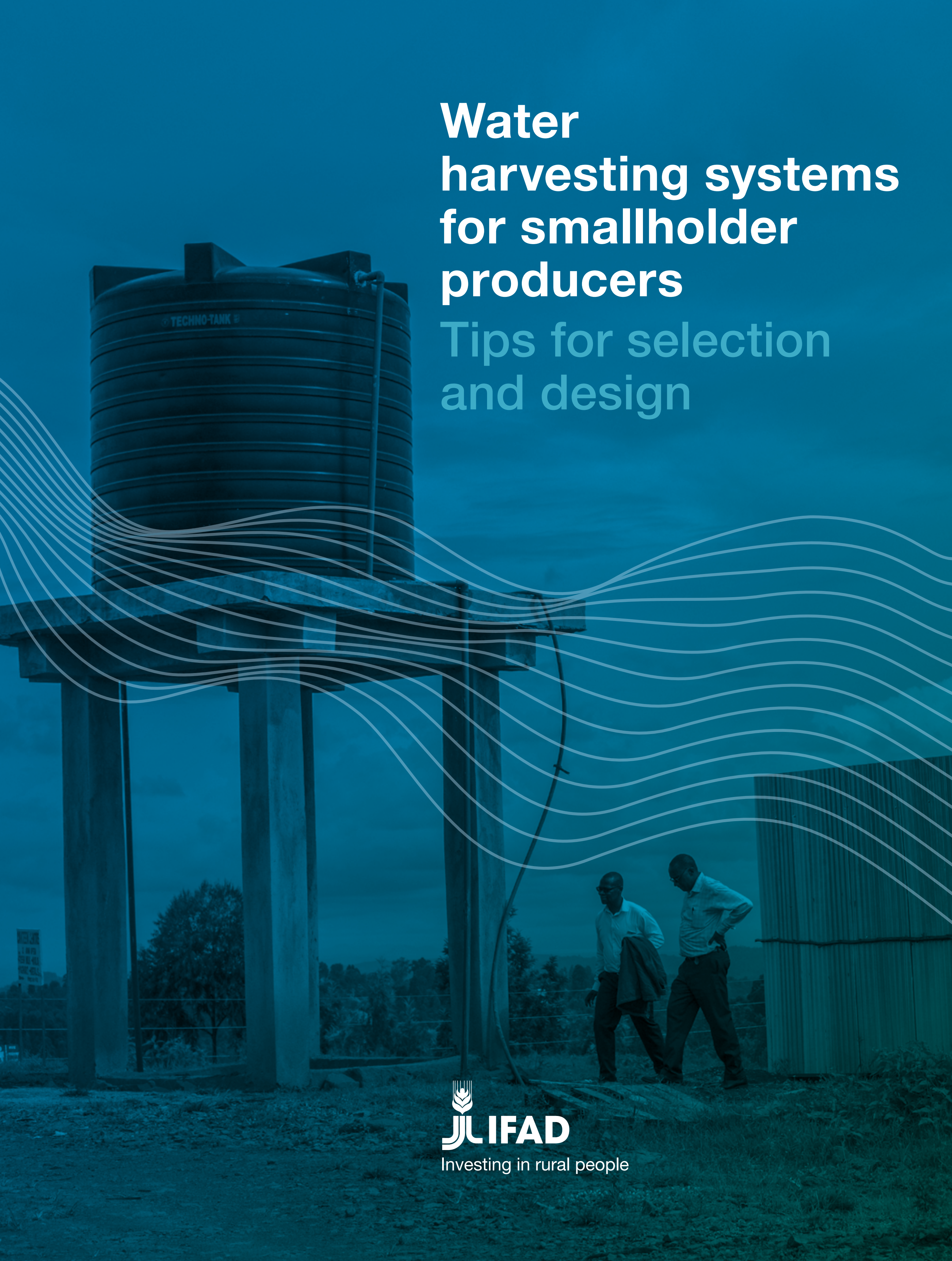
Water harvesting systems for smallholder producers

Tips for selection and design



IFAD

Investing in rural people

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Introduction

Rainfall water harvesting is the collection and storage of rainfall collected directly or from run-off to increase water availability for domestic, agricultural and industrial use. The rainwater harvested is mostly clean and suitable for drinking and domestic use after treatment, and can be used directly for crop irrigation, livestock and poultry, and post-harvest activities that add value to crops and energy production.

