Rainwater Harvesting

by Norma Khoury-Nolde

n.khoury-nolde@nolde-partner.de

Germany

What is rainwater harvesting?

Rainwater harvesting is a technology used to collect, convey and store rain for later use from relatively clean surfaces such as a roof, land surface or rock catchment. The water is generally stored in a rainwater tank or directed to recharge groundwater. Rainwater infiltration is another aspect of rainwater harvesting playing an important role in stormwater management and in the replenishment of the groundwater levels. Rainwater harvesting has been practiced for over 4,000 years throughout the world, acticed for over 4,000 years throughout the world, traditionally in arid and semi-arid areas, and has provided drinking water, domestic water and water for livestock and small irrigation. Today, rainwater harvesting has gained much on significance as a modern, water-saving and simple technology.

The practice of collecting rainwater from rainfall events can be classified into two broad categories: land-based and roof-based. Land-based rainwater harvesting occurs when runoff from land surfaces is collected in furrow dikes, ponds, tanks and reservoirs. Roof-based rainwater harvesting refers to collecting rainwater runoff from roof surfaces which usually provides a much cleaner source of water that can be also used for drinking.
Gould and Nissen-Petersen (1999) categorised rainwater harvesting according to the type of catchment surface used and the scale of activity (Figure 1).

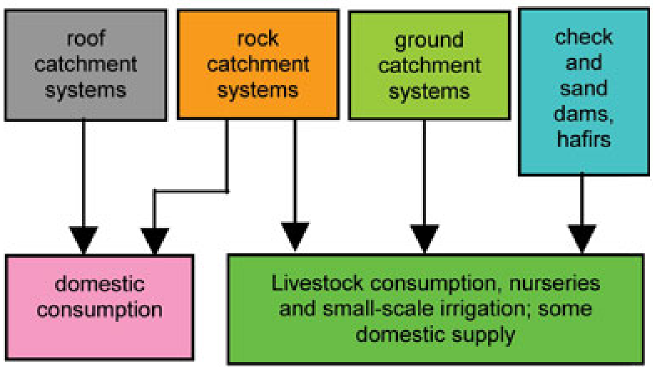

Fig. 1. Small-scale rainwater harvesting systems and uses (adapted from Gould and Nissen-Petersen, 1999).

Rooftop rainwater harvesting at the household level is most commonly used for domestic purposes. It is popular as a household option as the water source is close to people and thus requires a minimum of energy to collect it. An added advantage is that users own, maintain and control their system without the need to rely on other community members.

Why rainwater harvesting?

In many regions of the world, clean drinking water is not always available and this is only possible with tremendous investment costs and expenditure. Rainwater is a free source and relatively clean and with proper treatment it can be even used as a potable water source. Rainwater harvesting saves high-quality drinking water sources and relieves the pressure on sewers and the environment by mitigating floods, soil erosions and replenishing groundwater levels. In addition, rainwater harvesting reduces the potable water consumption and consequently, the volume of generated wastewater.

Application areas

Rainwater harvesting systems can be installed in both new and existing buildings and harvested rainwater used for different applications that do not require drinking water quality such as toilet flushing, garden watering, irrigation, cleaning and laundry washing. Harvested rainwater is also used in many parts of the world as a drinking water source. As rainwater is very soft there is also less consumption of washing and cleaning powder. With rainwater harvesting, the savings in potable water could amount up to 50% of the total household consumption.

Criteria for selection of rainwater harvesting technologies

Several factors should be considered when selecting rainwater harvesting systems for domestic use:

- type and size of catchment area
- local rainfall data and weather patterns
- family size
- length of the drought period
- alternative water sources
- cost of the rainwater harvesting system.

When rainwater harvesting is mainly considered for irrigation, several factors should be taken into consideration. These include:

- rainfall amounts, intensities, and evapo-transpiration rates
- soil infiltration rate, water holding capacity, fertility and depth of soil
- crop characteristics such as water requirement and length of growing period
- hydrogeology of the site
- socio-economic factors such as population density, labour, costs of materials and regulations governing water resources use.

Components of a rooftop rainwater harvesting system

Although rainwater can be harvested from many surfaces, rooftop harvesting systems are most commonly used as the quality of harvested rainwater is usually clean following proper installation and maintenance. The effective roof area and the material used in constructing the roof largely influence the efficiency of collection and the water quality.

