Rainwater Harvesting And Utilisation

*An Environmentally Sound Approach for Sustainable
Urban Water Management: An Introductory Guide for Decision-Makers*

In most urban areas, population is increasing rapidly and the issue of supplying adequate water to meet societal needs and to ensure equity in access to water is one of the most urgent and significant challenges faced by decision-makers.

With respect to the physical alternatives to fulfil sustainable management of freshwater, there are two solutions: finding alternate or additional water resources using conventional centralised approaches; or better utilising the limited amount of water resources available in a more efficient way. To date, much attention has been given to the first option and only limited attention has been given to optimising water management systems.
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Introduction

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Among the various alternative technologies to augment freshwater resources, rainwater harvesting and utilisation is a decentralised, environmentally sound solution, which can avoid many environmental problems often caused in conventional large-scale projects using centralised approaches.

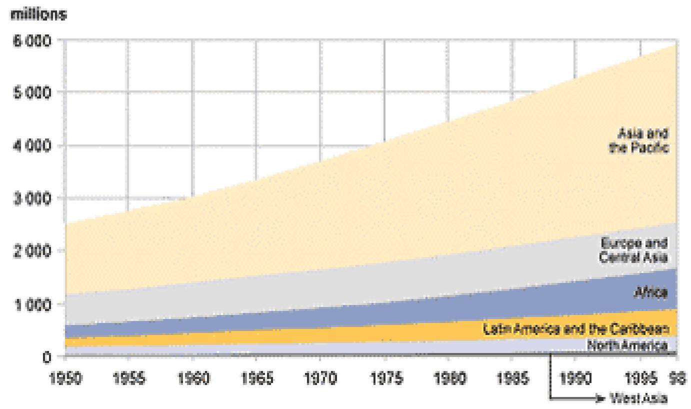
Rainwater harvesting, in its broadest sense, is a technology used for collecting and storing rainwater for human use from rooftops, land surfaces or rock catchments using simple techniques such as jars and pots as well as engineered techniques. Rainwater harvesting has been practiced for more than 4,000 years, owing to the temporal and spatial variability of rainfall. It is an important water source in many areas with significant rainfall but lacking any kind of conventional, centralised supply system. It is also a good option in areas where good quality fresh surface water or groundwater is lacking. The application of appropriate rainwater harvesting technology is important for the utilisation of rainwater as a water resource.

Why Should Rainwater Harvesting and Utilisation be promoted? — The Need for Environmentally Sound Solutions

Global Population Growth

Global population has more than doubled since 1950 and reached six billion in 1999. The most recent population forecasts from the United Nations indicate that, under a medium-fertility scenario, global population is likely to peak at about 8.9 billion in 2050.

Given that many natural resources (such as water, soil, forests and fish stocks) are already being exploited beyond their limits in some regions, significant effort will be required to meet the needs of an additional three billion people in the next 50 years.

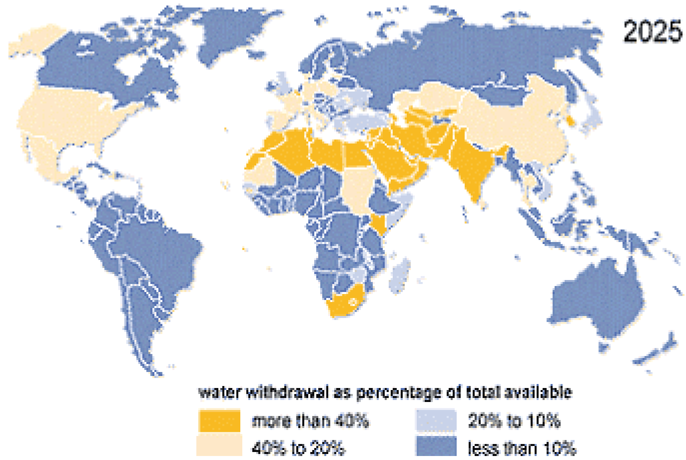


World population reached 6 billion in 1999.

In parallel with these changes, there have been profound demographic shifts as people continue to migrate from rural to urban areas in search of work and new opportunities. Since 1950, the number of people living in urban areas has jumped from 750 million to more than 2.5 billion people. Currently, some 61 million people are added to cities each year through rural to urban migration, natural increase within cities, and the transformation of villages into urban areas. Urbanisation creates new needs and aspirations, as people work, live, move and socialise in different ways, and require different products and services. Urban environmental impacts and demands are also different. By 2025, the total urban population is projected to double to more than five billion, and 90 per cent of this increase is expected to occur in developing countries.

The Global Water Crisis

Rapid population growth, combined with industrialisation, urbanisation, agricultural intensification and water-intensive lifestyles is resulting in a global water crisis. About 20 per cent of the population currently lacks access to safe drinking water, while 50 per cent lacks access to a safe sanitation system. Falling water tables are widespread and cause serious problems, both because they lead to water shortages and, in coastal areas, to salt intrusion. Both contamination of drinking water and nitrate and heavy metal pollution of rivers, lakes and reservoirs are common problems throughout the world. The world supply of freshwater cannot be increased. More and more people are becoming dependent on limited supplies of freshwater that are becoming more polluted. Water security, like food security, is becoming a major national and regional priority in many areas of the world.



By the year 2025, two thirds of the world population may be subject to water scarcity.

Advantages of Rainwater Harvesting

Rainwater harvesting systems can provide water at or near the point where water is needed or used. The systems can be both owner and utility operated and managed. Rainwater collected using existing structures (i.e., rooftops, parking lots, playgrounds, parks, ponds, flood plains, etc.), has few negative environmental impacts compared to other technologies for water resources development. Rainwater is relatively clean and the quality is usually acceptable for many purposes with little or even no treatment. The physical and chemical properties of rainwater are usually superior to sources of groundwater that may have been subjected to contamination.

Some Other Advantages of Rainwater Harvesting Include:

a. Rainwater harvesting can co-exist with and provide a good supplement to other water sources and utility systems, thus relieving pressure on other water sources.

b. Rainwater harvesting provides a water supply buffer for use in times of emergency or breakdown of the public water supply systems, particularly during natural disasters.

c. Rainwater harvesting can reduce storm drainage load and flooding in city streets.

d. Users of rainwater are usually the owners who operate and manage the catchment system, hence, they are more likely to exercise water conservation because they know how much water is in storage and they will try to prevent the storage tank from drying up.

e. Rainwater harvesting technologies are flexible and can be built to meet almost any requirements. Construction, operation, and maintenance are not labour intensive.

