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Concept and Technology of Rainwater Harvesting

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1.1 Introduction

"Rainwater harvesting" (RWH) is defined in this chapter as the collection of rainfall, usually collected and stored in either artificial reservoirs known as cisterns or natural surfaces used in micro-catchment rainwater harvesting.

Rainwater harvesting has been used in many locations in the world to provide water that is suitable for various domestic and irrigation uses. People continue to collect rainwater despite the availability of water distribution systems due to the shortage of water. In early civilization, people in deserts and semi-arid regions have relied on collecting rainwater from land surfaces and storing it in cisterns (Gorokhovich et al. 2011). A number of distinctive historical examples that incorporate effective water harvesting systems survive in different climatic zones, and can be found in areas which receive between 100 and 1000 mm of precipitation annually (Prinz 1995). The capture and utilization of rainwater today is based on an ancient tradition and uses techniques similar to those used around 5000 years ago. Building dams to tap stream water, channeled through canals and stored in reservoirs, was practiced by ancient civilizations about 5000 years ago to provide drinking water to the old city of Jawa (Abdelkhaleq and Ahmed 2007) and Umm el-Jimal city in the Early Roman period (de Vries 1997). In the Nabataean civilization that emerged in the arid region of southern Jordan more than 2500 years ago, people built dams to provide their capital city Petra and other settlements with water for drinking and irrigation (Abdelkhaleq and Ahmed 2007; Oleson 1995). The earliest known evidence of the use of the technology in Africa comes from northern Egypt, where tanks ranging from 200 to 2000 m^3 have been used for at least 2000 years – many are still operational today. Indians, over centuries, developed a range of techniques to harvest every possible form of water – from rainwater to groundwater, stream to river water, and floodwater. In the seventeenth century the small island of Malta built an aqueduct to collect rainwater for its growing population. In Meghalaya, a 200-year-old system of tapping stream and spring water for irrigating plants by using bamboo still exists (Agrawal and Narain 1997).

During the time of the Roman Empire, rainwater collection became something of an art and science, with many new cities incorporating state of the art for the time. The Romans were masters at these new developments and great progress was made right up until the sixth century AD. One of the most impressive rainwater harvesting construction can be found in Istanbul in the Sunken Palace which was used to collect rainwater from streets above.

Although rainwater harvesting has existed since the days of the early Romans, its popularity declined once central treatment facilities were able to supply treated drinking water. Today, rainwater harvesting is gaining popularity again for a variety of environmental and economic reasons. Obviously, technology and techniques have changed considerably from the days of the early Romans, but the theory remains the same.

Arid and semi-arid countries suffer deficits in water resources. These countries are the most water-stressed countries. The total renewable freshwater resources of these countries are less than the demand required by different sectors. The current water availability in these countries is less than the poverty level of 1000 m^3 per capita per year. The scarcity of water resources in these countries seems to be dictated by climatic conditions, such as aridity and abundance of high solar radiation, and by population pressure which grew at a location distant from water resources (Salameh and Bannayan 1993). Urban development and increasing demand are putting stress on existing water resources. This highlights the need to implement measures to ensure that the rain falling on rooftops is tapped as fully

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as possible through rooftop rainwater harvesting, either by recharging it into the groundwater aquifers or storing it for direct use. Attention is now focusing on alternative water sources, such as rainwater harvesting systems as supplementary water sources with multi-purpose functions. The increasing pressure on the available resources represent a challenge for scientists, engineers, and policy makers because the entire development of the country in a variety of fields depends on the availability of this vital resource (Abdulla and Al-Shareef 2009).

For many years, RWH was highly accepted and adopted in many places around the world (Okhravi et al. 2014). The practice of RWH systems is highly related to cultural values that were gained and transferred from one generation to another. The preliminary cost–benefit analysis suggests that implementing a rainwater collection system is not economically feasible at low water price. But this should not prevent implementing RWH because there are extra benefits that would be added to the system, such as reduced impact on the environment, research opportunities, and better public perception of government's goals toward sustainability. The cost of implementing a RWH system would be further reduced by including it in the construction of a new building or during a major renovation of an existing building. For all the reasons discussed above, it is highly recommended that RWH systems be installed in newly constructed buildings that have an area greater than 200 m^2 and located in zones of mean annual rainfall greater than 300 mm (Abdulla and Al-Shareef 2009).

The search for a new water source starts with an effort to decrease the present amount of water lost in the distribution system. Equally important is the collection of rainwater in economically feasible cisterns. It must be stressed that rainwater is the only source, which is easy to obtain individually and with minimum cost. The only thing a person needs is the roof of the house to collect the rainwater and a place to store it. In arid and semi-arid countries, where water supply to domestic sector is not based on demand but rather on a rotation system which in many times fails, people have to find other alternatives sources of water. In such case, water harvesting is an important source for drinking and other domestic usages.

Today there is a rapid increase of interest in rainwater harvesting and storage as a potential water supply to meet part of the urban, rural, and agricultural water demand. In this chapter, rainwater harvesting concepts and technologies have been reviewed and discussed. This chapter provides specific recommendations on the most appropriate methods and technologies of rainwater harvesting that should be adapted in different climatic zones. Both domestic and agricultural techniques of rainwater harvesting are addressed in this chapter. Tangible figures on quantities of collected water, water quality and its health and environmental impacts, appropriate designs of water harvesting systems, and cost–benefit analysis have been provided.

1.2 Concept of Rainwater Harvesting

Definition: Rainwater harvesting is a technology used for collecting and storing rainwater from rooftops, land surfaces, road surfaces, or rock catchments using simple techniques such as pots, tanks, and cisterns, as well as more complex techniques such as underground check dams (Appan 1999; Prinz 1995; Zhu et al. 2004). Currier (1973) has defined water harvesting as "the process of collecting natural precipitation from prepared watersheds for beneficial use." In the *Handbook on Water Harvesting*, Frazier and Myers (1983) have defined the term "water harvesting" as the process of collecting and storing water from an area that have been treated to increase precipitation runoff. In scientific terms, rainwater harvesting refers to the collection and storage of rainwater and also other activities aimed at harvesting surface and groundwater: prevention of losses through evaporation and seepage, other hydrological studies and engineering interventions aimed at conservation, and efficient utilization of the limited water endowment of physiographic unit as a watershed (Agrawal and Narain 1997). The basic principle of rainwater harvesting is to "*Capture rain where it falls*."

