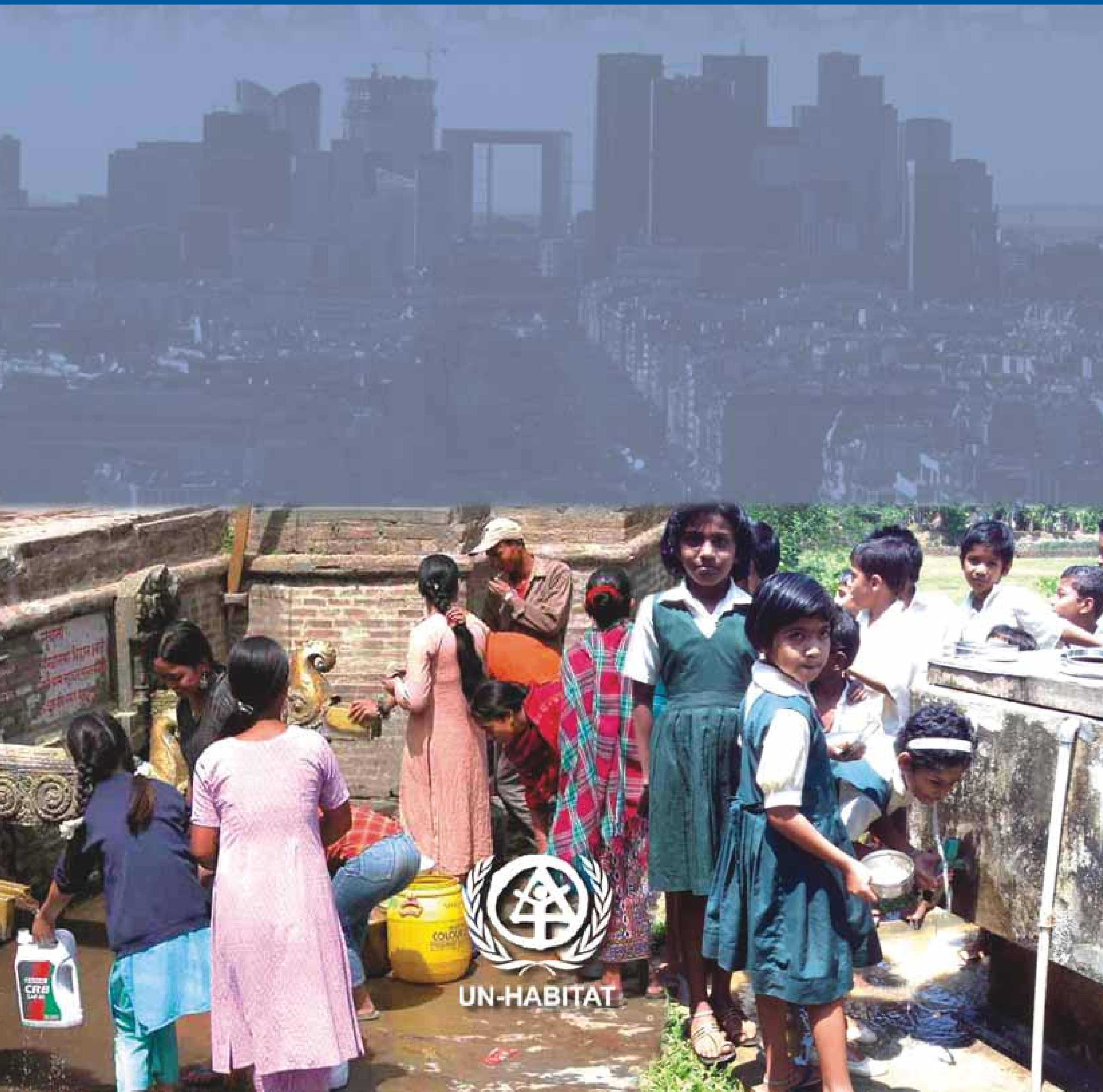
Blue Drop Series

Book 2: Beneficiaries & Capacity Builders

Rainwater Harvesting and Utilisation



UN-HABITAT

Foreword

Water is essential for the environment, food security and sustainable development. In 2000, at least 1.1 billion of the world's people - about one in five - did not have access to safe water. Asia contained 65 per cent of the population without safe water and Africa 28 per cent. Despite positive developments during the 1990s the number of urban dwellers lacking access to safe water increased by nearly 62 million. For this reason Millennium Summit set up target 10 to halve by 2015 the proportion of people without sustainable access to safe drinking water.

The increasing urbanization is a normal process of economic development and the challenge is to make this growth sustainable, efficient and equitable. Unfortunately, the positive role of urbanization is overshadowed by infrastructural deficiencies. Two million children die every year for the lack of water or for its poor quality. A billion people live in slums in overcrowded conditions without access to basic services particularly safe drinking water. The availability of water in the regions is constantly declining and health risks continue to rise. The poor pay more for water than the rich both within and between cities. Millions of girl children are forced to trade education for collecting water, or drop out from schools for the lack of even minimal sanitation facilities. Therefore, there is no better way to reduce child mortality or promote universal primary education than conserving the precious water resources for our cities especially for the poor.

Increasing access to safe water also requires addressing gender inequities. African women and girls spend three hours a day fetching water, expending more than a third of their caloric intake. Gender equality and empowering of women does require the unquestionable commitment of the policymakers to human settlements. The goals may be global but they need to be implemented locally in human settlements, where the people live and shelter and basic services like safe water are required.

Among the policy priorities for achieving target 10 of MDG 7, increasing resources and appropriate and affordable technologies for efficient water use are the important ones. Cost effective technologies are available to increase household and community access to safe water. Rainwater harvesting is one among such efficient but low-tech and cost effective technologies, which can help in meeting the challenge to provide fresh and safe water supplies. In order to harness local rainfall and local runoff to meet water needs, a variety of initiatives have been taken by some governments and communities around the world to promote water harvesting by urban households not only to encourage the use of rainwater for domestic use but also to reduce urban flooding and to increase ground water recharge.

In its pursuit to achieve the Millennium Development Goals relating to Water and Sanitation UN-HABITAT has been making an endeavour to strengthen the efforts of the cities and the communities by sharing knowledge and experiences, best practices and to help them use proven technologies for sustainable development. Hopefully a series of this UN-HABITAT publication on Rainwater Harvesting is another step in this direction, which may help undertaking rainwater harvesting programmes by communities, organizations and cities in the crisis regions of Asia, Africa, Latin America and the Caribbean.

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Preface

Rainwater harvesting is a technology which has been practiced for more than four thousand years. The rapid population growth, combined with industrialization, urbanization, agricultural intensification and changing life styles, is resulting in a global water crisis. UN-HABITAT in pursuance of targets 10 and 11 of MDG 7 has been working to promote technologies which may help water scarce cities and towns to meet the challenge on a sustainable basis. The current series on Rainwater Harvesting and Utilization has been brought out for the awareness and sensitization of the Policy Makers, for building the capacity of beneficiaries and developing the skills of Project Managers and implementing agencies.

Rainwater Harvesting has several policy dimensions. There are several conceptual and policy issues for community based rainwater harvesting. In order to encourage rainwater harvesting by city dwellers, there is a need for an appropriate fiscal and legal framework. Book - I has been mainly prepared for Policy Makers. Besides giving an overview of the concept of rainwater harvesting it has a focus on the legal and administrative framework for rainwater harvesting. There are many countries which have taken a variety of measures to promote water harvesting by urban households. Governments have used fiscal incentives to force households for water harvesting either for reducing urban flooding or for overloading of sewerage treatment plants. Subsidies have also been provided to promote urban water harvesting by the urban poor. Several case studies given in this Book - I share this knowledge and experience of many cities to be emulated by others.

The main objective of Book - II is to directly build the capacity of the beneficiaries. It fully explains the concept and technology of rainwater harvesting and water harvesting systems. In addition, the techniques for artificial aquifer recharging relevant for different topographies are explained.

UN-HABITAT would like to promote rainwater harvesting projects not only by the individual households but also by the industries, institutions like schools and encourage the communities to maintain and sustain underground water tables through artificial recharge. Book - III specially prepared for Project Managers and implementing agencies not only dwells on harvesting rainwater for direct use but also for rainwater harvesting for artificial recharge to groundwater and planning & monitoring of artificial projects. It is hoped that this attempt of UN-HABITAT in documenting rainwater harvesting experiences in technology and its use shall facilitate an extensive use of these techniques for harvesting rainwater and meet the challenge of achieving the Millennium Development Goal for Water and Sanitation.

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Acknowledgements

Water – being a precious item-rather a lifeline to the humanity – is getting scarce day by day. The more populous regions heading for rapid urbanization and fast depletion of water resources need utmost priority to act for conserving water and augmenting supply thereof. All this is possible through capturing rainwater. The most affected regions in the world are: Asia, Africa and Latin America & the Caribbean. Keeping in view the importance and urgent attention the subject of Rainwater Harvesting deserves, UN-HABITAT decided to undertake the task of preparing a generic guidebook on Rainwater Harvesting with a focus on rainwater harvesting and utilization in these most affected regions.

The preparation of the guidebook, called Blue Drop Series on Rainwater Harvesting and Utilization was entrusted to CITI Foundation, New Delhi, by the UN-HABITAT. Blue Drop Series was prepared under the overall supervision of Kalyan Ray, Senior Advisor, Office of the Executive Director, UN-HABITAT. Key substantive support in the form of concept and direction was provided by Andre Dzikus and design and coordination by Kulwant Singh of Water, Sanitation and Infrastructure Branch, UN-HABITAT.

An initial outline of the report was prepared by CITI Foundation in close consultation with UN-HABITAT. P.S. Mathur and Deependra Prashad did the field work and also desk-review of the available literature on the rainwater harvesting technologies as well as the best practices. Dilip Kumar Sharma together with Deependra Prashad through their commitment and professionalism did the writing and preparation of the draft guidebook. The CITI Foundation, apart from its own research, consulted, collected and collated huge information from various sources, which included available literature, contact with research institutions, experts, NGOs, discussions and other useful sources and also documented some of the case studies. The draft of the publication was circulated to experts for comments and suggestions.

The draft was extensively discussed in a workshop organized collaboratively by the Swiss NGO, the International Rainwater Harvesting Alliance (IRHA) and the Indian NGO, the Watershed Organization (WOTR) in India. IRHA also undertook the peer review of the guidebook and made useful recommendations of bringing out the guidebook in the form of Blue Drop Series in three volumes, each volume prepared for a separate target group. Based on IRHA's peer review, which analyzed the valuable information contained in the draft guidebook, the UN-HABITAT has brought out three Books on Rainwater Harvesting and Utilization under the caption "Blue Drop Series".

The report also benefited from the comments received from all the participants of the workshop organized in India. In particular those of Julie Perkins and Teshamulwa Okioga. Jogesh Kumar Arora provided valuable administrative and computer assistance.

CITI Foundation, New Delhi deserves special appreciation for completing the task of finalizing the three volumes on Rainwater Harvesting and Utilization.

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Contents

List of Boxes

List of Tables

Chapter 1

Introduction

Water forms the lifeline of any society. Water is essential for the environment, food security and sustainable development. All the known civilizations have flourished with water source as the base and it is true in the present context too. Availability of drinking water and provision of sanitation facilities are the basic minimum requirements for healthy living. Water supply and sanitation, being the two most important urban services, have wide ranging impact on human health, quality of life, environment and productivity. Despite the technological advancements, the global scenario still remains grim, as all the inhabitants of the world do not have access to safe water and adequate sanitation.

In most urban areas, the 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 the policy-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 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. Among the various technologies to augment freshwater resources, rainwater harvesting and utilisation is a decentralised, environmentally sound solution, which can avoid many environmental problems often caused by 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 ground water is lacking. The application of appropriate rainwater harvesting technology is important for the utilisation of rainwater as a water resource.

Global Demographic Trends

The World population has more than doubled since 1950 and reached 6.15 billion in 2001. 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.

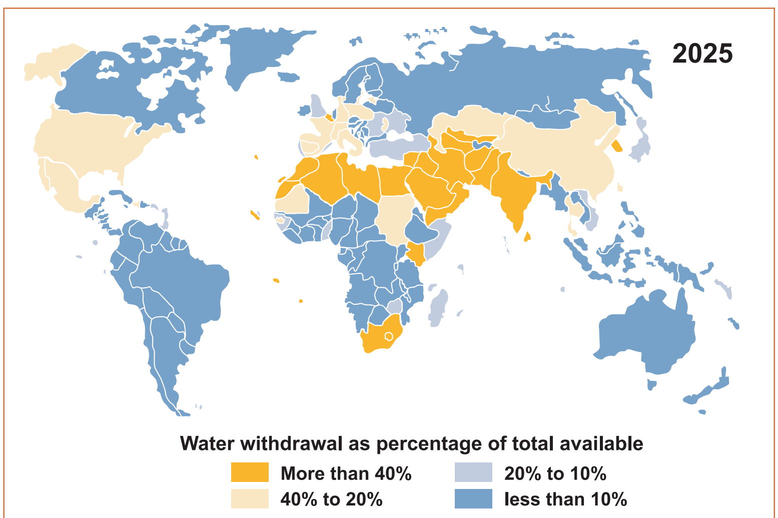
In parallel with these demographic changes, there have been profound demographic shifts as people continue to migrate from rural to urban areas in search of work and new opportunities. The number of people living in urban areas has jumped from 750 million in 1950 to nearly 2.93 billion in 2001. Currently, 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. By 2025, the total urban population is projected to increase to more than five billion, and 90 per cent of this increase is expected to occur in developing countries. Sixty per cent of the global population is living in Asia. Urban population growth in Asia at 2.7 per cent per annum is 27 per cent higher than the global average. Asia's population living in urban areas is projected at 43.0 per cent for 2010 and will represent 50.8 per cent of world's total urban population. Asia is expected to double its urban population by the year 2020. By 2025, the majority of this region's population will live in cities. By 2015, there will be 153 cities of one million inhabitants, 22 cities with 8 or more million people and 15 with 10 to 20 million people.

The population of urban Africa is estimated to increase from 37.2 per cent in 2000 to 42.7 percent in 2010 and will represent 12.1 per cent of the world's urban population. The share of Latin America & the Caribbean is projected to increase from 75.4 per cent in 2000 to 79.0 percent in 2010, representing 13.4 per cent of the world's urban population.

The urban population of Africa, Asia and Latin America and the Caribbean is now nearly three times the size of urban population of the rest of the world. This population is growing so much faster than the rural population that 85 per cent of the growth in the world's population between 2000 and 2010 will be in urban areas and virtually all this growth will be in Africa, Asia and Latin America. 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 additional people in the next 50 years.

The World Water Crisis

Rapid population growth, combined with industrialisation, urbanisation, agricultural intensification and water-intensive lifestyles is resulting in a global water crisis. In 2000, at least 1.1 billion of the world's people - about one in five – did not have access to safe water. Asia contains 65 per cent of the population without safe water and Africa 28 per cent. During the 1990s, there were some positive developments: about 438 million people in developing countries gained access to safe water but due to rapid population growth, the number of urban dwellers lacking access to safe water increased by nearly 62 million.



by the year 2025, two third of the world population may be subjected to water scarcity

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 is becoming more polluted. Water security, like food security, is becoming a major national and regional priority in many areas of the world.

Scenario in Selected Cities

In **Kolkata, India,** about half the population that lives in the slum or squatter settlements collect water from stand posts. The rest of the slum population do not have access to the municipal water supply and have to make their own arrangements – for instance relying on handpumps/drawing from tube wells. In **Bangalore, India** a city of some 6 million inhabitants, it is estimated that more than half depends on public fountains. Almost a third of the population has partial or no access to piped water. In **Dhaka, Bangladesh** it is estimated that in 2002 there were 2.5 million people in its 'slum' areas with most having very inadequate provision for water and sanitation. Tens of thousands of children die each year in Dhaka because of waterborne diseases and polluted water. In **Pakistan** more than half of **Karachi's** 12 million inhabitants live in *katchi abadis*. Only half the *katchi abadis* have piped water. In **Faisalabad, Pakistan** some two thirds of the city's two million inhabitants live in largely unserviced areas. Over half have no piped water supply.

In **Kampala (Uganda)** only inhabitants of affluent and middle-income districts in central and residential areas have private connections serviced by National Water & Sewerage Corporation. More than half the population in **Nairobi (Kenya)** depend on standpipe vendors for access to water; 30% of the population have a connection to the official network. In **Lima (Peru)** almost 2 million inhabitants have no water supply and 30% of those who do receive water (1996) is of dubious quality. The water shortage in **Tugucigalpa (Honduras)** is particularly acute as there is not even enough water to supply to consumers already having municipal water connections.

To further illustrate, **India's** population as per 2001 census is 1027.02 million. Over 60 per cent of households in India meet their drinking water requirements from underground water sources such as hand pumps, tube wells and wells. In urban areas while 68.7 per cent households use tap water, 29 per cent of the households directly use those underground water resources. Intense use of underground water has resulted in depletion of sub-terrene water resources in many parts of India.

Benefits of Rainwater Harvesting

Rainwater harvesting provides the long-term answers to the problem of water scarcity. Rainwater harvesting offers an ideal solution in areas where there is sufficient rain but inadequate ground water supply and surface water resources are either lacking or are insufficient. In hilly areas, rainwater can be used by humans, vegetation and animals. Rainwater harvesting system is particularly useful in remote and difficult terrain as it has the ability to operate independently. The whole process is environment friendly. There are a number of ways in which water harvesting can benefit a community – water harvesting enables efficient collection and storage of rainwater, makes it accessible and substitutes for poor quality water (Box 1.1). Water harvesting helps smooth out variation in water availability by collecting the rain and storing it more efficiently in closed stores or in sandy riverbeds. In doing so, water harvesting assures a continuous and reliable access to water.

A water harvesting system collects and stores water within accessible distance of its place of use. While traditional sources are located away from the community particularly in peri-urban areas, collecting and storing water close to households, villages or pastures greatly enhances the accessibility and convenience of water supplies.

Box 1.1 Rainwater Harvesting - Multiple Benefits

- Improvement in the quality of ground water
- Rise in the water levels in wells and bore wells that are drying up
- Mitigation of the effects of drought and attainment of drought proofing
- An ideal solution to water problems in areas having inadequate water resources
- Reduction in the soil erosion as the surface runoff is reduced
- Decrease in the choking of storm water drains and flooding of roads
- Saving of energy, to lift ground water. (One-meter rise in water level saves 0.40-kilowatt hour of electricity)

The rainwater collected can be stored for direct use or can be recharged into the ground water to improve the quality of ground water and rise in the water levels in wells and bore wells that are drying up as well as reduce the soil erosion as the surface runoff is reduced. Rainwater harvesting is an ideal solution to water problems in areas having inadequate water resources and helpful in mitigation of the effects of drought and attainment of drought proofing.

Water harvesting provides an alternative source for good quality water (rainwater is the cheapest form of raw water) seasonally or even the year round. This is relevant for areas where ground water or surface water is contaminated by harmful chemicals or pathogenic bacteria or pesticides and/or in areas with saline surface water. The rainwater harvesting systems can be both individual and community/utility operated and managed. Rainwater collected using various methods has less negative environmental impacts compared to other technologies for water resources development. The physical and chemical properties of rainwater are usually superior to sources of ground water that may have been subjected to contamination. Rainwater is relatively clean and the quality is usually acceptable for many purposes with little or even no treatment.

Rainwater harvesting technologies are flexible and can be built to meet almost any requirements. Construction, operation, and maintenance are not labour intensive. Predictions regarding global warming could have a major effect in significantly increasing water demand in many cities. At the same time increased evaporation from reservoirs and reduced river flows in some areas may decrease the available surface water supplies. A greater uncertainty regarding yields from major reservoirs and well fields is likely to make investments in the diversification of water sources, better water management and water conservation even more prudent in future. The role of rainwater harvesting systems as sources of supplementary, back-up, or emergency water supply will become more important especially in view of increased climate variability and the possibility of greater frequencies of droughts and floods in many areas. This will particularly be the case in areas where increasing pressure is put on existing water resources.

In urban areas, scarcity and accelerating demand of water is a major problem and it can be reduced by rainwater harvesting, using various existing structures like rooftops, parking lots, playgrounds, parks, ponds, flood plains, etc. to increase the ground water table, which saves the electric energy to lift the ground water because one-metre rise in water level saves 0.40 kilowatt hour of electricity. Subsequently it can also reduce storm drainage load and flooding in city streets.

As cities continue to grow in the future such problems are likely to become increasingly common. Since cities comprise numerous impervious surfaces designed to encourage rainwater runoff the scope for rainwater collection is substantial. Atmospheric pollution remains a major constraint as it contaminates both the rainwater and catchment surfaces making rainwater unsuitable for drinking in many cities around the world. Nevertheless, rainwater can still be used for non-potable uses such as toilet flushing, clothes washing and gardening. Furthermore, greater use of rainwater in urban areas could in future significantly strengthen the lobby to clean up the urban atmosphere entirely.

The Growing Global Interest in Rainwater Harvesting

With development of modern 'conventional' water supply systems in the first half of this century, many traditional water sources went out of favour. This was the case with rainwater harvesting technologies which came to be considered only as an option of last resort. While the exploitation of rainwater was considered appropriate in certain extreme situations such as on coral islands or at remote farms for which reticulated supplies were uneconomic, little serious consideration was given to the more general use of the technology.

Since around 1980, however, things have changed and there have been numerous grassroots initiatives supported by enlightened government and donor agencies promoting and implementing rainwater harvesting technologies. This has partly been a response to the growing technical feasibility of using roof catchment systems in the South due to the spread of impervious roofing materials in urban as well as rural areas. It has also been motivated by a paradigm shift regarding global attitudes to the environment and the growing realisation that water resource utilisation has to become more sustainable. In 1979 UNEP commissioned a series of regional case studies into *Rain and Storm water Harvesting in Rural Area*s. This included work from China, India, Mexico, the U.S., Africa, Australia, and the South Pacific. This was the first time a global overview of experiences with the technology was brought together in a single publication. Another even more influential overview by Pacey, A. & Cullis, A. 1986 followed soon after. At around the same time, UNICEF, several bi-lateral donor agencies (including DANIDA and SIDA), and many NGOs were promoting the use of household roof catchment tanks in East Africa and working on developing various low cost designs in Kenya. This work, much of which was done directly with community groups, led to rapid rates of adoption of roof tanks among rural communities. In a parallel development, the first conference on the use of rainwater cisterns for domestic water supply was held in Honolulu, Hawaii in 1982 attracting around 50 mainly academic participants. It was not envisaged at the time that the meeting would herald the beginning of a series of international conferences on the topic over the next 20 years which would include thousands of participants from a very broad cross-section of countries and professions.

The next three conferences took place in the U.S. Virgin Islands (1984), Thailand (1987), and the Philippines (1989) at which point the scope of the conference series was broadened to include other forms of rainwater catchment systems such as rainwater harvesting for agriculture. At the 1989 conference in Manila, it was also agreed to set up an Association to oversee the conference series and endeavour to promote the technology worldwide. Subsequent conferences took place in Taiwan (1991), Kenya (1993), China (1995), Iran (1997), Brazil (1999) and Germany (2001).

International Conferences on Rainwater Harvesting

- Hawaii (1982)
- U.S. Virgin Islands (1984)
- Thailand (1987)
- The Philippines (1989)
- Taiwan (1991)
- Kenya (1993)
- China (1995)
- Iran (1997)
- Brazil (1999)
- Germany (2001)

In addition to international conferences, many regional, national, and local meetings and initiatives took place during this period reinforcing the suggestion that the technology is now being given more attention globally than at any time prior to 1980. These have included the efforts by the New Delhi based Centre for Science and Environment to revive traditional rainwater harvesting practices in India (Agarwal & Narain 1997); the establishment of a rainwater harvesting forum in Sri Lanka (LRWHF 1999); setting up of People for Promoting

The Millennium Development Goal (7) of ensuring environmental sustainability has set out the target of reducing the proportion of people without sustainable access to safe drinking water to half by 2015.

