

Review

The Importance of Rainwater Harvesting and Its Usage Possibilities: Antalya Example (Turkey)

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Abstract: The significance and effective use of water, one of the most basic requirements for sustaining vital activities, is gaining importance every day. Population growth and unprogrammed industrialization accelerate the consumption of available water resources. However, drought, as a result of climate change, poses a threat to water resources. Factors such as the exhaustibility of water resources, rapid population growth, unscheduled industrialization and drought increase the tendency towards alternative water resources. Rainwater harvesting is based on the principle of using the rainwater falling into the regions after it is stored. Water collected through rain harvesting can be utilized in many different areas, such as agricultural irrigation, landscape irrigation and domestic use. Among agricultural activities, the idea of water harvesting in greenhouse areas comes to the fore. Due to the gutters on the greenhouse roofs, water can be stored. In Antalya, which has about half of the greenhouses in Turkey, the amount of water in the rain harvest that can be obtained in greenhouses is 224,992,795.8 m³ per year. Monthly calculations throughout the year showed that the minimum water can be harvested in August (938,447.53 m³) and the maximum (54,771,210 m³) in December. Therefore, it is thought that some plant water consumption can be met by building sufficient storage in areas close to the greenhouse.

Keywords: rainwater harvesting; rainwater harvesting structures; rainwater harvesting techniques; alternative water source



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1. Introduction

Although the water on Earth is in a continuous cycle, it is consumed before completing its cycle due to population growth, environmental pollution, cost, unconscious water consumption and changes in climatic conditions. Obtaining agricultural, industrial, drinking and utility water has become increasingly difficult for countries. Therefore, the strategic importance of water in the history of the world will continue to increase in the future [1].

Water is a vital and natural resource necessary for all living organisms to sustain their lives [2]. However, the amount of water on the Earth's surface is limited. Of the world's 1.4 billion km³ of water, 97.5% is salt water and 2.5% is freshwater resources. The distribution of the percentage of fresh water is 69.5% for polar glaciers, 30.1% for groundwater and 0.4% for surface water resources [3]. In addition to the problems related to the quantity of freshwater resources, there have recently been problems with water

quality on a global scale. The main reasons for the deterioration of these resources in terms of quantity and quality are rapid population growth, technological developments, urbanization and global climate change [4].

Apart from the way water resources are used, another issue affecting water resources is climate change. Agriculture is the largest global user of freshwater resources and is, therefore, highly vulnerable to climate change [5]. In addition, an increasing number of regions that are key to agricultural production are at higher risk of drought [6]. This contributes to an increasing demand for irrigation water. All these factors mean that water resources are threatened by expected production growth from the agricultural sector, and the gap between water availability and demand is exacerbated by global climate change [7]. Climate change, which has led to the deterioration of precipitation regimes in many parts of the world, has caused the amount of precipitation falling in long periods to fall suddenly in shorter periods, changing runoff rates and increasing soil erosion. In these regions, the soil water-holding capacity is expected to decrease soon, and irrigation water application schedules for agricultural activities are expected to change. In the last decade, changes in the average temperature and precipitation have been recognized as additional factors hindering the efficient use of water. This is expected to affect agricultural activities in form, scale, spatial and temporal terms in the coming decades [8].

The rapid increase in the world population, climate change, urbanization and industrialization have a negative impact on natural resources [9]. Despite the rapidly increasing demand for water, the gradual decrease in usable water resources due to the misuse of water and global warming places water at the top of the international agenda [10]. Water is vital for living beings to sustain their lives [11].

Increasing population growth is increasing agricultural expectations every day, and this increase is expected to continue unabated. Large increases in the world population are expected over the next 30 years [12]. It is estimated that the urban population, which is 57% of the world's population today, will increase to 69% by 2050. Approximately five billion people are expected to live in water-stressed regions by 2050 [13]. With this population increase, it is inevitable that not only the amount of water used in agricultural production but also the amount of water used in cities will increase with the density of the population. Toilets, garden irrigation, and vehicle and laundry washing account for 70% of the water consumed for drinking and utility purposes [11].

Due to the ever-growing population and increasing water use, the scale of the crisis is increasing daily, especially in water-poor countries. Because there will be no artificial substitute for water in the future, it is predicted that water will become a scarce strategic resource [14]. According to the World Health Organization, per capita, water consumption varies between 2 and 4 L. In contrast, the amount of water spent on food production consumed by one person varies between 2 and 5 tons per day on average. In the report that emphasizes that access to safe and clean drinking water and sanitation constitutes a "human right" in the resolution adopted by the UN General Assembly in 2015, it is stated that according to the 2015 figure, 3 in 10 people (2.1 billion) do not have access to safe drinking water [15,16]. With water consumption increasing daily, it is predicted that 5.7 billion people will suffer from water shortage for at least one month of the year after 2050 [17].

Today, treating seawater is economically costly, so rainwater harvesting can provide reliable and cost-effective domestic water. Due to increasing water scarcity, societies increasingly turn to alternative water sources and emphasize ways to reduce water consumption [18]. The world cannot meet the demand for clean water, and more people are becoming dependent on limited water resources. Therefore, the use of rainwater is coming to the fore. In arid and semi-arid regions, rainfall is very low and varies greatly within and between seasons. In addition, a large part of rainwater cannot be stored due to poor vegetation, surface runoff from shallow soils with a shallow surface and evaporation. It is, therefore, necessary to develop a strategy to maximize the use of rainwater. Irrigation is the best solution in case of droughts. Unfortunately, irrigation can be costly, and water

resources are scarce, so rainwater harvesting can be a good alternative. [19]. It is well recognized that rainwater harvesting can increase water supply and reduce stormwater pollutant discharges [20]. Due to the increasing water demand, rainwater harvesting is gaining importance as it provides an alternative source of drinking and potable water, can be used as irrigation water for the cultivation of crops, and reduces the amount of urban stormwater runoff. Rainwater harvesting is an application for collecting and using rainwater with artificial water collection systems to be created in residential areas, and it makes an important contribution to solving the problem of water scarcity, especially in countries with very low rainfall [21].