Rainwater harvesting can also mean collecting rainwater before it infiltrates into the ground and becomes underground water. Harvested rainwater is a renewable source of clean water that is ideal for domestic and landscape uses. Water harvesting systems provide flexible solutions that can effectively meet the needs of new and existing water demand for domestic and agricultural uses.

All water harvesting systems must have the following three components (see Figure 1.1):

(i) the catchment area, which is the part of land that contributes some or all of its share of rainwater to another area outside its boundaries. The catchment area can be small as few square meters or as large as several square kilometers. It can be agricultural, rocky, or marginal land or even a rooftop or paved road.
(ii) The storage facility, which holds surface runoff. Water can be stored in a surface reservoir, subsurface reservoirs (such as cisterns), in the soil profile (such as soil moisture), or a groundwater aquifer.
(iii) The target area, which is where the harvested water is used. It can be used for agricultural production in which the target is plants or livestock, in the domestic sector for drinking and cleaning, or it can be used for industrial purposes and other enterprises.

Figure 1.1 Components of a water harvesting system.

1.3 Technologies of Rainwater Harvesting

According to Oweis et al. (2004), there are several classifications of water-harvesting technologies, mostly based on the type of use or storage, but the method most widely used is based on the size of the catchment. Prinz (2011) presented wider classifications of water harvesting systems as shown in Figure 1.2. Also, Ngigi (2003) indicated that rainwater harvesting can fall into the following categories: in situ water conservation, conservation tillage, and runoff farming (i.e. storage systems for supplemental irrigation and direct runoff application, flood diversion and spreading systems, small external catchment systems, micro-catchment systems). Apart from in situ water conservation, normally rainwater harvesting systems have runoff producing areas, runoff collection structures, and storage facilities.

In situ water conservation technologies aim at conserving the rainfall where it falls in the cropped area or pasture. The in situ technology consists of making storage available in areas where the water is going to be utilized. Some water conservation methods such as mulching, deep tillage, contour farming, and ridging are often referred to as in situ rainwater harvesting techniques (Habitu and Mahoo 1999; Abu-Zreig and Tamimi 2011). The purpose of these methods is to ensure that rainwater is held long enough on the cropped area to allow more water infiltration into the soil. Deep tillage is a water conservation technique that improves soil moisture capacity by increasing soil porosity. In addition, runoff is reduced through increased roughness at the soil surface, which in turns increases the time available for water to infiltrate into the soil. The primary importance of such technologies is to reduce in-field runoff, increase the amount of water available within the root zone, and reduce soil erosion (Abu-Zreig et al. 2000). In situ water conservation practices are simple and cheap to apply. They include practices like; mulching, ridging, bench terraces, and addition of manure (FAO 2002). On not-so steep slopes, ridging, bench terraces, contour bunds, and small stone barriers can be used in order to slow down or prevent runoff so that rainwater sinks into the ground. On steeper hills, terracing can be applied, though it is quite labor-intensive.

Conservation tillage is a tillage system that conserves soil, water, and energy resources through the reduction of tillage intensity and retention of crop retention. It is also known as any tillage practice where about 30% mulch or crop residue cover is left in the field throughout the year, with the major objective to reduce soil and water loss (Dinnes 2004; Ngigi 2003). Conservation tillage increases infiltration and the water-holding capacity of the soil. The practice also saves labor due to reduced traction needs.

Runoff farming, a water harvesting technique, is the diversion of rainwater from a collecting area to a cropping area, thereby increasing the quantity water of available for crop growth. Runoff farming involves collecting runoff, generated either within the field or from external catchments, and applying the water either directly in the field or storing it for future use. Runoff farming involves technologies for storage of runoff for supplemental irrigation. In many dry parts of the world, simple and cheap structures (e.g. earth dams, farm ponds, and underground tanks) have been developed for storage of rainwater for supplemental irrigation (FAO 2002). Water loss from the tanks and ponds through seepage and evaporation reduces the value of this technology for rainwater harvesting. Runoff farming can be considered a rudimentary form of irrigated agriculture. The major differences are that with runoff farming the water is provided by natural runoff from catchment areas rather than artificial irrigation systems; water is stored in the soil of cultivated land rather than reservoirs, ponds, and cisterns; and the farmers have no control over timing since runoff can only be harvested when it rains. As a result, several innovations like lining tanks with plastic papers and cementing have been tried. However, such measures also imply additional costs to a farmer. Another technology for rainwater harvesting involves diversion of runoff and direct application in the cropland/garden. Under this technique, the soil profile acts as the reservoir. Direct runoff application systems include small external