It is generally believed that water and sanitation provision has been a serious constraint in urban areas in nations that have experienced the most rapid increase in their urban population as a proportion of their total population (i.e. urbanization levels) but this is not uniformly true. In fact some of the regions with the largest increase in urbanization levels have achieved much better levels of water and sanitation provision than some regions with smaller increases. Many of the world’s most rapidly growing cities over the last 50 years have very good water and sanitation provision and many slower growing cities or smaller urban centres have very poor provision. It is surprising that such large cities do not face serious water shortages. In the case of Asia, however, the picture, by and large, is quite disappointing.

Rainwater Utilisation (PPRU) in April 1995 in Tokyo, Japan and new initiatives such as the promotion on rainwater utilisation in modern mega cities such as Tokyo (Murase 1994). The Vision 21 initiative also placed the use of appropriate technologies such as rainwater harvesting at the centre of its proposed strategies for providing clean water, adequate sanitation, and hygiene education for 95% of the population by 2025.

Rainwater harvesting/collection is considered among the most appropriate technologies for efficient use. In pursuance of the Millennium Development Goals, UN-HABITAT, therefore, has decided to bring out a guidebook on rainwater harvesting under Water for Asian Cities Programme in "Blue Drop Series" to encourage rainwater harvesting as part of the strategy for integrated water resource management in the Asian Region, Africa and Latin America & the Caribbean.

Objectives of the UN-HABITAT Guide on Rainwater Harvesting

In the hydrological cycle, rain is the first form of water that we know and hence is a primary source of water for us. Rivers, lakes and ground water are all secondary sources of water. In the present times, we depend entirely on such secondary sources of water and the primary source has been neglected to a great extent.

The purpose of the "Blue Drop Series" is to introduce the planners, decision makers, project managers, beneficiaries and others to the concept and technology of rainwater harvesting in urban areas and to show them where it fits into the overall picture of appropriate and sustainable community water supply development in urban areas. Just like other water resources, rainwater harvesting is an option to be considered when planning an improved water supply system with a community. Depending on local environmental conditions, water harvesting may provide a supplementary supply, an alternative supply or the only feasible improved supply, especially in urban areas which are heavily dependent on underground water. The information provided on technical issues is quite specific, as considerable experience is available, in particular in the area of construction technologies involved in rainwater harvesting.

The information on socio-economic aspects though less specific has also been provided as no tailor-made approaches can be recommended and much will have to be developed to cope with the differences in size, social organization, leadership and complicity of the urban community concerned. This "Blue Drop Series" has been prepared with the objective of presenting the basics required for undertaking rainwater harvesting. The three books under the series have been written in a simple form so that these can be used even by ordinary householders.

Apart from various methods and techniques for water harvesting, selected case studies of harvesting systems designed by various organizations working in the field of rainwater harvesting have been cited so that establishments with similar conditions can take up water harvesting on the same lines. This volume specifically presents methods suitable for singular building/establishment level – residences, institutions and industries. The scope of water harvesting can be extended to a locality/community level by incorporating various such singular units into a group. As one may learn through the "Blue Drop Series", broadly there are two approaches to harvesting water – storing of water for direct use or recharging of ground water.

The "Blue Drop Series" on water harvesting is comprehensive enough and incorporates useful information on various innovations in techniques that can be applied. This guide on water harvesting has been conceived as part of the broader objectives of the Water for Asian Cities Programme.

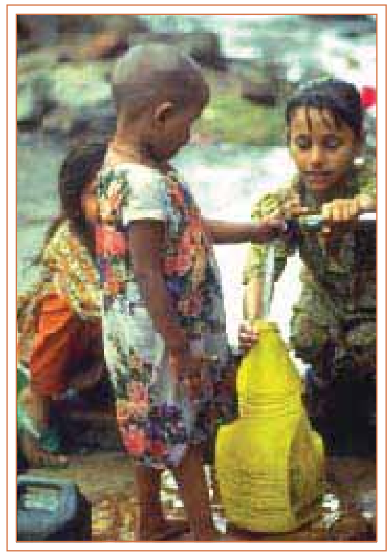
Water for Cities Programme

The objectives of the Water for African Cities programme and the Water for Asian Cities programme are to reduce the urban water crisis in cities through efficient and effective water demand management, to build capacity to reduce the environmental impact of urbanisation on fresh water resources and to boost awareness and information exchange on water management and conservation.

Water for African Cities Programme

A programme on Water for African cities was launched by UN-HABITAT in 1999 as a direct response to the Cape Town Resolution (1997) adopted by African Ministers addressing the urban water challenge facing the continent. This was the first comprehensive initiative to support African Countries to effectively manage the growing urban water crisis and protect the continent's threatened water resources from the increasing volume of land based pollution from the cities. The main objectives under the programme include:

- Development of water-related environmental education strategy for African cities.
- Establishment of water classrooms
- Schools water audit
- Water quality education
- Curriculum development and introducing water education in pilot schools
- Non-formal education with community initiatives
- Water health care education
- Information exchange and North-South twinning arrangements.



Water for Asian Cities Programme

To meet the Millennium Declaration Goal of halving the proportion of people without access to improved services by 2015, an additional 1.5 billion people in Asia will need access to adequate sanitation facilities, while an additional 980 million will need access to safe water. In urban areas, the corresponding figures are 675 million and 619 million respectively. Emphasis on urban water and sanitation has also been placed in the Millennium Declaration by setting a target of improving the living conditions of at least 100 million slum dwellers by 2020.

Following the New Delhi Consultation in April 2002, UN-HABITAT together with ADB launched this regional programme on Water for Asian Cities to promote pro-poor investments in water and sanitation in the region. The New Delhi Consultation made specific recommendations with regard to the implementation strategy and partnership arrangements for the proposed programme.

Programme Objectives

The Programme focuses on three inter-linked priorities.

(i) Introducing demand-responsive and demand management strategies to improve efficiency of water-use and give more influence to those currently deprived of water and sanitation

(ii) Scaling-up sanitation provision city-wide through innovative public-private-NGO partnerships, finance mechanisms and appropriate technical choices

(iii) New pro-poor investments in urban water supply and sanitation with emphasis on serving the urban poor with piped water and formal sanitation facilities

Key Programme Activities

- Monitoring of progress towards achieving Millennium Goal targets in the water and sanitation sector in Asian cities.
- Mobilization of political will through advocacy and exchange of information.
- Strengthening regional, country and city level capacities for integrated water and sanitation management. This requires human resource development in a focused manner, strengthening the capacity of existing institutions. Gender mainstreaming is an important crosscutting theme of capacity building at all levels.
- Creating a new ethic among children and community through Water, Sanitation and Hygiene Education. Interventions include: introducing value-based water education in schools; establishing water education classrooms in pilot cities; community education, training of trainers etc. Twinning of cities and schools is part of this initiative.
- Promoting pro-poor investments in the water and sanitation sector. This calls for the establishment of a pro-poor governance framework at the city level through stakeholder consultations, to facilitate the necessary policy and institutional reforms required for improving water and sanitation services for the urban poor. Investments in water supply and sanitation in Asian cities will provide the source developments, pipelines, treatment plants, reservoirs and distribution systems to bring water to those without direct access to piped water. It will also provide sanitation facilities in those cities, based on appropriate technology.

Partnership and Capacity Building for Pro-poor Investments

The programme commenced with a partnership development phase. The focus in this phase was on developing a framework for collaboration among city level actors as also with external support agencies and other ongoing programmes.

The central emphasis of the Water for Asian Cities Programme is on capacity building in the countries and cities in the region with a view to prepare the environment for pro-poor investments in the water and sanitation sector. While the Capacity Building Phase of the Programme is being directed to enhancing the willingness and commitment of the policy makers and creating the necessary institutional and human resource capacity to implement pro-poor policies and programmes, the investment promotion phase of the Programme shall be directed to creating the enabling environment for pro-poor investments.

Users of the "Blue Drop" Series

The "Blue Drop Series" on Rainwater Harvesting and Utilisation consists of three books and has been designed for policy makers, planners and all those involved in the implementation of urban water supply programmes. It has been prepared with a view to integrate the "state of the art" on Rainwater Harvesting to provide handy, self-contained reference volumes for use by all levels of functionaries in this sector in different regions of the world.

This volume, Blue Drop Series, Book 2, has been designed for Beneficiaries and Capacity Builders. The book consists of five chapters including introduction about the Rainwater harvesting requirements, benefits and the role of UN-HABITAT in Rainwater Harvesting. The information contained in the Book provides valuable exposure to those concerned, information/data on various issues on Rainwater Harvesting like concept & technology, RWH systems, ground water recharge, success stories around the world.

Concept and Technology of Rainwater Harvesting

Rainwater is a free source of nearly pure water and rainwater harvesting refers to collection and storage of rainwater and other activities aimed at harvesting surface and ground water. It also includes prevention of losses through evaporation and seepage and all other hydrological and engineering interventions, aimed at conservation and efficient utilisation of the limited water endowment of physiographic unit such as a watershed. In general, water harvesting is the activity of direct collection of rainwater. The rainwater collected can be stored for direct use or can be recharged into the ground water. Rain is the first form of water that we know in the hydrological cycle, hence is a primary source of water for us (see *figure* 2.1).

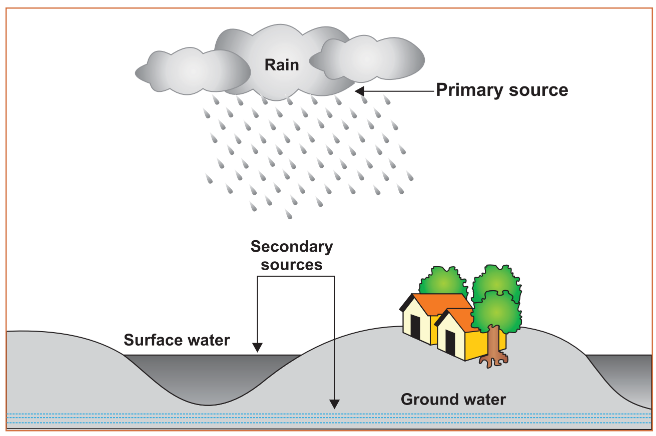


Figure 2.1: Where does all our water come from?

Rivers, lakes and ground water are all secondary sources of water. In present times, we depend entirely on such secondary sources of water. In the process, generally, it is forgotten that rain is the ultimate source that feeds all these secondary sources. Water harvesting means making optimum use of rainwater at the place where it falls so as to attain self-sufficiency in water supply, without being dependent on remote water sources.

Cities get lot of rain, yet cities have water shortage. Why? Because people living there have not reflected enough on the value of the raindrop. The annual rainfall over India is computed to be 1,170 mm (46 inches). This is higher compared to the global average of 800 mm (32 inches). However, this rainfall occurs during short spells of high intensity. Because of such intensities and short duration of heavy rain, most of the rain falling on the surface tends to flow away rapidly, leaving very little for the recharge of ground water. This makes most parts of India experience lack of water even for domestic uses. Ironically,

even Cherrapunji, India, which receives about 11,000 mm of rainfall annually, suffers from acute shortage of drinking water. This is because the rainwater is not conserved and is allowed to drain away. Thus it does not matter as to how much rain falls at a place, if it is not captured or harvested there for use. This highlights the need to implement measures to ensure that the rain falling over a region is tapped as fully as possible through water harvesting, either by recharging it into the ground water aquifers or storing it for direct use.

Many urban centres in Asia and other regions are facing an ironical situation today. On the one hand there is an acute water scarcity and on the other, streets are generally flooded during rains. This has led to serious problems with quality and quantity of ground water. One of the solutions to the urban water crisis is rainwater harvesting - capturing the runoff. The advantage of Rainwater Harvesting is more where surface water is inadequate to meet our demand and exploitation of ground water resource has resulted in decline in water levels in most part of the country.

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.

Around 850 B.C., King Mesha of Moab was victorious in war and conquered a considerable territory east of the Jordan. This he proudly commemorated in the famous "Moabite Stone" text. One detail in King Mesha's self-praise is: *I made two reservoirs in the midst of (qerkhah). Now there was no cistern in the city, so I said to all the people, "Make you every man a cistern in the house".*

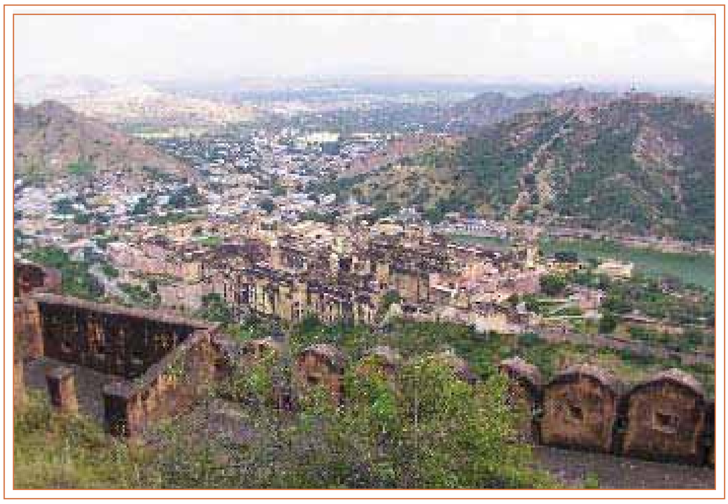
This may be the first time that cisterns were mentioned in a text, but the device itself must have been invented considerably earlier. A progression has been suggested *"from the primitive use or natural rock holes to the digging of open cisterns and finally the construction of roofed-over cisterns excavated in rock".*

According to an Archaeological Encyclopedia *"The first cisterns were dug in the middle and late bronze age (2200-1200 B.C, LW). The rainwater that collected in them during the short rainy season would be enough for at least one dry season. In some parts of Palestine cisterns were the main (sometimes even the only) source of drinking water in peacetime as well as in wartime. In the early Iron Age (1200 – 1000 B.C.; LW) the sides of cisterns began to be covered with watertight plaster, which considerably prolonged the time for which water could be stored. It was this important innovation that made it possible to extend the areas of settlement into the mountainous parts of the country."*

The rainwater was generally collected from the roof and courtyard of the house, in cities as well as in the countryside. A private cistern was seen as a necessary element in the planning of a new house in Tunis in the fourteenth century. A 1921 census in Jerusalem counted 7,000 cisterns collecting runoff water. One informant stated that even today in Amman it is legally required to include a cistern in any new house, but that some people fill them with piped water instead of rainwater.

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.

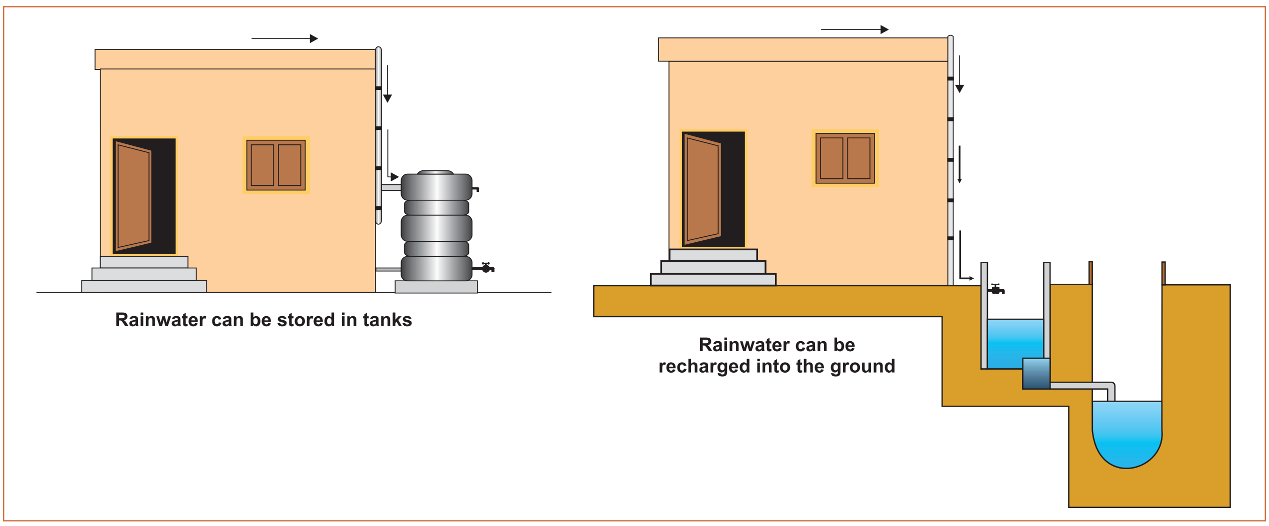

Traditional rainwater harvesting systems in Jaigarh military fort protecting the Maharajah's Palace and old city: Photo S.K. Mishra: City of Jaipur, Rajasthan

Around the globe there is a need to revive the traditional technologies blending them with modern methods to achieve the requirement present and future need of water. This is practiced on a large scale in many Indian cities like Chennai, Bangalore and Delhi where rainwater harvesting is a part of the state policy. Elsewhere, countries like Germany, Japan, United States, and Singapore are also adopting rainwater harvesting with modern methods.

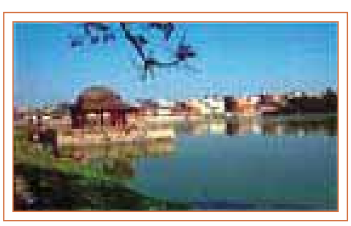
From Where We Can Harvest Rainwater

Rainwater can be harvested from the following surfaces:

Rooftops: If buildings with impervious roofs are already in place, the catchment area is effectively available free of charge and they provide a supply at the point of consumption.



Paved and unpaved areas: i.e., landscapes, open fields, parks, storm water drains, roads and pavements and other open areas can be effectively used to harvest the runoff. The main advantage in using ground as a collecting surface is that water can be collected from a larger area. This is particularly advantageous in areas of low rainfall.



Water bodies: The potential of water bodies such as lakes, tanks and ponds to store rainwater is immense. The harvested rainwater can be used not only to meet water requirements of the city; it also recharges ground water aquifers.

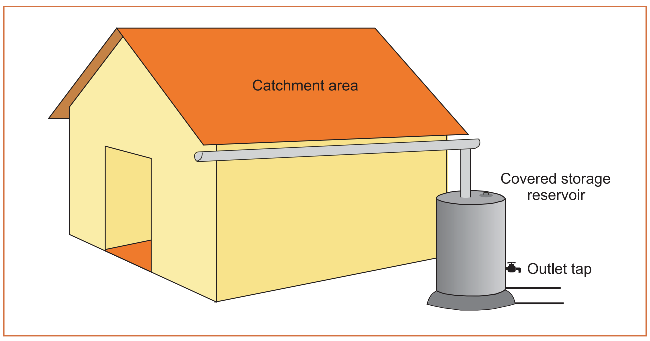
Storm water drains: Most of the residential colonies have proper network of storm water drains. If maintained neatly, these offer a simple and cost effective means for harvesting rainwater.

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 categorization 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.

Simple Roof Water Collection Systems

While the collection of rainwater by a single household may not be significant, the impact of thousands 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.



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.

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.

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.

Collection of Storm Water in Urbanised Catchments

The surface runoff (Box 2.1) collected in storm water 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.

Rainwater Harvesting Potential

The total amount of water that is received in the form of rainfall over an area is called the *rainwater endowment* of that area. Out of this, the amount that can be effectively harvested is called the *water harvesting potential*. Among the several factors that influence the rainwater harvesting potential of a site, climatic conditions specially rainfall and the catchment characteristics are considered to be the most important.

Rainfall

- **Quantity:** Rainfall is the most unpredictable variable in the calculation and hence, to determine the potential rainwater supply for a given catchment, reliable rainfall data are required, preferably for a period of at least 10 years. Also, it would be far better to use rainfall data from the nearest station with comparable conditions.
- **Pattern:** The number of annual rainy days also influences the need and design for rainwater harvesting. The fewer the annual rainy days or longer the dry period, the more the need for rainwater collection in a region. However, if the dry period was too long, big storage tanks would be needed to store rainwater. Hence in such regions, it is more feasible to use rainwater to recharge ground water aquifers rather than for storage.

Catchment Area Characteristics

The characteristics of the catchment area determine the storage conditions. All calculations relating to the performance of rainwater catchment systems involve the use of runoff coefficient (Box 2.1) to account for losses due to spillage, leakage, infiltration, catchment surface wetting and evaporation, which will all, contribute to reducing the amount of runoff. (Runoff coefficient for any catchment is the ratio of the volume of water that runs off a surface to the volume of rainfall that falls on the surface).

Water harvesting potential = Rainfall (mm) x Area of catchment x Runoff coefficient

or

Water harvesting potential = Rainfall (mm) x Collection efficiency

The *collection efficiency* accounts for the fact that all the rainwater falling over an area cannot be effectively harvested, because of evaporation, spillage etc. Factors like runoff coefficient *(see Table 2.1: Runoff coefficients for various catchment surfaces)* and the first-flush wastage *(refer section on Roof Washers/First-Flush device in Chapter 3)* are taken into account when estimating the collection efficiency.

The following illustration highlights the enormous potential for rainwater harvesting. The same procedure can be applied to get the potential for any plot of land or rooftop area, using rainfall data for that area. Consider a building with a flat terrace area of 100 sq.m. The average annual rainfall in the city is approximately 600 mm (24 inches). In simple terms, this means that if the terrace floor is assumed to be impermeable, and all the rain that falls on it is retained without evaporation, then, in one year, there will be rainwater on the terrace floor to a height of 600 mm.

Box 2.1 **Run-off**

Runoff is the term applied to the water that flows away from a catchment after falling on its surface in the form of rain. Runoff can be generated from both paved and unpaved catchment areas of buildings. The nature of the catchment determines the quantity of runoff that occurs from the area. For example, about 70 per cent of the rainfall that occurs over the tiled surface of a terrace would flow as runoff while only 10 per cent of the rainfall on a wooded or grassy area would flow, the rest being retained on the surface and getting percolated into the ground.

From the point of view of quality, runoff can be divided into two types: runoff from paved surfaces (e.g., roofs and courtyards) and runoff from unpaved surfaces (e.g., lawns and playgrounds). Quality of runoff from paved surfaces is better since runoff from unpaved surfaces may have bacterial or other contamination. If water is to be stored for drinking purposes, it is advisable that only runoff from paved surfaces is used for the purpose.

Runoff Coefficient

Runoff coefficient is the factor which accounts for the fact that all the rainfall falling on a catchment cannot be collected. Some rainfall will be lost from the catchment by evaporation and retention on the surface itself. *(Refer Table 2.1 for runoff coefficient)*. Rainwater yield varies with the size and texture of the catchment area. A smoother, cleaner, and more impervious roofing material contributes to better water quality and greater quantity. While loss is negligible for pitched metal roofs, concrete or asphalt roofs average less than 10 per cent loss, and built up tar and gravel roofs average a maximum of 15 per cent loss. Losses can also occur in the gutters and in storage. Regardless of roofing material, many designers assume loss on annual rainfall up to 25 per cent. These losses are due to several factors: the roofing material texture which slows down the flow; evaporation; and inefficiencies in the collection process.

Table 2.1: Runoff Coefficients for Various Catchment Surfaces

Type of Catchment	Coefficient
Roof Catchments	
❖ Tiles	0.8 - 0.9
❖ Corrugated metal sheets	0.7 - 0.9
Ground Surface Coverings	
❖ Concrete	0.6 - 0.8
❖ Brick pavement	0.5 - 0.6
Untreated Ground Catchments	
❖ Soil on slopes less than 10 per cent	0.0 - 0.3
❖ Rocky natural catchments	0.2 - 0.5
❖ Green area	0.05 - 0.10

Source: Pacey, Arnold and Cullis, Adrian 1989, Rainwater Harvesting: The collection of rainfall and runoff in rural areas, Intermediate Technology Publications, London

Area of plot = 100 sq.m. = 120 sq. yd

Height of rainfall = 0.6 m = 600 mm or 24 inches

Volume of rainfall = Area of plot x Height of rainfall over the plot

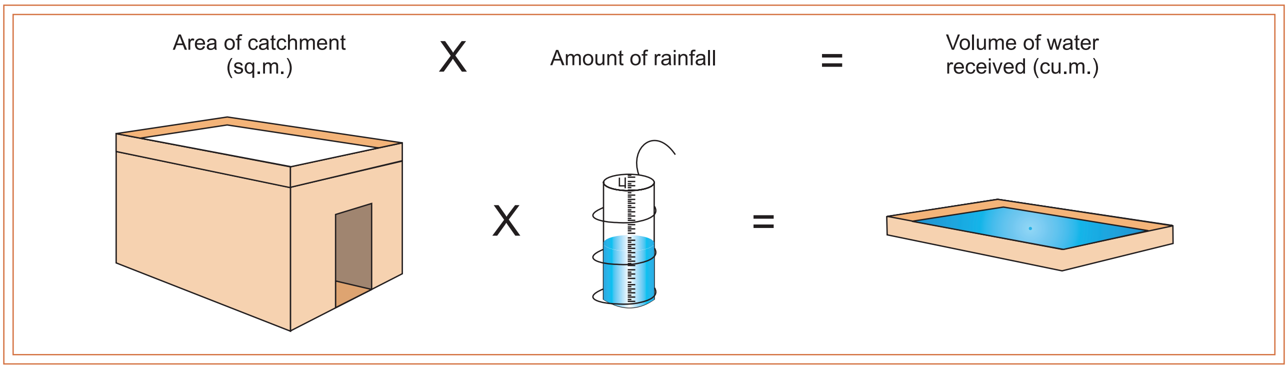
= 100 sq.m. x 0.6 m

= 60 cu.m. = 60,000 litres

Assuming that only 60% of the total rainfall is effectively harvested,

Volume of water harvested = 60,000 litres x 0.6 = 36,000 litres

This volume is about twice the annual drinking water requirement of a 5-member family. The average daily drinking water requirement per person is 10 litres.