It is very important that people use water, which is a natural resource, consciously and without waste. However, the limited number of freshwater resources and the costly methods of obtaining clean water have led people to different searches. It is technically and economically impossible to increase the number of clean water resources despite the increasing demand for water by the population. In this case, the search for alternative water resources for the sustainable management of natural resources is an issue that has been implemented and emphasized in many countries in recent years [22–24].

For the sustainability of water resources, the search for alternative water sources has recently become the focus of many countries [2]. Rainwater harvesting is one of the alternative water sources for collecting significant amounts of water [25,26]. However, it is important to select a suitable water harvesting system that is the most efficient and cost-effective. It has been noted that in selecting a good system, it is useful to carry out a cost analysis and to apply methods based on multi-criteria decision making, such as AHP [27]. By using rainwater harvesting systems, many countries save considerable domestic water, reduce the amount of water consumed by the network and provide economic gains [24]. In addition, rainwater harvesting promises high potential in rural areas, over long distances, and in cases where reliable water is unavailable [28]. Researchers emphasize that properly planning water retention activities is an extremely important aspect in this context [29]. Furthermore, it is also valuable that the water obtained through water harvesting is free of charge and of good quality. In emergencies (earthquakes, sudden drought, extreme drought, etc.), this type of harvested water can be easily used to help conserve existing water resources and ensure the sustainability of rural areas. Water collected through rainwater harvesting can be used for many purposes, such as irrigation of green areas, irrigation for agricultural purposes, washing clothes, toilet reservoirs and flushing, car washing and fire extinguishing. It can also be consumed for drinking if it passes through a simple treatment system [30].

2. Basic Definition of Rainwater Harvesting

Rainwater harvesting is the process of collecting rainwater and storing it on the ground or underground, in the soil or in reservoirs for various uses. Rainwater harvesting is a set of techniques developed to collect and utilize surface runoff rainfall instead of using non-continuous groundwater, i.e., drinking water, used in residential and agricultural irrigation. The water collected from rainwater harvesting in arid and semi-arid areas worldwide increases the rate of water use and productivity in these regions [31]. Various classifications are made according to the size of the water catchment area. In general, they are classified as farm systems (microsystems), roof systems (microsystems), valley floor systems (macrosystems) and non-valley systems (macrosystems) [31,32]. An appropriate system is preferred, depending on the area's water demand and climatic conditions. However, it has been observed in many studies that roof rainwater harvesting is the most widely used system recently [2,11,14,24,26,31–33]. In these systems, rainwater falling on the roof surface is collected and transferred to water storage areas with the help of gutters. Two methods are applied to collect rainwater: underground storage and storage on the soil surface. Soil and cisterns are used for underground storage of collected water, and tanks, reservoirs or ponds are used as storage areas on the ground surface [34].

Advantages of Rain Harvesting

Rain harvesting has many advantages. These advantages are as follows [35–38]:

- It can be used as an additional water source wherever water is scarce and needed.
- It is self-sufficient and ensures the protection of water resources.
- It is purified to provide safe drinking water.
- It is used for planting and landscape irrigation.
- It reduces rainwater runoff into surface runoff.
- It uses simple technology and is easy maintenance.
- It has a low cost of use.
- It reduces the demand for surface water and groundwater.
- Its invoice and operating costs are low.
- It is a simple and flexible system. The public can be informed about issues such as maintenance and operation.
- It can be built anywhere, regardless of the terrain, geology or infrastructure management plans.
- Water can be delivered directly to households or to closer locations. By preventing transportation from a distant location, time and energy savings are achieved.
- It also provides stormwater management by transforming rainwater into water resource assets by preventing the negativities caused by infrastructure problems, such as drainage and flooding during heavy rainfall in urban areas.
- It reduces surface runoff in urban areas and ensures that surface waters are less polluted by pollutants (fertilizers, pesticides and sediment) that can be carried by water.
- It provides additional water supply in case of any disruption in the water distribution network or during drought periods.
- It provides flood control during periods of heavy rainfall.
- It is an additional source for households with limited access to water for domestic use.
- Collecting and using rainwater with hard surfaces, such as roof areas and parking lots that are not specially constructed for rainwater harvesting systems, has a less negative impact on the environment than dams and piped distribution systems.
- Rain harvesting is inexpensive and sustainable. It provides high-quality water, and excess water can be diverted to storage areas to feed groundwater.

3. History of Rain Harvesting

Water harvesting is a technique that has been used in various parts of the world since ancient times [39]. It can be adapted to very different situations and has been used in the driest and wettest regions of the world, and in the poorest and richest societies of our planet. Examples of water harvesting can be found in all major societies throughout history. The roof basin system is known to have been used in Roman times. Roman houses and even entire cities have been designed to utilize rainwater as the main water source for drinking and domestic purposes since 2000 B.C. In Israel, in the Negev Desert, where rainfall is 100 mm per year, it is known that tanks are used to store rainfall runoff from hillsides in agricultural and residential areas. The oldest known evidence is that 200–2000 m³ tanks have been used in Egypt for about 2000 years and are still in use today. This practice also has a long history in Asia. In Thailand, water collection practices can be traced back almost 2000 years. In Africa and Asia, rainwater harvesting has been practiced for thousands of years in traditional earthen pots with simple waterways or through roof eaves. The largest water collection cistern in the world is thought to be the Yerebatan Cistern in Istanbul, which is 140 m long, 70 m wide and has a capacity of 80,000 m³. Throughout the long history of the Palestinian region, farmers have built stone terraces to reduce the negative impact of heavy rainfall, increase soil organic matter content by preventing runoff and soil erosion, and protect soil water structures [40]. It is known that rainwater harvesting systems have existed for thousands of years in different parts of the world and are still in use [41]. The Romans focused on various infrastructures, such as aqueducts for water supply and built reservoirs and rain cisterns to store the water supplied by the aqueducts.

In the 13th century, the Venetians developed and applied advanced rainwater harvesting techniques. Currently, rainwater harvesting uses modern materials and techniques with new technologies, such as wells, pumps, reinforced concrete, plastic or steel tanks, which are different from the old rainwater harvesting techniques [42].