The hotspots with the potential for effective water harvesting are located in East and West Africa and South-East Asia, where water can be harvested on 40-70 per cent of the agricultural land, with the highest increase in crop production (60-100 per cent) in Uganda, Burundi, the United Republic of Tanzania and India.

The objective of this technical brief is to raise awareness about existing water harvesting systems and their components and to describe an array of tools to aid the design of water harvesting interventions. It aims to inform government officials, project teams and consultants involved in design and implementation support of water harvesting about potential and options, and offer advice about the assessment of water demand, water available for harvesting, and the selection of suitable water harvesting systems.

What is rainfall water harvesting?

Rainwater can be collected from rooftops, courtyards, roads and other surfaces. It can also be harvested on slopes, such as hillsides and intermittent streams. It can be stored in appropriate storage facilities or infiltrated into the ground to increase soil moisture and aquifer recharge.

Rainwater is often harvested as a supplementary or primary water source, depending on the aridity of the climate and the availability, affordability and quality of traditional water sources. Rainwater harvesting can also reduce the consumption of household water from traditional sources, and hence costs, including the burden of water collection on women.

If the rainwater is clear, has little taste or smell and is from a well-maintained system, it is probably safe for human and animal consumption. Easy treatments can also be applied before consumption: (see Water harvesting toolbox: Tips for water safety.)

Water harvesting has been widely applied in different socio-ecological contexts and has proven to be a valuable approach for sustainable intensification of agriculture; the literature indicates that water harvesting in cultivated areas can significantly boost agricultural production.

Water harvesting is a buffer that helps smallholders cope with dry seasons and prolonged droughts, which are the major challenges facing rainfed agriculture, especially in the most arid and semi-arid areas of the world. It has become a necessary measure for adapting to the challenges of climate change and strengthening food security.

Components of water harvesting systems

A. Catchment or collection area: where rain, directly or in the form of run-off, is harvested – e.g. cultivated or uncultivated land, hillsides, impermeable sheets, rooftops, courtyards and paved roads.
B. Optional conveyance system: where run-off is conveyed through channels or pipes (e.g. in the case of rooftop water harvesting) and either diverted to storage structures, onto or near cultivated fields or to target users (houses, industry, etc.) or infiltrated into groundwater through pits or trenches.
C. Storage: where the harvested water is stored in the soil profile as soil moisture, as groundwater in aquifers or in specifically designed storage facilities such as ponds, reservoirs, tanks, cisterns and barrels.
D. Application area: where the harvested water is used for domestic purposes, consumption by livestock, fish farming, agriculture (including supplemental irrigation), industry, ecosystem conservation, etc.