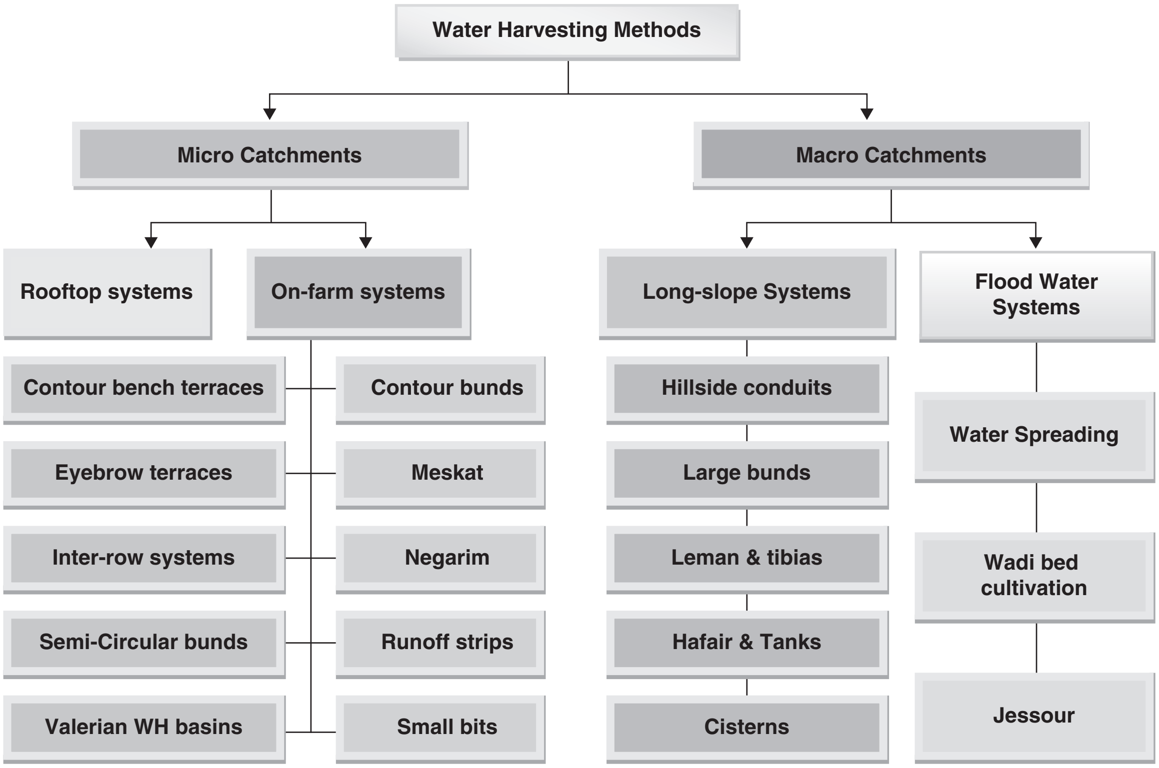

Figure 1.2 Rainwater harvesting technologies. Source: After Prinz 2011.

catchment systems, where small-scale runoff is diverted from roadsides and foot paths, and spread into the garden through a series of cut-off drains, contour bunds, ditches, and trenches (Ngigi 2003). In many cases, shrubs of various types and grass like Napier are planted on the lower sides of the rainwater harvesting structures to stabilize them. Another type of direct runoff application is micro-catchment systems, which involves generation of runoff within a field and concentration of the water on a single crop (i.e. fruit trees), or a garden established along a contour. In rainwater harvesting under micro-catchment systems, the crop land is subdivided into micro-catchments that supply runoff to single crops or a group of crops. Techniques under micro-catchment include moisture retention terraces, contour bunds, infiltration trenches/ditches, semi-circular earth bunds, circular depressions, etc. (e.g. Ngigi 2003). The improved traditional planting pits (zaï) widely used to rehabilitate degraded land in Burkina Faso also follow micro-catchment techniques Figure 1.3.

In this chapter, the classifications presented by Oweis et al. (2004) and Prinz (2011) will be described.

1.3.1 Micro-Catchment Systems

Micro-catchment method is a method of collecting surface runoff from a small catchment area and storing it in the root zone of an adjacent infiltration basin (Prinz and Singh 2006; Boers et al. 1986). Also, micro-catchment can be defined as a specially contoured area with slopes and berms designed to increase runoff from rain and concentrate it in a planting basin where it infiltrates and is effectively "stored" in the soil profile. The water is available to plants but protected from evaporation (Shanan and Tadmor 1979 and Li et al. 2004)

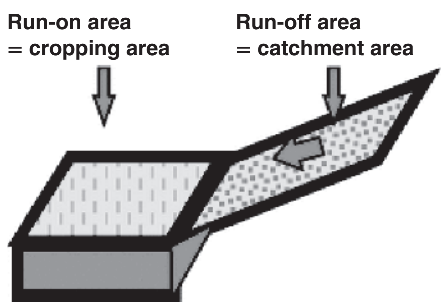

Figure 1.3 Definition of runoff farming. Source: Adapted with courtesy, FAO 1991.

1.3.1.1 Rooftop System

Rooftop rainwater harvesting is the technique through which rainwater is captured from roof catchments and stored in tanks/reservoirs/groundwater aquifers. It consists of conserving rooftop rainwater in urban and rural areas and utilizing it to augment groundwater storage by artificial recharge. It requires connecting the outlet point from the rooftop to divert collected water to an existing well/tube well/bore well or a specially designed well. Rooftop rainwater harvesting systems can be used to direct rainwater that falls on the roof of a building into containers or tanks. These tanks are usually elevated so that when the tap is opened, water flows at a high pressure. This method of rainwater harvesting is good because the accumulated water is mostly clean and usually requires no further treatment to make it fit for human use. This technique addressed by many researchers such as Zaizen et al. 1999; Kahinda et al. 2007; and Chisi et al. 2006.

1.3.1.2 On-Farm Systems

Contour bunds: This system consists of small trash, earth, or stone embankments, constructed along the contour lines (Garcia et al. 2002). The embankments trap the water flow behind the bunds allowing deeper infiltration into the soil. The height of the bund determines the net storage of the structure. This method is a traditional low-cost method of soil conservation suitable for sloping land; it promotes water retention and helps prevent erosion. Contour bunds are constructed in relatively low rainfall areas, having an annual rainfall or less than 600 mm, particularly in areas having light textured soils. For rolling and flatter lands having slopes from 2 to 6%, contour bunding is practiced, in red soils.

Semi-circular bunds: These are constructed in series in staggered formation. Runoff water is collected within the hoop from the area above it and impounded by the depth decided by the height of the bund and the position of the tips (Prinz 1995). Excess water is discharged around the tips and is intercepted by the second row and so on. Normally the semi-circles are of 4–12 m radius with height of 30 cm, base width of 80 cm, side slopes 1:1.5, and crest width of 20 cm. The percentage of enclosed area which is cultivated depends on the rainfall regime of the area. Basic requirements of the semi-circular bunds are:

(i) Ground slope must be less than 3%,
(ii) Soil depth, at least 1 m,
(iii) Average annual rainfall of at least 100 mm.

Meskat-type system: The meskat-type system is a type of micro-catchment system in which the catchment area diverts runoff water directly on to a cultivated area at the bottom of slope (Rosegrant et al. 2002). In this system instead of having CA (Catchment Area) and CB (Cropped basin) alternating like the previous methods, here the field is divided into two distinct parts, the CA and CB, whereby the CB is immediately below the CA.

1.3.2 Macro-Catchment Systems

Macro-catchment water harvesting, also called harvesting from external catchment, is a case where runoff from hill slope catchment is conveyed to the cropping area located at hill foot on flat terrain (Prinz and Singh 2006; Mzirai and Tumbo 2010). Macro-catchment rainwater harvesting includes the collection of water from large areas substantially far away from the cropped areas.

