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Operational Guidelines for Rainwater Harvesting Techniques

Pakistan Council of Research in Water Resources (PCRWR)
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Foreword

Existence of life itself is dependent on the availability of fresh water. On a global scale, the consumable fresh water is available in different forms including: rainfall, snow and glacier melt, and groundwater. In Pakistan, groundwater has played a very important role in the development of water supply system to meet the demand for domestic, industrial and irrigation requirements. Availability and occurrence of significant groundwater reservoirs in the Indus Plain and other isolated geographic regions is one of the salient and unique features of the water resources system of the country. The rapid growth in population, urbanization and excessive demands have brought about a steady increase in overall water use, which has resulted in an increased water demand. The climate change has had its implications on Pakistan, with occurrence of droughts and heavy rainfalls at unprecedented intervals. Meanwhile, the natural recharge has decreased due to urbanization and watershed degradation. Thus, depleting rate of aquifer has become a major issue associated with the growth of human settlements in the big cities.

The groundwater exploitation for meeting the ever-increasing domestic and industrial water requirements of the cities on long-term basis requires measures of sustainable supply of good quality water. Such measures cannot be made unless withdrawal of groundwater is replenished under a systemic and robust artificial recharge mechanism. Pakistan is blessed with Sufficient floodwater during rainy season, which either spreads over a large area and is evaporated without contributing to groundwater or escapes from the area due to high runoff intensity. Therefore, it is imperative that this precious water be stored though rainwater harvesting at suitable places with appropriate technologies so that maximum water infiltrates into soil and contributes to recharge the aquifer for its subsequent uses at the time of need. I am hopeful and optimistic that the project would help explore the potential of rainwater harvesting in urban areas for the sustainable management of water resources. This would improve the water availability in the cities especially where the groundwater is a dependable source of water supply.

Dr. Muhammad Ashraf
Chairman, PCRWR

Table of Contents

List of Figures

1. Background

The water resources of Pakistan are under immense pressure due to agricultural expansion, population growth and associated urbanization and industrialization. Climate change has further aggravated the situation. Due to this, the country is experiencing extreme events like intensive rainfall and prolonged droughts. The country has one of the largest irrigation systems in the world comprising three major reservoirs with a design capacity of about 20 billion cubic meters (BCM), 23 barrages, head works and siphons, 45 main irrigation canals commanding an area of about 16.6 million hectares (Mha). Irrigated agriculture is the backbone for economy of the country where over 93% of the available water resources are consumed. Irrigation is used on 80% of all arable land and meets almost 90% of all food and fiber requirements. It is the single largest sector of economy accounting for around a quarter of the country's gross domestic product (GDP). Agriculture employs 44% of the labor force, supports 75% of the population, and accounts for 60% of foreign exchange earnings (Qureshi, 2011; Biscoe and Qamar, 2006). The domestic sector uses very less water from surface supplies. Groundwater contributes about more than 90 % to meet the demands of domestic sector. Despite having ample freshwater resources only 39% population has access to safe and clean drinking water (Rasheed et al., 2021)

Wastage of water in all sectors is the biggest concern in all water use sectors. The agriculture sector is the biggest consumer of water and also more losses are there. Almost 60% of the water is lost from canals to farm gates (Qureshi & Ashraf, 2019). It is also predicted that water shortfall which was 11% in 2004 would be increased to 31% in 2025 (GoP,2001). Supply of freshwater through Indus Basin Irrigation System to the agriculture sector is more likely to remain a high priority for ensuring food security of the nation. Whereas, urban and rural habitat including industrial zones would continue to require a reliable source of water. Therefore, it would be a great challenge for the country to counter the issues of water shortage and food security. The country has to make tireless efforts and huge investments to cope with the issue of water shortage.

Pakistan exists in arid to semi-arid climate with average annual rainfall ranging between 150 mm to 1,000 mm across the country. About 60% of rainfall is received during three monsoon months. Climate induced changes have disrupted this pattern of rainfall and since 2010 some parts of Pakistan continue to receive historical rainfall during monsoon or any part of the year. On the other hand, anthropogenic changes in micro-catchments and unplanned urbanization have altered the hydrology of urban and peri-urban areas. As a consequence, even a rainfall event of 30 mm has the potential to create marginal scale urban flooding. Cumulative runoff from high elevation areas creates high flood situation for population settled in lower elevations.