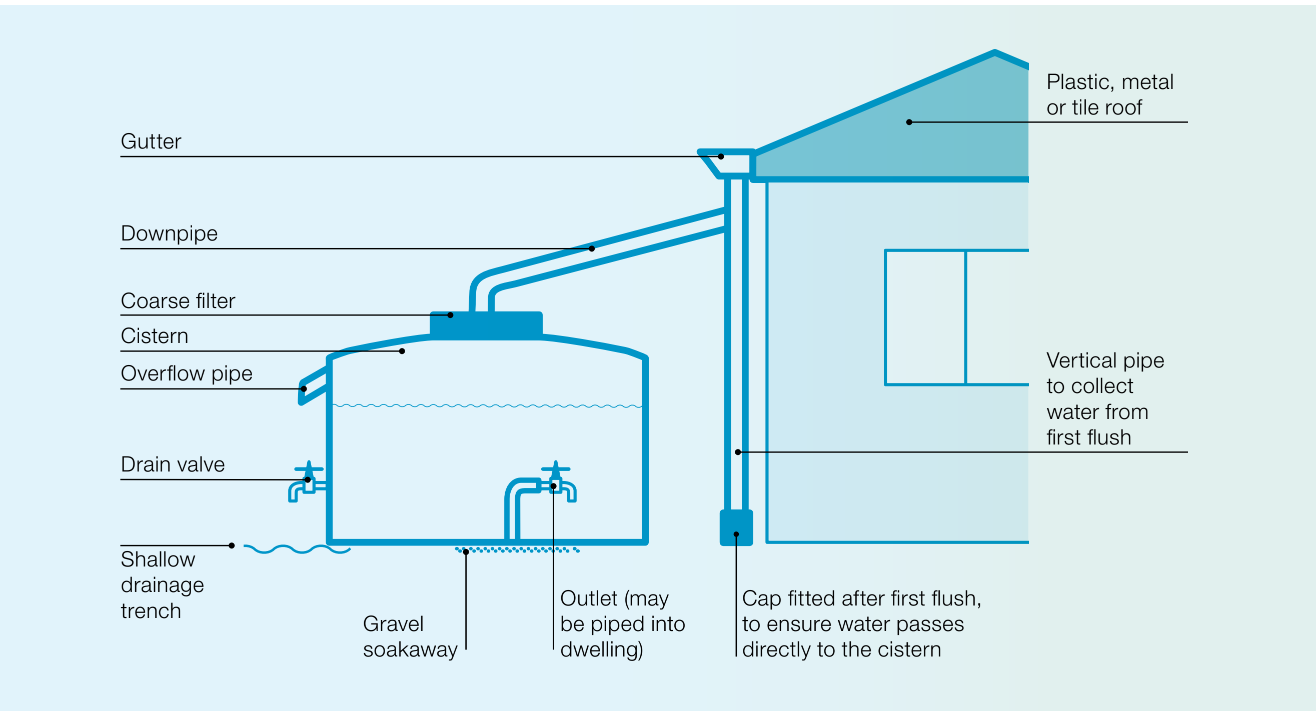

FIGURE 1-A: House rooftop water harvesting system

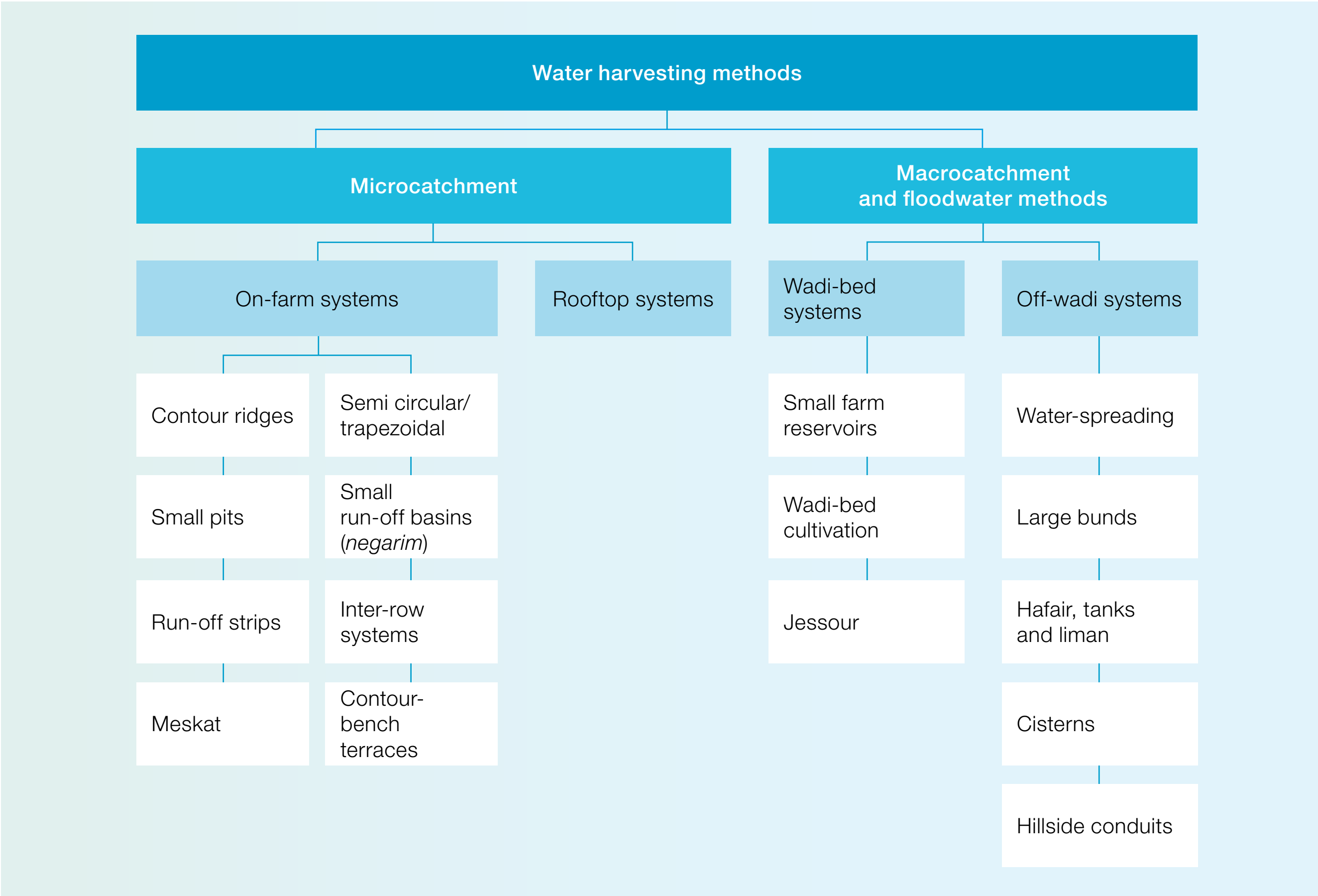

FIGURE 1-B: Catchment water harvesting system

Preliminary design considerations

Step 1: How much water is needed?

As the first step, it is essential to identify the need that water harvesting could fill. This entails estimating the needed volume per period, type of use and the required quality, while also accounting for dry and rainy seasons, as this will help assess the amount of water that needs to be harvested and the type of storage. Current and future water demand must also be considered in the most likely climate scenarios for the project area.

Household water demand. This is the sum of the water used for drinking, food preparation, sanitation, laundry and cleaning. The water should be safe for human consumption. Most African countries have adopted 20-35 litre/capita/day as the basic water requirement, or in the case of more arid zones with less rainfall, they follow the design guidelines to estimate the average minimum quantity of household (MQHH) daily consumption or average sufficient quantity of household (SQHH) daily consumption.

MQHH = 10 + (N X 5) litres (N = number of people in the household) or SQHH = 30 + (N X 7) litres. It is recommended that MQHH be used in areas with only one rainy season and a dry period of 6-8 months and SQHH in areas with two or more rainy seasons and a dry period of 3-5 months. Annual quantity for household consumption (AQ) = 365 X MQHH or SQHH. Examples can be found in African Development Bank. 2009. Rainwater Harvesting Handbook.

Livestock water demand. This is the sum of the water used for feed production, drinking, troughs and stable cleaning. In livestock and poultry production, over 90 per cent of water consumption tends to be associated with the production of feed crops. Water demand varies widely with the different livestock species, the size and composition of the livestock population (e.g. breed, age, sex, weight, stage of production, number of breeding females), as well as the production system. Tables for different species on water demand for drinking and meat processing are provided in FAO. 2019. Water use in livestock production systems and supply chains. Guidelines for assessment.