General Description of the Technology

Historical Development of Rainwater Harvesting and Utilisation

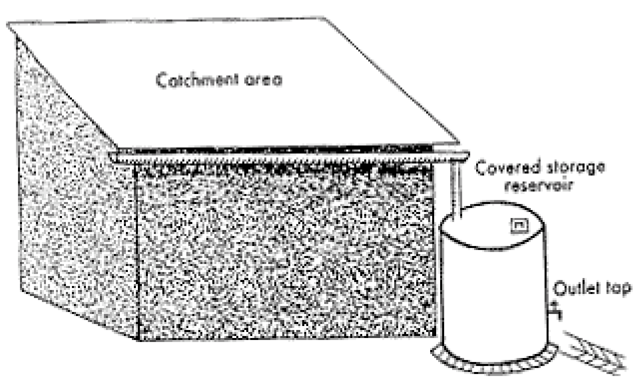
Rainwater harvesting and utilisation systems have been used since ancient times and evidence of roof catchment systems date back to early Roman times. Roman villas and even whole cities were designed to take advantage of rainwater as the principal water source for drinking and domestic purposes since at least 2000 B.C. In the Negev desert in Israel, tanks for storing runoff from hillsides for both domestic and agricultural purposes have allowed habitation and cultivation in areas with as little as 100mm of rain per year. The earliest known evidence of the use of the technology in Africa comes from northern Egypt, where tanks ranging from 200-2000m^3 have been used for at least 2000 years – many are still operational today. The technology also has a long history in Asia, where rainwater collection practices have been traced back almost 2000 years in Thailand. The small-scale collection of rainwater from the eaves of roofs or via simple gutters into traditional jars and pots has been practiced in Africa and Asia for thousands of years. In many remote rural areas, this is still the method used today. The world's largest rainwater tank is probably the Yerebatan Sarayi in Istanbul, Turkey. This was constructed during the rule of Caesar Justinian (A.D. 527-565). It measures 140m by 70m and has a capacity of 80,000 cubic metres.

Types of Rainwater Harvesting Systems

Typically, a rainwater harvesting system consists of three basic elements: the collection system, the conveyance system, and the storage system. Collection systems can vary from simple types within a household to bigger systems where a large catchment area contributes to an impounding reservoir from which water is either gravitated or pumped to water treatment plants. The categorisation of rainwater harvesting systems depends on factors like the size and nature of the catchment areas and whether the systems are in urban or rural settings. Some of the systems are described below.

(i) Simple roof water collection systems

While the collection of rainwater by a single household may not be significant, the impact ofthousands or even millions of household rainwater storage tanks can potentially be enormous. The main components in a simple roof water collection system are the cistern itself, the piping that leads to the cistern and the appurtenances within the cistern. The materials and the degree of sophistication of the whole system largely depend on the initial capital investment. Some cost effective systems involve cisterns made with ferro-cement, etc. In some cases, the harvested rainwater may be filtered. In other cases, the rainwater may be disinfected.



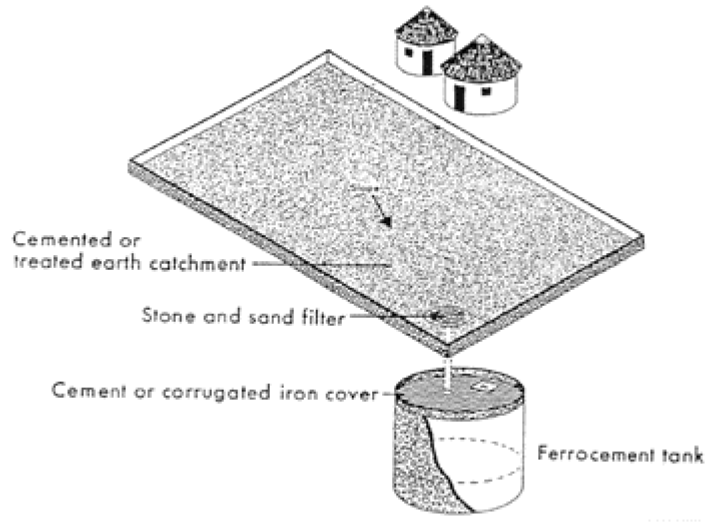
Example of a roof catchment system.

(ii) Larger systems for educational institutions, stadiums, airports, and other facilities
When the systems are larger, the overall system can become a bit more complicated, for example rainwater collection from the roofs and grounds of institutions, storage in underground reservoirs, treatment and then use for non-potable applications.

(iii) Roof water collection systems for high-rise buildings in urbanised areas
In high-rise buildings, roofs can be designed for catchment purposes and the collected roof water can be kept in separate cisterns on the roofs for non-potable uses.

At Kokugikan sumo wrestling arena in Tokyo, Japan, rainwater collected from the arena's 8,400 square meter rooftop is used for non-potable purpose.

(iv) Land surface catchments
Rainwater harvesting using ground or land surface catchment areas can be a simple way of collecting rainwater. Compared to rooftop catchment techniques, ground catchment techniques provide more opportunity for collecting water from a larger surface area. By retaining the flows (including flood flows) of small creeks and streams in small storage reservoirs (on surface or underground) created by low cost (e.g., earthen) dams, this technology can meet water demands during dry periods. There is a possibility of high rates of water loss due to infiltration into the ground, and because of the often marginal quality of the water collected, this technique is mainly suitable for storing water for agricultural purposes.



Example of a ground catchment system.

(v) Collection of stormwater in urbanised catchments
The surface runoff collected in stormwater ponds/reservoirs from urban areas is subject to a wide variety of contaminants. Keeping these catchments clean is of primary importance, and hence the cost of water pollution control can be considerable.

How Can Rainwater Harvesting and Utilisation Contribute to a Sustainable Water Strategy?

Self-Sufficiency in Water Supply, Without Being Dependent on Remote Water Sources

Many cities around the world obtain their water from great distances - often over 100km away. But this practice of increasing dependence on the upper streams of the water resource supply area is not sustainable. Building dams in the upper watershed often means submerging houses, fields and wooded areas. It can also cause significant socio-economic and cultural impacts in the affected communities. In addition, some existing dams have been gradually filling with silt. If not properly maintained by removing these sediments, the quantity of water collected may be significantly reduced.

Decentralised "Life-Points", Versus the Conventional "Life-Line" Approach
When the city increases the degree of its dependence on a remote water resource, and there is a long period without rainfall in the upstream dam sites, the ability of the city to function effectively is seriously compromised. The same can be said about a city's reliance on a pipeline for drawing water from a water resource area to the city. A city which is totally reliant on a large, centralised water supply pipeline (or "life-line") is vulnerable in the face of a large-scale natural disaster. A shift from "life-line" to decentralised "life-

points” should be encouraged. Numerous scattered water resource “life-points” within a city are more resilient and can draw on rainwater and groundwater, providing the city with greater flexibility in the face of water shortages and earthquakes.

Restoring the Hydrological Cycle

Due to the rapid pace of urbanisation, many of the world’s large cities are facing problems with urban floods. The natural hydrological cycle manifests itself at different scales, depending upon climatic, geographic and biological factors. As rain falls over time and seeps underground to become groundwater, it feeds submerged springs and rivers. The concrete and asphalt structures of cities have tended to disrupt the natural hydrological cycle, and reduce the amount of rainwater permeating underground. A decrease in the area where water can penetrate speeds up the surface flow of rainwater, causing water to accumulate in drains and streams within a short time. Every time there is concentrated heavy rain, there is an overflow of water from drains, and small and medium sized rivers and streams repeatedly flood. These conditions can often lead to an outpouring of sewage into rivers and streams from sewer outlets and sewer pumping stations, thus contaminating the quality of urban streams and rivers.