During the Ottoman Empire (1669–1898), considering the importance of water in the Muslim tradition, fountains and baths were quite common, and large hydraulic installations provided them with water. During the Ottoman period, the role of cisterns diminished in centralized areas served by centralized water systems. However, cisterns continued to be built and used in remote areas where water systems did not serve. In contrast to the rectangular plan of Byzantine cisterns, circular cisterns emerged in rural areas [43]. Today, these types of cisterns are frequently encountered and still used to meet the water needs of animals [44]. Evidence from many parts of the world shows that, since prehistoric times, people have tried to meet their water needs for domestic use, irrigation and livestock breeding by collecting and storing rainwater. Throughout history, rainwater has been the main water source for potable and non-potable uses. Rainwater harvesting is, therefore, crucial for human survival [45]. In addition, rainwater has been used since ancient times in arid regions and places where water access is difficult [44].

4. Rain Harvesting Components

Rainwater harvesting is a method that has been used by many people in the past. Water harvesting is a traditional practice; hence, a water harvesting system consists of three main components: a collection system, a transportation system and a storage system [46].

4.1. Collection Systems

Harvesting is a system used to collect water from different places after rainfall and flooding, but catchments are divided into two technical systems: land surface harvesting and roof surface harvesting [47]. Land surface harvesting is a very simple way to harvest water from building systems, such as paved areas (terraced, roads and courtyards), without spending much money and requiring more experience than other rainwater harvesting methods. Unpaved areas, such as bare soil, pastures, cultivated land, rocky areas with compacted surfaces, natural slopes and uncultivated areas, are also used to set up or create a harvesting location where the runoff of floodwater on the soil surface flows into the bed of a stream [48].

The roof collection system is a common method used to collect rainwater from the top of the roof through different components, such as galvanized sheet metal and corrugated sheet metal connected to the storage system [47]. The use of appropriate surface coatings in rainwater harvesting areas is also an important factor that can affect the maximum level of water that can be collected and the quality and efficiency of the water [49]. The roof's location, size and material influence the quantity and quality of rainwater collected. For example, a roof made of bamboo provides low-quality water, so other building materials such as galvanized, iron, aluminum, cement, etc. should be used instead of bamboo. The rainwater collection surface should be cleaned frequently to remove dirt, leaves and bird dropping [50]. The material of the collection site also influences the type and potential for the leaching of small amounts of toxins. For example, rainwater harvested from wood, asphalt and tar pavement roofs may only be suitable for irrigation [49]. During rainwater runoff on roofs, not all of the rainfall is collected due to wind action, roof slope, type of roofing material, evaporation, leaks and losses due to spillage [51].

4.2. Transportation Systems

This water conveyance system material, designed or used to transport water from the collection area to the storage area, depends on the collection system, the components of which may be a different material or system, such as galvanized iron or polyvinyl chloride. For example, in a roof collection system, the conveyance system in houses may consist of canals and ditches that carry water to underground storage [47]. In rainwater harvesting

systems, after rainwater is collected, it is filtered or unfiltered according to the need through transportation systems, transferred to storage vehicles, and stored in these areas [52]. In regions with heavy rainfall, there is a need for wider gutters than in regions with less rainfall. As a rule, it is recommended that the gutters should be at least 12.7 cm wide [53]. The gutter size should be designed for runoff during the highest intensity rainfall. Gutters are readily available in standard shapes and sizes, but custom-made profiles mounted on a slope can also be used to maximize the total amount of rainfall harvested. Gutters and downpipes, such as roof surfaces, should be made of chemically non-reactive materials such as wood, plastic, aluminum or fiberglass to avoid negative impacts on water quality [54].

4.3. Storage System

There are generally two ways in which harvested water can be stored: in a tank and underground storage. However, this storage system is the last water storage system used in water harvesting techniques [47]. The storage tank is the most important component of the rainwater harvesting system because of its high cost compared to other components. It requires proper design to ensure proper size at a low cost. The storage tank is designed according to the amount of water to be stored. Its location can be underground or above the ground [55].

The material, size and location of storage tanks depend on the intended use of the collected rainwater. The capacity of the tank should be proportional to the estimated monthly water demand, the location of the use, the monthly rainfall and the size of the collection area [56,57]. There are numerous alternatives for constructing these tanks according to the shape, size and material of the tank. Concrete tanks are usually built on-site and are long-lasting and durable [58].

The materials required for the construction of commonly used rainwater tanks and their properties are shown in Table 1 [49].

Table 1. Characteristics of storage tanks by material type based on Ling and Benham [49].

Material Type		Features
Concrete		They can be built on the ground or buried. They are very difficult to move due to their weight. Leakage may occur due to cracking.
		The storage tank reduces the corrosiveness of rainwater by allowing the CaCO_3 in its structure to dissolve from the walls and floor.
Cement/Reinforced Concrete		It consists of steel mesh woven around an iron frame and cement mortar. Although it is less expensive than other materials, maintenance is more frequent. It can be painted white to reduce evaporation and keep the water cool. Toxic compound content should be checked.
		Lightweight, affordable and long-lasting. Easy to procure and transport. Available in various sizes. The outer surface should be coated to prevent the passage of sunlight.
Fiberglass		Can be used in low-cost storage tanks made of materials such as plywood. Suitable for drinking water use.
		They vary in size, shape and color. They can be built underground or above the ground. Their cost is relatively low. More durable than fiberglass. Easy to clean as their inner surfaces are smooth. They can be easily transported because they are lightweight. They should be painted to prevent algae growth.
Plastic	Plastic Liner	
	Polyethylene	
Metal		Easy to obtain and affordable. It is highly desirable. Relatively light and convenient for transportation. May corrode in acidic conditions.

4.4. Water Purification

Dirt, rust, scale, silt and other suspended particles, bird and rodent droppings, airborne bacteria and cysts reach the storage tank when the first siphon, screens and covers are not installed according to the design. The potable use of the collected rainwater requires treatment and disinfection to remove sediment and pathogens to meet drinking water standards. Before deciding which method to use to treat the stored water, it should be analyzed by an accredited laboratory to determine whether the water is suitable for potable or non-potable uses [26].