Crop water consumption. A possible calculation of crop water and irrigation requirements, based on soil, climate and crop data can be made with FAO's CROPWAT 8.0. In addition, the programme allows for the development of irrigation schedules for different management conditions and the calculation of scheme water supply for varying crop patterns.

Processing of crop, livestock and fisheries products. Water demand can vary substantially among processing systems, from the cleaning and washing of products in simple systems, to chilling, scalding and pasteurization in sophisticated systems. Further variation occurs if water is treated and recirculated.

Box 1: Example of a water demand estimate for a small family farm

Knowing that water requirements vary widely with climate, breed of livestock, type of soil, type of crops and many other factors, an example of the water requirements of a small family farm in an arid climate is presented here. Water demand for livestock and small animals also varies widely, depending on feed intake, type and quality of the feed and increases with growth and increasing production processes such as milking, spawning and other factors.

Our small family farm has six members and therefore has an estimated AQ based on the MQHH assumption of 14,600 litres (AQ = (10 + 6 people x 5 litres) x 365 days = 14,600 litres/year). The family cultivates a 12 m^2 vegetable garden in a mulch basin, which has an estimated water demand of 31,000 litres/year (see FAO CROPWAT 8.0). Other crops and fodders are cultivated in a rainfed system. We can also estimate the water demand for livestock and poultry at 5 litres/day per sheep, 27 litres/day per cow, 4 litres/day per 10 chickens and 16 litres/day per donkey (see FAO. 2019. Water use in livestock production systems and supply chains. Guidelines for assessment), which comes to 41,619 litres/year if the property has 8 sheep, 2 cows, 10 chickens and a donkey.

Our example of a family farm will therefore need 87,219 litres/year of good-quality water. The project design should now assess the annual availability of water for different needs and plan to fill the gap through water harvesting.

Step 2: How much water can be harvested?

Design rainfall. This is defined as the total amount of annual rainfall received. The objective is to have enough cumulative rainfall run-off stored. The assertion that a certain volume of annual rainfall is a reliable estimate for design is based on the probability analysis of annual rainfall series data occurring with 90 per cent frequency (FAO, 2014-a).