Strip catchment tillage: Strip-tillage is defined as less than full-width tillage of varying intensity that is conducted parallel to the row direction. This involves tilling strips of land along crop rows and leaving appropriate sections of the inter-row space uncultivated to release runoff. It is normally used where the slopes are gentle and the runoff from the uncultivated parts added water to the cropped strips. The catchment:basin area ratios (CBAR) used are normally less than or equal to 2:1. The system can be used for nearly all types of crops and is easy to mechanize.

External (Macro) catchment RWH: This is a system that involves the collection of runoff from large areas which are at an appreciable distance from where it is being used (Gowing et al. 1999). This is sometimes used with intermediate storage of water outside the CB for later use as supplementary irrigation. It is difficult to differentiate this system from conventional irrigation systems but in this chapter the system is called RWH as long as the water for harvesting is not available beyond the rainy season. This system involves harvesting of water from catchments of areas ranging from 0.1 ha to thousands of hectares either located near the cropped basin or long distances away. The catchment areas usually have slopes ranging from 5 to 50%, while the harvested water is used on cropped areas which are either terraced or on flat lands. When the catchment is large and located at a significant distance from the cropped area, the runoff water is conveyed through structures of diversion and distribution networks. The most important systems are described in this section.

There are many ways in which rainwater can be harvested. Some of these methods are very effective and can aid in the collection of a lot of water – even for commercial activities – while others are only suitable for harvesting water meant for domestic use. Every system has its merits and demerits. These are the common methods of rainwater harvesting:

- **Surface catchment systems:** Surface water is simply water that accumulates on the ground's surface. When rainwater falls on the surface of the earth (rock outcrops/slopes, concrete surfaces, plastic sheets, or treated ground surfaces), it usually flows down slopes as it moves toward a point of depression where the moving water can collect. Surface water collection systems enable the collection of surface runoff before it flows to other locations. Examples of such systems include rivers, ponds, and wells. Drainage pipes can be used to direct water into these systems. Water can then be fetched from these sources and used for other purposes such as domestic and livestock consumption. Water quality could be acceptable to beneficiaries. Safe water for human consumption can be assured with proper O&M and simple disinfection techniques if needed. This method is recommended for arid and semi-arid regions.

- **Small-scale Dams:** These are barriers that are designed to trap water. Also, these structures may be a temporary structure constructed with locally available materials (Tiessen et al. 2011). These consist of storage structure (earth dams, concrete dams, or simple excavated ponds, etc.), and structures to extracting water such as horizontal intake pipes. Rainwater or surface runoff can accumulate directly in them or drainage systems can be created to direct water into them. Water collected in these structures is mostly used for irrigation purposes and livestock or treated and then distributed for domestic use. They can also be used to harvest a lot of water because of the way in which they are modeled. Unlike ponds, measures are put in place to reduce the amount of water draining into the ground. Water quality could be acceptable to users and normally consumed without any further treatment. Safe water for human consumption can be assured with proper water extraction structures and simple disinfection methods if needed. These structures are highly recommended in arid and semi-arid region (rainfall between 100 and 500 mm).
- **Underground Tanks:** The systems are mainly comprised of a guttering system, underground storage tank, pump, and walled structure. These are also ideal for collecting rainwater. They are constructed by digging into the ground and creating a space which is then cemented to reduce water infiltration. The top is also sealed, and water is obtained through pipes directed into the tank. To get water out, pumps are used. Underground tanks are wonderful for harvesting rainwater because the rate of evaporation is reduced since they are located underground where sunlight does not really penetrate.
- **Rainsaucer:** Sometimes one can decide to collect rainwater directly as it falls from the sky by using a rainsaucer (RainSaucers 2009). These look like upside-down umbrellas or big funnels. Some are usually attached to a pipe so that the collected water is directed elsewhere. Some people also do a little improvisation by placing the collecting container underground with only the rainsaucer above the ground. It is a simple method yet effective.
- **Water Collection Reservoirs:** Water collected through this method is not really clean and may be contaminated. However, it can still be used for crop irrigation. Such rainwater is harvested from roads and pavements.
- **Barrage:** A barrage is a dam that has several openings which can be closed or opened to control the quantity of water that passes through it. It is usually large and can be used to collect a lot of water.
- **Slopes:** Rainwater tends to collect at the bottom of slopes when it flows on the ground. When it rains heavily, water levels can rise to the hilltop. This is a simple and natural way to harvest rainwater.
- **Trenches:** This is another great way to harvest rainwater for irrigation. When it rains, the water is directed to the farm using trenches. It is one of the traditional methods of rainwater harvesting that is still very much in use today.
- **Rain Barrels:** These are also used for rainwater harvesting. They are specifically designed for this purpose and can be purchased from retail stores. Rain barrels are used for harvesting rainwater that falls on rooftops.

1.4 Advantages and Disadvantages of Rainwater Harvesting

1.4.1 Advantages of Roof Rainwater Harvesting (RRWH)

Roof Rainwater Harvesting (RRWH) technologies are simple to install and operate. Rainwater harvesting is a technology used for collecting and storing rainwater from rooftops, land surfaces, road surfaces, or rock catchments using simple techniques such as pots, tanks, and cisterns as well as more complex techniques such as underground check dams (Appan 1999; Prinz 1995; Zhu et al. 2004). Rainwater harvesting provides the long-term answers to the problem of water scarcity. Rainwater harvesting offers an ideal solution in areas where there is sufficient rain but inadequate ground water supply, and surface water resources are either lacking or are insufficient. Harvested rainwater is a renewable source of clean water that is ideal for domestic and landscape uses. Water harvesting systems provide flexible solutions that can effectively meet the needs of new and existing, as well as of small and large, sites. The greater attraction of the rainwater harvesting system is the low cost compared to other water supply systems, and they are accessible and easily maintained at a household level (Abdulla and Al-Shareef 2009). Harvesting rainwater has a long-term impact on the local water resources by reducing demands for surface and groundwater withdrawals. Also, harvesting rainwater protects the integrity of local water resources by reducing nonpoint source pollution. Including rainwater harvesting in national water supply plans offers an alternative and sustainable water source while protecting the local environment.