Storing Rainwater or Recharging Ground Water Aquifers

Rainwater can be stored for direct use or alternatively it can be charged into the ground water aquifers. This can be done through any suitable structures like dug wells, bore wells, recharge trenches and recharge pits.

The decision whether to store or recharge water depends on the rainfall pattern of a particular region. For example, in places like Kerala and Mizoram in India, rain falls throughout the year, barring a few dry periods. In such places, one can depend on a small domestic-sized water tank for storing rainwater, since the period between two spells of rain is short.

On the other hand, in dry areas like Delhi, Rajasthan and Gujarat, the total annual rainfall occurs only during 3 or 4 months of monsoon. The water collected during the monsoon has to be stored throughout the year; which means that huge volumes of storage containers would have to be provided. In Delhi, it is more feasible to use rainwater to recharge ground water aquifers rather than for storage.

Selection of a recharge location has to be done intelligently so as to ensure maximum collection of the rainwater runoff from the catchment area as well as to facilitate the maximum possible recharge. Scientifically there are various techniques available for geologically determining an ideal recharge location which is usually at the lowest point in the complex nearest to the existing out drainage point that shall facilitate collection of maximum rainwater runoff. Situating a recharge bore next to an existing tube well also enhances the rate of recharge into the ground and helps to sustain the existing ground water withdrawals. However, it is always advisable to maintain a minimum safe distance between the two bores. Subsequent chapters of this book focus on various techniques for aquifer recharging.

Generally, only runoff from paved surfaces is used for storing, since it is relatively free of bacteriological contamination. Drainpipes that collect water from the catchment (rooftop) are diverted to the storage container.

Contribution of Rainwater Harvesting to a Sustainable Water Strategy

Many cities around the world obtain their water from great distances - often over 100 km 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

Box 2.2 Potential of Water Availability Through Rooftop RWH in Selected Indian Cities

Bangalore (South India) Bangalore receives 970 mm rainfall annually and the number of rainy days are 60. Highest amount of rainfall is received during April to November, while the rest of the months receive scanty rainfall. Peak runoff is 50 millimeters per hour. Due to the availability of rainwater throughout the year, water is basically stored in the rainwater harvesting systems and used for non-potable purposes. Water from the rooftops is led into storage structures. Providing an extra length of pipe to collect the polluted 2.5 mm of rainfall normally does the first flushing. Filters are made of sponge and a mixture of sand, gravel and charcoal. After first flushing and filtration water is led into underground sumps (which are very common in Bangalore) or to a new storage tank. The overflow from this tank is taken to an open well to recharge the aquifer. The geological formations are predominantly granite and granitic gneiss, with joints and fractures in abundance due to intense chemical weathering of rocks. The depth of weathering varies from 0.2 m to 20 m. This geological set-up offers an immense scope for recharging of ground aquifers. The undulating terrain with gentle slopes draining into lakes offers an ideal situation for water harvesting. In the urban area of Bangalore water bodies cover about 5 per cent of land. A study made by the Centre for Ecological Studies and Indian Institute of Sciences revealed that out of 262 lakes in 1960 only 82 exist now, of which less than 10 have water. Forty per cent of the city population is dependent on ground water. The demand supply gap is met by ground water exploitation. Even the surface water is pumped from Cauvery river flowing at a distance of 95 kilometres and about 500 meters below the city necessitating huge pumping costs and energy usage.

Delhi (North India) The national capital territory (NCT) of Delhi receives 611 mm of rainfall on an average annually and the number of rainy days are as low as 20-30. (A rainy day is specified as a day with more than or equal to 2.5 mm of rainfall). The geology of Delhi comprises Alwar quartzites and alluvium whose vertical hydraulic conductivity, (permeability), is high compared to the horizontal permeability. This makes the conditions favourable for artificial recharge. Thus most of the urban rainwater harvesting efforts revolve around recharge of aquifers which is the best option available taking into consideration the rainfall pattern and availability.

Proposed Category of area for 2011 (sq.km.)		Annual water harvesting potential in billion litres: 100 per cent harvesting	50 per cent harvesting
Development area	597.0	579.10	289.55
Green Belt	682.0	661.54	330.77
Total area	1279	1240.64	620.32

Note: Average annual rainfall 970mm; Annual demand-supply gap 49.28 billion litres

Roof area in sq.m.	Annual rainfall in (litres)	Quantity of rainfall available for harvesting (litres)
50	30,550	18,330
100	61,100	36,660
500	305,500	183,300
1000	610,000	366,600

Note: a. Annual average rainfall of Delhi=611 mm; b. runoff coefficient is assumed as 0.60

An analysis of demand supply gap shows that even 50 per cent of the rainwater harvested can bridge the demand supply gap.

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 ground water, providing the city with greater flexibility in the face of water shortages and earthquakes.

Restoring the Hydrological Cycle

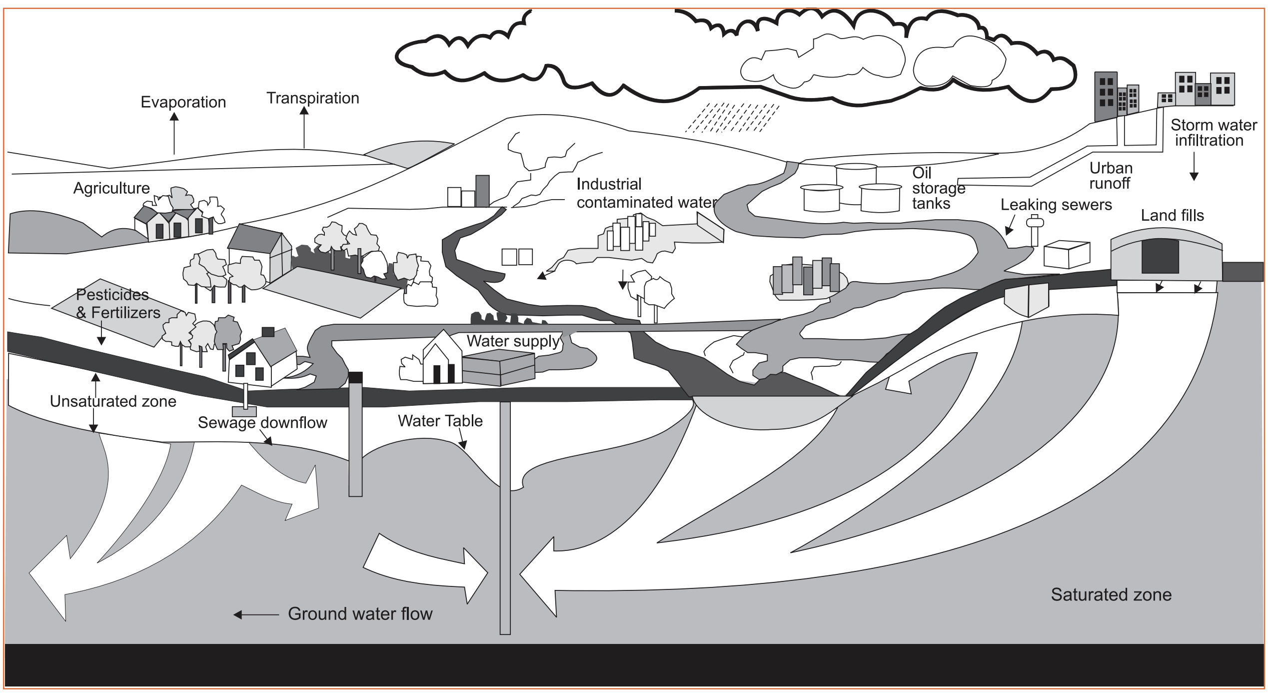


Diagram of the Hydrological Cycle (detail)

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 ground water, it feeds submerged springs and rivers. The impermeable surfaces of 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.

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 radiated by air conditioners can further aggravate this.

This alters the city's natural hydrological cycle and ecological environment in a big way.

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.

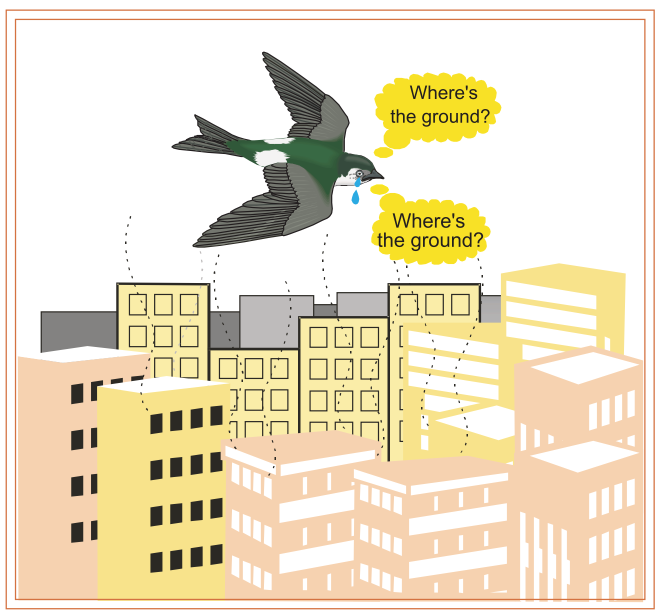

Urban Flood in Tokyo, Japan

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 to revive the hydrological cycle. The use of ground water should be considered from the point of view of cycle capacity. Rain seeps underground and over time becomes shallow stratum ground water. Then, over a very long period of time, it becomes deep stratum ground water. For sustainable use of ground water, it is necessary to consider the storage capacity for ground water over time. If this is neglected and ground water is extracted too quickly, it will disappear within a short time.

Demand Side Management of Water Supply (Water Demand Management)

In establishing their water supply plans, cities have usually assumed that the future demand for water will continue to increase. Typically, water utilities in cities 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 water conservation approaches, including the use of freely available, locally supplied rainwater.

Quality Considerations in Utilising Rainwater

It is generally believed that rainwater can provide clean, safe and reliable water which can be consumed without pre-treatment. This however may be used in some areas that are relatively unpolluted. Rainwater collected in many locations contains impurities. Therefore, in order to ensure quality of water, the collection systems will have to be properly built and maintained and the water shall also have to be treated appropriately for intended uses. Once rain comes in contact with a roof or collection surface, it can wash many types of bacteria, molds, algae, protozoa and other contaminants into the cistern or storage tank. Indeed, some samples of harvested rainwater have shown detectable levels of these contaminants.

Health concerns related to bacteria, such as salmonella, e-coli and legion Ella, and to physical contaminants, such as pesticides, lead and arsenic, are the primary criteria for drinking water quality analysis. Falling rain is generally free of most of these hazards. But, if the rainwater is intended for use *inside* the household, either for potable uses such as drinking and cooking or for non-potable uses including showering and toilet flushing, appropriate filtration and disinfection practices should be employed. If the rainwater is to be used *outside* for landscape irrigation, where human consumption of the untreated water is less likely, the presence of contaminants may not be of major concern and thus treatment requirement can be less stringent or not required at all. Depending on where the system is located, the quality of rainwater itself can vary, reflecting exposure to air pollution caused by industries such as cement kilns, gravel quarries, crop dusting and a high concentration of automobile emissions.

In many parts of the globe, “Acid Rain” has also 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) guidelines 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 need to 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.

*pH is the measure of acidity or alkalinity. In a scale from 0 to 14, 7 is neutral, values less than 7 represent more acid conditions, values greater than 7 represent more basic or alkaline conditions. The determination of whether water is acidic, neutral, or basic, is referred to as pH, which is a measure of the hydrogen ion concentration in water. The desired pH of potable water is pH 7, while the scale ranges from values of less than pH 7 down to pH 1 as increasingly acidic and greater than pH 7 up to pH 14 as increasingly basic. Soda pop and vinegar have a pH of about 3.0

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. The use of photo-oxidation based on available sunlight to remove both the coliforms and streptococci is still being researched. Other water quality concerns include colour, taste, smell and hardness. In many cities rainwater when assessed according to these characteristics proves to be of better quality than well or municipal tap water. Inorganic impurities such as suspended particles of sand, clay, and silt contribute to the water color and smell. Proper screening and removal of sedimentation help to decrease problems caused by these impurities. Rainwater is the softest natural occurring water available, with a hardness of zero level for all practical purposes. Rainwater contains almost no dissolved minerals and salts and is near distilled water.

In Texas (USA), the total dissolved minerals and salt levels average about 10 milligrams per litre (mg/l). Total Dissolved Solids (TDS) can range as high as 50 mg/l and as low as 2.0 mg/l. These values are very low when compared to city tap water across Texas, which typically is in the 200 to 600 mg/l range, making rainwater virtually sodium free. For people on restricted salt diets, this represents a decisive advantage over other water sources. The pH of rainfall would be 7.0 if there were nothing else in the air. However, as rain falls through the air, it dissolves carbon dioxide that is naturally present in the air and becomes slightly acidic. The resultant pH is 5.6; however, any sulfates or nitrates dissolved from the air will lower this number below pH 5.6.

Chapter 3

Rainwater Harvesting System

All sources of water are ultimately rain. Therefore, all water supply systems are, in effect, rainwater-harvesting systems. A proper definition for this term to understand its spirit would, in effect, necessarily have to take into consideration the difference in catchments. While previously catchments were typically far off from the urban area they served, now the city itself is seen as a catchment for its water requirement. Rooftops, paved areas and unpaved areas and the entire city itself is, therefore, to be managed as a water provision area. As the Centre for Science and Environment, Delhi (India) puts it 'CATCH WATER WHERE IT FALLS' would be a good definition of rainwater harvesting.

The process of rainwater harvesting would encompass catching rainwater, directing it to an appropriate location, filtering it if required and storing it for use. Storage could be in tanks, sumps, ponds or lakes wherever appropriate and conditions permitting recharge of ground water would also qualify as storage. Harvested water could be used immediately as a first choice thus saving city level supplies or ground water for a future date or a decision could be taken to store it for later use, say during water shortage days. Domestic rainwater harvesting or rooftop rainwater harvesting is the technique through which rainwater is captured from roof catchments and stored in tanks/reservoirs/ground water aquifers. It also consists of conservation of roof top rainwater in urban areas and utilizing it to augment ground water storage by artificial recharge. It requires connecting the outlet pipe from rooftop to divert collected water to existing well/tube well/bore well or a specially designed well. Rooftop harvested rainwater is more safe for drinking purposes than the runoff harvested water.

Rooftop harvesting needs to have safe storage facilities to keep the water fit for drinking. First flush of rainwater is discarded. A number of alternative technologies are available for rooftop harvesting and storage to suit the varying situations and the budgets.

Scale of Operations

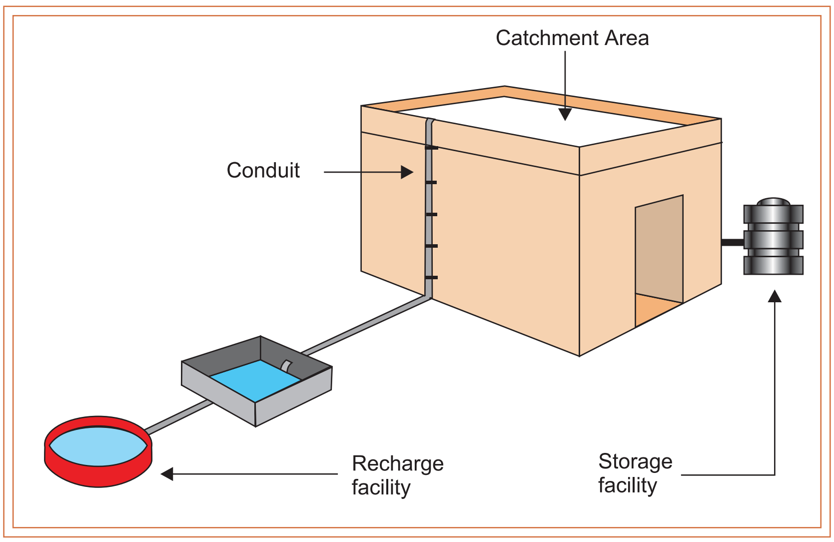
From a small rooftop to large areas such as that of institutions and industries, rainwater harvesting can work well. Neighborhoods and finally the city itself should be the ultimate scale of operation. Singapore for example plans to manage and harvest almost all rainwater at the city-level. One primary step would be to keep the catchments clean and this would mean managing all solid, liquid and gaseous waste streams of the city. There are many methods for rainwater harvesting. Each method is site specific. The flow from roofs of houses may also be collected using galvanized iron sheets, into a channel fitted on the edge of the roof. This water can be stored adjacent to the house after screening out the impurities.

Components of a Rainwater Harvesting System

All rainwater-harvesting systems comprise six basic components irrespective of the size of the system.

1. Catchment area/roof: The surface upon which the rain falls; the roof has to be appropriately sloped preferably towards the direction of storage and recharge.
2. Gutters and downspouts: The transport channels from catchment surface to storage; these have to be designed depending on site, rainfall characteristics and roof characteristics.
3. Leaf screens and roof washers: The systems that remove contaminants and debris; a first rain separator has to be put in place to divert and manage the first 2.5 mm of rain.
4. Cisterns or storage tanks: Sumps, tanks etc. where collected rain-water is safely stored or recharging the ground water through open wells, bore wells or percolation pits etc.;
5. Conveying: The delivery system for the treated rainwater, either by gravity or pump;
6. Water treatment: Filters to remove solids and organic material and equipment, and additives to settle, filter, and disinfect.

Briefly the system involves collecting water that falls on the roof of a house made of zinc, asbestos or other material during rain storms, and conveying it by an aluminium, PVC, wood, plastic or any other local material including bamboo drain or collector to a nearby covered storage unit or cistern. Rainwater yield varies with the size and texture of the catchment area. A smoother, cleaner and more impervious roofing material contributes to better water quality and greater quantity. Each component is briefly described below.



Elements of a Typical Water Harvesting System

Catchment Surface

The catchment area of a water harvesting system is the surface, which receives rainfall directly and contributes the water to the system. It can be a paved area like a terrace or courtyard of a building, or an unpaved area like a lawn or open ground. Temporary structures like sloping sheds can also act as catchments. In **Botswana**, house compounds and threshing floors are surfaced with clay / cow dung plaster and used effectively as rainwater catchments. Rainwater harvested from catchment surfaces along the ground, because of the increased risk of contamination, should only be used for non-potable uses such as lawn watering. For in house uses, rooftop harvested rainwater is safer for drinking purposes than the runoff harvested water.

Catchment Area: Some Features

- The nature of the catchment distinguishes rainwater collection from other kind of harvesting.
- Four types of catchment areas have been considered namely; roof, rainwater platforms, watershed management and hill slopes.
- Catchments used to collect rainwater are frequently artificial or else ground surfaces, which have been specifically prepared and demarcated.
- Rainwater may be collected from any kind of roof – tiles, metal, palm leaf, grass thatch.
- Lead flashing roof or roof painted with lead-based paint or asbestos roof is generally regarded as unsuitable.
- A well-thatched roof has been said not to be presenting much hazard to the collected water. These have been covered with plastic sheets in some areas in Manipur (NE India).

Catchment area consisting of rooftop area / the plot area or the complex area from where the rainwater runoff is proposed to be collected has to be maintained so as to ensure that the resultant rainwater runoff is not contaminated. At times paints, grease, oil etc. are often left on the roof or in the courtyards. These can result in contamination of the rainwater runoff. Therefore, the households have to ensure that they keep the catchment area clean at all times especially during the rainfall season.

Catchment Area Size

The size of a roof catchment area is the building's footprint under the roof. The catchment surface is limited to the area of roof which is guttered. To calculate the size of the catchment area, multiply the length times the width of the guttered area.

Type of Roofing Material

Rainwater may be collected from any kind of roof. Tiled or metal roofs are easier to use, and may give clean water, but it is perfectly feasible to use roofs made of palm leaf or grass thatch. The only common type of roof which is definitely unsuitable, especially to collect water for drinking, is a roof with lead flashings, or painted with a lead-based paint. It is suggested that roofs made of asbestos sheeting should also not be used if fibres are getting detached from damaged areas. In the Khon Kaen province of Thailand, many well-constructed houses have corrugated iron roofs which are used for collecting rainwater. Roof areas are large, often exceeding 100 m^2, though guttering may be installed on only half the area.

Caution is generally warranted regarding thatched roofs, which are reported to be sources of contamination, but there seems to be no evidence that water from a well-thatched roof presents any significantly great hazard to consumers than water from other roofs. Greater precaution may be advisable to ensure that debris from the roof does not enter the tank, and the water should usually be boiled before drinking. The most important consideration, however, is that if a project is to help low-income groups, there may be no choice but to tackle the problem of collecting water from thatch or palm-leaf roofs, either by using a low level collecting tank or by devising means of attaching gutters. If a new construction project is planned with a slanting roof, metal roofing is the preferred material because of its smooth surface and durability. Other material options such as clay tile or slate are also appropriate for rainwater intended to be used as potable water. These surfaces can be treated with a special non-toxic paint coating to discourage bacterial growth on an otherwise porous surface. Because composite asphalt, asbestos, chemically treated wood shingles and some painted roofs could leach toxic materials into the rainwater as it touches the roof surface, they are recommended only for non-potable water uses.

Gutters and Downspouts/Conduits

Most of the existing storm water conveyance systems are designed to drain out the rainwater that falls in the catchment area into the nearest storm water drain or the sewerage system. These connections should be redirected to the recharge location so that the rainwater runoff can now be directed into the recharge structure. In already built up structure it requires certain modifications to the existing drainage system but in ongoing construction it can be easily re-designed at almost no extra cost. The choice of the material and the design are as per the discretion of the individual owners and, like any other drainage system, can be constructed utilizing a variety of materials.

Table 3.1: Sizing of Rainwater Pipes for Roof Drainage

Roof area (Sq.m.)

Sl. No.	Diameter of Pipe (mm)	Average rate of rainfall in mm/h					
		50	75	100	125	150	200
1.	50	13.4	8.9	6.6	5.3	4.4	3.3
2.	65	24.1	16.0	12.0	9.6	8.0	6.0
3.	75	40.8	27.0	20.4	16.3	13.6	10.2
4.	100	85.4	57.0	42.7	34.2	28.5	21.3
5.	125	-	-	80.5	64.3	53.5	40.0
6.	150	-	-	-	-	83.6	62.7

Source: Indian National Building Code

mm/h - millimeters per hour; m - meters

Conduits are the pipelines or drains that carry rainwater from the catchment or rooftop to the harvesting system. Conduits may be of any material like Poly Vinyl Chloride (PVC), asbestos or Galvanized Iron (GI), materials that are commonly available. The diameter of pipe required for draining out rainwater based on rainfall intensity (average rate of rainfall in mm per hour) and roof surface area as shown in Table 3.1.

Channels have to be all around the edge of a sloping roof to collect and transport rainwater to the storage tank. Gutters can be semi-circular or rectangular and could be made using:

- Locally available material such as plain galvanised iron sheet (20 to 22 gauge), folded to the required shapes.
- Semi-circular gutters of PVC material which can be readily prepared by cutting the pipes into two equal semi-circular channels.
- Bamboo or betel trunks cut vertically in half.