Consider the current climate and predicted climate change scenarios in the region and locally, if available. Climate change has direct implications for temperature and the amount and timing of precipitation; hence, the design of the water harvesting components.

Water balance. This is calculated to assess how much rainfall runs off and can be collected and used, and how much evaporates, infiltrates or is otherwise lost. Note that the catchment area considered can be as large as a whole watershed or as small as a single rooftop. It can sometimes be challenging to obtain good quality, site specific time series for rainfall and other meteorological data. However, at a minimum, the following average monthly data is needed to calculate an overall water balance to plan for water harvesting: precipitation, run-off coefficient, temperature, evapotranspiration, as well as information on soil humidity and land use conditions. Solar radiation, wind, atmospheric pressure, type of soil (texture, structure), type of vegetation, interception of vegetative cover and infiltration are further useful data for fine-tuning a water balance.

There is a wide variety of hydrologic models for simulating small and large basins. The International Water Management Institute Water Data Portal (http://waterdata.iwmi.org) contains meteorological, hydrological, socio-economic and spatial data layers, satellite images and hydrological model setups. The Model Inventory provides a platform with access not only to model outputs across the globe but to the actual model set up files for free downloading.

Another useful tool that supports the calculation of rainwater run-off is the World Overview of Conservation Approaches and Technologies (WOCAT) Sustainable Land Management (SLM) Watershed Tool (https://www.wocat.net/en/projects-and-countries/projects/onsite-and-offsite-benefits-sustainable-land-management/wocat-slm-watershed-tool). The watershed tool helps to categorize and map different land use and management types, calculate their run-off rates and determine their contribution to total watershed run-off from daily rainfall events. Using Google satellite images and the Quantum Geographic Information System (QGIS: a free, open-source geographic information system), users can delineate small to medium-sized watersheds (<100 km^2) and understand how current land use and land management, soil types and slope conditions contribute to surface run-off. The watershed tool further allows users to analyse different land use scenarios and assess how changes in land management – such as the spread of SLM practices – affect run-off contributions within the watershed and to quantify the total outflow from the watershed (e.g. to understand flood risks). A prototype of this tool is available on request at: wocat@cde.unibe.ch.

To estimate the cumulative net run-off from a sloping surface such as a hill or roof, the rain falling on that surface should be multiplied by the footprint area of the surface and the run-off coefficient “C”.

$$\textit{Run-off (litre)} = \textit{Catchment area } (m^2) * \textit{Precipitation (mm)} * C$$

The run-off coefficient ranges from 0 (which means that the water is fully adsorbed, evaporated or lost in some other way, such as, for example, on a very mulched and vegetated landscape) to 1 (which means that 100 per cent of the rainwater runs off). The larger the catchment area, the more heterogeneous C will be. Use conservative (low) C values to avoid the risk of overestimating the amount of water harvested, which would disappoint beneficiaries and even jeopardize their livelihoods and investments. C depends on many factors, the most important of which are soil type, composition, porosity, regularity of run-off surface, topography, amount of vegetation, soil moisture from previous precipitation and climate.

For example, with a watershed of 100 m^2, a maximum of 1,000 litres of water could be collected for every 10 mm of rain falling on this basin if 100 per cent of the water were collected (C = 1), which is unrealistic. To use realistic values, consider that the cultivated areas and grass/lawn have C = 0.05-0.4, which means that 50-400 litres can be collected. For: (1) thatched roof/palm at C = 0.2, a maximum of 200 litres can be collected; (2) tiles or bricks (clay) at C = 0.6-0.9, a maximum of 600-900 litres can be collected; this latter value is also used for concrete or asphalt surfaces.

Resources for estimating C:

— http://water.me.vccs.edu/courses/CIV246/table2.htm;
— https://www.brighthubengineering.com/hydraulics-civil-engineering/93173-runoff-coefficients-for-use-in-rational-method-calculations/

Step 3: How to maintain the required water quality

Required water quality depends on its intended use: high-quality drinking water is needed for human consumption, while the quality of water for other uses such as domestic use, livestock and inland fisheries, horticulture and crop irrigation and different industrial processes does not have to meet these standards and can often be used without further treatment. If water is turbid, has a cloudy or muddy appearance or contains floating or suspended solids, which can be removed, consider installing sedimentation tanks or silt traps and granular media filters or ceramic filters before supplying it for drinking or animal watering.