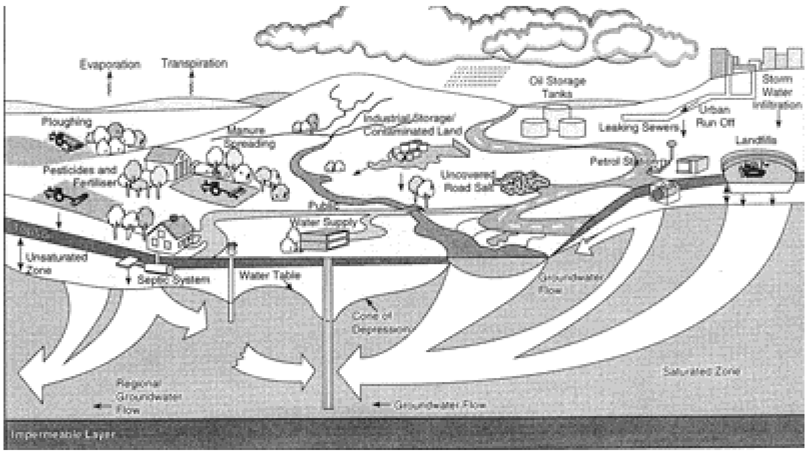


Diagram of the Hydrological Cycle (detail)

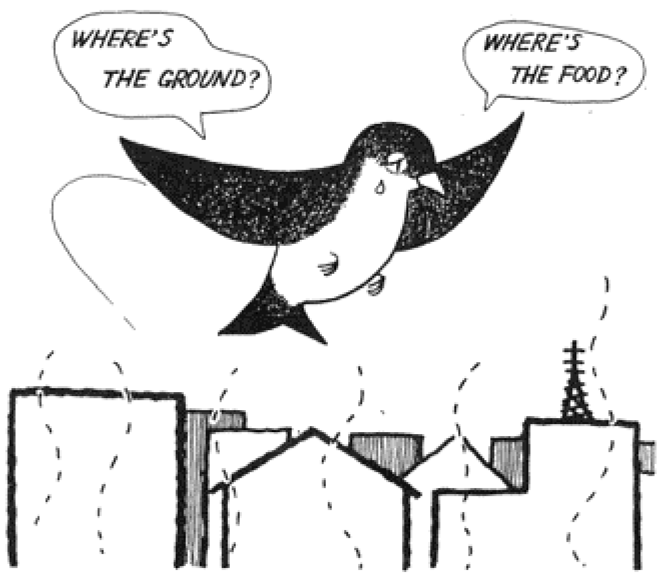
Concrete and asphalt have a profound impact on the ecology of the city. These include:

- Drying of the city – This happens as rivers and watercourses are covered, natural springs dry up, and greenery is cut down.
- Heat pollution – In some cities during the hot summer, an asphalt road at midday can reach temperatures of over 60°C. The heat expelled from air conditioners can further aggravate this.

This dramatically alters the city’s natural hydrological cycle and ecological environment.

Urban flood in Tokyo, Japan

In order to achieve a comprehensive solution to this problem, new approaches to urban development are required emphasising sustainability and the restoration of the urban hydrological cycle. Traditionally, storm sewer facilities have been developed based on the assumption that the amount of rainwater drained away will have to be increased. From the standpoint of preserving or restoring the natural water cycle, it is important to retain rainwater and to facilitate its permeation by preserving natural groundcover and greenery.



Introducing the Concept of "Cycle Capacity"

In thinking about sustainable development, one must view environmental capacity from a dynamic perspective and consider the time required for the restoration of the hydrological cycle. "Cycle capacity" refers to the time that nature needs revive the hydrological cycle. The use of groundwater should be considered from the point of view of cycle capacity. Rain seeps underground and over time becomes shallow stratum groundwater. Then, over a very long period of time, it becomes deep stratum groundwater. For sustainable use of groundwater, it is necessary to consider the storage capacity for groundwater over time. If this is neglected and groundwater is extracted too quickly, it will disappear within a short time.

Demand Side Management of Water Supply

In establishing their water supply plans, cities have usually assumed that the future demand for water will continue to increase. Typically, city waterworks departments have made excessive estimates of the demand for water and have built waterworks infrastructure based on the assumption of continued development of water resources and strategies to enlarge the area of water supply. The cost of development is usually recovered through water rates, and when there is plenty of water in the resource area, conservation of the resource is not promoted. This tends to create a conflict when drought occurs, due to the lack of policies and programmes to encourage water conservation. It has even been suggested that the lack of promotion of water conservation and rainwater harvesting is due to the need to recover infrastructure development costs through sales of piped water. The exaggerated projection of water demand leads to the over-development of water resources, which in turn encourages denser population and more consumption of water.

Sustainability of urban water supply requires a change from coping with water supply without controlling demand, to coping with supply by controlling demand. The introduction of demand side management encourages all citizens to adopt a water conservation approaches, including the use of freely available, locally supplied rainwater.

What Must be Considered From Quality and Health Aspects in Utilising Rainwater?

In the past, it was believed that rainwater was pure and could be consumed without pre-treatment. While this may be true in some areas that are relatively unpolluted, rainwater collected in many locations contains impurities. Particularly during the last three decades, “acid rain” has affected the quality of the collected water, to the point where it now usually requires treatment.

Rainwater quality varies for a number of reasons. While there are widely accepted standards for drinking water, the development of approved standards for water when it is used for non-potable applications would facilitate the use of rainwater sources.

In terms of physical-chemical parameters, collected roof water, rainwater and urban storm water tend to exhibit quality levels that are generally comparable to the World Health Organisation (WHO) guideline values for drinking water. However, low pH rainwater can occur as a result of sulphur dioxide, nitrous oxide and other industrial emissions, hence air quality standards must be reviewed and enforced. In addition, high lead values can sometimes be attributed to the composition of certain roofing materials – thus it is recommended that for roof water collection systems, the type of roofing material should be carefully considered.

A number of collected rainwater samples have exceeded the WHO values in terms of total coliform and faecal coliform. The ratios of faecal coliform to faecal streptococci from these samples indicated that the source of pollution was the droppings of birds, rodents, etc.

Currently, water quality control in roof water collection systems is limited to diverting first flushes and occasional cleaning of cisterns. Boiling, despite its limitations, is the easiest and surest way to achieve disinfection, although there is often a reluctance to accept this practice as taste is affected. Chlorine in the form of household bleach can be used for disinfection, however the cost of UV disinfection systems are usually prohibitive. One promising area of research is the use of photo-oxidation based on available sunlight to remove both the coliforms and streptococci.

What Must be Considered to Design and Maintain Facilities for Rainwater Utilisation?