Rainwater harvesting systems generally consist of four basic elements:
(1) a collection (catchment) area
(2) a conveyance system consisting of pipes and gutters
(3) a storage facility, and
(4) a delivery system consisting of a tap or pump.

Figure 2 shows a simple schematic diagram of a rooftop rainwater harvesting system including conveyance and storage facilities.

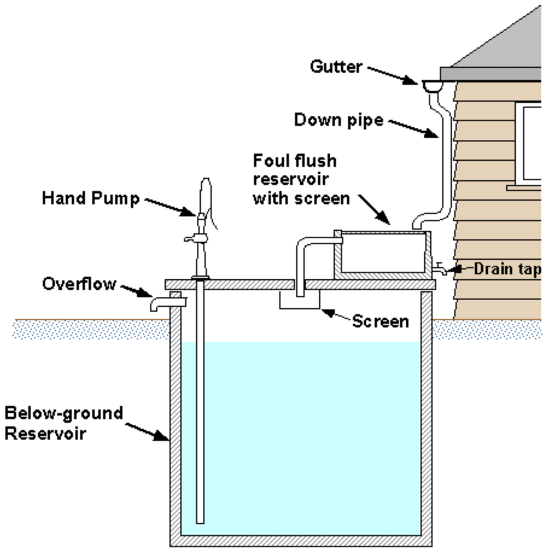

Fig. 2: A schematic diagram of a rooftop rainwater harvesting system.

(1) **A collection or catchment** system is generally a simple structure such as roofs and/or gutters that direct rainwater into the storage facility. Roofs are ideal as catchment areas as they easily collect large volumes of rainwater.

The amount and quality of rainwater collected from a catchment area depends upon the rain intensity, roof surface area, type of roofing material and the surrounding environment. Roofs should be constructed of chemically inert materials such as wood, plastic, aluminium, or fibreglass. Roofing materials that are well suited include slates, clay tiles and concrete tiles. Galvanised corrugated iron and thatched roofs made from palm leaves are also suitable. Generally, unpainted and uncoated surface areas are most suitable. If paint is used, it should be non-toxic (no lead-based paints).

(2) **A conveyance system** is required to transfer the rainwater from the roof catchment area to the storage system by connecting roof drains (drain pipes) and piping from the roof top to one or more downspouts that transport the rainwater

through a filter system to the storage tanks. Materials suitable for the pipework include polyethylene (PE), polypropylene (PP) or stainless steel.

Before water is stored in a storage tank or cistern, and prior to use, it should be filtered to remove particles and debris. The choice of the filtering system depends on the construction conditions. Low-maintenance filters with a good filter output and high water flow should be preferred. “First flush” systems which filter out the first rain and diverts it away from the storage tank should be also installed. This will remove the contaminants in rainwater which are highest in the first rain shower.

(3) **Storage tank or cistern** to store harvested rainwater for use when needed. Depending on the space available these tanks can be constructed above grade, partly underground, or below grade. They may be constructed as part of the building, or may be built as a separate unit located some distance away from the building.

The storage tank should be also constructed of an inert material such as reinforced concrete, ferrocement (reinforced steel and concrete), fibreglass, polyethylene, or stainless steel, or they could be made of wood, metal, or earth. The choice of material depends on local availability and affordability. Various types can be used including cylindrical ferrocement tanks, mortar jars (large jar shaped vessels constructed from wire reinforced mortar) and single and battery (interconnected) tanks. Polyethylene tanks are the most common and easiest to clean and connect to the piping system. Storage tanks must be opaque to inhibit algal growth and should be located near to the supply and demand points to reduce the distance water is conveyed.

Water flow into the storage tank or cistern is also decisive for the quality of the cistern water. Calm rainwater inlet will prevent the stirring up of the sediment. Upon leaving the cistern, the stored water is extracted from the cleanest part of the tank, just below the surface of the water, using a floating extraction filter. A sloping overflow trap is necessary to drain away any floating matter and to protect from sewer gases. Storage tanks should be also kept closed to prevent the entry of insects and other animals.

(4) **Delivery system** which delivers rainwater and it usually includes a small pump, a pressure tank and a tap, if delivery by means of simple gravity on site is not feasible. Disinfection of the harvested rainwater, which includes filtration and/or ozone or UV disinfection, is necessary if rainwater is to be used as a potable water source.