Harvested rainwater does not always meet drinking water standards, especially in terms of bacteriological values. However, this does not necessarily imply that the water is harmful to drink; this becomes more obvious when its quality is compared with that of the most unprotected traditional drinking water supply. Furthermore, solar disinfection, boiling or disinfection tablets can be used to purify water prior to consumption. More information on water safety can be found in Rainwater Harvesting in the Caribbean Tips for water safety in the Caribbean water harvesting toolbox.

See table 1 for guidance on preferred water harvesting techniques, depending on the intended use. The quality of water collected is largely affected by the harvesting technique and storage method. For domestic use, closed storage, such as cisterns, is recommended. For agricultural purposes, which normally require larger volumes and lower quality standards than domestic use, open storage, such as ponds or reservoirs, is more cost-effective. The least expensive storage means is infiltration into the soil in the form of soil moisture or possibly in the form of groundwater recharge if volumes, topography and geology are adequate. The type, size, location, available space and material of the storage structure should be planned along with the water harvesting system. Regular maintenance should be considered beforehand in terms of labour and material costs – e.g. for cleaning ponds and repairing and replacing plastic liners or pumping systems.

Step 4: Selection of a suitable water harvesting technique

When designing a suitable water harvesting system, the most essential starting point is to consider the needs and socio-economic conditions of key stakeholders in the project area, as well as the natural conditions of the surrounding watershed. When poor, scattered rural households are targeted, water harvesting measures, such as roof water harvesting or microcatchment water harvesting, should be preferred. If entire villages or producer organizations are targeted, more onerous macrocatchment water harvesting works or road water harvesting may be more convenient.

In macrocatchment water harvesting systems, aspects of water management must be taken into account from the start of the planning phase: there are a number of models for distributing harvested water, depending on the prioritization of uses – e.g. drinking, domestic use, agriculture and small industries. There may also be issues related to formal and customary water tenure, such as water rights inherited before water became less abundant due to climate change or the topography of the catchment, population increase, etc. There are also rules related to water tariffs, including the operation and maintenance of storage and conveyance facilities.

The following criteria have proven useful for determining the suitability of the water harvesting technique in the project area, as well as the socio-economic factors to ensure sustainability.

Rooftop water harvesting: Consider roof size (surface area), roofing material (corrugated iron sheets, brick roofs, etc.), type of building (community, industrial, etc.). Rooftop water harvesting is usually a good option for domestic water supply in any climate, as its quality is relatively high and its cost is low.

Micro- and macrocatchment water harvesting: Consider the size of the watershed, the topography from which water runs off (hilly areas, slopes, presence of gullies or channels, etc.), groundcover (vegetation, loose surface, compacted surface, clay soils, rocks, etc.) and the availability of space and depth for constructing storage structures (ponds, pits, dams, etc.), as well as the availability of areas for agricultural production at the foot of slopes to avoid pumping.

Box 2: Pastoral half-moons in Niger

The Family Farming Development Programme in Maradi, Tahoua and Zinder Regions (ProDAF) in Niger is achieving good vegetation recovery with a combination of different soil and water conservation and regeneration measures, among them pastoral half-moons upstream and on slopes, accompanied by other measures, such as assisted natural regeneration, restored meadows in transhumant passageways and protection by living hedges.

As a result, the average herbaceous biomass per hectare is around 300 kg and, in some cases, can reach over 1,000 kg. These good results at midterm review were recorded due to the good organization of the site management committees, which were able to maintain the defenses by making guardians available, creating multispecies nurseries managed by women and using several species of trees to protect the half-moons. The impact of the cash-for-asset method on beneficiary households contributes to food security, less exodus of young people and the purchase of small livestock by women.