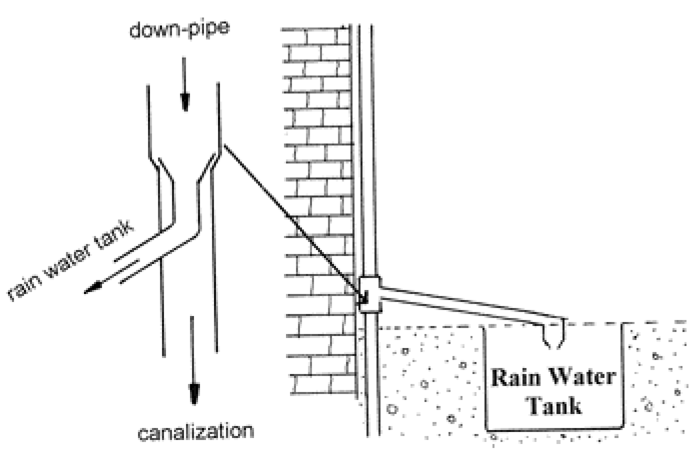
Catchment Surface

The effective catchment area and the material used in constructing the catchment surface influence the collection efficiency and water quality. Materials commonly used for roof catchment are corrugated aluminium and galvanized iron, concrete, fibreglass shingles, tiles, slates, etc. Mud is used primarily in rural areas. Bamboo roofs are least suitable because of possible health hazards. The materials of catchment surfaces must be non-toxic and not contain substances which impair water quality. For example, asbestos roofs should be avoided; also, painting or coating of catchment surfaces should be avoided if possible. If the use of paint or coating is unavoidable, only non-toxic paint or coating should be used; lead, chromium, and zinc-based paints/coatings should be avoided. Similarly, roofs with metallic paint or other coatings are not recommended as they may impart tastes or colour to the collected water. Catchment surfaces and collection devices should be cleaned regularly to remove dust, leaves and bird droppings so as to minimize bacterial contamination and maintain the quality of collected water. Roofs should also be free from over-hanging trees since birds and animals in the trees may defecate on the roof.

When land surfaces are used as catchment areas, various techniques are available to increase runoff capacity, including: i) clearing or altering vegetation cover, ii) increasing the land slope with artificial ground cover, and iii) reducing soil permeability by soil compaction. Specially constructed ground surfaces (concrete, paving stones, or some kind of liner) or paved runways can also be used to collect and convey rainwater to storage tanks or reservoirs. In the case of land surface catchments, care is required to avoid damage and contamination by people and animals. If required, these surfaces should be fenced to prevent the entry of people and animals. Large cracks in the paved catchment due to soil movement, earthquakes or exposure to the elements should be repaired immediately. Maintenance typically consists of the removal of dirt, leaves and other accumulated materials. Such cleaning should take place annually before the start of the major rainfall season.

Conveyance Systems

Conveyance systems are required to transfer the rainwater collected on catchment surfaces (e.g. rooftops) to the storage tanks. This is usually accomplished by making connections to one or more down-pipes connected to collection devices (e.g. rooftop gutters). The pipes used for conveying rainwater, wherever possible, should be made of plastic, PVC or other inert substance, as the pH of rainwater can be low (acidic) and may cause corrosion and mobilization of metals in metal pipes.



Example of a first flush device installation.

When selecting a conveyance system, consideration should be given to the fact that when it first starts to rain, dirt and debris from catchment surfaces and collection devices will be washed into the conveyance systems (e.g. down-pipes). Relatively clean water will only be available sometime later in the storm. The first part of each rainfall should be diverted from the storage tank. There are several possible options for selectively collecting clean water for the storage tanks. The common method is a sediment trap, which uses a tipping bucket to prevent the entry of debris from the catchment surface into the tank. Installing a first flush (or foul flush) device is also useful to divert the initial batch of rainwater away from the tank.

Gutters and down-pipes need to be periodically inspected and carefully cleaned. A good time to inspect gutters and down-pipes is while it is raining, so that leaks can be easily detected. Regular cleaning is necessary to avoid contamination.

Storage Tanks

Storage tanks for collected rainwater may be located either above or below the ground. They may be constructed as a part of the building, or may be built as a separate unit located some distance away from the building. The design considerations vary according to the type of tank and other factors.

Various types of rainwater storage facilities can be found in practice. Storage tanks should be constructed of inert material. Reinforced concrete, fibreglass, polyethylene, and stainless steel are suitable materials. Ferro-cement tanks and jars made of mortar or earthen materials are commonly used. As an alternative, interconnected tanks made of pottery or polyethylene may be suitable. The polyethylene tanks are compact but have a large storage capacity (1,000 to 2,000 litres). They are easy to clean and have many openings which can be fitted with connecting pipes. Bamboo reinforced tanks are less successful because the bamboo may become infested with termites, bacteria and fungus.

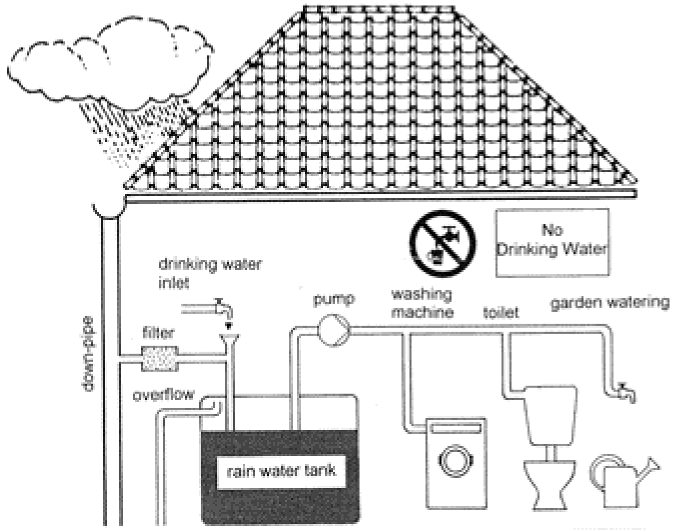
Precautions are required to prevent the entry of contaminants into storage tanks. The main sources of external contamination are pollution from debris, bird and animal droppings, and insects that enter the tank. Sometimes, human, animal and other environmental contaminants, which happen to fall into tanks, can cause contamination. Open containers are not recommended for storing water for drinking purposes. A solid and secure cover is required to avoid breeding of mosquitoes, to prevent insects and rodents from entering the tank, and to keep out sunlight to prevent the growth of algae inside the tank. A coarse inlet filter is also desirable for excluding coarse debris, dirt, leaves, and other solid materials.

The storage tank should be checked and cleaned periodically. All tanks need cleaning and their designs should allow for thorough scrubbing of the inner walls and floors. A sloped bottom and the provision of a sump and a drain are useful for collection and discharge of settled grit and sediment. An entrance hole is required for easy access for cleaning. The use of a chlorine solution is recommended for cleaning, followed by thorough rinsing. Chlorination of the cisterns or storage tanks is necessary if the water is to be used for drinking and domestic uses. Dividing tanks into two sections or dual tanks can facilitate cleaning. Cracks in the storage tanks can create major problems and should be repaired immediately.