Storage tanks or reservoirs

The storage reservoir is usually the most expensive part of the rainwater harvesting system such that a careful design and construction is needed. The reservoir must be constructed in such a way that it is durable and watertight and the collected water does not become contaminated.

All rainwater tank designs should include as a minimum requirement:

- a solid secure cover
- a coarse inlet filter

- an overflow pipe
- a manhole, sump, and drain to facilitate cleaning
- an extraction system that does not contaminate the water, e.g. a tap or pump.

Storage reservoirs for domestic rainwater harvesting are classified in two categories:

1. surface or above-ground tanks, most common for roof collection, and

2. sub-surface or underground tanks, common for ground catchment systems.

Materials and design for the walls of sub-surface tanks or cisterns must be able to resist the soil and soil water pressures from outside when the tank is empty. Tree roots can also damage the structure below ground.

The size of the storage tank needed for a particular application is mainly determined by the amount of water available for storage (a function of roof size and local average rainfall), the amount of water likely to be used (a function of occupancy and use purpose) and the projected length of time without rain (drought period).

First flush and filter screens

The first rain drains the dust, bird droppings, leaves, etc. which are found on the roof surface. To prevent these pollutants from entering the storage tank, the first rainwater containing the debris should be diverted or flushed. Automatic devices that prevent the first 20-25 litres of runoff from being collected in the storage tank are recommended.

Screens to retain larger debris such as leaves can be installed in the down-pipe or at the tank inlet. The same applies to the collection of rain runoff from a hard ground surface. In this case, simple gravel-sand filters can be installed at the entrance of the storage tank to filter the first rain.

Rainwater harvesting efficiency

The efficiency of rainwater harvesting depends on the materials used, design and construction, maintenance and the total amount of rainfall. A commonly used efficiency figure, **runoff coefficient**, which is the percentage of precipitation that appears as runoff, is 0.8.

For comparison, if cement tiles are used as a roofing material, the year-round roof runoff coefficient is about 75%, whereas clay tiles collect usually less than 50% depending on the harvesting technology. Plastic and metal sheets are best with an efficiency of 80-90%.

For effective operation of a rainwater harvesting system, a well designed and carefully constructed gutter system is also crucial. 90% or more of the rainwater collected on the roof will be drained to the storage tank if the gutter and down-pipe system is properly fitted and maintained. Common materials for gutters and down-pipes are metal and plastic, but also cement-based products, bamboo and wood can be used.

Designing a rainwater harvesting system

For the design of a rainwater harvesting system, rainfall data is required preferably for a period of at least 10 years. The more reliable and specific the data is for the location, the better the design will be. Data for a given area can be obtained at the meteorological departments, agricultural and hydrological research centres and airports.

One simple method of determining the required storage volume, and consequently the size of the storage tank, is shown below:

With an estimated water consumption of 20 l/c*d, which is the commonly accepted minimum, the water demand will be = 20 x n x 365 l/year, where n=number of people in the household. If there are five people in the household then the annual water demand is 36,500 litres or about 3,000 l/month. For a dry period of four months, the required minimum storage capacity would be about 12,000 litres.

As rainwater supply depends on the annual rainfall, roof surface and the runoff coefficient, the amount of rainwater that can be collected = rainfall (mm/year) x area (m^2) x runoff coefficient.

As an example: a metal sheet roof of 80 m^2 with 800 mm rainfall/year will yield = 80 x 800 x 0.8 = 51,200 l/year.

Figure 3 demonstrates the cumulative roof runoff (m^3) over a one-year period and the cumulative water demand (m^3). The greatest distance between these two lines gives the required storage volume (m^3) to minimise the loss of rainwater.

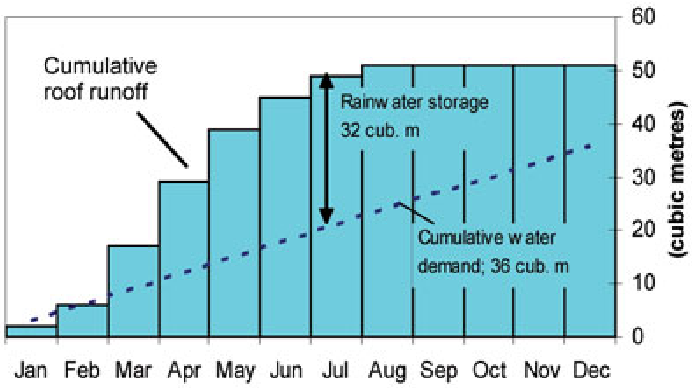

Fig. 3: Graphical method to determine the required storage volume for a rainwater cistern (adapted from Gould and Nissen-Petersen, 1999).