The size of the gutter should be according to the flow during the highest intensity rain. It is advisable to make them 10 to 15 per cent oversize. Gutters need to be supported so that they do not sag or fall off when loaded with water. The way in which gutters are fixed depends on the construction of the house; it is possible to fix iron or timber brackets into the walls, but for houses having wider eaves, some method of attachment to the rafters is necessary.

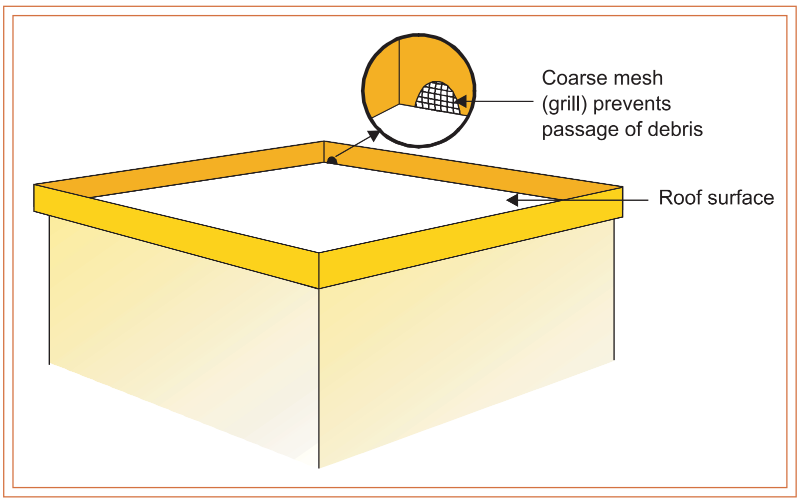
These are the components which catch the rain from the roof catchment surface and transport it to the cistern. Standard shapes and sizes are easily obtained and maintained, although custom fabricated profiles are also possible to maximize the total amount of harvested rainfall. Gutters and downspouts must be properly sized, sloped, and installed in order to maximize the quantity of harvested rain.

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.

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.

Leaf Screens/Roof Washers

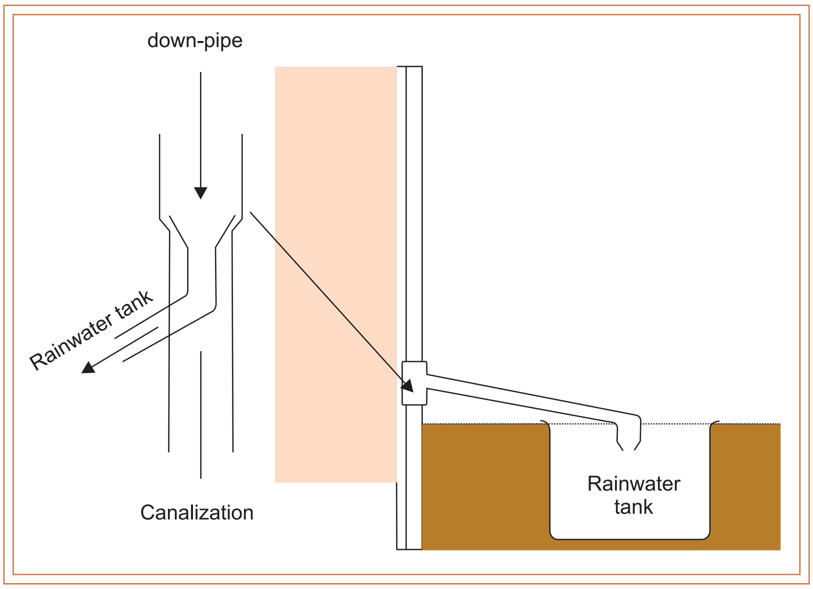


To keep leaves and other debris from entering the system, the gutters should have a continuous leaf screen, made of 1/4-inch wire mesh in a metal frame, installed along their entire length, and a screen or wire basket at the head of the downspout. Gutter hangers are generally placed every 3 feet. The outside face of the gutter should be lower than the inside face to encourage drainage away from the building wall. Where possible, the gutters should be placed about 1/4 inch below the slope line so that debris can clear without knocking down the gutter. To prevent leaves and debris from entering the system, mesh filters should be provided at the mouth of the drain pipe *(see figure*). Further, a first flush (foul flush) device section should be provided in the conduit before it connects to the storage container. If the stored water is to be used for drinking purposes, a sand filter should also be provided. *(see section:* Disinfecting water at domestic level)

First Flush Device

A first flush (foul flush) device is a valve that ensures that runoff from the first spell of rain is flushed out and does not enter the system. This needs to be done since the first spell of rain carries a relatively larger amount of pollutants from the air and catchment surface.

Roof washing, or the collection and disposal of the first flush of water from a roof, is of particular concern if the collected rainwater is to be used for human consumption, since the first flush picks up most of the dirt, debris, and contaminants, such as bird droppings that have collected on the roof and in the gutters during dry periods. The most simple of these systems consists of a standpipe and a gutter downspout located ahead of the downspout from the gutter to the cistern. The pipe is usually 6 or 8 inch PVC which has a valve and clean out at the bottom. Most of these types of roof washers extend from the gutter to the ground where they are supported. The gutter downspout and top of the pipe are fitted and sealed so water will not flow out of the top. Once the pipe has filled, the rest of the water flows to the downspout connected to the cistern. These systems should be designed so that at least 50 litres of water are diverted for every 1000 square feet of collection area. Rather than wasting the water, the first flush can be used for non-potable uses such as for lawn or garden irrigation. In USA several types of commercial roof washers which also contain filter or strainer boxes are available to prevent debris from being washed into the tank and to arrange for the dirty first flush rainwater after a dry spell to be discarded. In **Indonesia,** an inlet filter moulded in the tank roof is a prominent feature of the RWH system design. No specific provision is made for first flush diversion, but the length of guttering which takes the place of down pipe can be moved during any dry period and replaced after the first few minutes of rain in a new wet season. In **Thailand,** RWH system incorporates a device for holding back first flush water. It consists of a length of large diameter pipe suspended alongside the rainwater tank. This is sealed at the bottom with a plug. When rain begins to fall, this length of pipe must fill before any water can enter the tank. It will thus retain any sediment carried by the first flush water. After each storm, the plug is removed and the pipe is drained. *Also consider trimming any tree branches that overhang the roof. These branches are perches for birds and produce leaves and other debris.*



Example of a first flush device installation

Storage Tanks/Cisterns

Storage tanks for collecting rainwater may be located either above or below the ground. They may be constructed as part of the building, or may be built as a separate unit located some distance away from the building. The design considerations vary according to the type of tank and other factors. Various types of rainwater storage facilities are found in practice. Storage tanks should be constructed of inert material. Reinforced concrete, fibreglass, polyethylene, and stainless steel are also 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 are also found 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.

A storage tank made of galvanized iron sheets

Shape and Size

There are various options available for the construction of these tanks with respect to the shape, size and the material of construction. Shapes may be cylindrical, rectangular and square.

In **Thailand** tanks are made of bamboo-reinforced concrete and are of varying sizes from 1.4 m^3 (costing about US $25) to 11.3 m^3 (US $175) Table 3.2 gives some of the recommended rainwater tank capacities based on the assumption that water consumption can be returned to ensure an all year supply. The cisterns built in **Indonesia** and **Thailand** and the Ghala tank in **Kenya**, using bamboo reinforcement instead of metal, have been highly significant in making low-cost tanks, though their durability needs to be improved upon.

The quantity of water stored in a water harvesting system depends on the size of the catchment area and the size of the storage tank. The storage tank has to be designed according to the water requirements, rainfall and catchment availability.

Table 3.2: Tank Capacities

Region	Average Annual Rainfall * (mm)	Sample Roof Area * (m^3)	Recommended Tank Capacity (m^3)	Estimated Daily Supply (litres)
AFRICA				
Ghana, N.E.region	800 in two wet seasons	30	7.5	66
Swaziland, Lowveld	635 with 6 dry months	30	5.0	37
Botswana Francistown	470 with 7-9 dry months	30	4.5 4.5 8.0	31 66 31
INDONESIA				
Java, Jakarta area	1800, no really dry months	30	1.2 5.5 3.6 7.8	30 60 30 60
Madura	1500 with 5 dry months	30	5.1	30
Java, Yogyakarta	1800 with 6 dry months	30	5.0	30
THAILAND				
Khon Kaen area	1300 with 4 dry months	60 30	11.5 5.8	90 45
AUSTRALIA				
Sydney	1210 no dry months	320 30	126 11.8	800 74
Griffith, New South Wales	390 with no defined wet season	965 30	336 10.5	800 25
BERMUDA				
	1500 no dry months	30	11.7	–

Source: Journal: Aqua (A-126)

Suppose the system has to be designed for meeting drinking water requirement of a 5-member family living in a building with a rooftop area of 100 sq.m. Average annual rainfall in the region is 600 mm. Daily drinking water requirement per person (drinking and cooking) is 10 litres.

We shall first calculate the maximum amount of rainfall that can be harvested from the rooftop

Following details are available:

Area of the catchment (A) = 100 sq.m.

Average annual rainfall (R) = 600 mm (0.6 m)

Runoff coefficient (C) = 0.85

Annual water harvesting potential from 100 sq.m. roof

= A x R x C

= 100 x 0.6 x 0.85

= 51 cu.m. (51,000 litres)

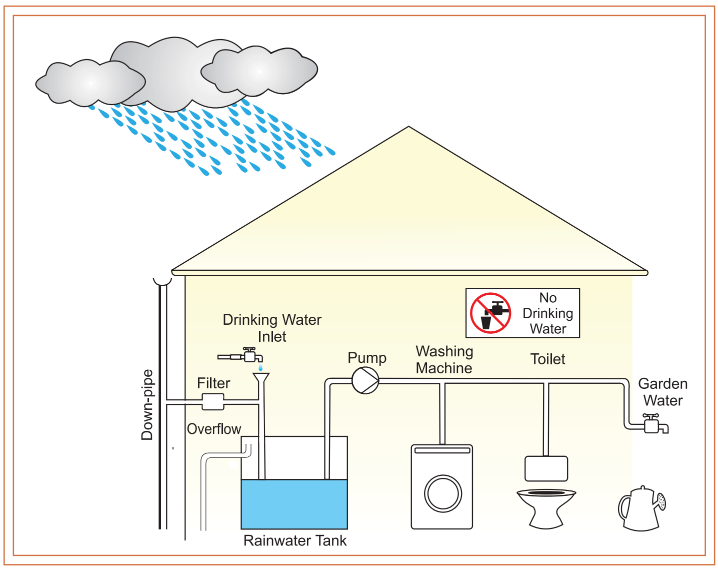
The tank capacity has to be designed for the dry period, i.e., the period between the two consecutive rainy seasons. With the rainy season extending over four months, the dry season is of 245 days.

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

Drinking water requirement for the family (dry season) = 245 x 5 x 10

= 12,250 litres.

As a safety factor, the tank should be built 20 per cent larger than required, i.e., 14,700 litres. This tank can meet the basic drinking water requirement of a 5-member family for the dry period.



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

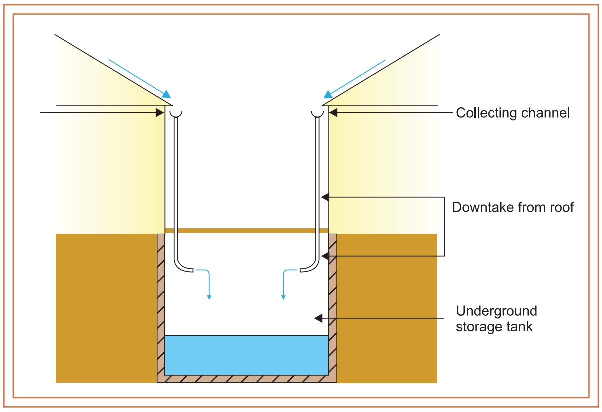
The most commonly used material of construction is Reinforced Cement Concrete (RCC), ferrocement, masonry, plastic (polyethlene) or metal (galvanised iron). Materials needed for the construction of some widely used types of rainwater tank are given in Table 3.3.

Material for Construction

Concrete

Reinforced concrete tanks can be built above or below ground by a commercial contractor or owner builder. Because of their weight, they are usually poured in place to specifications and are not portable. However, concrete tanks can also be fashioned from prefabricated components, such as septic tanks and storm drain culverts, and from concrete blocks. Concrete is durable and long lasting, but is subject to cracking; below ground tanks should be checked periodically for leaks, especially in clayey soils where expansion and contraction may place extra stress on the tank. An advantage of concrete cistern chambers is their ability to decrease the corrosiveness of rainwater by allowing the dissolution of calcium carbonate from the walls and floors.

An underground RCC/masonry tank can be used for storage of rainwater. The tank can be installed inside the basement of a building or outside the building. Pre-fabricated tanks such as PVC can be installed above the ground. Each tank must have an overflow system for situations when excess water enters the tank. The overflow can be connected to drainage system.



Rainwater can be stored in underground tanks as in this traditional rainwater harvesting system in Ahmedabad

Ferrocement

Ferrocement is a term used to describe a relatively low cost steel mortar composite material. Unlike reinforced concrete, ferrocement's reinforcement is comprised of multiple layers of steel mesh (often chicken wire), shaped around a light framework of rebar, that are impregnated with cement mortar. Because its walls can be as thin

Table 3.3: Materials for Rainwater Tanks

	Unreinforced Cement Mortar Jar	Ghala Tank	Ferrocement Tank	Bamboo Reinforced Concrete Tank
Capacity	1.0 m^3	2.3 m^3	9.0 m^3	11.3 m^3
Local Materials	Rice husks, sawdust or sand to stuff sacking formwork	Woven stick granary basket—murram or clay		
Special Requirement	Hessian Sacking 4m x 1.7 m		Corrugated Iron Formwork	Metal formwork
Cement (50 kg bags)	2 bags	5 bags	12 bags	13 bags
Sand	200 kg	500 kg	1300 kg	1300 kg
Gravel, 25 mm	—	200 kg	500 kg	2000 kg
Quarry chippings	—	300 kg	—	800 kg
Chicken wire 50 mm mesh.	—	—	16 m^3	—
Straight wire 2.5 mm guage.	—	—	200 m	—
Water pipe, 15 mm	—	1 m	2 m	1 m
Overflow pipe 50mm	—	—	0.2 m	0.2 m
Taps	—	1 no.	1 no.	1 no.
Roof or lid	Made of wood or cement mortar	Cement mortar	6 m^2 sheet metal	Concrete
Bags of cement per m^3 storage	2.0	2.2	1.3	1.15

Source: Journal: Aqua (A-126)

as 1", it uses less material than conventional poured-in-place concrete tanks, and thus is generally much less expensive. Ferrocement tanks are likely to require greater ongoing maintenance than tanks constructed of other materials. Small cracks and leaks can be easily repaired with a mixture of cement and water, and also applied where wet spots appear on the tank's exterior. Some sources also recommend that it is advantageous to paint above ground tanks white to reflect the sun's rays so as to reduce evaporation and keep the water cool. It is important to check that the ferrocement mix does not contain any toxic compounds which may make the water unfit for use.

Plastic

Fiberglass: Fiberglass tanks are lightweight, reasonably priced, and long lasting, making them one of the most popular tanks in contemporary installations. As with the polyethylene and galvanized tanks, fiberglass tanks are commercially available and easy to transport. They are available in a wide range of sizes and can be specified for potable water. Fiberglass tanks should be coated or constructed to prevent penetration of sunlight into the tank.

Plastic Liner: Plastic liners are sometimes used to line concrete tanks or tanks that have developed leaks. These liners can also be used to line low-cost, temporary collection tanks constructed of materials such as plywood. Plastic liners that are specified for potable use are commercially available.

Polyethylene: In many countries these tanks are commercially available in a variety of sizes, shapes, and colors, and can be constructed for above or below ground installations. Polyethylene tanks are gaining popularity due to their relatively low cost and because they one slightly more durable than fiberglass with comparable life expectancy. Their light weight makes them easy to transport and relocate, if needed, while their smooth interior surface makes them easy to clean. Repairs are relatively easy to carry out – use heat to soften the plastic and reshape as necessary. To ensure their long-life, polyethylene tanks should be chosen which have ultra-violet (UV) inhibitors for outdoors use, or can be placed in an enclosure or painted with a protective surface to provide protection from the sun. Black tanks have the greatest UV resistance, with a life expectancy of 25 years, though they tend to absorb heat and thus can affect water quality. Painting or shading the tank will minimize the effects of UV light and is recommended. Again, light penetration may promote algae growth.

Metal

In the U.S. galvanized steel tanks are also used. These are commercially available and reasonably priced and are quite popular. They are noted for their strength, yet are relatively lightweight and easy to move. Corrosion can be a problem if exposed to acidic conditions; some suppliers provide an inside liner to guard against this problem. In addition, high and low pH water conditions can result in the release of zinc. Galvanised corrugated iron tanks in many areas are the most readily available tanks for those householders able to purchase at full market prices. In some places – including parts of Kenya and Papua New Guinea – the tank construction provides jobs for a significant number of 'tin-smiths'.

Position of Storage Tanks/Cisterns

Depending on space availability these tanks could be constructed above ground, partly underground or fully underground. Some maintenance measures like cleaning and disinfection are required to ensure the quality of water stored in the container. Other than the roof, which is an assumed cost in most building projects, the storage tank represents the largest investment in a rainwater harvesting system.

While above ground installations avoid the costs associated with excavation and certain maintenance issues, cisterns that are below ground benefit from the cooler year round ground temperatures. To maximize efficiency, cisterns should be located as close to both the supply and demand points as possible. And, to facilitate the use of gravity or lower stress on a pump, the cistern should be placed on the highest level that is workable. While the catchment area (roof) should not be shaded by trees, the cistern can benefit from the shade since direct sunlight can heat the stored rainwater in the tank and thereby encourage algae and bacterial growth, which can lower water quality. Most cities do not have specific regulations concerning rainwater systems; however, to ensure a safe water supply, cisterns should be sited at least 50 feet away from any sources of pollution such as latrines, or, if the tank is below ground, away from septic tanks.

Tank placement should also take into consideration the possible need to add water to the tank from an auxiliary source, such as a water truck, in the event that the household water supply is depleted due to over-use or drought conditions. For this reason, the cistern should be located in a site accessible to a water truck, preferably near a driveway or roadway, and positioned to avoid crossing over water or sewer lines, lawns or gardens. To maximize the efficiency of the RWH system, the building plan should reflect decisions about optimal placement, capacity, and material selection for the cistern/storage tank.

Cleaning and Maintenance of Storage Tanks

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. 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 any misuse by the 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 to 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.

General Safety Guidelines for Storage Tanks/Cisterns

- A cistern must not be located closer than 50 feet to a source of contamination, such as a septic tank.
- A cistern must be located on a grade lower than the roof washer to ensure that it can fill completely.
- A rainwater system must include installation of an overflow pipe which empties into a non-flooding area.
- Inlets to cisterns must be designed to dissipate pressure of influent stream and minimize the stirring of any settled solids.
- An aboveground roof washer or filtering device shall be provided on all cisterns.

- The water intake for a pump in a cistern should be attached to a floatation device and be located a minimum of 4 inches below the surface of the water.
- Overflow from rainwater systems should not flow into wastewater systems.
- Cisterns shall be accessible for cleaning.
- All openings into the cistern should be screened.
- Cisterns cannot be relied upon to provide potable water without adequate treatment consisting of roof washing and continuous disinfection.

Table 3.4: Big vs. Small Tank: Cost Comparison

(Comparative cost of the one large tank collecting water from both sides of a roof as compared with two small tanks.)

(US $)

	Large Tanks Collecting from Both Sides of a Roof	Two Small Tanks Each Collecting from One Side of the Roof
Cost of Tanks:		
10 m³ size	100	___
5 m³ size	___	56
		56
Cost of guttering	57	17
Cost of down pipes	15	3
	172	132

Note: Figures are based on experience in Zimbabwe
Source: Journal: Aqua (A-126)

Table 3.5: Comparative Cost for Rainwater Tanks

(US $)

Type of Tank	Tank Capacity 2.5 m^3 Unit Cost per m^3	Total Cost	Tank Capacity 9-10 m^3 Unit Cost per m^3	Total Cost
Fibre glass	160	400	180	1800
Sheet metal	-	-	90	900
Galvanised corrugated iron	60	150	35	350
Ferrocement West Java type	38	94	20	200
Ferrocement Zimbabwe type materials only	-	-	15	150
Materials & Labour	-	-	22	220
Bamboo reinforced concrete (Thailand) materials only	-	-	14	135
Materials & Labour (contractors price)	-	-	32	360
Bamboo cement (West Java type)	28	70		
(Ghala tank Kenya) Materials only	18	45		

Source: Journal: Aqua (A-126)

Conveying

It should be remembered that water only flows downhill unless you pump it. The old adage that, gravity flow works only if the tank is higher than the kitchen sink, accurately portrays the physics at work. The water pressure for a gravity system depends on the difference in elevation between the storage tank and the faucet. Water gains one pound per square inch of pressure for every 2.31 feet of rise or lift. Many plumbing fixtures and appliances require 20 psi for proper operation, while standard municipal water supply pressures are typically in the 40-psi to 60 psi range. To achieve comparable pressure, a cistern would have to be 92.4 feet (2.31 feet X 40 psi = 92.4 feet) above the home's highest plumbing fixture. That explains why pumps are frequently used, much in the way they are used to extract well water. Pumps prefer to push water, not pull it. To approximate the water pressure one would get from a municipal system, pressure tanks are often installed with the pump. Pressure tanks have a pressure switch with adjustable settings between 5 and 65 psi. For example, to keep the in house pressure at about 35 psi, the switch should be set to turn off the pump when the pressure reaches 40 psi and turn it on again when the pressure drops down to 30 psi.

Water Treatment

Before making a decision about what type of water treatment methods to use, water should be got tested by an approved laboratory and determine whether the water could be used for potable or non-potable uses. The types of treatment (Table 3.6) discussed are filtration, disinfection, and buffering for pH control. Dirt, rust, scale, silt and other suspended particles, bird and rodent feces, airborne bacteria and cysts will inadvertently find their way into the cistern or storage tank even when design features such as roof washers, screens and tight-fitting lids are properly installed. Water can be unsatisfactory without being unsafe; therefore, filtration and some form of disinfection is the minimum recommended treatment if the water is to be used for human consumption (drinking, brushing teeth, or cooking). The types of treatment units most commonly used by rainwater systems are filters that remove sediment, in consort with either ultraviolet light or chemical disinfection.

Filters

A filter is an important part of the inflow structure of a RWH System. Once screens and roof washers remove large debris, other filters are available which help improve rainwater quality. Keep in mind that most filters available in the market are designed to treat municipal water or well water. Therefore, filter selection requires careful consideration. Screening, sedimentation, and pre-filtering occur between catchment and storage or within the tank. A cartridge sediment filter, which traps and removes particles of five microns or larger is the most common filter used for rainwater harvesting. Sediment filters used in series, referred to as multi-cartridge or inline filters, sieve the particles from increasing to decreasing size.

These sediment filters are often used as a pre-filters for other treatment techniques such as ultra-violet light or reverse osmosis filters which can become clogged with large particles. Unless something is added to rainwater, there is no need to filter out something that is not present. When a disinfectant such as chlorine is added to rainwater, an activated carbon filter at the tap may be used to remove the chlorine prior to use. It should be remembered that activated carbon filters are subject to becoming sites of bacterial growth. Chemical disinfectants such as chlorine or iodine must be added to the water prior to the activated carbon filter. If ultraviolet light or ozone is used for disinfection, the system should be placed after the activated carbon filter. Many water treatment standards require some type of disinfection after filtration with activated carbon. Ultraviolet light disinfection is often the method of choice.