To be usable, the collected rainwater must be pollution-free, safe and cost-effective. Properly constructed filtration systems, such as sand and gravel filters, charcoal filters, PVC pipe filters and sponge filters, can be used to meet these requirements [59]. In addition, rainwater can be filtered according to the need. For example, while there is no need for a filter in an area to be irrigated, it is required for needs such as drinking water [52].

5. Water Harvesting Techniques

There are several classifications of water harvesting methods, but the most widely used system is the one that is based on the size of the basin, i.e., micro-basins and macro-basins. Figure 1 shows examples of water harvesting methods based on Oweis et al. [39]. The main characteristics of the main classification groups are given in Table 2, which is based on information from the study by Prinz and Malik [60].

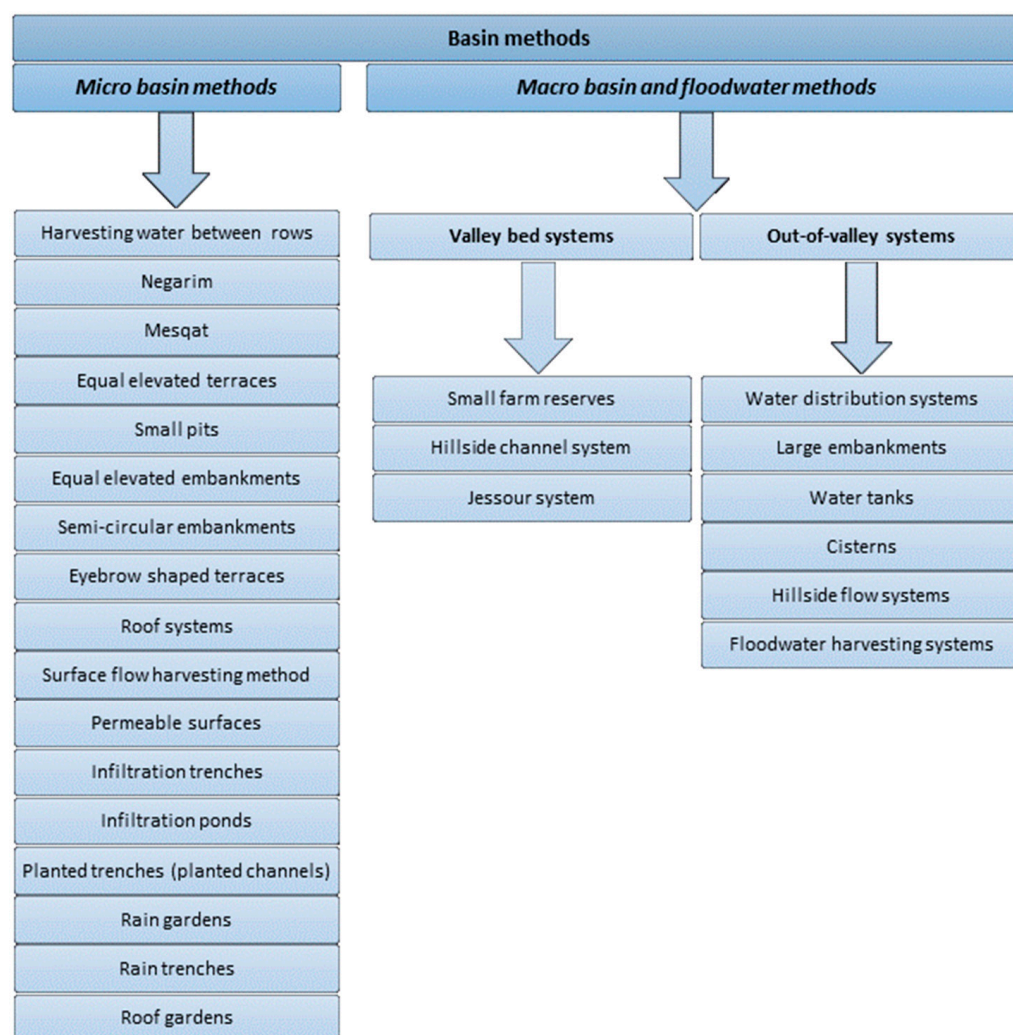


Figure 1. Classification of water harvesting system based on Oweis et al. [39].

Table 2. Main characteristics of the main groups of water harvesting methods [60].

Parameters	Micro-Basin Systems		Macro-Basin Systems	
	Farm Systems	Roof Systems	Valley Bed Systems	Out of Valley Systems
Size of the System	<0.02 ha	<0.1 ha	0.1–200 ha	>200 ha
Common Flow Type	Artificial slope or gutter flow	Artificial slope or gutter flow	Turbulent surface runoff, stream or gully flow, infrequently flow in short channels.	Channel flow with well-designed routes (complex structures required)
Basin/production area ratio	-	1:1–25:1	10:1–100:1	100:1–10,000:1
The general slope of the basin area	0–50%	0–50%	5–60%	0–100%
Basin surface	Galvanized sheet metal and plastic gutters, tiles, cement, etc.	Usually, the existing surface is treated	Usually, with or without treatment (natural) of the existing surface	Natural
Target Region Location	Mainly for home use	The lowest point of altitude of the land	On terraced or flat land	

5.1. Micro-Basin Methods

5.1.1. Harvesting Water between Rows

It is used on flat land and gentle slopes with a maximum slope of 4% with the soil at least 1 m deep. It is based on the logic of creating elevations between rows where crops are not planted. Rainwater falling on the ridges is directed to the cultivated plants in the furrows [41]. Therefore, it is suitable for regions with an average annual rainfall of more than 200 mm. This system has two prominent features. First, it is the only water harvesting technique that can be used on completely flat land as all other techniques require a slope. Second, its construction can be completely mechanized; therefore, it can be created without the need for manpower [32].