This rainfall run-off if harnessed may be brought into beneficial use beside curtailing urban flooding. These uses may include; rainwater harvesting for artificial groundwater recharge in urban and rural areas, rooftop rainwater harvesting for domestic use other than drinking, surface rainwater harvesting for multiple uses. Over the time, research institutions have developed some techniques for water conservation and management but these techniques have not been disseminated to the stakeholders in an easy and understandable way. One of the key reasons of this lag is limited or no operational guidelines for the development of rainwater harvesting systems according to the requirements of the urban areas. Objective of this manual is to provide simple guidelines and procedures to the practitioners for the design of the rainwater harvesting technologies. These guidelines offer step by step approach to implement rainwater harvesting technologies for various uses.

1.1 Rationale for Rainwater Harvesting in Communal Habitat for Flood Resilience

Rainwater is a blessing, absence and abundance of it causes two types of phenomena; droughts and floods respectively. The harvesting of rainwater is the oldest technique known to civilizations for sustaining their water supplies in the wake of challenging climates. Some 10,000 years ago Mayan's used to harvest their rainfall runoff to meet their daily needs. Likewise, in today's North America, 20% of surface water resources are comprised of 2.6 million man-made surface water bodies developed during "Dust Bowl" drought period of 1921-40 (Fatima et al, 2019). Likewise, Pakistan Council of Research in Water Resources has developed 110 rainwater harvesting ponds in Cholistan Desert. These surface rainwater harvesting ponds are developed to capture the historical rainfall events in the desert and serve as oasis for communities and their livestock living in the desert. PCRWR has also demonstrated surface rainwater harvesting techniques in the Union Council Musa Zai of Dera Ismail Khan district. Communities in this region are mostly settled around a harvested rainwater body and suffer from hill torrent flash floods during monsoon and water crisis during remaining parts of the year.

PCRWR has also demonstrated surface rainwater harvesting techniques for artificial groundwater recharge in dry and urban areas. In Balochistan province, surface rainwater harvesting techniques including watershed management and inverted well techniques were introduced. The surface rainwater harvesting consisted of gabion and check structures meant to slow down the velocity of flash floods allowing them to seep into groundwater through a recharge well. The hilly terrain of Balochistan province allows such space for the construction of check structures, whereas in urban areas the same objective is achieved through smart catchment management. In collaboration with Capital Development Authority (CDA), PCRWR established artificial groundwater water recharge wells. Each well is designed according to the topography of catchment area.

The aforementioned examples from history as well as from Pakistan's context reveal that floods and droughts are closely linked to climate change. To avoid the ruins of both events, there is a need to adopt fit-for-purpose techniques to harvesting rainwater during flood season for its later use during the drought period. The following section will briefly discuss floods and droughts with respect to its focus on urban habitat.

1.2 Floods

Flooding is globally a major natural hazard. Floods result in property and life loss and poor economic development. Though it is not possible to prevent the occurrence of floods, but their adverse impacts could be minimized considerably through proper planning and effective preparation. The vulnerability to floods could be reduced by accurate and timely prediction (forecasting and warning) and by impact-reducing measures. Pakistan is also adversely affected by floods. It has been reported that Pakistan is fifth most flood effected country in South Asia. On average, every year floods affect approximately 0.715 population of Pakistan and by 2030 about 2.7 million people in Pakistan may be affected by floods (Aslam, 2018). Floods have following types, but this document will focus only on urban flooding and community resilience to it:

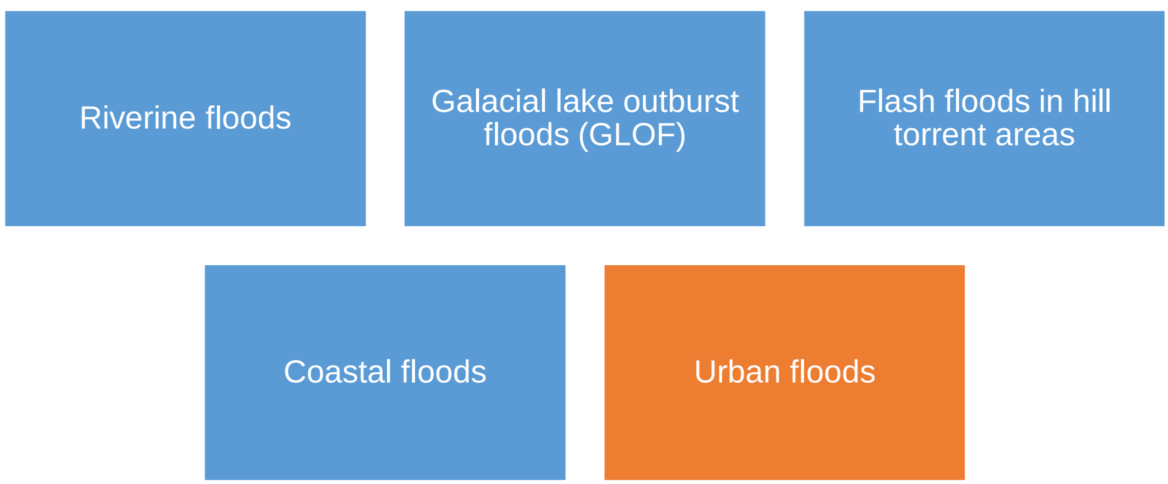

Figure 1: Types of Floods

1.2.1 Urban Floods

Urban flooding by the rainfall runoff of monsoon period has become a common feature in Pakistan. The urban planning has transformed cities into concrete jungles. Construction of metal roads, converging natural drainage paths and lining them with concrete, combined sewerage and storm drains, conversion of agricultural land into housing societies due to horizontal expansion, deforestation, and urbanization beyond the design threshold of cities are the major causes. Consequently, this has caused to a plethora of issues with respect to water availability and demand; formation of peri-urban and slum areas, over abstraction of groundwater, and poor drainage followed by urban flooding after a normal rainfall event. In recent years, this scenario is witnessed in major cities of Pakistan including; Islamabad, Karachi, Lahore, Rawalpindi, Hyderabad, and Peshawar.

Due to climate change, disturbance in rainfall frequency and intensity demands for major structural changes in the cities, such as separation of storm drainage system from the sewerage for avoiding urban flooding. However, such infrastructural changes also require regulatory and governance arrangements which is a long-term process. The immediate response strategy may include a number of rainwater harvesting techniques at household and community level to minimize the flood situation followed by storage for dry period.

1.3 Drought

A drought is an extended period of months or years when a region experiences a deficiency in its water supply. Generally, this occurs when a region receives consistently below average precipitation. It can have a substantial impact on the ecosystem and agriculture of the effected region. Although droughts can persist for several years, even a short, intense drought can cause significant damage and harm the local economy (Wilhite and Glantz, 1985). Different types and characteristics of droughts are discussed in Figure 2.