Table 3.6: Treatment Techniques

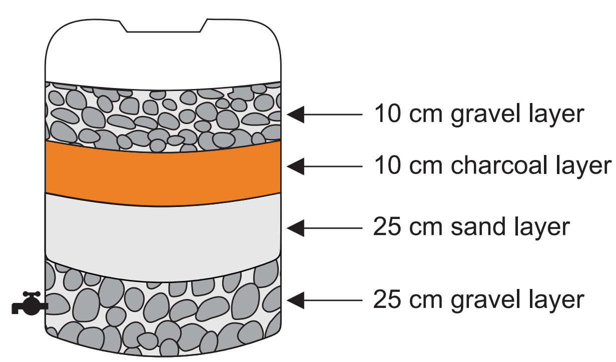
Method	Location	Result
Screening		
Strainers and Leaf Screens	Gutters and Leaders	Prevent leaves and other debris from entering tank
Settling		
Sedimentation	Within Tank	Settles particulate matter
Filtering		
In-line/Multi Cartridge	After Pump	Sieves sediment
Activated Carbon*	At Tap	Removes chlorine
Reverse Osmosis	At Tap	Removes contaminants
Mixed Media	Separate Tank	Traps particulate matter
Slow Sand	Separate Tank	Traps particulate matter
Disinfecting		
Boiling/Distilling	Before Use	Kills microorganisms
Chemical Treatments (Chlorine or Iodine)	Within Tank or Pump	Kills microorganisms (liquid, tablet or granule)
Ultraviolet Light	Should be located after the activated carbon filter before trap	Kills microorganisms
Ozonation	Before Tap	Kills microorganisms

* Should only be used after chlorine or iodine has been used as a disinfectant. Ultraviolet light and ozone systems should be located after the activated carbon filter but before the tap.

Types of Filtration Systems

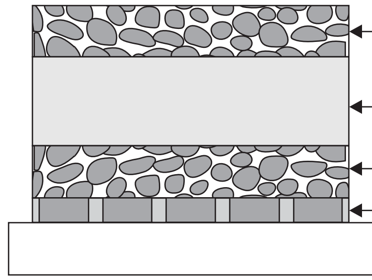
Gravity Based Filter

This consists of construction of an underground / above ground filtration chamber consisting of layers of fine sand / coarse sand and gravel. The ideal depths from below are 60 cm thick coarse gravel layer, 40 cm coarse sand and 40 cm fine sand. Alternatively only fine sand can also be used along with the gravel layer. Further deepening of the filter media shall not result in an appreciable increase in the rate of recharge and the rate of filtration is proportional to the surface area of the filter media. A unit sq.m. surface area of such a filter shall facilitate approx. 60 litres./hr of filtration of rainwater runoff. In order to determine the optimum size of the surface area just divide the total design recharge potential with this figure. A system of coarse and fine screen is essential to be put up before the rainwater runoff is allowed to flow into the filtration pit. A simple charcoal can be made in a drum or an earthen pot. The filter is made of gravel, sand and charcoal, all of which are easily available.



Source: A water-harvesting manual for urban areas

Sand Filters



Source: A water-harvesting manual for urban areas

Sand filters are commonly available, easy and inexpensive to construct. These filters can be employed for treatment of water to effectively remove turbidity (suspended particles like silt and clay), colour and microorganisms. In a simple sand filter that can be constructed domestically, the top layer comprises of coarse sand followed by a 5-10 mm layer of gravel followed by another 5-25 cm layer of gravel and boulders. These filters are manufactured commercially on a wide scale. Most of the water purifiers available in the market are of this type.

Pressure Based Filter

Pressure based filters facilitate a higher rate of filtration in a pressurized system. It requires a siltation pit of about 6-15 cu.m. in capacity so as to facilitate sedimentation before it is pumped through the filter into the ground. Being a pressure based system it involves a pump of capacity 0.5-1 hp. The rate of filtration is evidently high and the quality of water is also claimed to be as per WHO guidelines. They are successful for areas with larger rainwater runoff (>6 cu.m./hr) and limited space availability. Also these filters can be put in combination with an existing tube well so as to recharge water into the same bore.

Quality of Stored Water

Rainwater collected from rooftops is free of mineral pollutants like fluoride and calcium salts which are generally found in ground water. But it is likely to be contaminated with other types of pollutants:

- Air pollutants
- Surface contamination (e.g., silt, dust)

Measures to Ensure Water Quality

Many institutions have concerns for quality and the high cost needed to make rainwater harvesting available in modern houses. Use of rainwater for purposes like gardening, cleaning and decentralized seepage is generally accepted. There are, however, reservations for using rainwater for drinking purposes. For rooftop harvesting, the roofing material may affect the quality of rainwater harvested. Some of the roof materials such as bitumen add unwanted organic chemicals to the water. The water from the roof therefore, should pass through a filter to remove leaves and other particulate dirt before entering the storage tank.

Since water quality is of prime importance, systems should be designed to ensure that only acceptable quality water is pumped into the reservoir. To ensure that quality water is collected and pumped, appropriate systems should be designed to ensure that only better quality water is trapped and monitoring of water quality is carried out on a regular basis.

Trapping Urban Runoff

Studies have shown that dry weather flows in urban areas are generally of poor quality and hence such flows should not be collected. These dry weather flows normally flow through rectangular channels. During storms, flows often exceed the capacity of the channels and, hence, there is a need to remove any debris before diverting the storm water to detention ponds where there will be some settlement. These functions should be carried out as follows:

- Removal of debris: During a downpour, storm runoff collected in the drain will increase the normal water level and overflow into the gratings which serve as a debris preventer. The storm water is collected in a pond and then pumped or allowed to flow by gravity into the reservoirs.

- Diversion of storm waters: Tropical storms tend to attain peak values very early and first flushes tend to carry a lot of debris, particularly when the antecedent period has been quite dry. But when storms follow one after another during the wet season, the debris level gets considerably reduced.

In **Singapore** in the event of a storm, a particular system is adopted to collect the storm water. A level sensor in the monsoon drain at the diversion point will sense the rise in storm water level and thereby initiate the full closure of the barrage gate. A second sensor in the diversion channel downstream of the sluice gate indicates whether there is any raw water in the channel.

A level differential computer then compares the two level signals and if it finds that the water level is more than 50 mm above the diversion channel water level, the sluice gate opens to divert all the flow into the diversion channel which leads to the reservoir. This system prevents the reservoir water from flowing out into the monsoon drain when the reservoir water levels are high. When the storm water in the monsoon drain finally recedes, the level differential computer causes the sluice gate to close the moment the levels in the monsoon drain and the diversion channel are the same. In the event of a power failure, the barrage gate will automatically remain open and the sluice gate closed.

- Sediment removal: In spite of the precautions taken, wet weather flows can be full of sediments and they are largely trapped in the detention ponds. Therefore, the first one metre of water which accumulates in ponds during small rainfall events is also pumped out. As suspended solid contents as high as 110 milligrammes per litre (mg/l) can be encountered, detailed settling column analyses are carried out and a monogram prepared. Using these values and adjusting the rate of pumping, achieving higher rates of suspended solid removals is possible.

Quality of Water in Storm Water Ponds

The average raw water quality in all the storm water detention ponds is shown in *Table 3.7*. The conductivity is on the high side in some cases, primarily due to the chloride content because of the proximity of the sea. The other values are comparable to the other water sources in Singapore. The raw water in the Bedok reservoir will actually be a mix of urban runoff and of runoff from semi-urban areas. When compared to raw water from a 'protected' catchment, most of the parameters are comparable except for the tendency of the Bedok waters to be more alkaline and have a higher total solid content due to the higher chloride content that is prevalent *(see Table 3.8)*. Metallic contents of the urban runoff are also very similar to that of the upland sources and, most important of all, bacteriological contamination levels are also identical.

Table 3.7: Raw Water Quality in Storm Water Ponds

Parameter	Average Value
Conductivity	275 micromhos/cm
Total Organic Content	7.8 mg/l
Nitrogen from Ammonia	0.33 mg/l
Nitrogen from Nitrates	0.37 mg/l

Preventing Pollution

Dry weather flows are generally of poor quality and should be allowed to flow to waste. However, as catchment areas are better looked after, such flow quality can be improved and can then be utilized. Flow qualities should thus be monitored over a period of time.

Table 3.8: Good in Comparison

Average raw water quality of Bedok reservoir versus water from protected catchment

Parameter	Bedok Reservoir	Protected Catchment
Colour (Hazen)	12	20
Turbidity (NTU)	2	2.9
pH	7.4	6.3
Total Alkalinity ($CaCO_3$)	43	7
Total Organic Content	2.9	3.1
Total solids	205	25
Chlorides	56	4
Ammonia Nitrate	<0.02	<0.03
Phosphorus	<0.03	<0.03
Iron	0.04	0.52
Cadmium	<0.0005	<0.0005
Chromium	<0.005	<0.005
Lead	<0.001	<0.001
Coliform/100ml	18	14

Note: All parameters, except pH, in milligrammes per litre (mg/l) unless mentioned otherwise;
ml: milliliter; NTU: nephlometric turbidity units; Hazens: unit of colour

When there are tropical storms which tend to peak early, there is the need to have some form of treatment to ensure that the debris in such flows is removed. The storm water flows are progressively diverted. In effect they are diverted based primarily on water levels or when close to the sea, chloride sensors. Perhaps, diversions can be arranged to occur based on other sensors and the diversions should not be gradual.

Ultimately, it is both the quantity and quality of diverted water that is of prime importance. Hence, waters that are diverted to the detention ponds should attain a quality that is acceptable, or at least comparable with, other raw water sources.

All these types of contaminations can be prevented to a large extent by ensuring that the runoff from the first 10-20 minutes of rainfall is flushed off. Most of the debris carried by the water from the rooftop like leaves, plastic bags and paper pieces are arrested by the grill at the terrace outlet for rainwater. Remaining contaminants like silt and blow dirt can be removed by sedimentation (settlement) and filtration. Contrary to popular belief, water quality improves over time during storage in the tank because impurities settle in the tank if the water is not disturbed. Even pathogenic (harmful) organisms gradually die out due to storage. Additionally, biological contamination can be removed by disinfecting the water. Many simple methods of disinfections are available which can be done at a domestic level. Specifications for drinking water are given by IS: 10500 and World Health Organisation (WHO).

Disinfecting Water at Household Level

Boiling

Boiling is a very effective method of purification and very simple to carry out. Boiling water for 10 to 20 minutes is enough to remove all biological contaminants.

Chemical Disinfection

- *Chlorination:* Chlorination is done with stabilised bleaching powder (calcium hypochlorite – $CaOCl_2$) which is a mixture of chlorine and lime. Chlorination can kill all types of bacteria and make water safe for drinking purposes. About 1 gm (approximately 1/4 teaspoon) of bleaching powder is sufficient to treat 200 litres of water.
- *Chlorine tablets:* Chlorine tablets are easily available commercially. One tablet of 0.5g is enough to disinfect 20 litres (a bucketful) of water.

If the harvested rainwater is used to wash clothes, water plants, or other tasks that do not involve direct human consumption or contact, treatment beyond screening and sedimentation removal is optional. However, if the water is plumbed into the house for general indoor use such as for drinking, bathing, and cooking, disinfection is needed.

While filtering is quite common in private water systems, disinfection is less common for these reasons: the Safe Drinking Water Act is neither enforced nor applicable to private systems; chlorine is disliked due to taste, fear associated with trihalomethanes (THMs), and other concerns. Chlorine is the most common disinfectant because of its dependability, water solubility, and availability. Granular or tablet form is available (calcium hypochlorite), but the recommended application for rainwater disinfecting is in a liquid solution (sodium hypochlorite).

Other Methods of Disinfection

Ultraviolet Light (UV) water disinfection, a physical process, kills most microbiological organisms that pass through them. Since particulates offer a hiding place for bacteria and microorganisms, prefiltering is necessary for UV systems. To determine whether the minimum dosage is distributed throughout the disinfection chamber, UV water treatment units should be equipped with a light sensor. Either an alarm or shut-off switch is activated when the water does not receive the adequate level of UV radiation. The UV unit must be correctly calibrated and tested after installation to insure that the water is being disinfected. Several systems in US utilize ultraviolet light.

Ozone is the disinfectant of choice in many European countries, but it has not been used in American water treatment facilities until recently. Ozone is a form of oxygen (O_3) produced by passing air through a strong electric field. Ozone readily kills microorganisms and oxidizes organic matter in the water into carbon dioxide and water. Any remaining ozone reverts back to dissolved oxygen (O_2) in the water. Recent developments have produced compact ozone units for home use. Since ozone is produced by equipment at the point of use with electricity as the only input, many rainwater catchment systems owners in US use it to avoid having to handle chlorine or other chemicals. Ozone can also be used to keep the water in cisterns "fresh". When used as the final disinfectant, it should be added prior to the tap, but after an activated carbon filter, if such a filter is used.

Buffering

Baking soda for buffering. The composition and pH of rainwater differs from chemically treated municipal water and mineral rich well water. Controlling the pH of rainwater by buffering can be easily accomplished by adding one level tablespoon of baking soda to the storage tank for each 100 gallons of water collected. (About four ounces by weight of baking soda for every 1,000 gallons of water collected.) An easy method is to mix this amount of baking soda in a jar of water and pour it into the tank. Mixing will occur naturally over a day or two or a clean paddle may be used to hasten the process, but avoid disturbing materials that have settled at the bottom of the cistern.

Considerations for Selecting Rainwater as a Water Supply Source

Advantages	Difficulties/Disadvantages
❖ Rainwater harvesting is an appropriate option for augmenting ground water storage in urban areas, where natural recharge has been considerably reduced due to increased urban activities and not much land is available for implementing any other artificial recharge measure. ❖ Monsoon runoff which otherwise flows into sewers and storm drains and is wasted, may be harvested and utilized. ❖ Rainwater is generally bacteriologically safe, free from organic matter and is soft in nature. ❖ It helps in reducing the flood hazard. ❖ It improves the quality of ground water through dilution, especially for fluoride and nitrate. ❖ Rainwater may be harnessed at place of need and may be utilized at the time of need. ❖ The structures required for harvesting rainwater are simple, economical and eco-friendly.	❖ 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.

Frequently Asked Questions

General Guidelines for Gutters/Inflow Pipes

Gutters

- Total number of gutters depends upon the type of roof. Single-slope roof system needs only one gutter.
- The water from roof is collected into a gutter, of size suitable for carrying the rainwater coming over the surface of the roof and conveyed to the pipe connecting the gutter to the tank.
- Size of the gutter should be selected keeping in view flow during highest intensity of rain. It is advisable to provide gutter of 10 to 15 per cent oversize.
- There are various methods of gutter fixing. The gutter could be made using:
    - Plain galvanized iron sheet of 20 to 22 gauge. Thin sheet should not be used, as number of gutter supports will have to be increased in such a case. Bending the edge and fixing G.I. wire in it should reinforce the gutter edges.
    - Half cut PVC, rigid pipe, provided the skill for PVC pipe jointing is available.
    - Half cut large diameter bamboo/betel nut trunk.
    - The point where the gutter is joined to the pipe leading from gutter to the tank/reservoir, should be enlarged for preventing overflow as water coming with speed changes its direction at this point and may splash out.

- The pipe leading from the gutter to the reservoir should be raised about 1 cm above the bottom level of the gutter for enabling sediments to settle in gutter rather than entering the tank. Raising the pipe should be only 1 cm for preventing mosquito breeding in accumulated water.
- A galvanized or plastic *Jali* (net) with square openings of 1 cm x 1 cm be fixed over the pipe for preventing entry of large leaves, birds, rats, etc.
- In no case should M.S. sheet be used for making gutter structure. For keeping gutter in position suitable steel or wooden brackets may be used keeping spacing in such a way that the gutter does not sag when with full of water.

Inflow Pipe

Inflow pipe is the pipe which connects the gutter to the tank/reservoir.

- G.I sheet bent to the shape of a pipe, rigid PVC pipe or galvanized iron pipes of 'A' class may be used as inflow pipes.
- The size of pipe used should be selected in such a manner that it can carry the water collected (min. dia 10 cms).
- The position of the tank should be selected in such a manner that the distance between the roof gutter and reservoir is minimum i.e. minimum length of inflow pipe is used.
- Do not use mild steel sheets for fabricating of inflow pipe. M.S pipes should not be used as inflow pipes.
- A bypass arrangement is required to be made at the point where this pipe is connected to the filter. This is needed for moving out first shower water from the roof. This can be done by using two methods:
  - By providing a removable canvas pipe connection between two points.
  - By making an in-built stopper for stopping water entry in the filter and conveying the water into a bypass pipe carrying water outside the system. For preventing entry of first rain for few minutes the stopper at filter end is closed and the stopper at bypass end is opened. By operating the bypass system the water bringing dust and other undesired matter from the catchment area is made to flow out of the system and its entry in the tank is prevented.

Chapter 4

Techniques of Artificial Aquifer Recharge

Artificial recharge to ground water is a process by which the ground water reservoirs is augmented at a rate exceeding that obtaining under natural conditions or replenishment. Any man-made schemes or facilities that add water to an aquifer may be considered to be artificial recharge systems.

To ensure that rainwater percolates into the ground instead of draining away from the surface, various kinds of recharge structures are possible. Some structures like recharge trenches and permeable pavements promote the percolation of water through soil strata at shallower depth, while others like recharge wells carry water to greater depths from where it joins the ground water.

At many locations, existing structures like wells, pits and tanks can be modified to be used as recharge structures, eliminating the need to construct any new structures. A few commonly used recharging methods are explained here. Innumerable innovations and combinations of these methods are possible. Rainwater may be charged into the ground water aquifers through any suitable structures like dug wells, bore wells, recharge trenches and recharge pits.

A wide spectrum of techniques is in vogue in different countries to recharge ground water reservoirs. Similar to the variations in hydrogeological framework, the artificial recharge techniques too vary widely. The artificial recharge techniques can be broadly categorized as follows:

- Direct surface techniques/spreading methods
  - Flooding techniques
  - Basins or percolation tanks
  - Stream augmentation/channel method
  - Ditch and furrow system
  - Over irrigation
- Direct sub-surface techniques/pit method
  - Injection wells or recharge wells
  - Recharge pits and shafts

- Dug well recharge
- Bore hole flooding
- Natural openings, cavity fillings.

- Combination of surface-cum-sub-surface techniques/well method
  - Basin or percolation tanks with pit shaft or wells.

- Indirect techniques
  - Induced recharge method
  - Aquifer modification

Besides the above, ground water conservation structures like ground water dams, sub-surface dykes, are quite prevalent to arrest sub-surface flows. Similarly in hard rock areas, rock-fracturing techniques including sectional blasting of boreholes with suitable techniques have been applied to inter-connect the fractures and increase recharge. Cement sealing of fractures through specially constructed bore well have been utilised in Maharashtra (Western India) to conserve sub-surface flow and augment bore well yield.

Check Dams, Cement Plugs, *Nala Bunds*

Check dams are constructed across small streams having gentle slope and are feasible both in hard rock as well as alluvial formation. The site selected for check dam should have sufficient thickness of permeable bed or weathered formation to facilitate recharge of stored water within a short span of time. The water stored in these structures is mostly confined to stream course and the height is normally less than 2 m. These are designed based on stream width and excess water is allowed to flow over the way. In order to avoid scouring from excess run off, water cushions are provided at downstream side. To harness the maximum run off in the stream, a series of such check dams can be constructed to have recharge on regional scale.

A series of small bunds or weirs are made across selected *nala* sections such that the flow of surface water in the stream channel is impeded and water is retained on pervious soil/rock surface for longer body. *Nala bunds* are constructed across bigger *nalas* of second order streams in areas having gentler slopes. A nala bund acts like a mini percolation tank.

Site Characteristics and Design Guidelines

For selecting a site for check dams/*nala bunds* the following conditions may be observed:

- The total catchment of the nala should normally be between 40 to 100 hectares though the local situations can be the guiding factor in this.
- The rainfall in the catchment should be less than 1000 mm/annum.
- The width of *nala* bed should be at least 5 metres and not exceed 15 metres and the depth of bed should not be less than 1 metre.
- The soil downstream of the bund should not be prone to water logging and should have pH between 6.5 to 8.
- The lands downstream of check dam/*bund* should have irrigable land under well irrigation.
- The check dams should preferably be located in areas where contour or graded bunding of lands has been carried out.

- The rock strata exposed in the ponded area should be adequately permeable to cause ground water recharge through ponded water.
- *Nala bund*/check dam is generally a small earthen dam, with a cut off core wall of brickwork, though cement bunds/plugs are now prevalent.
- For the foundation for core wall, a trench is dug 0.6 m wide in hard rock or 1.2 metres in soft rock of impervious nature. A core brick cement wall is erected 0.6 m wide to stand at least 2.5 metres above *nala* bed and the remaining portion of the trench is back filled on upstream side by impervious clay. The core wall is buttressed on both sides by a *bund* made up of local clays and on the upstream face, stone pitching is done.
- Normally the final dimensions of the *nala bund* are: length 10 to 15 metres, height 2 to 3 metres and width 1 to 3 metres, generally constructed in a trapezoidal form. If the bedrock is highly fractured, cement grouting is done to make the foundation leakage free.

Gabion Structure

This is a kind of check dam being commonly constructed across small streams to conserve stream flows with practically no submergence beyond stream course. The boulders locally available are stored in a steel wire. This is put up across the stream's mesh to make a small dam by anchoring it to the streamside. The height of such structures is around 0.5 m and is normally used in streams of width about 10 to 15 m. The excess water overflows this structure storing some water to serve as source of recharge. The silt content of stream water in due course is deposited in the interstices of the boulders to make it more impermeable.

Water Use Management

Water harvesting is the deliberate collection and storage of rainwater that runs off on natural or manmade catchment areas. Catchment includes

- Rooftops
- Compounds
- Rocky surface or hill slopes or
- Artificially prepared impervious/ semi-pervious land surfaces.

The amount of water harvested depends on the frequency and intensity of rainfall, catchment characteristics, water demands, how much runoff occurs and how quickly or how easy it is for the water to infiltrate through the subsoil and percolate down to recharge the aquifers. In urban areas, where adequate space for surface storage is not available and water levels are deep enough to accommodate additional rainwater to recharge the aquifers, roof top rainwater harvesting is the ideal solution to solve the water supply problems.

Though the concept of roof top rainwater harvesting is an age old one, systematic collection and recharging to ground water is of recent times. Recent developments in the field of hydrogeology especially in ground water exploration resulted in efficient and scientific design of ground water recharge structures. As surface water sources fail to meet the rising demands of water supply in urban areas, ground water reserves are being tapped and over-exploited, resulting in decline in ground water levels and deterioration of ground water quality. This precarious situation needs to be rectified by immediately recharging the depleted aquifers. In urban areas, the roof top rainwater can be conserved and used for recharge of ground water. This approach requires connecting the outlet pipe from rooftop to divert the water to either existing wells/tubewells/borewell or specially designed wells. The urban housing complexes or institutional buildings have large roof area and can be utilized for harvesting roof top rainwater to recharge aquifer in urban areas. Table 4.1 shows availability of rainwater through roof top rainwater harvesting.