Arid and semi-arid countries suffer deficits in water resources. These countries are the most water-stressed countries. The total renewable freshwater resources of these countries are less than the demand required by different sectors. The current water availability in these countries is less than the poverty level of 1000 m^3 per capita per year. The scarcity of water resources in these countries seems to be dictated by climatic conditions, such as aridity and abundance of high solar radiation, and by population pressure which grew at a location distant from water resources. Urban development and increasing demand are putting stress on existing water resources. Attention is now focusing on alternative water sources, such as rainwater harvesting systems, as supplementary water sources with multi-purpose functions. The increasing pressure on the available resources represent the challenge for scientists, engineers, and policy makers because the entire development of the country in different fields depends on the availability of this vital resource (Abdulla and Al-Shareef 2009).

For many years, RWH has been a highly accepted and adopted practice in many places in the world. The practice of RWH systems is highly related to some cultural values that were gained and transferred from one generation to another. The preliminary cost–benefit analysis suggests that implementing a rainwater collection system is not economically feasible at low water price. But this should not prevent implementing RWH because there are extra benefits that would be added to the system, such as reduced impact on the environment, research opportunities, and better public perception of government's goals toward sustainability. The cost of implementing a RWH system would be further reduced by including it in the construction of a new building or during a major renovation of an existing building. For all the reasons discussed above, it is highly recommended that RWH systems should be installed in newly constructed buildings that have an area greater than 200 m^2 and located in zones of mean annual rainfall greater than 300 mm (Abdulla and Al-Shareef 2009).

Due to the variable topographic features of different locations in the world, the distribution of rainfall varies considerably with location. Rainfall amounts vary from 100 mm in arid countries to more than 1000 mm in humid and semi-humid countries.

Search for a new water source starts with an effort to decrease the present amount of water lost in the distribution system. Equally important is the collection of rainwater in economically feasible cisterns. It must be stressed that rainwater is the only source, which is easy to obtain individually and with minimum cost. The only thing which a person needs, is the roof of the house to collect the rainwater and a place to store it. In arid and semi-arid countries where water supply to domestic sectors is not based on demand but rather on a rotation system which in many times fails, people have to find other alternatives sources of water. In such case, water harvesting is an important source for drinking and other domestic usages (Okhravi et al. 2015)

Since WH provides water at the point of consumption, owners (either single-home owners or commercial building owners) have full control of their systems, which greatly reduces operation and maintenance problems. Running costs are also almost negligible. Water collected from roof catchments is usually of acceptable quality for domestic purposes. In addition, rooftop catchments are usually best for satisfactory domestic water requirements because they are close to the dwelling and isolated from many sources of contamination. Rainwater may be utilized for drinking and cooking, for which high water quality is required, or for other domestic purposes, such as washing, bathing, toilet flushing, and landscape irrigation after filtration and disinfection. As it is collected using existing structures not specially constructed for the purpose, rainwater harvesting has few negative environmental impacts compared to other water supply project technologies. In summary, the main advantages of RRWH are:

- Saves water and energy.
- Water for domestic use: Rainwater harvesting is beneficial because it provides a source of water for domestic use. The collected water can be used for house cleaning purposes, washing laundry, and for cooking. When treated, rainwater is good for drinking. It is an easy way of obtaining water for use in the home.
- Sources of energy are not needed to operate the system.
- Water for industrial use: Industries can also harvest rainwater for use in some of their processes. Rainwater meant for industrial use is normally harvested in large scale. Such companies can construct their own dams or have underground tanks to store rainwater.
- Supplementary water source: Many areas experience water shortages during summer due to lack of rain and as a result of the high rate of evaporation. It can be difficult to get a reliable source of water during these periods. Those who sell water may also increase their prices because of the high demand and short supply. Harvesting rainwater is therefore seen as a way of preparing for the sunny days when water is scarce.
- Quality of rainwater can be used as a primary source for specific uses and so reduce the water bill.
- Does not come into contact with soil and rocks where it dissolves salts and minerals. It is soft and can

significantly reduce the quantity of detergents and soaps needed for cleaning.

- Very good for areas that are not served with water.
- Relatively limited technical knowledge is required.
- It uses local construction materials and labor.
- The owner user can easily maintain the system.
- Decreases local erosion and flooding caused by runoff from impervious cover such as pavement and roofs.
- The RRWH is usually found to be socially and environmentally acceptable.

1.4.2 Disadvantages of RRWH

Disadvantages of rainwater harvesting technologies are mainly due to the limited supply and uncertainty of rainfall. Adoption of this technology requires a "bottom-up" approach rather than the more usual "top-down" approach employed in other water resource development projects. This may make rainwater harvesting less attractive to some governmental agencies tasked with providing water supplies in developing countries, but the mobilization of local government and NGO resources can serve the same basic role in the development of rainwater-based schemes as water resource development agencies in the larger, more traditional public water supply schemes.

The main disadvantages are:

- The high initial cost of building the permanent storage facilities; the primary expense is the storage tank.
- The quantity of rainwater available depends on rainfall; for long periods of drought it is necessary to store excessively large volumes of water.
- The mineral-free water is tasteless and could cause nutritional deficiencies; people prefer to drink water rich in minerals.

1.5 Feasibility of Rainwater Harvesting across Different Climatic Zones

There are three important questions that should be asked when undertaking any project in a developing country: Does the community need it? Does the community want it? And can it be done? For a rainwater harvesting system, these translate into assessment of the physical, social, and technical aspects.

1.5.1 Physical Feasibility

The feasibility of rainwater harvesting is highly dependent upon the amount and intensity of rainfall. Other variables, such as catchment area and type of catchment surface, can usually be adjusted according to household needs. As rainfall is usually unevenly distributed throughout the year, rainwater collection methods can serve as only supplementary sources 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 and per capita water requirements; and budget available.

Physical feasibility depends on the amount of rainfall in the area, the duration of dry periods, and the availability of other water sources. The rainfall pattern over the year plays a key role on determining whether RWH can compete with other water supply systems. Various questions arise: For the given location, does it rain and how often? Does the amount of rainfall per month or per season warrant the usefulness of a rainwater harvesting system? There is no recommended minimum amount of annual rainfall that can be used a guide to the implementation of RWH. As a general rule, rainfall should be over 50 mm/month for at least half the year or 300 mm/year to make RWH physically feasible. This rule may not seem applicable for arid and semi-arid regions. Another source recommends 400 mm per year (United Nations Environmental Programme 1997) for feasible RWH. Past experiences and reviewing of existing RWH in arid and semi-arid regions indicated that RWH technology is adopted in areas having annual rainfall around 100 mm. Not all rainfall storms can generate surface runoff, even on impervious surfaces such as roofed buildings made from cement and concrete. For example, storms of less than 5 mm of rainfall will not generate surface runoff.