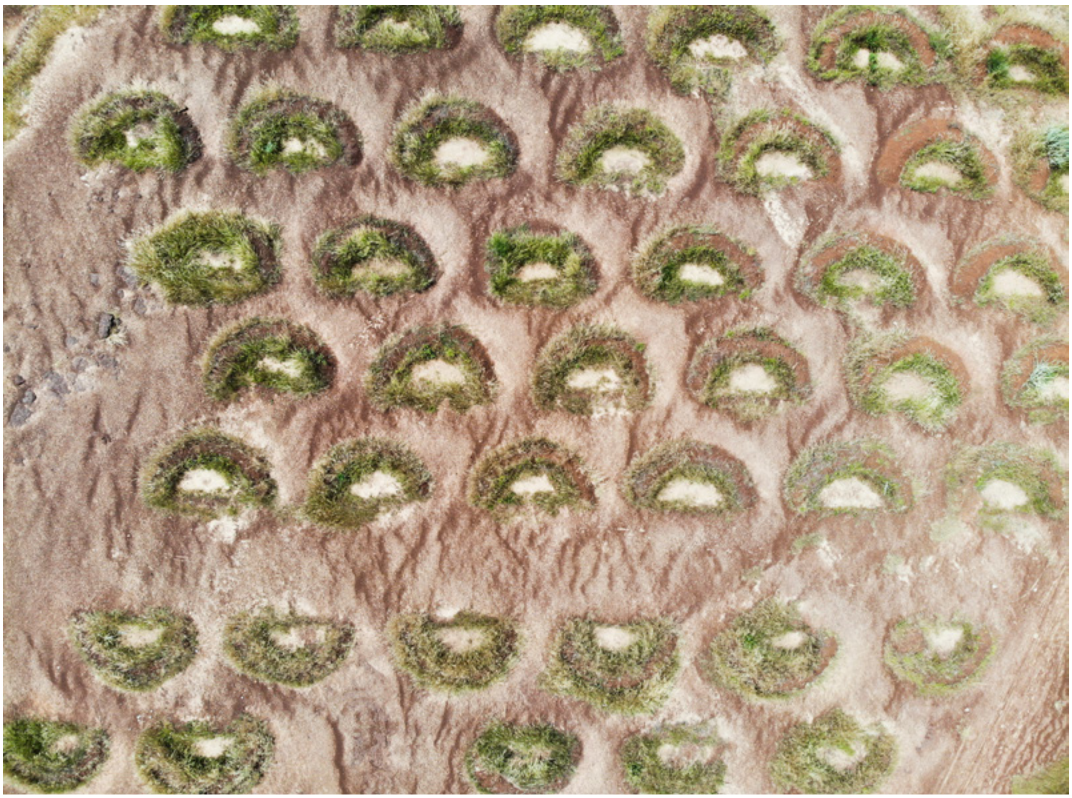

FIGURE 2: Half-moon technique, Niger, in the Zinder–Mirriah region

Box 3: Water harvesting and erosion control in Lebanon

Given the limited arable land resources, the deterioration of the natural resource base and the steadily growing population, land and water conservation and development are a high priority in the mountainous areas of Lebanon.

By terracing steep hilly lands, conserving their soils, planting high-value fruit trees in lieu of erosion conducive annual crops and storing potentially erosive run-off water in hill ponds and reservoirs for supplemental summer irrigation, well-to-do farmers have been able to create employment for their families and neighbors, have developed and protected natural resources from erosion, and have substantially increased their income. (IFAD, Agricultural Infrastructure Development Project, Lebanon).

Road water harvesting: Consider the water concentration points (low points, culverts, drains, etc.) and the final destination of concentrated water and run-off (assess the possibility of storage in storage structures or infiltration into the soil).

TABLE 1: Overview of intended water use and recommended water harvesting technique

	Water use	Water harvesting technique
Domestic	For human consumption (drinking and cooking) and personal hygiene	Roof water harvesting
	Other domestic uses	Roof water harvesting or water harvested from other impermeable surfaces (e.g. rocks)
Livestock	Drinking water	Roof water harvesting; macrocatchment water harvesting, especially from impermeable surfaces
	Stable cleaning	Roof water harvesting; macrocatchment water harvesting, especially from impermeable surfaces
Cropping	Vegetable gardens	Water harvesting from roof, yard or other impermeable surfaces Microcatchment water harvesting, macrocatchment water harvesting, fog water harvesting
	Fruit orchards and fodder	Microcatchment water harvesting, macrocatchment water harvesting, road water harvesting
	Crop irrigation	Microcatchment water harvesting, macrocatchment water harvesting, road water harvesting

SOURCE: FAO, 2013

Step 5:
Cost estimate for water harvesting systems

Comprehensive economic analyses of the costs of alternative water supply, in comparison with the costs of the current water available to the community, including costs in the form of women's time, labour and poor health due to water collection, need to be done to select the suitable technology to be implemented (UN Water, 2020). The WOCAT SLM database provides many examples of water harvesting projects and showcases useful information, including costs, as included in table 2. Costs are very country- and site-specific and are highly dependent on the components of the water harvesting system and the material and labour used. The table shows the maximum cost captured when the elements of the water harvesting system are fully used and the materials and labour have the highest prices.