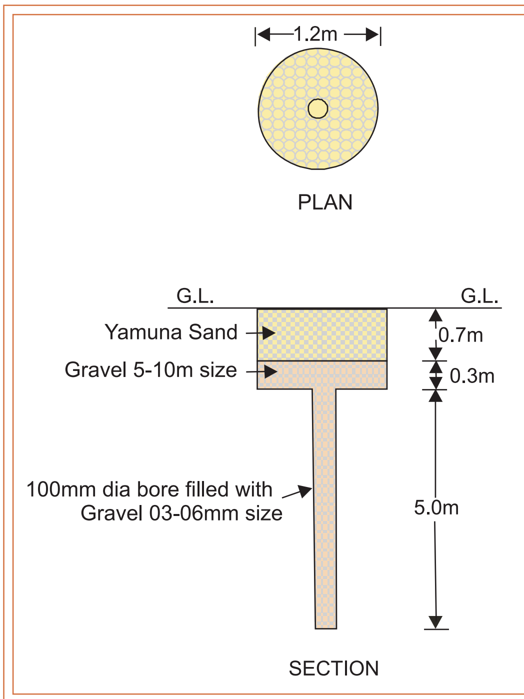
Table 4.1: Availability of Rainwater Through Roof Top Rainwater Harvesting

Rainfall mm	100	200	300	400	500	600	800	1000	1200	1400	1600	1800	2000
Roof Top Area (sq.m.)	Harvested Water from Roof Top (m^3)												
20	1.6	3.2	4.8	6.4	8.0	9.6	12.8	16	19.2	22.4	25.6	28.8	32
30	2.4	4.8	7.2	9.6	12	14.4	19.2	24	28.8	33.6	38.4	43.2	48
40	3.2	6.4	9.6	12.8	16	19.2	25.6	32	38.4	44.8	51.2	57.6	64
50	4.0	8.0	12	16	20	24	32	40	48	56	64	72	80
60	4.8	9.6	14.4	19.2	24	28.8	38.4	48	57.6	67.2	76.8	86.4	96
70	5.6	11.2	16.8	22.4	28	33.6	44.8	56	67.2	78.4	89.6	100.8	112
80	6.4	12.8	19.2	25.6	32	38.4	51.2	64	76.8	89.6	102.4	115.2	128
90	7.2	14.4	21.6	28.8	36	43.2	57.6	72	86.4	100.8	115.2	129.6	144
100	8.0	16	24	32	40	48	64	80	96	112	128	144	160
150	12	24	36	48	60	72	96	120	144	168	192	216	240
200	16	32	48	64	80	96	128	160	192	224	256	288	320
250	20	40	60	80	100	120	160	200	240	280	320	360	400
300	24	48	72	96	120	144	192	240	288	336	384	432	480
400	32	64	96	128	160	192	256	320	384	448	512	576	640
500	40	80	120	160	200	240	320	400	480	560	640	720	800
1000	80	160	240	320	400	480	640	800	960	1120	1280	1440	1600
2000	160	320	480	640	800	960	1280	1600	1920	2240	2560	2880	3200
3000	240	480	720	960	1200	1440	1920	2400	2880	3360	3840	4320	4800

Source: Guide on Artificial Recharge to Ground Water 2000, CGWB, GOI, New Delhi
Note: Run-off coefficient of 0.8 is assumed.

Artificial Recharge Structures Particularly in Urban Context

Recharge Pits are constructed for recharging the shallow aquifers. These are generally constructed 1 to 2 m. wide and 2 to 3 m. deep. After excavation, the pits are refilled with pebbles and boulders as well as coarse sand. The excavated pit is lined with a brick/stone wall with openings (weep-holes) at regular intervals. The top area of the pit can be covered with a perforated cover.



Design procedure is the same as that of a settlement tank. The size of filter material is generally taken as below:

Coarse sand : 1.5 - 2 mm

Gravels : 5 - 10 mm

Boulders : 5 - 20 cm

The filter material should be filled in graded form. Boulders at the bottom, gravels in between and coarse sand at the top so that the silt content that will come with runoff will be deposited on the top of the coarse sand layer and can easily be removed. If clay layer is encountered at shallow depth, it should be punctured with auger hole and the auger hole should be refilled with fine gravel of 3 to 6 mm size.

- Recharge pits 1 to 2 m wide and 2 to 3 m deep are constructed to recharge shallow aquifers.
- After excavation, the pit is refilled with boulders and pebbles at the bottom followed by gravel and then sand at the top.
- The collected water from the rooftop is diverted to the pit through a drainpipe.
- Recharge pit can be of any shape i.e. circular, square or rectangular. If the pit is trapezoidal in shape, the side slopes should be steep enough to avoid silt deposition.
- This method is suitable for small buildings having the rooftop area up to 100 sq.m.

Percolation pits are one of the easiest and most effective means of rainwater harvesting. These are generally not more than 60 x 60 x 60 cm pits generally designed on the basis of expected runoff. They are filled with pebbles or brick jelly and river sand and are covered with perforated concrete slabs wherever necessary.

Percolation pits are made to make the rainwater enter directly into the aquifer. The structure is covered with perforated concrete slabs in paved areas. If the depth of clay soil is more, recharge through percolation pits with bore is preferable. This bore can be at the centre of the square pit and is filled with pebbles and the top portion with river sand and covered with perforated concrete slab. Depending on the lithology, necessary casing may be provided in the recharge shaft to avoid clogging.

Roof water and surface water from buildings can be diverted to percolation pits. It is good to have a minimum of one percolation pit for every 20 sq.m. in every house with open area.

Soakaway is a bored hole of up to 30 cm diameter drilled in the ground to a depth of 3 to 10 m. The soakaway can be drilled with a manual auger unless hard rock is found at a shallow depth. The borehole can be left unlined if a stable soil formation like clay is present. In such a case, the soakaway may be filled up with a filter media like brickbats. In unstable formations like sand, the soakaway should be lined with a PVC or MS pipe to prevent collapse of the vertical sides. The pipe may be slotted/perforated to promote percolation through the sides.

A small sump is built at the top end of the soakaway where some amount of runoff can be retained before it infiltrates through the soakaway. Since the sump also acts like a buffer in the system, it has to be designed on the basis of expected runoff.

The above figures show typical systems of recharging wells directly with rooftop runoff. Rainwater that is collected on the rooftop of the building is diverted by drainpipes to a settlement or filtration tank, from which it flows into the recharge well (bore well or dug well).

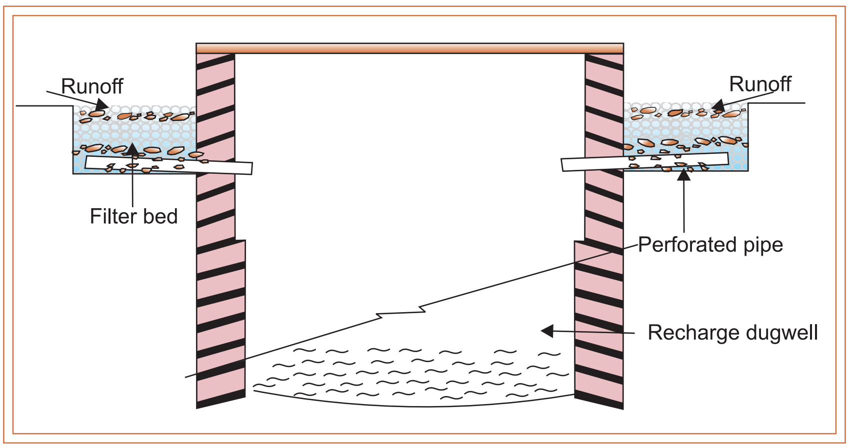
If a borewell is used for recharging, then the casing (outer pipe) of the borewell should preferably be a slotted or perforated pipe so that more surface area is available for the water to percolate. Developing a borewell would increase its recharging capacity (developing is the process where water or air is forced into the well under pressure to loosen the soil strata surrounding the bore to make it more permeable). If a dugwell is used for recharge, the well lining should have openings (weep-holes) at regular intervals to allow seepage of water through the sides. Dugwells should be covered to prevent mosquito breeding and entry of leaves and debris. The bottom of recharge dugwells should be desilted annually to maintain the intake capacity.

Precautions should be taken to ensure that physical matter in the runoff like silt and floating debris do not enter the well since it may cause clogging of the recharge structure. It is preferred that the dugwell or borewell used for recharging be shallower than the water table. This ensures that the water recharged through the well has a sufficient thickness of soil medium through which it has to pass before it joins the ground water. Any old well, which has become defunct, can be used for recharging, since the depth of such wells is above the water level.

Dug cum bore well is a type of percolation pit with a large chamber and deeper in well bore. If necessary, more than one shaft is installed in the same recharge well. Apart from filtering of recharge water through filter media, necessary coir packing can also be provided to achieve maximum efficiency in filtering the recharge water. If the area is prone to flooding, it is advisable to provide air vent to the DCB to avoid air locking.

Quality of Water Recharged

The quality of water entering the recharging wells can be ensured by providing the various elements in the system. These are: (1) Filter mesh at entrance point of rooftop drains; (2) Settlement chamber; (3) Filter bed.



Recharge assembly for dugwell with runoff from ground areas (non-rooftop)

Mini Artificial Aquifer System (MAAS) is a unique artificial recharge structure, which is ideally suitable for open areas particularly low-lying areas. This structure is also suitable for junctions of roads, street corners, parks, stadiums, play grounds, bus terminus, theatres, open area of public buildings, schools, colleges etc.

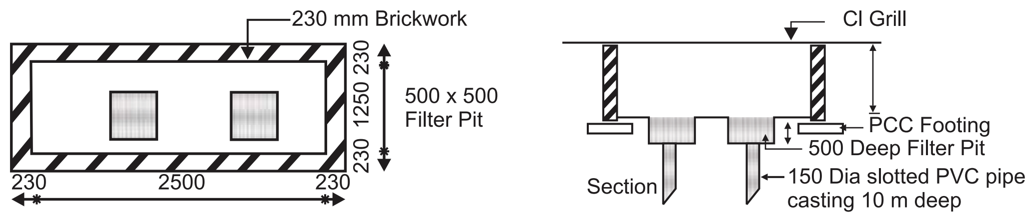
In open areas, the topsoil and clayey portion of sub-surface should be excavated and the excavated portion may be filled with locally available boulders of various sizes in ascending order from the top. The top portion may be filled with river sand.

Two or three recharge shafts may be constructed at the bottom of the excavated portion. These recharge shafts of site-specific dimensions can be constructed penetrating through the layers of impermeable horizon to the potential to prevent clogging.

Recharge Trenches: Recharging through recharge trenches, recharge pits and soakaways is simpler compared to recharge through wells. Fewer precautions have to be taken to maintain the quality of the rainfall runoff. For these types of structures, there is no restriction on the type of catchment from which water is to be harvested, i.e., both paved and unpaved catchments can be tapped.

A recharge trench is a continuous trench excavated in the ground. These are constructed when the permeable strata is available at shallow depths. The trench may be 0.5 to 1 m. wide, 1 to 1.5 m. deep and 10 to 20 m. long depending upon availability of water. It is back filled with filter materials like pebbles, boulders or broken bricks. In case a clay layer is encountered at shallow depth, a number of auger holes may be constructed and back filled with fine gravels. The length of the recharge trench is decided as per the amount of runoff expected. The recharge trench should be periodically cleaned of accumulated debris to maintain the intake capacity. In terms of recharge rates, recharge trenches are relatively less effective since the soil strata at depth of about 1.5 metres is generally less permeable. For recharging through recharge trenches, fewer precautions have to be taken to maintain the quality of the rainfall runoff. Runoff from both paved and unpaved catchments can be tapped.

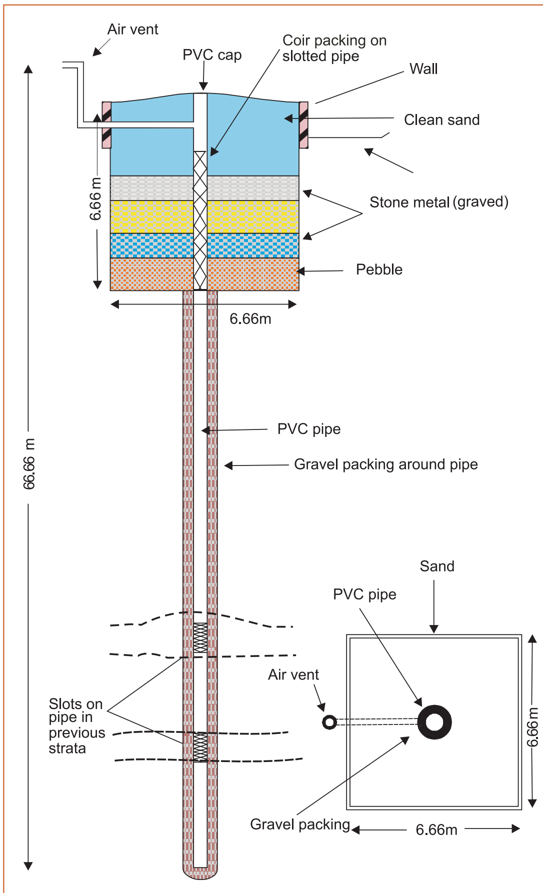
Recharge troughs: To collect the runoff from paved or unpaved areas draining out of a compound, recharge troughs are commonly placed at the entrance of a residential/institutional complex. These structures are similar to recharge trenches except for the fact that the excavated portion is not filled with filter materials. In order to facilitate speedy recharge, boreholes are drilled at regular intervals in this trench. In design part, there is no need of incorporating the influence of filter materials.



Source: A water-harvesting manual for urban areas CSE

This structure is capable of harvesting only a limited amount of runoff because of the limitation with regard to size.

Modified injection well: In this method water is not pumped into the aquifer but allowed to percolate through a filter bed, which is comprised of sand and gravel. A modified injection well is generally a borehole, 500 mm diameter, which is drilled to the desired depth depending upon the geological conditions, preferably 2 to 3 m below the water table in the area. Inside this hole a slotted casing pipe of 200 mm diameter is inserted. The annular space between the borehole and the pipe is filled with gravel and developed with a compressor till it gives clear water. To stop the suspended solids from entering the recharge tubewell, a filter mechanism is provided at the top.



Recharging through defunct open wells, bore wells and hand pumps: Due to severe depletion of ground water table many open wells, bore wells and hand pumps become dry. Instead of discarding these wells, they can be converted into useful recharge wells. Roof water and run-off water can be diverted into these wells after filling them with pebbles and river sand. The wells should be fully desilted before diverting the water into them.

In alluvial and hard rock areas, there are thousands of wells which have either gone dry or whose water levels have declined considerably. These can be recharged directly with rooftop run-off. Rainwater that is collected on the rooftop of the building is diverted by drainpipes to a settlement or filtration tank, from which it flows into the recharge well (bore well or dug well).

If a tubewell is used for recharging, then the casing (outer pipe) should preferably be a slotted or perforated pipe so that more surface area is available for the water to percolate. Developing a bore well would increase its recharging capacity (developing is the process where water or air is forced into the well under pressure to loosen the soil strata surrounding the bore to make it more permeable).

If a dug well is used for recharge, the well lining should have openings (weep-holes) at regular intervals to allow seepage of water through the sides. Dug wells should be covered to prevent mosquito breeding and entry of leaves and debris. The bottom of recharge wells should be desilted annually to maintain the intake capacity.

Providing the following elements in the system can ensure the quality of water entering the recharge wells:

- Filter mesh at entrance point of rooftop drains
- Settlement chamber
- Filter bed

Settlement tank: Settlement tanks are used to remove silt and other floating impurities from rainwater. A settlement tank is like an ordinary storage container having provision for inflow (bringing water from the catchment), outflow (carrying water to the recharge well) and overflow. A settlement tank can have an unpaved bottom surface to allow standing water to percolate into the soil.

Apart from removing silt from the water, the desilting chamber acts like a buffer in the system. In case of excess rainfall, the rate of recharge, especially of bore wells, may not match the rate of rainfall. In such situations, the desilting chamber holds the excess amount of water till it is soaked up by the recharge structure.

Any container with adequate storage capacity can be used as a settlement tank. Generally, masonry or concrete underground tanks are preferred since they do not occupy any surface area. Old disused tanks can be modified to be used as settlement tanks.

For over ground tanks, pre-fabricated PVC or ferrocement tanks can be used. Pre-fabricated tanks are easier to install compared to masonry and concrete tanks.

Recharging of service tubewells: In this case the rooftop runoff is not directly led into the service tubewells to avoid chances of contamination of ground water. Instead rainwater is collected in a recharge well, which is a temporary storage tank (located near the service tubewell), with a borehole, which is shallower than the water table. This borehole has to be provided with a casing pipe to prevent the caving in of soil, if the strata are loose. A filter chamber comprised of sand, gravel and boulders is provided to arrest the impurities.

Recharge wells: Bore wells / tubewells can be used as recharge structures for recharging the deeper aquifers and roof top rainwater is diverted to recharge well for further recharging to ground water. The runoff water may be passed through filter media to avoid choking of recharge wells.

Vertical recharge shafts: For recharging the shallow aquifers which are located below clayey surface at a depth of about 10 to 15 m, recharge shafts 0.5 to 3 m. diameter and 10 to 15 m. deep are constructed depending upon availability of runoff. These are back filled with boulders, gravels and coarse sand. For lesser diameter shafts, reverse / direct rotary rigs are used and larger diameter shafts may be dug manually. In the upper portion of 1 or 2 m depth, the brick masonry work is carried out for the stability of the structure.

Shaft with recharge well: If the aquifer is available at greater depth say 20 or 30 m, a shallow shaft of diameter 2 to 5 m and depth 5 to 6 m may be constructed depending upon availability of runoff. Inside the shaft, a recharge well of 100 to 300 mm diameter is constructed for recharging the available water to deeper aquifer. At the bottom of the shaft a filter media is provided to avoid choking of the recharge well.

Lateral trench with bore wells: For recharging the upper as well as deeper aquifers, lateral trench 1.5 to 3 m. wide and 10 to 30 m. long with one or more bore wells may be constructed depending upon availability of water. The lateral trench is back filled with boulders, gravels and coarse sand.

Recharge trench cum tubewell under construction: After construction the trench can be covered with detachable slabs. Vehicles can move over it and children can play without fear or lawn can be grown over it after putting soil over the slabs leaving provision for periodical cleaning.

Rainwater harvesting through ponds: Rainwater collected from the terraces of a row of houses may be led into the nearby ponds through pipelines for recharging the ground water aquifers. Run-off water can be diverted into this pond after proper desilting.

Preservation of run-off water before leaving the compound: The ground level near the gate should be raised to retain as much water as possible inside the compound. Alternatively, a sloping gutter may be constructed across the gates and the rushing water directed towards the rainwater harvesting structure. For multistoreyed buildings, it is better to direct this water to a recharge well.

Artificial recharge in roads and colonies: An enormous quantity of surface water generated during the rainy season flows through paved roads particularly concrete roads of residential colonies. This precious water can be checked and made to recharge then and there by constructing site-specific recharge structures on the road itself. All the water extracting structures of colonies, particularly bore wells and hand pumps of houses on the sides of the roads, are likely to give sustainable yield in due course.

Artificial recharge through storm water drains: By constructing artificial recharge structures like percolation pits and Dug Cum Bore well (DCB) on the storm water drains or on the sides, the run-off water can be effectively used for recharge purpose.

Permeable surfaces: Unpaved surfaces have a greater capacity of retaining rainwater on the surface. A patch of grass would retain a large proportion of rainwater falling on it, yielding only 10-15 per cent as runoff. A considerable amount of water retained on such a surface will naturally percolate into the ground. Such surfaces contribute to the natural recharge of ground water. If paving of ground surfaces is unavoidable, one may use pavements which retain rainwater and allow it to percolate into the ground.

Merits and Demerits of Different Methods

Artificial recharge by spreading has the following important advantages over the injection method. The infiltration is almost like natural rainfall infiltration and purity of infiltrating water is not needed. Normal storm run-off or primarily treated drainage waters (removal of harmful chemical constituents and suspended materials) can be utilized for artificial recharge. Cleaning of the infiltrating surface of the recharge structure, once in a while, is an easy process as it involves only scrapping of the surface. Spreading methods, however, are useful only for recharge of unconfined aquifers. The meager downward leakage through the aquitards and slow sub-surface lateral movement of the ground water, make it uneconomical to artificially recharge the confined or semi-confined aquifers either by downward infiltration or lateral infiltration through the recharge zone. Artificial recharge by spreading has the disadvantage of loss of surface waters by evaporation and decrease in infiltration capacity of spreading structures by deposition of silt from the source water, deposition of dust from the atmosphere and growth of vegetation in the infiltration structures. Spreading method which involves stagnation of water, sometimes creates environmental problems. It is, therefore, necessary to adjust supply of water to these structures in such a way that large pools of stagnant water are not produced. The recharge rates also need to be controlled as higher ground water mounds reduce the infiltration rates.

Recharge by injection is the only method for artificial recharge of confined aquifers or deep-seated aquifers with poorly permeable overburden. The recharge is instantaneous and there are no transit and evaporation losses. Injection method is also very effective in case of highly fractured hard rocks and karstic limestones. However, requirement of extreme purity of the source water as well as compatibility of source water and water from the aquifer to be injected, are the necessary pre-requisites. Otherwise, frequent clogging of injection structures by bacterial growth, chemical precipitation or deposition of silt, results in heavy expenditure on well cleaning. As pumping wells are self-cleaning, dual-purpose injection (that is injection cum pumping) wells are more efficient.

The suitability of a particular method is based on the hydrogeological conditions, quality of source water and proposed use of recharge water as indicated below:

❖ Highly permeable surface formations	Spreading method
❖ Shallow aquifers	Spreading method
❖ Source water of inferior quality	Spreading method
❖ Deep aquifers with permeable or semi-permeable overburden	Spreading method
❖ Aquifers with limited storage capacity	Induced recharge method
❖ Deep aquifers with impervious over-burden	Injection method
❖ Source water of very good quality	Injection method and / or spreading method

Compatibility of Source Water and Ground Water

For artificial recharge, there is need to identify whether the qualities of ground water and surface water are compatible. With temperature variations and with reversible flow direction with ion exchanges, the soluble salts have a tendency to precipitate which results in clogging of pore space in spreading basins and clogging of slots in injection wells which reduce artificial recharge rates. Although, no distinction can be drawn between good and poor water sources, water generally with less than 50% sodium or containing more than 60 ppm of calcium and magnesium is considered satisfactory for the purpose of artificial recharge. De-clogging, however, can be done by scrapping the spreading basins and by chemical treatment of injection wells at additional cost. Thus, the compatibility of these two sources needs careful consideration.

The feasibility of artificially recharging ground water is governed by the following factors:

- Availability of suitable site, mainly from topographical and cultural considerations, for establishing recharge facilities.
- Presence of suitable source to supply water of required quality in requisite quantity.
- Lithological composition, thickness and permeability characteristics of rocks in the zone of aeration saturation.
- Hydrodynamic conditions in the aquifer to ensure adequate head.
- Cost-benefit considerations.
- Social benefits and legal implications including water rights.

Experience in Selected Countries

Water Resource Management in Israel

Israel, primarily a desert country, has emerged as leader in optimal use of water resources. It has harnessed its water resources and the whole of Israel - two-thirds of which is desert - is verdant green today. Their effective management is a multi-pronged system of harnessing scant water resources, efficient use of water, and developing new crops and strains that can survive in the hard conditions of Israel.

The Israeli system of water management comprises of a national water carrier, a canal system which transports water from the surplus northern and coastal regions to the deficit areas. The entire transportation of the water is based on the principle of minimizing evaporation and seepage with covered channels and piped water supply.

Using the most modern technology, Israel has perfected hydrologic exploration.

- Isotopes are used to estimate aquifer storage, recharge and mixing rates;
- Computer based models are used to stimulate the dynamic balance of water and evaluate the consequences of alternative water use scenarios;
- Wells are monitored continuously so that there is no over-exploitation of aquifers;
- Artificial recharge of ground water is practiced widely;
- Ground water is not considered separate from surface water. In fact, the canal systems depend substantially on ground water.
- Municipal sewage is treated and used for irrigation and industrial purposes.
- Water application per unit of agricultural production has been dramatically reduced through the use of drip and sprinkler irrigation. An irrigation efficiency of 80 per cent is claimed to have been achieved.

Scientists working at Israel's Weizmann Institute of Science are trying to look into the sun-protection mechanism of plants with a view to cultivating agricultural crops resistant to strong sunlight. They have successfully cultivated particularly sturdy salt-water algae, Dunaliella bardawil, in scorching sunlight. It may be possible in the future to manipulate a similar mechanism existing in higher plants, including crops, in order to enhance their resistance to sun. This alga is known for its legendary resistance to the salt and sun, which allows it to thrive in the brackish marshes of the Sinai desert and even in the Dead Sea.

Aquifer Recharging

In the United States the volumes of ground water replaced annually through natural mechanisms are relatively small because of the slow rates of movement of ground waters and the limited opportunity for surface waters to penetrate the earth's surface. To supplement this natural recharge process, a recent trend toward artificial recharge has been developing. In 1955, over 700 million gallons of water per day were artificially recharged in the United States. This water was derived from natural surface sources and returns from air conditioning, industrial wastes, and municipal water supplies. The total recharge volume was equal, however, to only about 1.5% of the ground water withdrawn that year.

Extensive recharge facilities of the basin type are common in California, USA. The recharge rates in spreading basins in operation vary from 0.1 to 2.88 m/day. Basins for putting storm water into the ground have been in operation in Long Island, New York, since 1936. These facilities have salvaged and recharged into the aquifer storm water that otherwise would have been lost to the sea.