Due to the variable topographic features, the distribution of rainfall varies considerably with location. In most countries, the rainy season extends for about six months (for example, in the Middle East and North Africa [MENA] region it extends from October to May), with the peak of precipitation taking place during January and February. Rainfall data in this region indicate that there is a significant amount of rainwater that can be harvested. The highest rates of precipitation are commenced over the highlands which receive the long-term annual average.

1.5.2 Technical Aspects

The technical assessment seeks to answer the question "Can it be done?" by taking into consideration the resources required for the implementation of the system, by determining expected supply and demand for water based on gathered data, and, where applicable, by taking into consideration previously attempted projects and their reception by the people. In summary, the construction of a RWH system is determined by several critical technical factors:

- Use of impermeable roofing material such as concrete surfaces, tiles, etc.
- Availability of sufficient roof area
- Water consumption rate (number of users and types of uses) and storage capacity required
- Availability of other water sources, either groundwater or surface water that can be used when stored rainwater runs out
- Availability of laborers with technical building skills
- Availability of required, suitable local construction material

1.5.3 Social Aspects

The social assessment goes on to answer the whys of the physical assessment. For example, why is one source of water more preferred than another? Is a water source located in an area by choice or by circumstance? Why do people not practice rainwater harvesting? Is there a real need for better water provision?

People may have the need for an improved water supply, but there are several reasons the people may not be receptive to the idea of a RWH system. Depending on the kind of system presented, the technology may be above the education level of the people. There may be other priorities, depending on the season. It may not be considered an immediate need, or there may already be multiple sources of water, each with its own specified purpose. There may be traditional RWH systems already in place.

Cultural perceptions and religious views regarding the use of water, as well as traditional preferences for its location, taste, smell, or color are all important and need to be taken into consideration. It is those very traditions and social roles that will determine the successful implementation and use of a rainwater harvesting system. It is important to know the people, to be aware of their concerns, and to encourage their participation in every step of the rainwater harvesting process. It has been shown that the more a community is involved, the more potential for a successful project. These and likely other factors not mentioned here can positively or negatively affect a RWH system (Abdulla and Al-Shareef 2009). This practice of RWH systems is highly related to some cultural values that were gained and transferred from one generation to another.

The following social aspects should be considered when designing a household-based system:

- There should be a real felt need in the family for better water provision;
- The design should be affordable and cost effective;
- The family or community should be enthusiastic and fully involved;
- In the case of multi-story (apartment) building, it is difficult to implement such a system because the ownership of roof is not well identified.

1.5.4 Financial Aspects

The financial circumstances may also influence the design of a RWH structure. However, one should realize that financial reasons can hardly be a restriction for building a RWH system. Almost every house or building has a suitable roof, but guttering and the water storage do require some investments. The water storage tank usually represents the biggest capital investment element of the RWH system and therefore requires careful design to provide optimal storage capacity while keeping the costs as low as possible.

Installing a water harvesting system at the household level can cost anywhere from $400 USD to more than $2000 USD. It is difficult to make an exact estimate of cost because it varies widely depending on the availability of existing structures like pipes, tanks, and other materials. Actual cost depends on the final design and size of the tank. The cost would be comparatively less if the system was incorporated during construction of the building.

1.6 Roof Rainwater Harvesting System Components

A rainwater harvesting system consists of six basic components: a collection area (roof), a conveyance system, and a cistern or storage tank, with filtration, delivery system, and treatment. Figure 1.1 shows a schematic of a rooftop catchment system.

1.6.1 Catchment Area

The catchment of a rainwater harvesting system is the surface upon which the rain falls; the surface has to be appropriately sloped, preferably in the direction of the storage facility or the recharge area. The collection area in most cases is the roof of a house or a building; however, catchment areas may include driveways or swales in yards. Rainwater harvested from catchment surfaces along the ground should only be used for irrigation because of the increased risk of contamination. The effective roof area and the material used in constructing the roof influence the efficiency of collection and the water quality. Smoother, cleaner, and more impervious roofing materials are preferred; they contribute to better water quality and greater quantity. Tiled roofs or roofs sheeted with corrugated mild steel, etc., are preferable since they are the easiest to use and give the cleanest water (Abdulla and Al-Shareef 2009). Cement and tiled roofs are the most common roofs used in many parts of the world (Abdulla and Al-Shareef 2009). These types of roofs have good durability and provide good quality water. Composite asphalt and some painted roofs are recommended only for non-potable water use because they could leach toxic materials into rainwater as it touches the roof surface. Roofs that have lead materials should be prohibited because acidic rain may cause contamination of collected water from these roofs. Regardless of the roof material, many designers assume about a 20% loss of annual rainfall. These losses are due to roofing material texture, evaporation, losses occurring in gutters and storage tanks, and inefficiencies in the collection process (Abdulla and Al-Shareef 2009).

1.6.2 Conveyance System

A conveyance system usually consists of gutters or pipes that deliver rainwater falling on the rooftop to cisterns. Gutters or pipes must be properly sized, sloped and installed in order to maximize the quantity of harvested water. The most common materials of gutters are galvanized steel, fiberglass, plastic, stainless steel, copper, cast iron, and UPVC (unplasticized polyvinyl chloride). The gutters and downpipes are usually installed in the wall of the building, and sometimes the downpipes are fitted inside the wall during construction. The size of the gutters depends on the area of the roof and the rainfall amount; the size of the gutters used ranges between 5 and 10 cm diameter (Abdulla and Al-Shareef 2009).The diameter of the gutters can be determined using the Rational Equation ($Q = CIA$), where Q is the discharge in m^3/sec, C is the runoff coefficient (0.8), A is the roof area in m^2, and I is the rainfall intensity in mm/hr and can be obtained using the Intensity-Duration-Frequency (IDF) curves. Both drainpipes and roof surfaces should be constructed of chemically inert materials such as wood, plastic, aluminum, or fiberglass, in order to avoid adverse effects on water quality. Leaf screens are important to keep leaves and other debris from entering the system; the gutter should have a continuous leaf screen made of 0.4 mm fine mesh installed along their entire length.