The extraction system (e.g., taps/faucets, pumps) must not contaminate the stored water. Taps/faucets should be installed at least 10 cm above the base of the tank as this allows any debris entering the tank to settle on the bottom, where if it remains undisturbed, will not affect the quality of the water. Rainwater pipes must be permanently marked in such a way that there is no risk of confusing them with drinking water pipes. Taps must also be clearly labelled for the user both in the local language and in clear graphic images. The handle of taps might be detachable to avoid the misuse by children. Periodic maintenance should also be carried out on any pumps used to lift water to selected areas in the house or building.

The following devices are also desirable.

- An overflow pipe leading into either infiltration plants, drainage pipes with sufficient capacity or the municipal sewage pipe system.
- An indicator of the amount of water in the storage tank
- A vent for air circulation (often the overflow pipe can substitute)
- Protection against insects, rodents, vermin, etc. may also be required.



Particular care must be taken to ensure that potable water is not contaminated by the collected rainwater.

Calculation of Required Storage Size

When using rainwater, it is important to recognize that the rainfall is not constant throughout the year; therefore, planning the storage system with an adequate capacity is required for the constant use of rainwater even during dry periods. Knowledge of the rainfall quantity and seasonality, the area of the catchment surface and volume of the storage tank, and quantity and period of use required for water supply purposes is critical. For example, in Tokyo, the average annual rainfall is about 1,400 mm. Assuming that the effective catchment area of a house is equal to the horizontal line of its roof surface area, and given that that the roof surface area is 50 m^2, the average annual volume of rainwater falling on the roof may be calculated as 70 m^3. However, in practice, this volume can never be achieved since a portion of the rainwater evaporates from the roof surface and a portion may be lost to the drainage system, including the first flush. Furthermore, a portion of collected rainwater volume may be lost as overflow from the storage container if the storage tank has insufficient capacity to store the entire collected volume even in a heavy rain. Thus, the net usable or available amount of rainwater from the roof surface would be approximately 70% to 80% of the gross volume of rainfall. In the above example, the actual usable amount of rainwater would be about 49 m^3 to 56 m^3 in a year.

What Must be Considered When Selecting Rainwater as a Water Supply Source?

The disadvantages of the rainwater harvesting and utilisation systems are:

- The catchment area and storage capacity of a system are relatively small. There is a great variation in weather. During a prolonged drought, the storage tank may dry up.
- Maintenance of rainwater harvesting systems, and the quality of collected water, can be difficult for users.
- Extensive development of rainwater harvesting systems may reduce the income of public water systems.
- Rainwater harvesting systems are often not part of the building code and lack clear guidelines for users/developers to follow.
- Rainwater utilisation has not been recognized as an alternative of water supply system by the public sector. Governments typically do not include rainwater utilisation in their water management policies, and citizens do not demand rainwater utilisation in their communities.
- Rainwater storage tanks may be a hazard to children who play around it.
- Rainwater storage tanks may take up valuable space.
- Some development costs of larger rainwater catchment system may be too high if the costs are not shared with other systems as part of a multi-purpose network

Learning from these advantages and disadvantages, the decision to use rainwater as a new water source should be discussed among citizen/user groups and government water officials. Topics of such discussion might include:

- What are the alternatives for new water supply sources?
- What are the advantages and disadvantages of each alternative of new water source?
- How is rainwater utilisation ranked among the alternatives of new water supply sources, taking into account the viewpoints of private citizens and governmental officials?
- What are the responsibilities of users and communities for the participation in new water source development?

After these discussions, if rainwater utilisation is selected for development, then a detailed engineering feasibility study can be undertaken.

What is Necessary for Promotion and Further Development of Rainwater Utilisation?

A Systematic Approach

Rainwater utilisation, together with water conservation and wastewater reclamation, should be incorporated into municipal ordinances and regulations. Some standardisation of materials, at least at regional level, may be desirable from a maintenance and replacement point of view. It may be also appropriate to standardise the design of the rainwater utilisation system, at least at the regional level.

Implementation Policy

Various implementation policies should be established to make rainwater utilisation and other measures a part of the social system. Leadership is very important and local governments must take the initiative to promote the concept of water resource independence and restoration of the natural hydrological cycle. Consideration should be given to subsidising facilities for rainwater utilisation.

Technology Development and training

Encouraging technology and human resources development to support rainwater utilisation is very important. It is also important to promote the development of efficient and affordable devices to conserve water, facilities to use rainwater and devices to enhance the underground seepage of rainwater. Together with this, there is a need to train specialists with a thorough grasp of these technologies and devices.

Networking

To promote rainwater harvesting and utilisation as an environmentally sound approach for sustainable urban water management, a network should be established involving government administrators, citizens, architects, plumbers and representatives of equipment manufacturers. It is essential to encourage regional exchanges amongst public servants, citizens and industry representatives involved in rainwater storage, seepage and use, as well as the conservation and reclamation of water.

Examples of Rainwater Harvesting and Utilisation Around the World

Singapore

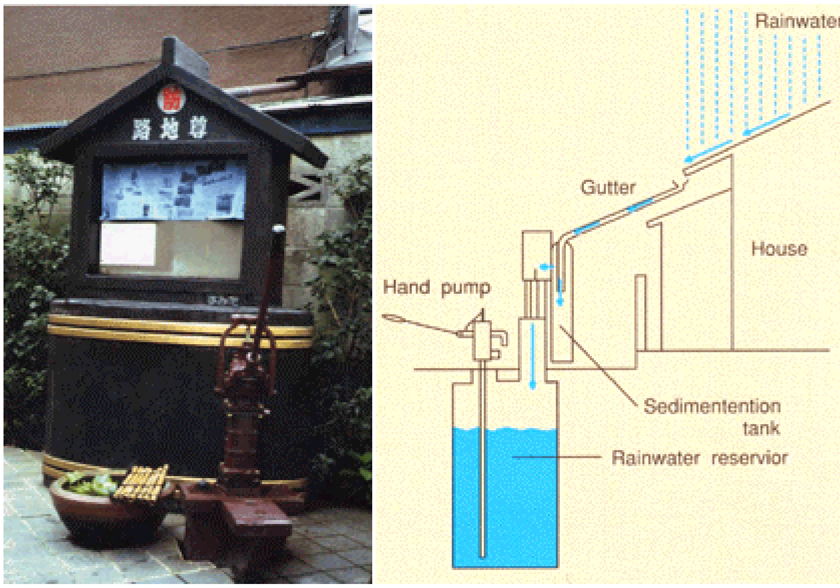
Singapore, which has limited land resources and a rising demand for water, is on the lookout for alternative sources and innovative methods of harvesting water. Almost 86% of Singapore's population lives in high-rise buildings. A light roofing is placed on the roofs to act as catchment. Collected roof water is kept in separate cisterns on the roofs for non-potable uses. A recent study of an urban residential area of about 742 ha used a model to determine the optimal storage volume of the rooftop cisterns, taking into consideration non-potable water demand and actual rainfall at 15-minute intervals. This study demonstrated an effective saving of 4% of the water used, the volume of which did not have to be pumped from the ground floor. As a result of savings in terms of water, energy costs, and deferred capital, the cost of collected roof water was calculated to be S$0.96 against the previous cost of S$1.17 per cubic meter.