Channel methods have been used extensively in California and Colorado, USA. Streambeds in the Bhabar and Kandi regions, along the foothills of the Himalayas, have favorable infiltration characteristics and deep water table. The average infiltration rate of the Kandi deposits is about 5 m/day.

In Sweden, pits constructed in the tops of eskers are used to recharge aquifers. The recharged water is extracted by wells located at the fringe of the aquifer. The rate of infiltration in the pits ranges from about 1.5 to 15 m per day.

The results of experiments carried out at Peoria, Illinois, USA to demonstrate the efficacy of the pit method to recharge a glacial-drift aquifer comprising sand and gravel showed that a maximum infiltration rate of 60 m/day and mean rates of 12 to 31 m/day could be reached. The specification of one of the pits is given below:

Bottom dimension	16 m x 12.2 m
Depth	3.7 m
Side slopes	horizontal 2: vertical 1
Thickness of filter layer on bottom and side slopes	15 cm

Filtering Medium

- Initially sand having ES = 0.3 to 0.4
  UC = 2.0
- Subsequently 3.4 to 9.3 mm pea gravel

Use of clean sand in the initial stages of the experiment resulted in repeated clogging by silt carried by the water (turbidity of 100 to 200 ppm) supplied from the Illinois River. The recharge rate decreased by as much as 60% in three months' time. The average recharge rate in a period of 146 days was 6.84 million l/day. Replacement of the fine sand filter by pea gravel gave satisfactory performance and increased the recharge rate to 8.36 million l/yr. Experiments carried out on pits having different side slopes showed that pits with flatter side slopes, providing a greater proportion of wet table surface area per unit of submergence, give higher rates of infiltration.

Some wells have high recharge capacities, such as those at Louisville, Kentucky, and Orlando. In Florida, USA, rates up to 6.5 and 40 million l/yr.have been obtained. However, there are reports of recharge wells having lost 50 % of their capacity within one to ten weeks. Many successful recharge wells either receive filtered water or re-circulate clean water.

Wells have been used to dispose of sewage water, excess irrigation water and storm run-off. Recharge wells have been extensively used in Long Island, New York and in coastal tracts of Los Angles, California, and USA, to build up and maintain a ground water ridge to control seawater intrusion. Re-circulation of water for cooling purposes is another application of the recharge well method. In recent years, wells are being used increasingly to store heat underground by recharging hot water into confined aquifers. Results of a recharge experiment carried out in 1946 at Camp Peary, Virginia indicate that it is possible to store fresh water in saline water bearing aquifers and extract it subsequently without significant losses.

The basin method is most common in the USSR. It is implemented into the largest AGWR-systems in Tbilissi, Riga, and Tashkent etc. Another method which is widely used in some AGWR-systems (with capacity of 100,000 m^3/day) in Kazakhstan and the Crimea implies periodical flooding in river valleys, as well as periodical discharges of water from water storages into a system of recharge basins.

Ground Water Recharge in Nile Valley and Delta, Egypt

There are two interconnected ground water bodies in the Nile Valley. The first one is the water in the clay cap (aquitard), which is known as the shallow subsoil water table and controlled by irrigation and development activities; the second is that in the semi-confined aquifer forming the main reservoir and referred to as the "piezometric head". The difference in heads between those two water bodies is responsible for the movement of water in vertical direction. Although the observed head difference is relatively small and vertical conductivity of the clay cap is very low, great amounts of water leak vertically. The interaction between the two bodies also has implications for agricultural production. Another concern for agriculture is the effect of upward ground water flow at the North area of the delta.

The ground water system is recharged from river and canals, irrigation water infiltrated through the aquitard and drainage of flash rains from east desert wadies. The ground water reservoir loses water along Rosetta and Western desert depressions. Some of the fresh water escapes to the North Delta lagoons and directly or indirectly towards the Mediterranean Sea and Suez Canal which form the north and east boundaries, where the seawater is intruded and the transition zone between fresh water boundary and salt water depends on the dynamic conditions of the system.

Rainwater Harvesting Around the World – Case Studies & Success Stories

The increasing demand for water has accelerated and reviving the old system of rainwater storage with the pace of technology has been adopted. The concept of rainwater harvesting has been accepted by many cities, government agencies, societies, individuals, etc in different countries around the world. They have the set examples of RWH systems. There are many success stories of RWH in developing and developed countries of Asia, Africa, Latin America, USA, Japan, Germany, Singapore and others. These case studies can further accelerate the adoption and future strategy for rainwater harvesting to reduce the water crisis in the world for integrated water resource management.

ASIA

South Asia

India

Rainwater Harvesting in Bangalore

Bangalore, a city of over 270 lakes and tanks, is now down to 80 or thereabouts. The city is located at 920 metres above sea level. The decline in ground water levels as well as the effects of pollution with nitrates poses a threat. The Bangalore Water Supply and Sewerage Board manages water supply to the city. Two major sources are the River Arkavathy and the River Cauvery. The latter is now the predominant source but is located 95 kilometers away and about 500 meters below the city necessitating huge pumping costs and energy usage. As loss of water is high, there is a large section of the population dependent on ground water through bore wells.

Nearly 3000 million litres per day of rainwater is incident on the city of Bangalore with area of 1279 square kilometers. This is in contrast to approximately 1500 million litres per day which will be pumped in after the completion of two augmentation projects under implementation. The study points out that about 20 per cent of the city’s water requirement can be met through rainwater harvesting provided a strategy is put in place to persuade owners to go in for rooftop rainwater harvesting and also if surface storage structures like lakes and ponds are maintained well. Recharge structures to augment aquifers and their utilisation in a sustainable manner would benefit the city immensely.

Integrating Rainwater Harvesting Systems into Neighborhood Design: A residential colony in Bangalore of about 4 square kilometers has managed to put in place a decentralized water management system incorporating rainwater harvesting more by serendipity than by design. Two small tanks, Narasipura 1 and Narasipura 2, collect rainwater and act as percolation tanks to recharge the aquifer. About 15 bore-wells then supply water to the colony of about 2000 houses. Sewage discharged from each house is collected and treated both physically and biologically through an artificial wetland system and led into Narasipura 2. The loop of water supply and sewage treatment is completed within a small geographical area, in an ecologically and economically appropriate manner.

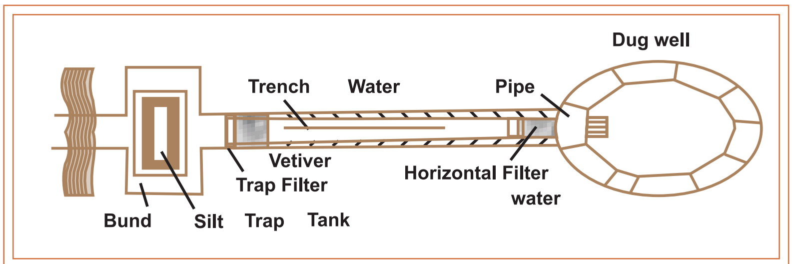
Source: A conceptual Frame for RWH in Bangalore (2000): A study undertaken by Centre for Symbiosis of Technology, Environment and Management (STEM) commissioned by GOK.

Rainwater Harvesting Initiatives in Indore, Madhya Pradesh, Central India

The commercial capital of the state of Madhya Pradesh has been facing acute shortage of drinking water. This is reflected in the wide gap in the demand and supply of 152 MLD drinking water in the city. The ever-growing water demand made the administration think about rainwater harvesting.

Indore, one of the cities in Madhya Pradesh, is located on the basaltic lava flows of the Deccan Trap. Weathered/vesicular/fractured and jointed basalt form aquifers in the area. The average annual rainfall in this area is 930 mm and one-hour peak rainfall is 35 mm. Indore has got large areas of roofs and paved areas and hence a large quantum of runoff is produced from these areas during the rainy season. This runoff goes waste as overland flow and also creates problems of flooding in low-lying streets. In such a scenario, rooftop water harvesting provides the desired solution. Essentially aquifer recharging practices are being used. In order to motivate the public, Indore Municipal Corporation (IMC) has announced a rebate of 6 per cent on property tax for those who have implemented the rainwater harvesting work in their house/bungalow/building. To operate these activities three committees – technical, education and execution – were formed by the IMC in which various experts of this field were involved. The various methods of ground water recharge used are open wells, soak pit, recharge shaft/trench with and without injection well, lateral recharge shaft, injection wells and in big schemes suitable combination of different methods of RWH are employed.

Techniques of water recharge used in Indore: The technique essentially comprises diverting rainwater through trench or swale into silt trap tank. Water from the silt trap tank is allowed to pass through a sand filter (sand, medium and big size pebbles). A cement pipe of 300 mm diameter, fitted with wire net (10 mm mesh) has been fitted on the wall of wells through which rainwater flows into the well.

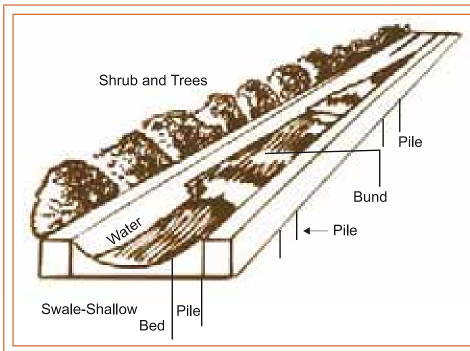


Elements of the Typical Water Harvesting System

Permeable box: Permeable boxes of 1 cubic metre, filled with big size pebbles and brick pieces and lower portion with sand are provided at the top of the pile.

Source: Proceedings of the workshop on Rainwater Harvesting, Indore.

Pile and Swales: Pile is a commonly used technique for RWH in gardens, playgrounds and public places. A two-three m. deep hole is manually dug. The bottom one-third is filled with large (40-50 mm) pebbles, the middle portion with medium size (20 to 30 mm)



Pile and Swales

pebbles and the upper one-third portion with sand (two-three mm). Swales are shallow, saucer like beds locally known as khantis. Making of swales do not in any way affect usual activities on the playground or on the road.

Panchsheel: The Water–rich Colony of South Delhi

When almost all the colonies and associations crib about water supply in summer, Panchsheel Cooperative Group Housing Society has set an example by funding rainwater harvesting projects and harvesting each drop of rain.

Panchsheel Success Story – Some Highlights

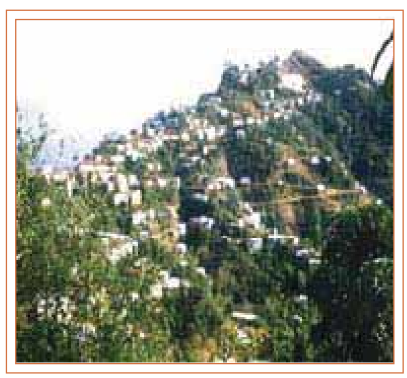
- Total rooftop and surface area 3,57,150 square metres.
- Total volume of rainwater harvested: 1,74,575 cubic metre (m^3), or 174,575,000 litres (2002)
- This represents 80 per cent of the total water harvesting potential.
- Before implementing rainwater harvesting, the water level was around 28.6 m below ground level. The water level was 26.1 m in September 2002 and 27.6 m in May 2003. The water level in July 2003 after the monsoon is 27.3 m, representing a total rise of 0.7 m, or 2.29 feet. The final report is yet to come, as the monsoon is still on.

The water-harvesting project covering all the plots in the colony involved Rs. 0.8 million (US $20,000) investment and the money was invested by the society rather than asking individual financial help. After registering the success for two consecutive years, now the society is planning to spread the awareness to 'use less water' in the locality, as the area is largely dependent on tube wells.

After the success of rainwater harvesting, the society has made the detailed plan of the wastewater treatment project in the colony. The plan has been prepared in association with the Centre for Scientific and Industrial Research (CSIR), which will provide the bacteria to purify the water. As per the plan, initially the pilot project will have the capacity to treat about 20,000 litres per day and the project will require not more than Rs. 0.1 million. The treated water will be used for irrigation purposes in the colony and a major portion of it will also be used in the society office and Panchsheel Club, including the use in flush. But the society is planning to take it extensively after the initial success, which will include supplying the treated water to toilets of flats in the coming years. In this case the residents have to spend to get the water from the main pipe to their toilets. This project can even set another example for other associations, as according to experts the use of specially developed bacteria to purify the water will bring down the cost of wastewater treatment.

Lesson: Associations having money in banks should take up such projects rather than wait for help from the government.

Aizawl (North-East India)



The water supply system in the capital of Mizoram, originally designed in 1988 for 80,000 people, is now catering to the needs of over 150,000 residents, making it grossly inadequate. Due to inadequate and unreliable water supply people are resorting to rooftop water harvesting, the most convenient and economical water supply system. Mizoram receives an average rainfall of 2,500 mm annually which is distributed throughout the year. The major advantage is that most of the buildings are constructed with sloping roofs that use Corrugated Galvanised Iron (CGI) sheets which are conducive to rainwater harvesting. Even today, most buildings in Aizawl are constructed with sloping roofs that use Corrugated Galvanised Iron

sheets. Rain gutters either of PVC pipes or bamboo are used to drain water into the cylindrical storage tanks with galvanised iron semi-circular rain gutters to catch rainwater. Gradually, reinforced cement concrete (RCC), ferrocement and plastic tanks are being introduced. Tanks of 10,000 litres capacity are commonly used.

At present, Aizawl has more than 10,000 rainwater harvesting tanks in individual houses which have been constructed by the residents at their own expense or with state government assistance. In a pollution-free state like Mizoram where major industries are yet to come, rainwater is free from undesirable chemicals and is of potable quality.

Rainwater Harvesting through Recharge Structures in Chennai

Recharge trenches: To prevent the runoff from paved areas of the road, a kerb is made at the gate which diverts the water into a trench within the plot. This trench is 229 mm wide, constructed around the periphery of the plot. The depth varies from 114 mm near the gate to 457 mm in the rear. As the trench is sloped towards the rear of the plot the water gets filled in the trench. As the trench is filled with the water there will be a constant water head for the percolation bore pit. Any excess water from the trench overflows into the sandy bed at the corner of the building and percolates into the well.

Percolation pits: To enable the water collected to percolate and disperse back into the sub-soil, boreholes 254 mm in diameter and 5.56 m in depth are made at three metre intervals with collection chambers. The borehole is filled with broken bricks and sand. A collection chamber 457 mm x 457 mm x 457 mm size is provided, the top of which is filled with broken bricks and a silt arrester.

Source: Making Water Everybody's Business by CSE

Recharge of dug wells: For recharging the well, the rainwater pipe can be connected to the open well to divert the rainwater from the terrace into the well through rainwater down take pipes. The rainwater falling around the open space surrounding the building can be diverted to the front gate where a gutter is provided for a depth of 457.2 mm and a width of 609 mm with perforated slabs. The rainwater collected in the gutter in front of the entrance is discharged into another recharge well of 914.4 mm diameter and 6.9 m depth, provided nearby through necessary piping arrangements.

RWH in Kuil Thottam, a slum in Chennai[*]: Kuil Thottam, a slum settlement in Santhome, Chennai is meeting a substantial part of its daily water requirements through rainwater harvesting. The rainwater harvesting technology adopted here as a 'model project' incorporates a catchment area of approximately 1.85 m x 1.85 m on the terrace. The accumulated rainwater is diverted to a separate water pipe, which directs the flow into the filtration tank. The water then passes through the filtration tank and after decontamination, flows into a main tank. The stored water is being used for all domestic applications after chlorination and boiling. The tests done by Rotary Club of Madras Central and Chennai Metropolitan Water Supply and Sewage Board (CMWSSB) indicated that the quality of water was better than borewell or tap water. Based on the success of the 'Model Project', water harvesting was undertaken in a catchment area of 6 m x 6 m. Runoff is diverted to a filtration tank with a capacity of 200 litre and finally to a storage tank with a capacity of 3,000 litres capacity. Periodic chlorination is done to obtain bacteria free drinking water. The total cost of the water harvesting structure installed at Kuil Thottam was Rs. 100, 000 (US $2500) at the rate of Rs. 4,200 (US $100) per tenement.

[*] Projects implemented by R Jeya Kumar, Rajparis Civil Construction Company

Projects implemented by individuals: R. Ramani, resident of Korattur (Chennai) has evolved various methods of water harvesting at his residence. Runoff from 100.0 sq.m. of area is collected out of which rainwater from 50.0 sq.m. is used for domestic purposes. The remaining quantity is used for gardening and to recharge ground water recharging the well through a recharge pit and for watering the garden. He has resurfaced his roof with Mangalore terrace tiles to generate a mild slope to the lentil level storage tank with a capacity of about 3,000 litres.

To keep this tank free from microbial contamination he has mixed a waterproofing chemical with the cement slurry to give an acrylic-poly-sulphate cement slurry coating. Through simple treatment and later filtering through 'Aqua -Guards' a commercially available water purifying product that kills germs, the rainwater is used for drinking and kitchen purposes. Each filling of the tank can sustain the drinking and kitchen needs for about 2 months. In a year the tank gets filled four to five times. Sometimes, the tank gets filled up more than once in a week. During these times, the excess water is diverted to recharge the ground water aquifer. Ramani had to invest Rs. 8,000.00 (US $200) in this project which was implemented in 1994.

South-East Asia

Japan

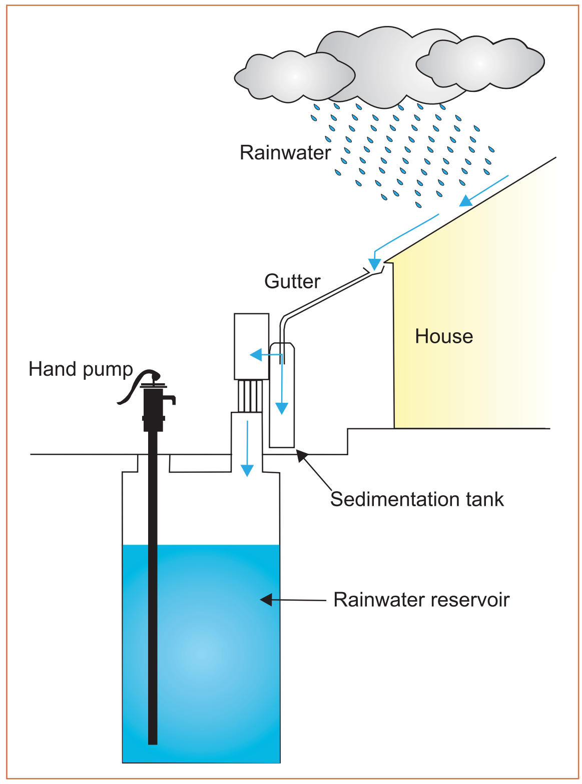
In 1994, the Tokyo International Rainwater Utilisation Conference was hosted in Japan (Murase 1994) regarding the role, applications, and potential for rainwater catchment system technologies worldwide. From 1994 onwards, there was a growing recognition that rainwater collection could play a vital role in addressing many of the water problems faced by the rapidly growing mega cities around the world, especially in Asia. Tokyo provided an interesting case study as the city faced several water related problems.

- Existing dams supplying the city were stretched to capacity and new dam and pipeline developments faced increasing opposition from environmentalists and other affected groups;
- Subsidence due to ground water over-exploitation had left over 2 million people in some parts of the city living below sea level and seriously at risk from the impacts of a tsunami;
- There was also a growing concern about the possible impact of flooding within the city and the risks associated with the worst case scenario of an earthquake and typhoon striking simultaneously and flood waters entering the subway system during the rush hour.

Such fears have generated considerable interest in all methods for disaster mitigation and they are not unfounded. In 1923 the Great Kanto Earthquake killed over 120,000 people in the city and most of those who perished were victims of the firestorms which raged through the city. In Tokyo and elsewhere in Japan there has, thus, been much interest in the use of household water storage systems to provide water for fire fighting purposes especially following an earthquake when pipe supplies might not be available.

Such household reservoirs could also provide emergency domestic water supplies in the period immediately following any major seismic event. A number of interesting demonstration projects have also been developed to illustrate this potential. At the main sumo wrestling stadium, the Kokugikan, the rainwater runoff from the 8400 m^2 roof is diverted into a 1000 m^3 basement tank for toilet flushing and cooling the building. Following the example of Kokugikan, many new public facilities have started introducing rainwater utilisation systems in Tokyo.

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.



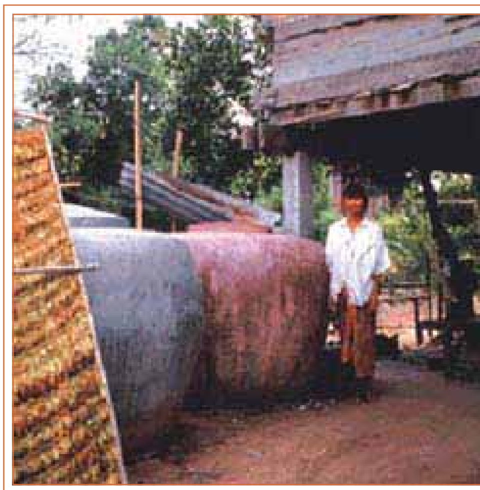
'Rajison' a simple and unique rainwater utilisation facility at the community level in Tokyo, Japan.

Thailand

Thai Jar Programme of the Thai Government remains as an unparalleled rain harvesting movement of the world. In a couple of years starting from 1985, the country constructed six million jars to harvest the rain for drinking purpose. This way, about 36 million people had minimum amount of good drinking water at their households. Probably no other developing country has been successful in providing clean and safe drinking water to a majority of its population this way. Based on the survey of 513 households done in 1985, the following conclusions were drawn:

- Storing rainwater is the best solution for the provision of drinking water
- Each person needs 5 litres of water per day for drinking
- Average family size is 6 persons per family
- In a year, there are 150 days during which water from jar has to be used
- Jars of 2,000 litres capacity are adequate for these families

The survey also revealed that roof areas of the houses varied from 50 to 150 square metres with an average size of 80 square metres. For a roof of 80 metres, 25 mm rainfall is sufficient to fill up 2 cubic metre (2,000 litres) of water. Thailand has an average of 1000 mm of annual rainfall. As such, even in relatively dry years, amount of rainfall during any one month of the rainy season is sufficien to supply drinking water through the dry season. It is estimated that there are 6,00,000 households in rural Thailand.



Thai Jar: RWH System in Thailand

If 80 per cent of this number has to be provided with one jar, required total of jars is 4,80,000. A committee was set up with the target of providing 5 million jars. It was decided that the target should be met in the year 1987 when His Majesty, the King of Thailand would celebrate his 60th birthday.

A national plan for drinking and domestic water was prepared. Though this plan was of five-year duration, 80 per cent target was fixed for the first two years. Committees were set up for technical development, training, public relations and promotion, fund acquisition and monitoring the progress. A construction manual was published. Tempos carrying the model of roof-water harvesting with a jar crisscrossed the country with stopovers at villages for small meetings. Government would supply cement and inputs plus training. Labour and cost of all the materials had to be borne by the consumers.

Masons were trained at district level. Strict specific instructions were given on the materials and method of construction of the jars. The monitoring and evaluation sub-committee kept a close watch on the progress of the programme. In all the regions of Thailand, from April to October, they get good rains. November to March (150 days) is the dry period. In the rainy season, they can go on consuming water from the jar liberally since there is a guarantee that it will get refilled soon. In October, they have to ensure that the jar remains full for use during the next five months. Southern zone is lucky to get good rains in November and December. This means, they will have the dry spell of only about 90 days.

Material cost for one jar of two cubic metre amounts in between 15 to 20 US dollars depending on the location where it is constructed. Each jar needs two man-days for making. To lend a helping hand to the villagers to help themselves, Thai Government set up a revolving fund. It works like this: Government will provide 10,000 baht as initial fund. Each household that participates in the project has to pay 400 bahts to the fund to cover the cost of materials. Training of villagers in jar construction technique was funded by Thai Government and conducted by the provincial universities. Each village sent two trainees to learn the construction method, operation and maintenance techniques. After their training, they had to teach this to others in the village. The idea was to have users involved in drinking water supply development so that they can acquire the skills and confidence to operate in future.