1.6.3 Storage Tank

The water is ultimately stored in a storage tank or cistern. For a long time, people have been building cisterns to collect and store rainfall from roofs of their houses. There are many options for the construction of these tanks with respect to the shape (cylindrical, rectangular, and square), the size, and the material of construction (brickwork, stonework, cement bricks, plain cement concrete, and reinforced cement concrete). Storage tanks may be constructed as part of the building, or may be built as a separate unit located some distance away from the building. Concrete tanks are the most commonly used tanks in many countries; they can be built above or below ground (Abdulla and Al-Shareef 2009). They are usually made on site and are durable and long lasting. Above-ground tanks make it easy to detect cracks and leaks; water can be extracted via gravity and/or pumps; they can be raised off ground to increase water pressure; they are easy to drain for cleaning; and usually cost less than below-ground tanks (Abdulla and Al-Shareef 2009). But they take up space, they are subject to weather conditions, and require anchoring to the ground for when the tank has lees water. Below-ground tanks can save space, but they are more difficult to extract water from – they usually need a pump; it is hard to detect leaks or problems; they are difficult to drain for cleaning; there is a risk of contamination from septic tanks or floodwaters; they can be damaged by tree roots; if the access point is left uncovered, there is a risk of children, adults, and animals drowning or contaminating the water; and they usually have a large excavation costs. In addition, they can sometimes crack, especially when they are below ground in clay soil. They're good for preventing algal growth (light cannot penetrate) and they keep water cool. The storage tank represents the major cost in the system. Some storage tank (cistern) considerations are:

- A cistern should be durable and watertight;
- It should be close to the water supply and demand source;
- Select maximum height location to avoid pumping costs and extract water by gravity;
- Keep away from contaminant source of a septic tank at least 30 m;
- Make it possible to add water from other sources such as tanker water in arid seasons (near entrance preferred);
- A smooth clean interior surface is needed;
- Joints must be sealed with nontoxic waterproof material;
- They should have a cover to prevent evaporation and mosquito breeding and algae growth from contact with sunlight;
- Should not present an excessive danger to users falling in or by the tank failing in a dangerous way;
- Should provide water of a quality commensurate with its intended use – water that is used for drinking requires particular care;
- The tank should be covered to prevent entry of light, and sealed against intrusion by mosquitoes and small creatures;

- The tank should be ventilated to prevent anaerobic decomposition of any matter that is washed in. Ideally, it should also:
  - Be affordable;
  - Be easy and cheap to maintain in good condition;
  - Have a means by which water can easily enter and easily be withdrawn (into the normal household receptacle used in the area);
  - Have some arrangement to satisfactorily handle tank overflow;
  - Be easy to clean or “self-cleaning”

1.6.4 First Flush

Contaminants washed from a roof are usually concentrated in the first part of the runoff. Such contaminants contain various impurities such as bird droppings and dust. After this initial runoff has washed the roof, the collected water can be considered safe. This process is called the first-flush diversion. The purpose of the first-flush diversion is to collect and disposal of the first flush of water from a roof, especially where the collected rainwater is to be used for human consumption. First-flush devices ensure a certain degree of water quality in harvested rainwater. The first-flush volume is assumed to be about 40 l for each 100 m^2 of roof area. Many first-flush devices are simply and cleverly designed. Such devices include tipping buckets that dump when water reaches a certain level. The most simple of these systems consists of a stand pipe and gutter downspout located ahead of the downspout from the gutter to the cistern; the gutter downspout and top of the pipe are fitted and sealed so water will not flow out the top, and once the pipe has filled, the rest of the water flows to the downspout connected to the cistern (Figure 1.4).

1.7 Calculation of Potential Harvested Water

Water harvesting yields can be calculated for roof areas ranging from 100 m^2 to more 1000 m^2. These roof areas cover residential buildings (single houses, villas, and apartments) and public, commercial, and industrial roofs. Monthly rainfall data can be obtained from the country’s Ministry of Water or Meteorological Department for a particular location. The volume of rainwater that could be harvested from each roof for each rainfall zone can be calculated considering the annual rainfall data, the total roof area, and a runoff coefficient (efficiency) of 0.8. Runoff coefficient is the factor which accounts for the fact that all the rainfall falling on a catchment cannot be collected. Such a runoff coefficient indicates a loss of 20% of the rainwater that is discarded for roof cleaning and evaporation. The runoff coefficient, or efficiency, takes into account the losses from the collection surface. Recommended values of 0.8–0.85 are often used for the runoff coefficient, however it may be as high as 0.9 or as low as 0.24, depending on the surface material and other factors which may reduce the efficiency (Gould and Nissen-Peterson 1999). These factors include evaporation, clogging, leakage, infiltration, overspill, and retention. A smooth, clean, impervious surface yields better water quality and greater quantity (Texas Water Development Board 1997). The runoff coefficient is also a measure of the performance of the gutters and downspouts, as this is where most system losses tend to occur (Gould and Nissen-Peterson 1999). Table 1.1 shows the runoff coefficient for various surfaces of rooftops.

Thus, the volume of rainwater that could be harvested from each roof was determined by using Eq. (1.1).

$$VR = R \times A \times C \tag{1.1}$$

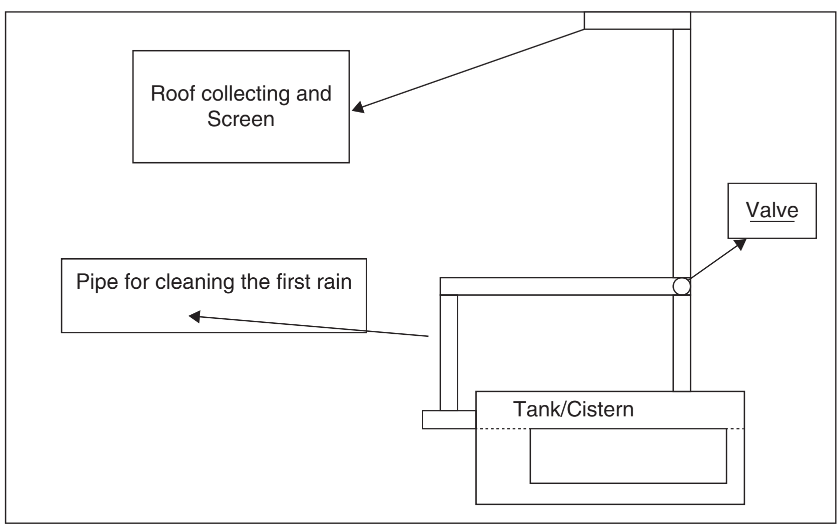

Figure 1.4 Rainwater harvesting system.

