-international-dissemination-event-in-zimbabwe.html.

Nyamangara J. (2007). Final evaluation of the “Farmer Creativity and Innovations” project. [Unpublished report] Africare-Zimbabwe, Harare, Zimbabwe.

Nyamangara, J. and Nyagumbo, I. (2010). Interactive effects of selected nutrient resources and tied-ridging on plant performance in a semi-arid smallholder farming environment in central Zimbabwe. Nutrient Cycling in Agroecosystems 88, 103-109.

Nyamangara, J., Chikowo, R., Rusinamhodzi, L and Mazvimavi, K. (2013). Conservation agriculture in southern Africa, pp 339-351. In: R.A. Jat, K.L. Sahrawat and A.H. Kassam (Eds.) Conservation agriculture: Global prospects and challenges. CABI, Wallingford, U.K.

O

Oduor, A. and Malesu, M. (2015). Selected Best Practices of RWHI Experiences from [Conference presentation]. 3rd AFRHINET Networking, Dissemination and Roundtable Event, Harare, Zimbabwe, 28th September 2015. Available at http://afrhinet.eu/materials/viewcategory/39-international-dissemination-event-in-zimbabwe.html.

Oguge, N. and Oremo, F. (2014). Assessment of Capacity Needs, Potential and Market Oriented Products in Rainwater Harvesting and Small-Scale Irrigation in Kenya. AFRHINET Project. Available at http://afrhinet.eu/materials/viewcategory/12-baseline-study-kenya.html.

Oweis, T., Hachum, A. and Kijne, J. (1999). Water Harvesting and Supplemental Irrigation for Improved Water Use Efficiency. SWIM Paper No. 7. IWMI, Colombo, Sri Lanka. p 41

P

Pachauri, R.K., Allen, M.R., Barros, V.R., Broome, J., Cramer, W., Christ, R., Church, J.A., Clarke, L., Dahe, Q., Dasgupta, P. and Dubash, N.K. (2014). Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.

Park, P. (2016). Improved irrigation backed to halve food gap. Available at http://m.scidev.net/global/agriculture/news/irrigation-backed-food-gap-food-security.html.

Payen, J., Faurès, J.M., Vallée, D. (2012). Small Reservoirs and Water Storage for Smallholder Farming: The Case for a New Approach. AWM Business Proposal Document, AgWater Solutions, International Water Management Institute (IWMI)

Prinz, D. (2002). The role of water harvesting in alleviating water scarcity in arid areas. [Conference paper]. International Conference on Water Resources Management in Arid Regions (pp. 23-27).

R

Rockström, J. (2000). Water resources management in smallholder farms in Eastern and Southern Africa: an overview. *Physics and Chemistry of the Earth,* Part B: Hydrology, Oceans and Atmosphere, 25(3), 275-283.

Rockström, J. and Falkenmark, M. (2015). Increase water harvesting in Africa. Nature 519, 283 – 285.

Rockström, J., Folke, C., Gordon, L., Hatibu, N., Jewitt, G., Penning de Vries, F., Rwehumbiza, F., Sally, H., Savenije, H., and Schulze, R. (2004). A watershed approach to upgrade rainfed agriculture in water scarce regions through Water System Innovations: an integrated research initiative on water for food and rural livelihoods in balance with ecosystem functions. *Physics and Chemistry of the Earth 29:* 1109–1118.

Rockström, J., Karlberg, L., Wani, S.P., Barron, J., Hatibu, N., Oweis, T., Bruggeman, A., Farahani, .J, Qiang, Z. (2010). Managing water in rainfed agriculture -The need for a paradigm shift. *Agricultural Water Management,* 97, 543-550.

Rosegrant, M.W. (1997). Water resources in the twenty-first century: challenges and implications for action. Food, agriculture and the environment. Discussion Paper 20, IFPRI, Washington, U.S.

Rosegrant, W., Ringler, C., Benson, T., Diao, X., Resnick, D., Thurlow, J., Torero, M.,Orden, D. (2006). Agriculture and Achieving the Millennium Development Goals.Report No. 32729-GLB. World Bank, Washington, U.S.