A marginally larger rainwater harvesting and utilisation system exists in the Changi Airport. Rainfall from the runways and the surrounding green areas is diverted to two impounding reservoirs. One of the reservoirs is designed to balance the flows during the coincident high runoffs and incoming tides, and the other reservoir is used to collect the runoff. The water is used primarily for non-potable functions such fire-fighting drills and toilet flushing. Such collected and treated water accounts for 28 to 33% of the total water used, resulting in savings of approximately S$ 390,000 per annum.

Tokyo, Japan

In Tokyo, rainwater harvesting and utilisation is promoted to mitigate water shortages, control floods, and secure water for emergencies.

The Ryogoku Kokugikan Sumo-wrestling Arena, built in 1985 in Sumida City, is a well-known facility that utilises rainwater on a large scale. The 8,400 m2 rooftop of this arena is the catchment surface of the rainwater utilisation system. Collected rainwater is drained into a 1,000 m3 underground storage tank and used for toilet flushing and air conditioning. Sumida City Hall uses a similar system. Following the example of Kokugikan, many new public facilities have begun to introduce rainwater utilisation systems in Tokyo.



"Rojison", a simple and unique rainwater utilisation facility at the community level in Tokyo, Japan.

At the community level, a simple and unique rainwater utilisation facility, "Rojison", has been set up by local residents in the Mukojima district of Tokyo to utilise rainwater collected from the roofs of private houses for garden watering, fire-fighting and drinking water in emergencies.

To date, about 750 private and public buildings in Tokyo have introduced rainwater collection and utilisation systems. Rainwater utilisation is now flourishing at both the public and private levels.

Berlin, Germany

In October 1998, rainwater utilization systems were introduced in Berlin as part of a large scale urban re-development, the DaimlerChrysler Potsdamer Platz, to control urban flooding, save city water and create a better micro climate. Rainwater falling on the rooftops (32,000 m^2) of 19 buildings is collected and stored in a 3500 m^3 rainwater basement tank. It is then used for toilet flushing, watering of green areas (including roofs with vegetative cover) and the replenishment of an artificial pond.

In another project at Belss-Luedecke-Strasse building estate in Berlin, rainwater from all roof areas (with an approximate area of 7,000 m^2) is discharged into a separate public rainwater sewer and transferred into a cistern with a capacity of 160 m^3, together with the runoff from streets, parking spaces and pathways (representing an area of 4,200 m^2). The water is treated in several stages and used for toilet flushing as well as for garden watering. The system design ensures that the majority of the pollutants in the initial flow are flushed out of the rainwater sewer into the sanitary sewer for proper treatment in a sewage plant. It is estimated that 58% of the rainwater can be retained locally through the use of this system. Based on a 10-year simulation, the savings of potable water through the utilisation of rainwater are estimated to be about 2,430 m^3 per year, thus preserving the groundwater reservoirs of Berlin by a similar estimated amount.

Both of these systems not only conserve city water, but also reduce the potential for pollutant discharges from sewerage systems into surface waters that might result from stormwater overflows. This approach to the control of non point sources of pollution is an important part of a broader strategy for the protection of surface water quality in urban areas.

Thailand

Storing rainwater from rooftop run-off in jars is an appropriate and inexpensive means of obtaining high quality drinking water in Thailand. Prior to the introduction of jars for rainwater storage, many communities had no means of protecting drinking water from waste and mosquito infestation. The jars come in various capacities, from 100 to 3,000 litres and are equipped with lid, faucet, and drain. The most popular size is 2,000 litres, which costs 750 Baht, and holds sufficient rainwater for a six-person household during the dry season, lasting up to six months.

Example of the rainwater jar used in Thailand.

Two approaches are used for the acquisition of water jars. The first approach involves technical assistance and training villagers on water jar fabrication. This approach is suitable for many villages, and encourages the villagers to work cooperatively. Added benefits are that this environmentally appropriate technology is easy to learn, and villagers can fabricate water jars for sale at local markets. The second approach is applicable to those villages that do not have sufficient labour for making water jars. It involves access to a revolving loan fund to assist these villages in purchasing the jars. For both approaches, ownership and self-maintenance of the water jars are important. Villagers are also trained on how to ensure a safe supply of water and how to extend the life of the jars.

Initially implemented by the Population and Community Development Association (PDA) in Thailand, the demonstrated success of the rainwater jar project has encouraged the Thai government to embark on an extensive national program for rainwater harvesting.

Indonesia

In Indonesia, groundwater is becoming more scarce in large urban areas due to reduced water infiltration. The decrease of groundwater recharge in the cities is directly proportional to the increase in the pavement and roof area. In addition, high population density is has brought about high groundwater consumption. Recognising the need to alter the drainage system, the Indonesian government introduced a regulation requiring that all buildings have an infiltration well. The regulation applies to two-thirds of the territory, including the Special Province of Yogyakarta, the Capital Special Province of Jakarta, West Java and Central Java Province. It is estimated that if each house in Java and Madura had its own infiltration well, the water deficit of 53% by the year of 2000 would be reduced to 37%, which translates into a net savings of 16% through conservation.

Capiz Province, the Philippines

In the Philippines, a rainwater harvesting programme was initiated in 1989 in Capiz Province with the assistance of the Canadian International Development Research Centre (IDRC). About 500 rainwater storage tanks were constructed made of wire-framed ferro-cement, with capacities varying from 2 to 10 m^3. The construction of the tanks involved building a frame of steel reinforcing bars (rebar) and wire mesh on a sturdy reinforced concrete foundation. The tanks were then plastered both inside and outside, thereby reducing their susceptibility to corrosion relative to metal storage tanks.

The rainwater harvesting programme in Capiz Province was implemented as part of an income generation initiative. Under this arrangement, loans were provided to fund the capital cost of the tanks and related agricultural operations. Loans of US$200, repayable over a three-year period, covered not only the cost of the tank but also one or more income generating activities such as the purchase and rearing of pigs, costing around US$25 each. Mature pigs can sell for up to US$90 each, providing an income opportunity for generating that could provide sufficient income to repay the loan. This type of innovative mechanism for financing rural water supplies can help avoid the requirement for water resources development subsidies.

Bangladesh

In Bangladesh, rainwater collection is seen as a viable alternative for providing safe drinking water in arsenic affected areas. Since 1997, about 1000 rainwater harvesting systems have been installed in the country, primarily in rural areas, by the NGO Forum for Drinking Water Supply & Sanitation. This Forum is the national networking and service delivery agency for NGOs, community-based organisations and the private sector concerned with the implementation of water and sanitation programmes in unserved and underserved rural and urban communities. Its primary objective is to improve access to safe, sustainable, affordable water and sanitation services and facilities in Bangladesh.