5.1.2. Negarim

This technique uses small diamond or rectangular grid earth embankments surrounded by constructed artificial embankments, called dikes, applied in small flow catchments [61]. A Negarim can be built on almost any slope. However, on slopes above 10%, soil erosion can occur, and the embankment height can increase to a non-ideal level. Therefore, this technique is recommended for regions with 150–500 mm annual rainfall. The Negarim water harvesting technique also prevents soil erosion [62].

5.1.3. Mesqat

It is a term used in Tunisia, where this system is widely used [63,64]. Mesqats are suitable for land with an annual rainfall of 200–400 mm and slopes of 2% to 15% [63]. A mesqat has a catchment area but may also feed more than one cultivated area (target area), which aims to send excess runoff water from one cultivated area to another to send water to effective areas [32]. The system is about 500 m² in size, consisting of a water catchment basin area surrounded by dikes, called a meskat, and a planting area of about 250 m², called a manka. The entire mesqat system is surrounded by a 20 cm high embankment and is equipped with spillways that allow runoff without causing erosion to flow into the manka plots and excess water to leave the manka. The mesqat system is a micro-catchment technique used exclusively for growing trees, and in Tunisia, olive trees are grown in manka plots covering 300,000 hectares [41].

5.1.4. Equal Elevated Terraces

They are built on steep terrain with 20% and 50% slopes. The technique, therefore, also aims to protect the soil against erosion. Cultivated terraces are usually built to be flat and supported by stone walls to slow runoff and control erosion. The terraces have simple sewage systems to safely remove excess water. The terrace method can be used in areas where annual rainfall is between 200 and 600 mm. Although construction can be performed by hand, heavy machinery may be needed, and installation, maintenance costs and labor requirements are high [65].

5.1.5. Small Pits

It consists of 5 to 15 cm deep pits that are 0.3 to 2.0 m in diameter [66]. Fertilizers and herbs are mixed with part of the soil and placed in the pits to improve the fertility and structure of the soil in the pits. The rest of the soil forms a small embankment at the bottom of the pit. This so-called “Zay system” is also combined with embankments to slow down surface runoff. The small pit method is used for growing annual crops, especially cereals such as millet, maize and sorghum [62]. The method is found in areas with an annual rainfall of 350–600 mm and is commonly used on flat land or slopes approaching 5%. On flat terrain, small pits are used to conserve or retain moisture in the soil rather than for water harvesting [65].

5.1.6. Equal Elevated Embankments

They are formed along isohypses (isohypsometric elevation) curves ranging from 5 to 20 m. The 1 or 2 m area between the ridges is cultivated, while the rest is the catchment area for water collection. The height of the ridges depends on the slope and the runoff depth immediately behind them. Each ridge is made of compacted soil but can be supported by stones if necessary. Ridges can be constructed on land, with slopes ranging from 1% to 50%. This method is ideal for growing forage crops and hardwoods in dry climates, and sorghum, millet, cowpeas and beans in semi-arid regions [65].

5.1.7. Semi-Circular Embankments

They appear as semicircles or trapezoids. The ends of the ridges along the elevation curve lines are set so that they face the slope. The embankments are usually made of soil. They are spaced at intervals that allow a sufficient catchment area to provide the minimum water flow required by the plant in each embankment. The distance between each embankment is between 1 and 8 m. The height of the embankments varies between 30 and 50 cm, and the width of the tops is between 10 and 25 cm. In areas where annual rainfall exceeds 300 mm, they are used for pasture improvement or for the production of fodder crops. They are also found in areas where trees, field crops and vegetables are grown [65].

5.1.8. Eyebrow-Shaped Terraces

They are semicircular structures supported by stones along the direction of the slope. Eyebrow-shaped terraces are micro-basins that only provide enough water for trees or shrubs. These terraces are also called “platform terraces” because they keep the runoff flat. The basin sizes are 5–50 m² and the planting area is 1–5 m². This technique can be used on slopes between 1% and 50%; steeper slopes mean the embankments must be reinforced with stone material. Eyebrow-shaped terraces are applicable in areas with annual rainfall between 200 and 600 mm [41].

5.1.9. Roof Systems

Rain harvested from rooftops is used as drinking water, especially in rural areas where even tap water is difficult to provide [55]. Between 80% and 85% of the rainfall can be harvested and stored. With a well-designed system, a family can meet its needs for a year with the water harvested and stored by roof systems in areas with less than 200 mm of

rainfall per year [67]. The system's working principle is simple; water is stored in tanks using the slope already on the roofs. In recent years, rainwater collected from greenhouse roofs is stored and used for agricultural irrigation after being filtered.

5.1.10. Surface Flow Harvesting Method

Rainfall falling on ground surfaces is transported through diverter pipes and can be stored and used in underground or aboveground tanks, or in basins and canals. Runoff harvesting can be used in many areas on the ground surface, such as asphalt, pavement, parking lots and soil. Rainwater collected from ground surfaces in open areas can be used untreated to irrigate green areas or as domestic flushing water, as it is more likely to be polluted than water collected from roofs. It can also be filtered and used to recharge groundwater [68]. Compared to rooftop rainwater harvesting techniques, ground harvesting techniques allow water to be collected from a larger surface area. In surface rain harvesting, rainwater collected in storage areas such as dams can be transported and diverted through streams and rivers, and stored rainwater can meet the water demand during the dry season [69].

5.1.11. Permeable Surfaces

Grass, gravel, porous concrete or asphalt, permeable concrete blocks and permeable concrete blocks interrupt the flow rate of surface water and allow rainwater to meet the soil. The materials used in the design of permeable surfaces, rainwater retention capacity and storage area are also important in the calculations. Roads, parking areas, sports fields and squares are suitable large areas for permeable surfaces [44]. Compared to existing roads in cities with heavily concreted areas, roads with porous/permeable asphalt pavement surfaces allow surface runoff to reach the lower layers and infiltrate into groundwater. In addition, these permeable pavements can mitigate the urban heat island effect and reduce excessive surface runoff during heavy rainfall and pressure on a city's drainage system, vehicle noise, comfort and safety [70].