TABLE 2: Indicative costs for water harvesting systems

Technology	Cost up to	Unit
Roof	130	US$/m^3
Macrocatchment	110	US$/m^3
Microcatchment	150	US$/ha
Microterracing	525	US$/ha
Storage	130	US$/m^3

Conclusion

Water harvesting has proven to be an effective technique across the globe for reducing the agricultural yield gap in a sustainable and cost-effective manner. Although water harvesting is context-specific and there is no one-size-fits-all solution, research so far has shown that approximately 19 per cent of the world's cropland can replicate the increase in agricultural production achieved through success with water harvesting. The highest potential for effective water harvesting is found in East and West Africa and South-East Asia, where water harvesting can be implemented in 40-70 per cent of agricultural land, with peaks of increase in agricultural production of 60-100 per cent.

And yet, the potential of water harvesting at the small household producer level remains largely unknown, unrecognized and unappreciated. This note gives planners, managers and project professionals at different scales an initial overview of the steps and assessments needed to evaluate the potential and plan for a water harvesting system. Links are provided to guidelines and tools for estimating water requirements, potential water harvest volumes, necessary water quality, maintenance and the selection of an appropriate water harvesting system.

General water harvesting guides

Mekdaschi Studer, R. and Liniger, H. 2013. Water Harvesting: Guidelines to Good Practice. http://www.rainfoundation.org/wp-content/uploads/2017/10/rainwater-harvesting-a-guid-to-good-practices.pdf

These guidelines are intended to inform decision makers and donors but are mainly geared to be of direct use to practitioners in the field, all the way up to watershed and river basin planners. They cover a wide range of technologies, from large-scale floodwater spreading that makes alluvial plains cultivable, to systems that boost crop, fodder and tree production in small farms, as well as practices for collecting and storing water from household compounds.

African Development Bank. 2009. Rainwater Harvesting Handbook. https://sswm.info/sites/default/files/reference_attachments/ADB%202008%20Rainwater%20Harvesting%20Handbook_0.pdf

The main objective of this handbook on rainwater harvesting is to provide the African Development Bank with an effective reference tool for including various rainwater harvesting approaches and techniques in the programming and design of projects. The data and recommendations in the handbook are based on the available literature and the findings of a field trip to three African countries in March 2006.

Nile Basin Initiative. 2009. Best Practices and Guidelines for Water Harvesting and Community Based (Small-Scale) Irrigation in the Nile Basin. https://entrospace.nilebasin.org/handle/20.500.12351/251. These comprehensive guidelines include the full range of water harvesting techniques, their planning, construction, maintenance, use and best practices, with many examples, including costs.

1. Water Harvesting Report. Part I – Best Practices in Water Harvesting, provides an overview of the best practices in water harvesting in the Nile Basin countries, constraints and options for improvement, needs and concerns and case studies.
2. Water Harvesting Report. Part II – Guidelines for the implementation of best practices in water harvesting. Practical working guideline with a focus on simple, field scale systems for improved production of crops, trees and rangeland species in drought prone areas.

FAO. 1991. A Manual for the Design and Construction of Water Harvesting Schemes for Plant Production. http://www.fao.org/docrep/u3160e/u3160e00.htm#Contents

FAO. 2013. Captación y Almacenamiento de Agua de Lluvia. Opciones técnicas para la agricultura familiar en América Latina y el Caribe. http://www.fao.org/docrep/019/i3247s/i3247s.pdf

For use as a field document for extension workers who work with small family farmers in conditions where water is a constraint to livestock and crop production. It offers guidance on concepts, strategies and methods for improving water capture and use in rural areas, especially those with deficient or intermittent availability.

FAO. 2014-a Compendium on Rainwater Harvesting for Agriculture in the Caribbean Subregion. Concepts, calculations and definitions for small rainfed farm systems. https://www.fao.org/3/br326e/br326e.pdf

Its purpose is to provide a practical tool to train and build human capacity in the practice of rainwater harvesting.

FAO. 2014-b Feasibility Study of Rainwater Harvesting for Agriculture in the Caribbean Subregion. https://www.fao.org/3/bq747e/bq747e.pdf

A study on the feasibility of water harvesting for agriculture, it provides outputs that justify promotion of the technology as a support tool to extend the duration of access to water for irrigation on rainfed farms during dry periods. The document is geared to agricultural smallholders operating on two hectares of land or less, as well as backyard gardeners and school gardening projects.

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