Types of rainwater use

Rainwater systems can be classified according to their reliability, yielding four types of user regimes:

- Occasional - water is stored for only a few days in a small container. This is suitable when there is a uniform rainfall pattern with very few days without rain and when a reliable alternative water source is available.
- Intermittent - in situations with one long rainy season when all water demands are met by rainwater. During the dry season, water is collected from other sources.
- Partial - rainwater is used throughout the year but the 'harvest' is not sufficient for all domestic demands. For example, rainwater is used for drinking and cooking, while for other domestic uses (e.g. bathing and laundry) water from other sources is used.
- Full - for the whole year, all water for all domestic purposes comes from rainwater. In such cases, there is usually no alternative water source other than rainwater, and the available water should be well managed, with enough storage to bridge the dry period.

Which of the user regimes to be followed depends on many variables including rainfall quantity and pattern, available surface area and storage capacity, daily consumption rate, number of users, cost and affordability, and the presence of alternative water sources.

Benefits of rainwater harvesting

Rainwater harvesting in urban and rural areas offers several benefits including provision of supplemental water, increasing soil moisture levels for urban greenery, increasing the groundwater table via artificial recharge, mitigating urban flooding and improving the quality of groundwater. In homes and buildings, collected rainwater can be used for irrigation, toilet flushing and laundry. With proper filtration and treatment, harvested rainwater can also be used for showering, bathing, or drinking. The major benefits of rainwater harvesting are summarised below:

- rainwater is a relatively clean and free source of water
- rainwater harvesting provides a source of water at the point where it is needed
- it is owner-operated and managed
- it is socially acceptable and environmentally responsible
- it promotes self-sufficiency and conserves water resources
- rainwater is friendly to landscape plants and gardens
- it reduces stormwater runoff and non-point source pollution
- it uses simple, flexible technologies that are easy to maintain
- offers potential cost savings especially with rising water costs
- provides safe water for human consumption after proper treatment
- low running costs
- construction, operation and maintenance are not labour-intensive.

Disadvantages

The main disadvantages of rainwater harvesting technologies are the limited supply and uncertainty of rainfall. Rainwater is not a reliable water source in times of dry periods or prolonged drought. Other disadvantages include:

- low storage capacity which will limit rainwater harvesting, whereas, increasing the storage capacity will add to the construction and operating costs making the technology less economically feasible
- possible contamination of the rainwater with animal wastes and organic matter which may result in health risks if rainwater is not treated prior to consumption as a drinking water source
- leakage from cisterns can cause the deterioration of load-bearing slopes
- cisterns and storage tanks can be unsafe for small children if proper access protection is not provided.

Sustainability

Rainwater harvesting is one of the most promising alternatives for supplying water in the face of increasing water scarcity and escalating demand. The pressure on water supplies, increased environmental impact from large projects and deteriorating water quality, constrain the ability to meet the demand for freshwater from traditional sources. Rainwater harvesting presents an opportunity for the augmentation of water supplies allowing t the same time for self-reliance and sustainability.

Cultural acceptability

Rainwater harvesting is an accepted freshwater augmentation technology in many parts of the world. While the bacteriological quality of rainwater collected from ground catchments is poor, rainwater from properly maintained rooftop catchment systems, which are equipped with tight storage tanks and taps, is generally suitable for drinking and often meets the WHO drinking water standards. This water is generally of higher quality than most traditional water sources found in the developing world. Rooftop catchment of rainwater can provide a good quality water which is clean enough for drinking, as long as the rooftop is clean, impervious and made from non-toxic materials and located away from over-hanging trees.

Maintenance

Maintenance is generally limited to the annual cleaning of the tank and regular inspection and cleaning of gutters and down-pipes. Maintenance typically consists of the removal of dirt, leaves and other accumulated material. Cleaning should take place annually before the start of the major rainfall season. Filters in the inlet should be inspected every about three months. Cracks in storage tanks can create major problems and should be repaired immediately.