5.1.12. Infiltration Trenches

Infiltration trenches are rectangular trenches filled with granular stones. They provide temporary underground storage for stormwater runoff. The granular filter maintains the original permeability of the soil by capturing finer sediments. Infiltration trenches are usually long, slightly wide and shallow. Infiltration trenches collect water from the surrounding impervious surfaces, allowing the water to infiltrate and percolate through the subsoil and along the edges into the surrounding soils. The coarse pebbles in the infiltration trenches are more permeable than the underlying soil, making it easier for rainwater to percolate into the soil in the depression. Water-percolating vegetation can be planted in the area, feeding groundwater, which can then be reused [71,72].

5.1.13. Infiltration Ponds

Infiltration basins, which are similar to infiltration trenches, are open vegetated facilities that, unlike infiltration trenches, are not filled with anything. They are constructed in soils with high permeability for groundwater recharge. Rainwater reaches these ponds at a lower elevation than that of impermeable surfaces. The water collected here can either infiltrate into the soil and be used by plants or be captured in a surface aquifer and pumped out for reuse [71].

The structural characteristics of the soil profile, the condition of the soil surface and the amount of moisture initially contained in the soil are factors affecting the infiltration rate of rainwater [73]. Therefore, rainwater infiltration is an important alternative method that prevents floods and overflows, controls pollution and improves water quality [74].

5.1.14. Planted Trenches (Planted Channels)

Planted trenches are shallow open channels designed to reduce and convey excess runoff water and treat pollutants. By taking up more area, planted trenches perform the same task as curbside stormwater conveyance gutters and better manage excess stormwater runoff into surface runoff. As surface runoff moves along the planted trenches, the plants slow the runoff and help it infiltrate into the soil by filtering the water. Although planted trenches infiltrate rainwater into the soil, they primarily transport water. In addition to all these benefits, it can be seen as a landscape area [73]. The rainwater collected in these trenches can be taken directly and used for various purposes, or it can seep into the soil and groundwater [71].

5.1.15. Rain Gardens

Rain gardens are systems in which rainwater collected from roofs, sidewalks, pedestrian or driveways, parking lots and various other water collection areas is directed to rain gardens, which are depressed landscape areas, or rainfall falling directly on these areas is collected and infiltrated into the soil. It is a very important rainwater management system because it reduces the pressure on water resources, is cost-effective and, at the same time, provides a habitat for living organisms such as flora and fauna [75].

5.1.16. Rain Trenches

Rain trenches can contribute to the unsustainable features of traditional stormwater drainage systems that are widely used in urban areas, such as flood control, water quality and groundwater supply. For this reason, the use of rain trenches alone or in combination with other green infrastructure applications, especially in urban areas, is important for the environmental sustainability of urban areas [76].

5.1.17. Roof Gardens

Green roof, living roof, eco-roof and roof garden are some of the terms used and confused with each other, but roof gardens are used in a different sense. A roof garden is an additional outdoor social living space, such as an entertainment and recreation area [77]. The green roof concept is a roof surface area covered with soil and plant elements on waterproof materials that provide a social and ecological balance [78].

5.2. Macro-Basin and Floodwater Methods

5.2.1. Valley Bed Systems

Small Farm Reserves

These are small ponds constructed by farmers whose lands are located in the valley to store all or part of the surface runoff flowing through the valley if they have suitable locations [39]. The capacities of these reservoirs vary between 1000 m³ and 500,000 m³. The reservoirs have high installation and maintenance costs. Projects and designs are required for their planning, and there is a need for continuous cleaning of materials, such as soil and bushes, that accumulate in the ponds with the flow. Since the water storage is not in a closed area, it is affected by evaporation and is subject to leakage. In order to minimize these losses, the stored water should be delivered to the plants as soon as possible [39].

Hillside Channel System

In hillside canal systems, small conveyance channels direct water from long slopes to the cultivated areas at the foot of the hill. This technique is applicable in areas with an annual rainfall of 200–600 mm and slopes exceeding 10%. In addition to the need to remove excess water, the structures must be robust and require good planning [41].

Jessour System

Jessour is an Arabic term for walls built along and perpendicular to the slope in relatively steep valleys in southern Tunisia. This system consists of small dams made of

earth, rock or sand baskets built either at the foot of the slope or in seasonal stream channels. The Jessour system is a hydraulic unit consisting of a barrier, terrace and catchment area. The barrier retains the sediment and runoff water. They are equipped with main and lateral spillways that allow the discharge of excess water. The terrace is an area reserved for vegetation and is formed over time by sediment accumulation. Fruit trees, such as olives, figs, almonds, dates, and legume crops (peas, chickpeas, lentils, and broad beans), are usually grown near the barrier [79].

5.2.2. Out-of-Valley Systems

Water Distribution Systems

It is based on a traditional working principle that dates back to ancient times. It is the diversion of water flowing naturally from the valley and directing it to storage areas for the purpose of accumulation. Since the storage areas in this method are in the plant root zone, their use is limited compared to other methods. Diversions are usually realized with small water arcs, and the arcs are usually located far from the valley path. In the world, there are examples where diversion arcs are positioned or activated/deactivated according to the plant pattern of the lands where the systems are located. These examples are seen as the most modern forms of water distribution systems [32].

Large Embankments

This is also called “Rabla” in the literature. This technique harvests water from large mountains and surfaces during the rainy season [80]. The distance between the slopes is approximately 10–100 m per embankment. The height of the embankment is expected to be at least 1 m. The embankments are mostly located parallel to the slope and the slopes are located with their endpoints perpendicular to the slope. The distance between successive embankments along the isohypses is approximately half the length of the embankment. Since the slopes are the most exposed to erosion, they need to be protected. Although machines have constructed structures in recent years, there are still manual embankments [81].

Water Tanks

These are water accumulation areas created to meet the water needs of humans and animals. Their capacities start at 1000 m³ on average, but it is also possible to come across examples of 50,000 m³. The water flowing in the valleys is diverted and allowed to flow into these tanks created by excavation, and the storage process is realized. These tanks are usually built with stone walls [32].