Table 1.1 Runoff coefficient for various surfaces.

Types of catchments	Runoff Coeff.
Roof Catchments	
– Tiles	0.8–0.9
– Corrugated metal sheets	0.7–0.9
Ground surface coverings	
– Concrete	0.6–0.8
– Bricks Pavement	0.5–0.6
Untreated ground catchment	
– Soil on slopes less than 10%	0.0–0.3
– Rocky natural catchments	0.2–0.5

Source: Pecey and Cullis (1989)

Where:

VR = Annual volume of rainwater that could be harvested (m^3),
R = Average annual rainfall in each rainfall zone (m/y),
A = Roof area (m^2),
C = Runoff coefficient (non-dimensional).

1.8 Water Quality and its Health and Environmental Impacts

Rainwater itself is of excellent quality; it has very little contamination, even in urban or industrial areas, so it is clear, soft, and tastes good. Contaminants can however be introduced into the system after the water has fallen onto a surface. Studies show that RRWH yields harvested waters with contaminants in levels acceptable by international drinking water standards (Kahinda et al. 2007; Zhu et al. 2004; Abdulla and Al-Shareef 2009) and is thus thought to be a superior option when considering domestic water supply, in particular potable water. Among these studies is one carried out by Abdulla and Al-Shareef (2009). Their analysis of samples of harvested rainwater from residential roofs indicated that the measured inorganic compounds generally matched the WHO standards for drinking water. On the other hand, fecal coliform, which is an important bacteriological parameter, exceeded the limits for drinking water. To be effective, high water quality must be both available during collection and maintained until the water is consumed. In the past, this aspect has not been adequately addressed.

Accounts of serious illness linked to rainwater supplies are few, suggesting that rainwater harvesting technologies are effective sources of water supply for many household purposes. 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 least 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. Ideally, storage tanks should be cleaned annually, and sieves should be fitted to the gutters and downpipes to further minimize particulate contamination. A coarse sieve should be fitted in the gutter where the downpipe is located. Such sieves are available made of plastic coated steel-wire or plastic, and may be wedged on top and/or inside gutter and near the downpipe. It is also possible to fit a fine sieve within the downpipe itself, but this must be removable for cleaning.

As a result, the following research priorities were identified:

(i) Investigation of the effects on the physicochemical quality of stored rainwater of roofing material and construction materials of containers;
(ii) Investigation of the effect on health of use of roofing materials made of asbestos, asphalt, and various metals;
(iii) Use of alternative roofing materials to improve the taste and color of stored rainwater;
(iv) Investigation of the effect of screening devices in preventing mosquitoes in the stored water;
(v) Investigation of the change in bacterial contamination levels of stored rainwater.

1.9 System Operation and Maintenance

Operation and maintenance are simple and depend mainly on cleaning the harvesting system annually before the start of the major rainfall season. Maintenance is generally limited to the annual cleaning of the tank and regular inspection of the gutters and downpipes. Maintenance typically consists of the removal of dirt, leaves, and other accumulated materials. However, cracks in the storage tanks can create major problems and should be repaired immediately. In the case of ground and rock catchments, additional care is required to avoid damage and contamination by people and animals, and proper fencing is required as well.

It is recommended that a tank be flushed at least once a year to remove all silt accumulation from the previous year. The sediment which builds up on the bottom of tanks should be cleaned when significant buildup occurs; if your tank does not provide a bottom clean-out valve then the tank usually must be drained in order to clean it, and all piping systems should be flushed and cleaned.

Roof catchments should also be cleaned regularly to remove dust, leaves, and bird droppings to maintain the quality of the product water; if you need to clean your catchment surface (e.g. roof and gutters) you should be careful that the water used for cleaning does not go into your rainwater tank.

1.10 Conclusion

The practice of harvesting rainwater is an old tradition adopted in many parts of the world and still used as a means for dealing with water problems of today, as well as a new technology that is growing in popularity. Rainfall water harvesting is a source of water and is very critical for the growth of crops and farming. This technology has been adapted in arid and semi-arid areas, rural and urban areas, and can serve as a primary or supplementary water source. The flexibility and the many benefits associated with rainwater harvesting make it a welcomed, widely accepted, and increasingly promoted alternative for the water demands of today. The collection of rainwater is today one of the easiest and cheapest methods of providing a good water supply to urban and rural communities in arid and semi-arid zones. The first reason for this is that does not require mobilizing vast quantities of resources and importing materials and expertise involved as in the planning and building large dams and reservoirs. A small RWH and storage system relies and builds upon local skills and experiences in construction, water consumption rate, and rainfall patterns.

As water shortages become more serious in many regions of the world, rainwater-harvesting systems will become more essential. Building codes must be updated to include these important water-conserving systems. If water-efficient technologies are incorporated at the code level, the resulting cumulative effects on water conservation across the country will be significant, as market opportunities open up for new products, customers demand more water-efficient designs, and designers face less resistance to incorporating efficient systems in buildings. Until they are included in the plumbing codes, it is up to the plumbing engineer to specify them and work with building officials in order to help conserve our increasingly scarce water resources.

Benefit–cost analyses of two roof harvesting systems (pear and concrete tanks) have been applied in this report. The unit price that is assigned for the water harvesting plays an important role in deciding whether the proposed system is economically feasible or not. The results revealed that pear-shaped tanks will be economically feasible in all rainfall zones when a \$1.0 USD m^{-3} is assigned as a cost of harvested water. Concrete tanks will not be economically feasible at this cost. The construction and installation costs of rooftop rainwater harvesting could cost as little as \$2000 USD for concrete tank sizes less than 20 $m^3$and might go up to \$6000 USD for tank size around 100 m^3. In general, the overall system cost typically rises with increasing tank volume, but system cost per m^3 of storage falls.

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