Regulations and technical standards

The most important aspect during the construction of a rainwater harvesting system is to completely separate the rainwater and drinking water networks. All rainwater pipework and tapping points should be clearly designated and secured against unauthorised use.

In Germany, the construction of a rainwater harvesting system does not require a building approval but it is advisable to report it to the local public health office as well as the local water supplier. Some regulations and standards (especially DIN 1989) should be taken into consideration during construction and maintenance of a rainwater harvesting system.

Effectiveness of technology

The feasibility of rainwater harvesting in a particular locality is highly dependent on the amount and intensity of rainfall. As rainfall is usually unevenly distributed throughout the year, rainwater harvesting can usually only serve as a supplementary source of household water. The viability of rainwater harvesting systems is also a function of the quantity and quality of water available from other sources, household size, per capita water requirements and available budget.

Accounts of serious illness linked to rainwater supplies are few, suggesting that rainwater harvesting technologies are effective sources of water supply. It would appear that the potential for slight contamination of roof runoff from occasional bird droppings does not represent a major health risk. Nevertheless, placing taps at about 10 cm above the base of the rainwater storage tanks allows any debris entering the tank to settle on the bottom, where it will not affect the quality of the stored water, provided it remains undisturbed.

Finally, effective water harvesting schemes require community participation which is enhanced by:

- sensitivity to people's needs
- indigenous knowledge and local expertise
- full participation and consideration of gender issues, and
- taking consideration of prevailing farming systems as well as national policies and community by-laws.

Economic efficiency

Valid data on the economic efficiency of rainwater harvesting systems is not possible. Dependent on the regional conditions (water and wastewater prices, available subsidies), the amortisation period may vary between 10 and 20 years. However, it should be taken into consideration that for the major investment (storage and pipework) a period of use of several decades is expected.

Costs

The associated costs of a rainwater harvesting system are for installation, operation and maintenance. Of the costs for installation, the storage tank represents the largest investment which can vary between 30 and 45% of the total cost of the system dependent on system size. A pump, a pressure controller and fittings in addition to plumber's labour represent other major costs of the investment.

In general, a rainwater harvesting system designed as an integrated element of a new construction project is more cost-effective than retrofitting a system. This can be explained by the fact that many of the shared costs (such as for roofs and gutters) can be designed to optimise system performance and the investment can be spread over time.

Rainwater quality standards

The quality of rainwater used for domestic supply is of vital importance because, in most cases, it is used for drinking. Rainwater does not always meet drinking water standards especially with respect to bacteriological water quality. However, just because water quality does not meet some arbitrary national or international standards, it does not automatically mean that the water is harmful to drink.

Compared with most unprotected traditional water resources, drinking rainwater from well-maintained roof catchments is usually safe, even if it is untreated. The official policy of the Australian Government towards the question “Is rainwater safe to drink?” is as follows: “Providing the rainwater is clear, has little taste or smell and is from a well-maintained system, it is probably safe and unlikely to cause any illness for most users”. For immuno-compromised persons, however, it is recommended that rainwater is disinfected through boiling prior to consumption.

Drinking water from rainwater

In many countries of the world where water resources are not available at a sufficient quality fit for human consumption, rainwater acts as a substitute for drinking water and other domestic uses. In some remote islands around the globe, rainwater may even act as the major potable water source for their population.

The most important issue in collecting rainwater is keeping it free of dirt such as leaves, bird droppings and dead animals, and avoiding contamination with pollutants like heavy metals and dust.

Rainwater can be also treated for use as a potable water source. The use of slow sand filtration has proved to be a simple and effective treatment technology for the elimination of most of the organic and inorganic pollutants that may be present in rainwater, as well as producing a virtually pathogen-free water for drinking.

Key references

DIN 1989-1. 2002. Rainwater Harvesting Systems – Part 1: Planning, Installation, Operation and Maintenance. German Institute for Standardisation, Berlin, 2002.

Gould, J. and Nissen-Petersen, E. (1999) Rainwater Catchment Systems for Domestic Supply: Design, construction and implementation. IT Publications, London.

Rainwater Harvesting Project at the Development Technology Unit of School of Engineering, University of Warwick, UK
http://www.eng.warwick.ac.uk/DTU