Cisterns

These systems are used as a solution to water shortages in residential areas. They are usually built underground and are watertight. The water flowing from the roofs, courtyards or terraces of buildings in the city is transferred to the cisterns [82].

Hillside Flow Systems

These structures are created to allow water flowing through the valley to leave its natural course and direct it to agricultural land. This technique is also called “flood water diversion”. Similar structures can also be used to collect rainwater from the puddles outside the watercourse. In this system, water is stored only in the crop’s root zone, thus supplementing the missing rainfall. The process requires relatively uniform land with low slopes. Farmlands can be graded into embankments and divided into basins to store enough water for the season. Soils must be deep and have a good water-holding capacity to efficiently use the system. It is recommended that a producer who decides to use the system should install it with a project designed by an engineer [65].

Floodwater Harvesting Systems

Floodwater is used for afforestation in many parts of the arid region of the world. Floodwater harvesting involves a large valley (an ephemeral riverbed) with many kilometers of surface runoff water flowing through it and systems that require more complex dams and distribution networks. Floodwater harvesting techniques have already been practiced for several millennia, and systems are found in NW Mexico, Pakistan, Tunisia, Kenya and China [83].

6. The Calculation on the Rain Harvest from Greenhouses

In the calculation of the amount of rainwater that can be harvested, long-term precipitation values of Antalya Province for the years 1930–2022 were used (Table 3) [84].

Table 3. Long-term average monthly total precipitation for Antalya Province (mm).

Months	Average Monthly Precipitation (mm)
January	234.9
February	151.8
March	91.7
April	49.3
May	32.4
June	11
July	4.5
August	4.4
September	17.1
October	71.5
November	129.5
December	256.8
Annual	1054.9

The values calculated according to FAO Blaney–Criddle and FAO Radiation methods were used for the monthly water consumption of tomatoes (Table 4) [85].

The calculations assumed that production in the unheated plastic greenhouse started in September and ended at the end of June. Furthermore, it was assumed that plantings were made at different row spacings and densities in the greenhouses [86].

According to 2022 TÜİK data, the plastic greenhouse area in Turkey is 47,128.4 hectares, and in Antalya, this area is 23,698.2 hectares. For Antalya, which accounts for approximately 50.28% of the plastic greenhouse area in Turkey, this value was used in rainwater harvesting calculations, and greenhouse areas were considered roof areas. The following equation calculates rainwater harvested from greenhouse roofs [21].

$$ACR = TRA \times ARA \times FC / 1000 \quad (1)$$

where:

ACR = Amount of Collectible Rainwater (m³)

TRA = Total Roof Area (m²)

ARA = Average Rainfall Amount (mm)

FC = Flow Coefficient (R_C: Ratio of rainfall to the collected water)

R_C: (R_C coefficient is taken as 0.9 for plastic greenhouse [87].

Table 4. Monthly water consumption of tomato plants according to FAO Blaney–Criddle and FAO Radiation methods.

Months	Monthly Water Consumption According to FAO Blaney–Criddle Method (mm)	Monthly Water Consumption According to FAO Radiation Method (mm)
January	46.4	30.9
February	52.4	41.9
March	96.7	85.1
April	127.2	108.5
May	177.9	146.9
June	139.7	109.8
July	0	0
August	0	0
September	84.2	59.9
October	61.9	42.5
November	37.4	22.5
December	50.3	30.9

The maximum amount of water that can be obtained by rain harvesting is 54,771,210.504 m³ in December, and the minimum amount is 938,447.532 m³ in August. The results obtained for each month are summarized in Table 5. It is assumed that the storage structures required for storing rainwater that can be obtained on the roof surfaces of greenhouses are designed as underground structures according to the terrain conditions. In this way, it is assumed that a possible land occupation can be prevented by preventing the use of the aboveground part of the land other than greenhouse activities. However, it is thought that the water transmission pipes in the greenhouse gutters are adjacent to the greenhouses and will be at the shortest distance to the storage structure to be designed under the ground. While designing greenhouses in any area, long-term meteorological data are considered to protect greenhouses from the negative effects of precipitation and wind on the greenhouses. Therefore, while designing greenhouses in the study area, it is assumed that the greenhouses are designed using materials that are resistant to environmental factors, such as rainfall and wind in terms of strength.

Table 5. Amount of water that can be obtained by rain harvesting.

Months	Amount of Rain Harvest That Can Be Obtained (m ³)
January	50,100,301.197
February	32,376,439.854
March	19,558,099.701
April	10,514,878.029
May	6,910,386.372
June	2,346,118.830
July	959,775.885
August	938,447.532
September	3,647,148.363
October	15,249,772.395
November	27,620,217.135
December	54,771,210.504

The study determined that the amount of rainwater that can be obtained according to the long-term (1930–2022) average rainfall is 224,992,795.797 m³ at the end of 12 months. Between 1991 and 2021, the amount of rainwater that could be obtained due to decreases in the precipitation regime was calculated as 22,3947,706,500 m³ at the end of 12 months. The observations show that the average rainfall in January, February, June and July between 1930 and 1922 was higher than that in January, February, June and July between 1991 and 2021. Therefore, changes in rainfall amounts also affect the rain harvest. When rainwater harvesting is carried out during periods of high or low average rainfall, the importance of saving and using water can be better understood. In this context, the importance of rainwater harvesting in terms of creating new water resources, especially during dry periods, can be more clearly understood.

Based on the amount of rainfall harvest that can be obtained, storage structures should be designed according to different rainfall regime scenarios. In this context, it may be important to design storage structures according to the highest rainfall regime as much as possible to avoid additional construction costs.

The irrigation fees used by producers in greenhouse irrigation are USD $0.0055 \times m^{-3}$ for gravity irrigation and USD $0.014 \cdot m^{-3}$ for pressurized irrigation [88] (1 Turkish Lira = USD 0.048). In light of this information, the data on the economic gain that can be obtained from the irrigation fee by utilizing the values in Table 5 are given in Table 6.

Table 6. Economic savings from irrigation fees.