S

Schilling, J., Akuno, M., Scheffran, J., Weinzierl, T. (2014). On raids and relations: Climate change, pastoral conflict and adaptation in north-west Kenya. In: B. Urmilla and S. Bronkhorst (Eds.) Conflict-senstive adaptation to climate change in Africa. Berliner Wissenshafts-Verlag.

Simane, B., Tulu, T., Dawit, D. (2014). Baseline Report on RWH and SSI in Ethiopia. AFRHINET Project. Available at http://afrhinet.eu/materials/viewcategory/16-baseline-studiy-ethiopia.html.

Simane, B. (2015). Capacity needs, potential and market oriented products in RWH & SSI – Ethiopia's perspective [conference presentation] 2nd AFRHINET Networking and Dissemination Event, Nairobi, Kenya, 25th February 2015. Available at http://afrhinet.eu/materials/viewcategory/35-international-dissemination-event-in-kenya.html.

Staufer, B. (2010). Drip irrigation. In the SSWM Toolbox. Basel: Seecon international gmbh. Accessed at http://www.sswm.info/category/implementation-tools/water-use/hardware/optimisation-water-use-agriculture/drip-irrigation. Retrieved on January 2015.

Staufer, B. and Spuhler, D. (2010a). Manual Irrigation. In the SSWM Toolbox. Basel: Seecon international gmbh. Accessed at http://www.sswm.info/category/implementation-tools/water-use/hardware/optimisation-water-use-agriculture/manual-irrigatio. Retrieved on January 2015.

Staufer, B. and Spuhler, D. (2010b). Sprinkler irrigation. In the SSWM Toolbox. Basel: Seecon international gmbh. Accessed at http://www.sswm.info/category/implementation-tools/water-use/hardware/optimisation-water-use-agriculture/sprinkler-irriga. Retrieved on January 2015.

Staufer, B. and Spuhler, D. (2010c). Surface irrigation. In the SSWM Toolbox. Basel: Seecon international gmbh. Accessed at http://www.sswm.info/category/implementation-tools/water-use/hardware/optimisation-water-use-agriculture/surface-irrigati. Retrieved on January 2015.

Studer, M. and Liniger, H. (2013). Water Harvesting: Guidelines to Good Practice. Centre for Development and Environment (CDE), Bern; Rainwater Harvesting Implementation Network (RAIN), Amsterdam; MetaMeta, Wageningen. The International Fund for Agricultural Development (IFAD), Rome.

U

United Nations (UN) (2015). The Millennium Development Goals Report 2015. United Nations, New York, U.S.

V

Van Koppen B. (2003). Water reform in Sub-Saharan Africa: what is the difference? *Physics and Chemistry of the Earth*, 28, 1047-1053.

W

Wichelns, D. (2014). Investing in small, private irrigation to increase production and enhance livelihoods. *Agricultural Water Management, 131,* 163-166.

Wuta, M., Nyamadzawo, G., Magonziwa, B. (2014). Afrhinet Baseline Survey Report for Zimbabwe. AFRHINET Project. Available at http://afrhinet.eu/materials/viewcategory/13-baseline-study-zimbabwe.html.

X

Xie, H., You, L., Wielgosz, B., & Ringler, C. (2014). Estimating the potential for expanding smallholder irrigation in Sub-Saharan Africa. Agricultural Water Management, 131, 183-193.

ISBN 978-3-00-054353-1

Register to the AFRHINET network at: www.afrhinet.eu/transnational-network.html
Visit the virtual AFRHINET Research and Technology Transfer Centres at: www.rainwatertechcentres.net

www.AFRHINET.eu

Implemented by the ACP Group of States

ACP S&T PROGRAMME

Funded by the European Union

The AFRHINET Project is funded by ACP-EU Cooperation Programme in Science and Technology
(ACP-S&T II).A programme of the ACP Group of States, with the financial assistance of the European Union.