The rainwater harvesting tanks in Bangladesh vary in capacity from 500 litres to 3,200 litres, costing from Tk. 3000-Tk.8000 (US$ 50 to US$ 150). The composition and structure of the tanks also vary, and include ferro-cement tanks, brick tanks, RCC ring tanks, and sub-surface tanks.

The rainwater that is harvested is used for drinking and cooking and its acceptance as a safe, easy-to-use source of water is increasing amongst local users. Water quality testing has shown that water can be preserved for four to five months without bacterial contamination. The NGO Forum has also undertaken some recent initiatives in urban areas to promote rainwater harvesting as an alternative source of water for all household purposes.

Gansu Province, China

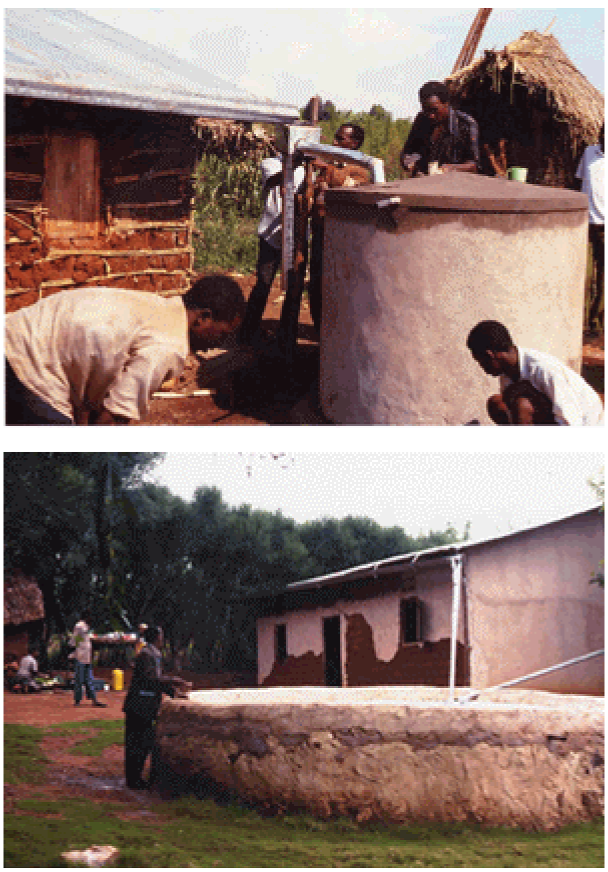
Gansu is one of the driest provinces in China. The annual precipitation is about 300 mm, while potential evaporation amounts to 1500-2000 mm. Surface water and groundwater is limited, thus agriculture in the province relies on rainfall and people generally suffer from inadequate supplies of drinking water.

Since the 1980s, research, demonstration and extension projects on rainwater harvesting have been carried out with very positive results. In 1995/96, the “121” Rainwater Catchment Project implemented by the Gansu Provincial Government supported farmers by building one rainwater collection field, two water storage tanks and providing one piece of land to grow cash crops. This project has proven successful in supplying drinking water for 1.3 million people and developing irrigated land for a courtyard economy. As of 2000, a total of 2,183,000 rainwater tanks had been built with a total capacity of 73.1 million m^3 in Gansu Province, supplying drinking water for 1.97 million people and supplementary irrigation for 236,400 ha of land.

Rainwater harvesting has become an important option for Gansu Province to supply drinking water, develop rain-fed agriculture and improve the ecosystem in dry areas. Seventeen provinces in China have since adopted the rainwater utilization technique, building 5.6 million tanks with a total capacity of 1.8 billion m^3, supplying drinking water for approximately 15 million people and supplemental irrigation for 1.2 million ha of land.

Africa

Although in some parts of Africa rapid expansion of rainwater catchment systems has occurred in recent years, progress has been slower than Southeast Asia. This is due in part to the lower rainfall and its seasonal nature, the smaller number and size of impervious roofs and the higher costs of constructing catchment systems in relation to typical household incomes. The lack of availability of cement and clean graded river sand in some parts of Africa and a lack of sufficient water for construction in others, add to overall cost. Nevertheless, rainwater collection is becoming more widespread in Africa with projects currently in Botswana, Togo, Mali, Malawi, South Africa, Namibia, Zimbabwe, Mozambique, Sierra Leone and Tanzania among others. Kenya is leading the way. Since the late 1970s, many projects have emerged in different parts of Kenya, each with their own designs and implementation strategies. These projects, in combination with the efforts of local builders called "fundis" operating privately and using their own indigenous designs, have been responsible for the construction of many tens of thousands of rainwater tanks throughout the country. Where cheap, abundant, locally available building materials and appropriate construction skills and experience are absent; ferro-cement tanks have been used for both surface and sub-surface catchment.



Rainwater tanks constructed by local builders called "fundis" in Kenya.

Dar es Salaam, Tanzania

Due to inadequate piped water supplies, the University of Dar es Salaam has applied rainwater harvesting and utilisation technology to supplement the piped water supply in some of the newly built staff housing. Rainwater is collected from the hipped roof made with corrugated iron sheets and led into two "foul" tanks, each with a 70-litre capacity. After the first rain is flushed out, the foul tanks are filled up with rainwater. As the foul tanks fill up, settled water in the foul tanks flows to two underground storage tanks with a total capacity of 80,000 litres. Then, the water is pumped to a distribution tank with 400 litres capacity that is connected to the plumbing system of the house. The principles for the operation of this system are: (i) only one underground tank should be filled at a time; (ii) while one tank is being filled, water can be consumed from the other tank, (iii) rainwater should not be mixed with tap water; (iv) underground storage tanks must be cleaned thoroughly when they are empty; (v) in order to conserve water, water should only be used from one distribution tank per day.

Botswana

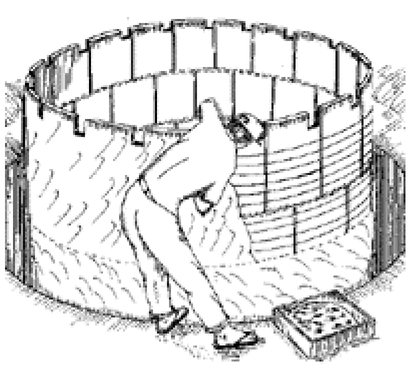
Thousands of roof catchment and tank systems have been constructed at a number of primary schools, health clinics and government houses throughout Botswana by the town and district councils under the Ministry of Local Government, Land and Housing (MLGLH). The original tanks were prefabricated galvanized steel tanks and brick tanks. The galvanized steel tanks have not performed well, with a short life of approximately 5 years. The brick tanks are unpopular, due to leakage caused by cracks, and high installation costs. In the early 1980s, the MLGLH replaced these tanks in some areas with 10-20 m^3 ferro-cement tanks promoted by the Botswana Technology Centre. The experience with ferro-cement tanks in Botswana is mixed; some have performed very well, but some have leaked, possibly due to poor quality control.