Apart from the Government contribution, considerable resources were pooled from non-government and private sector. Three private cement companies donated 1,503 tons of cement. There were incentives for implementation agencies too. The province where all the households were serviced by a jar was awarded the prestigious 'golden jar'. Mahasurakham Province was first to bag this award. Subsequently, Phayakaphumpisai, Nakhon Ratchasima Buriham and Phetchaburi Provinces also followed suit. By 1986, a total of 1.3 million jars had been completed. By 1987, this figure rose to 2.9 million, providing drinking water to 46,75,000 households. Taking into account the large number of small capacity jars (about 14 million) that were made, the equivalent capacity totals to 5.7 million jars by 1987. This way, 80 percent of the households were covered.

Mekong Region

Tiny Taiwan

The tiny island of Taiwan is better known for the electronic products it exports. Giant electronic companies have opened up their branches there to exploit the availability of inexpensive labour.

Taiwan an annual rainfall that can make any other country jealous – an average of 2500 mm. This is 2.6 times the world average. But Taiwan's topographic conditions come in the way of enjoying this water wealth. The island has so many mountainous regions that its rivers and streams flow very quickly. More than 70 percent of Taiwan's rainwater flows out into the ocean or is lost through evaporation. As a result, the per capita water availability of a Taiwanian is reduced to a paltry figure of 4,348 cubic metres (43,48,000 litres) as against the world average of 28,300 cubic metres. With one-seventh availability of water as compared to the world average, Taiwan is ranked as 18th country in the world in water shortage. However, this country has realised its crisis very fast. Five years ago, to meet the challenges, it has opened a Water Resources Bureau (WRB) under its Ministry of Economic Affairs.

WRB has given priority to the agriculture sector and has been giving subsides for installing RWH systems for farming. Aluminium and reinforced concrete tanks are constructed for this purpose. More than 3,000 farmers have benefited from this project. These users have set up approximately 80,000 ton (One ton=1000 litres) capacity to collect nearly 3 million tons of water every year. WRB has spread RWH very efficiently to some of the schools too. San-chi elementary school of Taipei County is the best example. Rainwater from roofs of all the buildings is collected in a storage tank. The capacity of the tank is 1,287 tons. This system now completely serves the need of toilet flushing for the school. In other words, the substitution ratio reaches 100 per cent.

In the industrial sector, Chenghwa Picture Tubes (20,000 tons of rainwater collection per year) and among charity organisations, the Thu Chi Hospital and Tzu Chi Institute of Technology in Hualian of Eastern Taiwan (10,000 tons; work in progress for 50,000 tons utilisation) are some of the models for RWH systems WRB has created. The Industrial Technology Research Institute harvests rain from its 375 square metre area roof. This is adequate for flushing toilets for 200 workers, for irrigating the garden etc. The substitution rate here is about 60 per cent. However, the best example of RWH and its education in Taiwan lies with the Taipei zoo. It is the first successful example of rainwater utilised for the zoos of the world. Taipei zoo, spread over 164 hectares, is located in Wen-Shang District which gets 2,700 mm rainfall. The zoo houses about 3,000 animals. The number of visitors per year is half a crore. For the lawns, gardens, fountain, man-made river, Hippopotamus Lake, lakes of other animals, toilet flushing and taps, the zoo requires 12 to 15 lakh tons of water per annum. With the help of WRB, Taipei zoo has implemented RWH systems. The runoff coming from nearby hillocks is processed and stored in a 250 ton tank. This water is used to irrigate eucalyptus trees and other plants, for filling the animal lakes and for flushing the toilets. Eucalyptus leaves are the food for the pet animals called Kola.

The administrative building of the zoo has a roof area of 5,000 square metres. All the water from the roof gets stored in a 500 ton tank. This tank provides additional supply for toilets and gardens. The handicraft section has a 800 square metre roof whose water is stored in a 50 ton tank. Taipei zoo has spent 14,000,000 NT $ (400,000 US$) on all these RWH arrangements. The Government has given 60 per cent subsidy for the same. Some of the systems are still under construction. The zoo was earlier spending 10 million NT$ per annum on municipal tap water.

In 1998, they spent NT$230,000 to replace the old type taps with an economy model. In the new type of tap, instead of gushing out, water spreads out as a thin film. As a result of this change, the zoo could achieve savings of 40 per cent in the consumption of tap water. Formerly toilet flushes were releasing 9 litres of water on a single pressing. A new type of flush that works at two stages was introduced. This releases only 4.5 litres in the first stage. This change and utilisation of rainwater has brought down the usage of water in toilets by 60 per cent.

Apart from implementing some full pledged RWH systems, the zoo gives education to housewives and children in various ways. Brochures and colourful books are produced to teach rainwater harvesting to the public. One such attractive book, "Water, Rain down here" explains with ample colourful pictures the importance of water, how the zoo is successful in reducing the water consumption and in augmenting its water resources by RWH. Zoo has set up 15 piggy banks (or rain-banks) at various spots. Rainwater from the roof is filtered and stored in colourful piggy banks. Says zoo director Yang-shanh-hsiung, "Rain-bank is a simple miniature rainwater catchment system. People have to recognise water resource as money value and save water like their savings money in the bank. We aim at drawing visitors' attention and curiosity to rain harvesting. They can water the garden from rain-bank instead of municipal tap water. All these advantages are illustrated on walls and in pictures on boards".

Now, the harvested water amounts for 20-30 per cent of the total consumption in the zoo. That means 3,00,000 ton saved resulting in a net profit of 60 to 90,000 US dollars. Over the years, Taipei zoo has turned out to be an education centre for rain harvesting. There is a souvenir shop touching the entry and exit points of the zoo. It has some demonstrations of rainwater harvesting and messages of water conservation. After these were introduced, total water consumption in the souvenir shop has come down to 500 to 550 tons per day from 700 to 750 tons. A neat 30-35 per cent saving!

All the families that visit Taipei zoo cannot escape from the education on water. While entering, each family is given a colourful folder on water conservation. Most of the programmes attached with the zoo never get completed without emphasising on the water issue. Apart from this, the zoo has a web site *(http://www.zoo.gov.tw)* that has a separate section on water conservation.

EUROPE

Germany

Subsidies for Household Rainwater Systems in Germany

In Germany there is currently a growing interest in the promotion of household rainwater collection, particularly at local government level. Due to serious industrial air pollution and strict regulations regarding drinking water standards, household rainwater supplies are limited to non-potable uses such as toilet flushing, clothes washing, and garden watering. In addition to reducing overall domestic water demand, benefits from rainwater utilisation include flood control and reduced storm water drainage capacity requirements. When used in conjunction with a seepage well to return any overflow to the ground, the systems also enhance ground water recharge. Most household tanks are constructed underground and one recent design incorporates a porous ring at the top of the tank so when it is more than half full, water seeps back into the ground.

The main advantage of designing rainwater collection systems in this way or in conjunction with seepage wells is that many German cities charge householders an annual rainwater drainage fee, which is waived if rainwater runoff is retained or returned to the ground, allowing significant savings. In Bonn, for example, current annual fees are $1.80 per m^2 of roof area and sealed surround, respectively (König, 1998).

In many German towns and cities, grants and subsidies are available to encourage householders to construct rainwater tanks and seepage wells. In Osnabruck, Wessels, R. 1994 reported that a grant of $600-$1200 per household was available along with a further subsidy of $3 per m^2 of roof area draining to any tank linked to a seepage well. On the basis of this subsidy, savings in water charges ($0.56/m^3) and an annual rainwater drainage fee waiver of $1.30 per m^2, the pay back period for investment in a tank seepage well system constructed at a new house was estimated to be 12 years. Even without the subsidy and constructing a system at an existing house, the investment would be recouped in 19 years. Costs and the return period on investments would be greatly reduced if householders were prepared to undertake some of the work themselves.

Berlin

In October 1998, rainwater utilisation 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 ground water 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 storm water 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.

Frankfurt Airport & TU Darmstadt

Rainwater is being harvested at two huge complexes in Germany: Frankfurt Airport and the Technical University of Darmstadt. The combination of huge catchment areas and simple technology have worked wonders. The Frankfurt Airport is the biggest airport in the European continent. The city of Frankfurt is situated in the middle of Germany, where adequate quantities of water have been a problem. Most buildings in the airport have water saving installations.

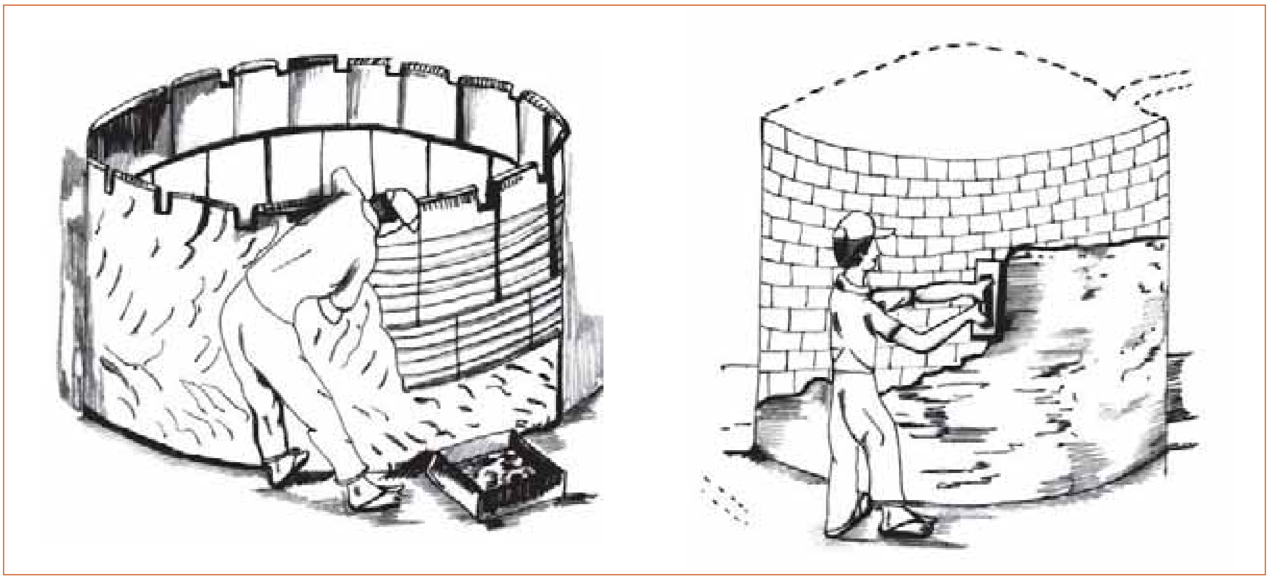
In 1993, when a new terminal building was being constructed, a system for rainwater harvesting was installed. With an expectation of handling 13 million people every year, detailed studies were made on the future demands of water. For instance, toilet flushing was estimated at 20,000 litres per day. The rainwater system collects water from the roof of the new terminal which has an area of 26,800 square metres. The water is collected in the basement of the airport where six tanks have been put up, each with a storage capacity of 100 cubic metres (cu.m.). This water is used mainly for flushing the toilets, watering the plants, and cleaning the air conditioning system with refined river water. In case of scarcity, this refined river water is also fed into the rainwater system. The rainwater harvesting system is one of the biggest in Germany and helps save approximately 100,000 cu.m. of water per year. The costs of the system were 1.5 million DM (US $63,000). Some 50 per cent of the project was financed by the federal state of Hessen. The remaining investments will pay for themselves in approximately four years by reduction in the costs of water supply.

The Technical University of Darmstadt has another colossal rainwater harvesting system. Since 1993, a combination of rainwater harvesting and used-water is being supplied to the university. The water is used for flushing the toilets and is also supplied to the laboratories of the university for cooling and cleaning purposes, for which the water is cleaned prior to use. Ever since this system has been installed, only 20 per cent of the water demand is covered by drinking water, amounting to a saving of 80,000 cu.m. of drinking water per year.

AMERICA: NORTH, SOUTH & CENTRAL

Brazil

In 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



Tanks made of pre-cast concrete plates & wire mesh concrete

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, benefitting 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.

Rainwater Survey in Squatter Areas of Tegucigalpa, Honduras, Central America

In a two-month survey of Israel Norte and Villa Nueva squatter settlements in Tegucigalpa in 1990 by local water NGO Agua para el Pueblo, the widespread use and importance of makeshift household roof catchment systems was observed (Brand & Bradford 1991). About 85% of households were collecting roof runoff and over three-quarters of these were using rainwater for over half of their domestic needs. Like many of the barrio settlements on the steep peripheral hillsides high above Tegucigalpa, Israel Norte and Villa Nueva were not serviced by the main piped water system.

Apart from rainwater, residents here depended on the purchase of trucked water from communal tanks, new boreholes, or water vendors and many poorer families typically spent 30-40% of their income on sub-standard water. Over two-thirds of the 535 households surveyed expressed an interest in upgrading their existing storage tanks, usually consisting of a 200-litre oil drum with a 1000-3000 litre cement tank. Some also wanted to improve roofing and guttering or construct new corrugated iron roofs. These families were prepared to take loans of between $18 and $490 to pay for improvements ranging from new gutters to entirely new roof, gutter, and tank systems. In most cases such loans could have been administered through an existing scheme and, in theory at least, repaid over 2 years with savings from the water purchases no longer required.

Island of Hawaii, USA

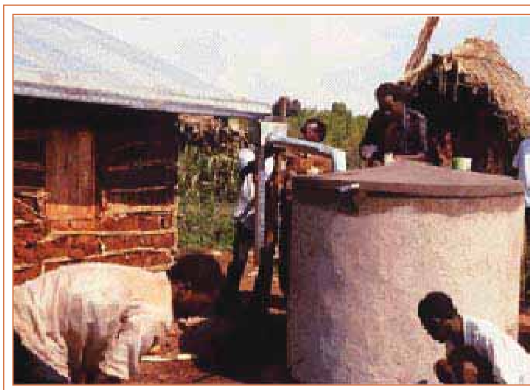
A wooden water tank in Hawaii, USA

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 m^3 capacities each, and 18 redwood water tanks with 95 m^3 capacities 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.

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 m^2 and a storage tank with 45 m^3 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.

AFRICA



Rainwater tanks constructed by local builders called 'fundis' in Kenya

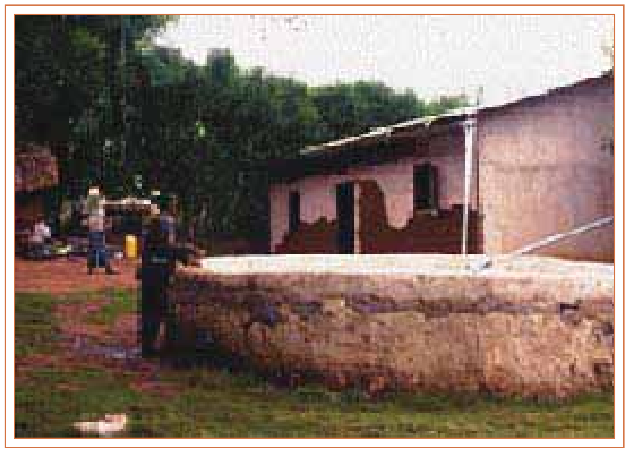
Although in some parts of Africa rapid expansion of rainwater catchment systems has occurred in recent years, progress has been slower than Southeast Asia. This is due in part to the lower rainfall and its seasonal nature, the smaller number and size of impervious roofs and the higher costs of constructing 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.

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.



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Glossary

Air gap: A vertical space between a water or drain line and the flood level of a receptacle used to prevent backflow or siphonage from the receptacle in the event of negative pressure or vacuum.

Aquifer: A porous geological formation which can store an appreciable amount of ground water and from which water can be extracted in useful quantities.

Artificial recharge: Any man made scheme or facility that adds water to an aquifer is artificial recharge system.

Backflow preventer: A device or system installed in a water line to stop backflow from a nonpotable source.

Backflow: Flow of water in a pipe or water line in a direction opposite to normal flow.

Backwater: The wastewater from toilets and kitchen sinks.

Bore well: Small diameter wells, which are generally deeper than open wells.

Buffer: To shift pH to a specific value.

Building footprint: The area of a building on the ground.

Catchment Area: The area from which runoff flows into a river, reservoir, etc.

Check Dam: Small dam constructed in a gully or other small watercourse to decrease the stream flow velocity, minimize channel scour and promote deposition of sediment.

Chlorination: The use of chlorine for the treatment of water, sewage or industrial wastes for disinfection or oxidation.

Cistern: An above or below ground tank used to store water, generally made of galvanized metal, fiberglass, ferrocement or concrete.

Contamination: To introduce a substance that would cause the concentration of that substance to exceed the maximum contaminant level and make the water unsuitable for its intended use.

Disinfection: A process in which pathogenic (disease producing) bacteria are killed by use of chlorine or physical processes.

Diverter: A mechanism designed to divert the first flush rainwater from entering the cistern.

Dug wells: Traditionally used large diameter wells. Defined precisely as pits excavated in the ground until the water table is reached, supported on the sides by RCC/Bricks/Stones/Walls, Diameters could vary from 0.6 metres onwards.

Erosion: The loss of topsoil that occurs as a result of run-off.

Filtration: The process of separating particles of 2 microns or larger in diameter from water by means of a porous substance such as a permeable fabric or layers of inert material housed in a media filter or removable cartridge filter.

First flush: Generally the first 50 litres of rainwater per 1,000 square feet of roof surface thatis diverted due to potential for contamination.

Flow rate: The quantity of water which passes a given point in a specified unit of time, expressed in litres per minute.

Force breaker: An extension of the fill pipe to a point 1" above the bottom of the cistern, which dissipates the pressure of incoming rainwater and thus minimizes the stirring of settled solids.

Greywater: The wastewater from residential appliances or fixtures except toilets and kitchen sinks.

Ground Water Draft: It is the quantity of Ground Water withdrawn from Ground Water Reservoirs.

Ground Water: The water retained in the intergranular pores of soil or fissures of rock below the water table is called ground water.

Hardness: A characteristic of ground water due to the presence of dissolved calcium and magnesium, which is responsible for most scale formation in pipes and water heaters.

Hydrologic cycle: The continual exchange of water from the atmosphere to the land and oceans and back again.

Katchi Abadis: Settlements/living colonies where people live in not so durable houses/shelters which may be made of mud, thatch, wood etc. or other non durable materials.

Leaf screen: A mesh installed over gutters and entry points to downspouts to prevent leaves and other debris from clogging the flow of rainwater.

Masonry: A wall or other structures made using building blocks like bricks or stone with binding materials like cement or lime.

Micron: A linear measure equal to one millionth of a meter, or .00003937 inch.

Nonpotable water: Water intended for non-human consumption purposes, such as irrigation, toilet flushing, and dishwashing.

Open Wells: Same as dug well. These wells were kept open in earlier days for manual withdrawal of water. Today, with electrical or diesel/patrol pumps, these can be fully covered.

Pathogen: An organism which may cause disease.

pH: A logarithmic scale of values of 0 to 14 that measure of hydrogen ion concentration in water which determines whether the water is neutral (pH 7), acidic (pH 0-7) or basic (pH 7-14).

Potable water: Water which is suitable and safe for human consumption.

Pressure tank: A component of a plumbing system that provides the constant level of water pressure necessary for the proper operation of plumbing fixtures and appliances.

Rainwater harvesting: The principle of collecting and using precipitation from a catchment surface.

Recharge: The process of surface water (from rain or reservoirs) joining the ground water aquifer.

Replenishable Ground Water: It is the portion of precipitation which after infiltration percolates down and joins the ground water reservoir.

Reservoir: A pond or lake built for the storage of water, usually by the construction of dam across a river.

Roof washer: A device used to divert the first flush rainwater from entering a cistern.

Runoff: Runoff is the term applied to the water that flows away from a surface after falling on the surface in the form of rain.

Sedimentation: The process in which solid suspended particles settle out (sink to the bottom) of water, frequently after the particles have coagulated.

Total dissolved solids: A measure of the mineral content of water supplies.

Water Pollution: The addition of harmful or objectionable material causing an alteration of water quality.

Water Quality: A graded value of the components which comprise the nature of water. Established criteria determine the upper and/or lower limits of those values which are suitable for particular uses (organic, inorganic, chemical, physical).

Water Table: The level of water within it granular pores of soil or fissures of rock, below which the pores of the host are saturated.

Wetlands: Areas of marsh, fen, peatlands or water, natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt including areas of marine water less than six metres deep at low tide.

Rainwater Harvesting FAQs

1. **What is Roof Top Harvesting?**

   To collect and store the rainwater which falls on the terrace of the buildings/houses. The water collected from the terrace is of good quality and it can be stored in tanks/sumps either for direct use or can be diverted to the existing bore well/open well for ground water recharge and storage.

2. **What are the precautions to be taken for roof top harvesting?**

   The terrace of the building should be maintained clean. A grill/mesh has to be fixed at the entrance of the rainwater pipe in the terrace to arrest large particles such as papers, leaves, etc. A filter chamber has to be provided to filter small/minute dust particles before diverting the rainwater into the storage tank or open well/bore well.

3. **How to harvest rainwater in the open spaces?**

   Rainwater collected in the open spaces, being relatively dirty in nature, cannot be used for direct recharge of the well and therefore used for ground water recharge, using appropriate recharge methods/structures. In the absence of open well, the roof-top water may also be harvested along with open space water.

4. **What are the precautions to be taken while harvesting rainwater from open space around the building?**

   A dwarf wall of (7.5 cm height) has to be constructed at the entrance/gate to avoid run off into the street/road. If man holes are present (sewerage/waste water line) the height has to be raised a little to avoid draining of rainwater through the manholes.

5. **What are the RWH methods used for ground water recharge?**

   There are various methods available for rainwater recharge into the ground which depend on the nature of sub-surface formation, extent of the area from where rainwater is collected. Some of the simple and cost effective RWH structure methods are:

   - Percolation Pit
   - Percolation Pit with Bore
   - Recharge Trench
   - Recharge Trench with Bore
   - Recharge well (shallow/small)
   - Recharge well (deep/large)

6. **What are the methods suitable for sandy sub-soil area?**

   As the sandy soil facilitates easy percolation of rainwater, shallow recharge structures such as percolation pits, recharge trenches and shallow/small recharge wells are enough for sandy sub-soil areas.

7. **What are the methods suitable for areas with clay sub-soil and hard rock areas?**

Since clay sub-soil formation is impervious in nature and is having poor permeability, deep recharge structures such as percolation pit with bore, recharge trench with bore and deep/large recharge wells are needed for deep percolation into the underlying sandy layer.

For hard rock areas it is advisable to construct recharge wells the size of which depend on the extent of the area/ building.

8. **Can existing structures be used for RWH?**

Yes. Existing structures such as defunct bore wells, unused/dried up open wells, unused sump, etc. can be very well used for RWH instead of constructing recharge structures to reduce the total cost.

9. **Does RWH help to get immediate benefits?**

Yes. In case of roof top rainwater harvesting where the water is collected in storage tanks/sumps after filtering, the water is available for use the moment it rains.

In case of ground water recharge where the quality of ground water is poor or moderate considerable improvement in quality would be observed from three to five years, if continuous recharge of rainwater is effected into an open well. However, slight improvement can be seen within weeks of rain if RWH structures have been installed. As far as improvement in ground water table is concerned, the improvement can be seen even during one rain fall season if large number of people have done RWH in a locality. In short, rainwater is relatively pure form of water and when it is added to the relatively poor quality of ground water, the quality of that water will improve due to dilution. More the water harvested better will be the result.

10. **Is it necessary to construct all types of recharge structures in buildings?**

Not necessary. In areas with alluvial sand, recharge structures would not be required unless the open spaces are covered with cement pavements. In other areas depending upon the area one or two recharge structures are enough to meet the requirement of an average sized house. Preference must be given to roof-top harvesting using existing open well. When roof-top harvesting using sumps and existing sumps and open well is practiced, it would take care of 60 to 75 percent of the rainwater recharge in an ordinary/normal house. In such cases, one or two simple structures would suffice to harvest the rainwater from the remaining open spaces around the building.

11. **Is roof top water suitable for drinking and cooking?**

Though the rainwater which falls on roof is pure but, still when it falls on roof and on the way to sump, some dirt, dust particles etc. are carried away with it. Therefore, it is advisable to filter this water and boil it before using for cooking and drinking.

12. **What kind of catchment surfaces are most efficient?**

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 should 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.

13. **How can the runoff capacity be increased?**

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.

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