Months	Gravity Irrigation	Pressurized Irrigation
	Obtainable Irrigation Pay Saving (USD)	
January	275,551.66	701,404.22
February	178,070.42	453,270.16
March	107,569.55	273,813.40
April	57,831.83	147,208.29
May	38,007.13	96,745.41
June	12,903.65	32,845.66
July	52,78.77	13,436.86
August	51,61.46	13,138.27
September	20,059.32	51,060.08
October	83,873.75	21,3496.81
November	151,911.19	38,6683.04
December	301,241.66	76,6796.95

According to this scenario calculation, as a result of a one-year rain harvest, it was determined that the producers could obtain a total economic gain of USD 1,237,460.38 for gravity irrigation and USD 3,149,899.14 for pressurized irrigation. Thus, it can be assumed that no payment will be made for an irrigation fee, and the profit obtained from tomato cultivation may increase. As a result, greenhouse growers may have a positive tendency towards rain harvesting.

Furthermore, according to FAO Blaney–Criddle and FAO Radiation methods in a PE plastic greenhouse which is not heated regularly in Antalya conditions, the area where the water requirement can be met by rain harvesting is given in Tables 7 and 8.

Table 7. According to the FAO Blaney–Criddle method, the water consumption of tomato plants according to different planting densities in areas where rain harvesting can meet water needs.

Months	Plant Density (Plant m ⁻²)						
	1.67	1.11	2.38	2.05	3.09	2.37	1.93
Area That Can Meet Water Needs with Rain Harvesting (ha)							
January	0.27283	0.41047	0.19144	0.22226	0.14745	0.19224	0.23607
February	0.15612	0.23489	0.10955	0.12718	0.08437	0.11001	0.13509
March	0.05111	0.07689	0.03586	0.04163	0.02762	0.03601	0.04422
April	0.02089	0.03143	0.01466	0.01701	0.01129	0.01472	0.01807
May	0.0098	0.01477	0.00689	0.00799	0.0053	0.00692	0.00849
June	0.00424	0.00638	0.00298	0.00346	0.00229	0.00299	0.00367
July	0	0	0	0	0	0	0
August	0	0	0	0	0	0	0
September	0.01095	0.01647	0.00768	0.00892	0.00592	0.00771	0.00947
October	0.06225	0.09366	0.04368	0.05071	0.03364	0.04386	0.05386
November	0.18661	0.28075	0.13094	0.15201	0.10085	0.13149	0.16146
December	0.27514	0.41395	0.19301	0.22414	0.1487	0.19388	0.23807

Table 8. According to the FAO Radiation method, the water consumption of tomato plants according to different planting densities in areas where water needs can be met by rain harvesting.

Months	Plant Density (Plant m ⁻²)						
	1.67	1.11	2.38	2.05	3.09	2.37	1.93
Area That Can Meet Water Needs with Rain Harvesting (ha)							
January	0.40968	0.61637	0.28746	0.33374	0.22141	0.28868	0.35449
February	0.19524	0.29375	0.137	0.15905	0.10552	0.13757	0.16894
March	0.05807	0.08736	0.04074	0.0473	0.03138	0.04092	0.05024
April	0.02448	0.03684	0.01718	0.01994	0.01323	0.01725	0.02118
May	0.01188	0.01788	0.00834	0.00968	0.00642	0.00837	0.01028
June	0.00539	0.00812	0.00378	0.00439	0.00291	0.0038	0.00467
July	0	0	0	0	0	0	0
August	0	0	0	0	0	0	0
September	0.01538	0.02314	0.01079	0.01253	0.00831	0.01084	0.01331
October	0.09066	0.1364	0.06361	0.07385	0.049	0.06388	0.07845
November	0.31018	0.46666	0.21764	0.25268	0.16763	0.21856	0.26839
December	0.44788	0.67383	0.31426	0.36485	0.24205	0.31559	0.38754

Based on the water consumption of tomatoes calculated according to the FAO Blaney–Criddle method, it was determined that the water requirement of an area of 0.27283 ha in January when the plant density was 16,700 per hectare and 0.41047 ha when the plant density was 11,100 per hectare could be met by rain harvesting. Similarly, based on the water consumption of tomatoes calculated according to the FAO Radiation method, it was determined that the water requirement of an area of 0.40968 ha in January when the plant density was 16,700 per hectare and 0.61637 ha when the plant density was 11,100 per hectare can be met by rain harvesting.

7. Conclusions

This review tried to raise awareness about the general definitions of rain harvesting, the advantages of rain harvesting and the history of rain harvesting. The applicability of both micro-basin systems for small locations and macro-basin systems for large locations is important for the continuity of water. In this context, to raise awareness about the importance of water conservation, both micro- and macro-watershed systems are mentioned in the paper as water harvesting techniques. As components of rain harvesting, collection, transportation, storage and water treatment systems according to the intended use of the stored water are mentioned in this review. The aim here was to draw attention to the components in the applicability of rain harvesting, regardless of the system size.

In addition, as an example, it was also calculated to which extent the rain harvest that can be obtained from plastic greenhouses in Antalya Province can meet the water needs of tomatoes. As a result, based on the water consumption of tomatoes calculated according to the FAO Blaney–Criddle method, it was determined that the water needs of 0.22226 ha in January when the plant density is 20,500 per hectare and 0.23607 ha when the plant density is 19,300 per hectare can be met by rain harvesting. Similarly, based on the water consumption of tomatoes calculated according to the FAO Radiation method, it was determined that the water requirement of an area of 0.33374 ha in January when the plant density is 20,500 per hectare and 0.35449 ha when the plant density is 19,300 per hectare can be met by rain harvesting. Therefore, it is believed that rainwater harvesting can be utilized in tomato cultivation to ensure the sustainability of existing water resources and save water.

As a result of the calculations and examinations, it can be said that rainwater harvesting is an advantageous system. Regarding the sustainability of agricultural production, producers should be informed about rain harvesting systems for irrigation needs and their use should be expanded. It can be assumed that with the widespread use of rain harvesting, water continuity can be maintained, sustainable development can be achieved and water resources can be used more efficiently.

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