Brazil

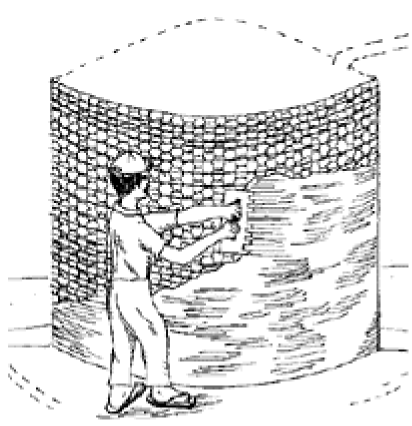
Over the past decade, many NGOs and grassroots organisations have focused their work on the supply of drinking water using rainwater harvesting, and the irrigation of small-scale agriculture using sub-surface impoundments. In the semi-arid tropics of the north-eastern part of Brazil, annual rainfall varies widely from 200 to 1,000 mm, with an uneven regional and seasonal rainfall pattern. People have traditionally utilised rainwater collected in hand-dug rock catchments and river bedrock catchments.

To address the problem of unreliable rural drinking water supply in north-eastern Brazil, a group of NGOs combined their efforts with government to initiate a project involving the construction of one million rainwater tanks over a five year period, with benefits to 5 million people. Most of these tanks are made of pre-cast concrete plates or wire mesh concrete.

Rainwater harvesting and utilisation is now an integrated part of educational programs for sustainable living in the semi-arid regions of Brazil. The rainwater utilisation concept is also spreading to other parts of Brazil, especially urban areas. A further example of the growing interest in rainwater harvesting and utilisation is the establishment of the Brazilian Rainwater Catchment Systems Association, which was founded in 1999 and held its 3rd Brazilian Rainwater Utilisation Symposium in the fall of 2001.



A tank made of pre-cast



A tank made of wire mesh

concrete plates. *concrete.*

Bermuda

The island of Bermuda is located 917 km east of the North American coast. The island is 30 km long, with a width ranging from 1.5 to 3 km. The total area is 53.1 km^2. The elevation of most of the land mass is less than 30 m above sea level, rising to a maximum of less than 100 m. The average annual rainfall is 1,470 mm. A unique feature of Bermuda roofs is the wedge-shaped limestone “glides” which have been laid to form sloping gutters, diverting rainwater into vertical leaders and then into storage tanks. Most systems use rainwater storage tanks under buildings with electric pumps to supply piped indoor water. Storage tanks have reinforced concrete floors and roofs, and the walls are constructed of mortar-filled concrete blocks with an interior mortar application approximately 1.5 cm thick. Rainwater utilisation systems in Bermuda are regulated by a Public Health Act which requires that catchments be whitewashed by white latex paint; the paint must be free from metals that might leach into water supplies. Owners must also keep catchments, tanks, gutters, pipes, vents, and screens in good repair. Roofs are commonly repainted every two to three years and storage tanks must be cleaned at least once every six years.

St. Thomas, US Virgin Islands

St. Thomas, US Virgin Islands, is an island city which is 4.8 km wide and 19 km long. It is situated adjacent to a ridge of mountains which rise to 457 m above sea level. Annual rainfall is in the range of 1,020 to 1,520 mm. A rainwater utilisation system is a mandatory requirement for a residential building permit in St. Thomas. A single-family house must have a catchment area of 112 m2 and a storage tank with 45 m3 capacity. There are no restrictions on the types of rooftop and water collection system construction materials. Many of the homes on St. Thomas are constructed so that at least part of the roof collects rainwater and transports it to storage tanks located within or below the house. Water quality test of samples collected from the rainwater utilisation systems in St. Thomas found that contamination from faecal coliform and Hg concentration was higher than EPA water quality standards, which limits the use of this water to non-potable applications unless adequate treatment is provided.

Island of Hawaii, USA

A wooden water tank in Hawaii, USA

At the U.S. National Volcano Park, on the Island of Hawaii, rainwater utilisation systems have been built to supply water for 1,000 workers and residents of the park and 10,000 visitors per day. The Park’s rainwater utilisation system includes the rooftop of a building with an area of 0.4 hectares, a ground catchment area of more than two hectares, storage tanks with two reinforced concrete water tanks with 3,800 m3 capacity each, and 18 redwood water tanks with 95 m3 capacity each. Several smaller buildings have their own rainwater utilisation systems as well. A water treatment and pumping plant was built to provide users with good quality water.

Where to Access Information on Rainwater Harvesting and Utilisation?

Centre for Science and Environment (CSE)
41, Tughlakabad Institutional area, New Delhi - 110062, India
Fax: +91-11-6085879
Email: cse@cseindia.org
Website: http://www.cseindia.org

International Rainwater Catchment Systems Association (IRCSA)
Contact: Dr. Jessica Calfoforo Salas
Kahublagan Sang Panimalay Foundation Inc.
25B Magsaysay Village, La Paz, Iloilo City 5000 Philippines
Fax: +63-33-3200854
Website: http://www.ircsa.org/

fbr - German Professional Association for Water Recycling and Rainwater Utilisation
Fachvereinigung Betriebs- und Regenwassernutzung e.V.
Havelstrasse 7A, 64295 Darmstadt, Germany
Fax: 49-6151-339258
E-mail: info@fbr.de
Website: http://www.fbr.de/

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Fax: +44-24-7641-8922
E-mail: dtu@eng.warwick.ac.uk
Website: http://www.eng.warwick.ac.uk/dtu/rwh/index.html

Texas Water Development Board
1700 North Congress Avenue, P.O. Box 13231 Austin, Texas 78711-3231 USA
Fax: +1-512-475-2053
Website: http://www.twdb.state.tx.us/assistance/conservation/Rain.htm

International Development Research Centre
250 Albert Street, PO Box 8500 Ottawa, Ontario, Canada K1G 3H9
Fax: +1-613-238-7230
E-mail: info@idrc.ca
Website: http://www.idrc.ca/

WaterWiser-The Water Efficiency Clearinghouse
6666 W. Quincy Ave., Denver, CO 80235, USA
Fax: +1-303-347-0804
E-mail: bewiser@waterwiser.org
Website: www.waterwiser.org

Sustainable Sources
108 Royal Way, Suite 1004, Austin, TX 78737 USA

E-mail: info@greenbuilder.com
Website: http://www.greenbuilder.com/Sourcebook/Rainwater.html

People for Promoting Rainwater Utilization
1-8-1 Higashi Mukojima Sumida-ku, Tokyo 131-0032 Japan
Fax: +81-3-3611-0574
Website: http://www.rain-water.org/book_e.html

IRC International Water and Sanitation Centre
P.O. Box 2869, 2601 CW Delft, The Netherlands
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Email: info@wsp.org
Website: http://www.wsp.org/