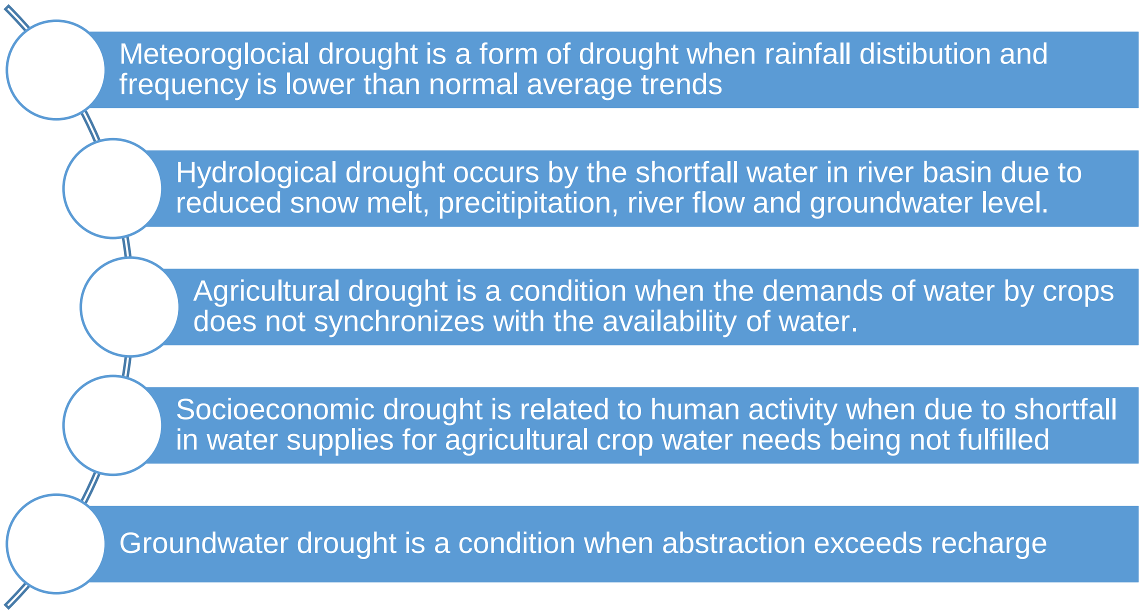

Figure 2: Different Types and Characteristics of Droughts

Classification of droughts also highlights that rainfall runoff plays a key role in availability of freshwater. Meteorological and hydrological droughts are the results of natural disturbance in snowfall, rainfall and snow melt. However, if this natural disturbance is not managed, it may cause agricultural, socio-economic and groundwater drought. This scenario demands for rainwater harvesting in urban as well as rural areas to avoid the situation of droughts and floods.

Occurrence of rainfall in a particular region depends mainly on climatic and hydrological characteristic of that region. Climate factors include; rainfall frequency and intensity during a year. Hydrological factors include; characteristics of land surface receiving rainfall, its slope and catchment areas. The intensity and duration of rainfall over a land surface defines the amount of runoff that will be generated.

2. Theoretical Design Concepts of Rainwater Harvesting

Rainwater harvesting is a technique of collection and storage of rainwater at surface or sub-surface, before it is lost into a natural drainage. The aim of rainwater harvesting is to collect runoff from areas of surplus or where it is not used, store it and make it available, when there is water shortage. In this way, rainwater harvesting in urban areas may reduce the volume of flow generated in streets after rainfall event. Rainwater harvesting may be performed in a number of places in urban areas; houses, housing societies, apartment complexes, public and private buildings, parks, green belts, parking and industrial areas.

In order to design a rainwater harvesting system there is a need to know some basic mathematical relationship between the hydrology of surface area and intensity of rainfall in a given time span. These guidelines focus on designing rainwater harvesting techniques for urban areas in three scenarios:

- Rainwater harvesting from rooftop
- Rainwater harvesting from surface
- Rainwater harvesting for groundwater recharge

Basic element of rainwater harvesting design is understanding of rainfall pattern and discharge in particular area. There are two methods for determining the rainfall:

i) Historical rainfall trends; and
ii) Rain gauge recorded data at local level

Historical rainfall data may be collected from Pakistan Meteorological Department. This data is more useful because it helps in determining an average for an optimum design of any rainwater harvesting system. Second method is installing a rain gauge, which may help the users for determining rainfall intensity at an instant of rainfall followed by peak discharge estimate of rainfall at any particular event. It does not provide idea about historical trends, therefore, if the design is based on one-time rainfall record of locally installed rain gauge, a number of modifications may be required rendering the design economical.

2.1 Understanding of Rainfall Data

Historical rainfall data of the area is collected and analyzed for average rainfall calculations. For example, the rainfall data of the Rawalpindi and Nowshera collected from Pakistan Meteorological Department was analyzed for the last 30 years (1990-2020) and 38 years (1970-2008). The average annual rainfall is found to be about 1,260 mm and 56 mm respectively (Figures 3&4).

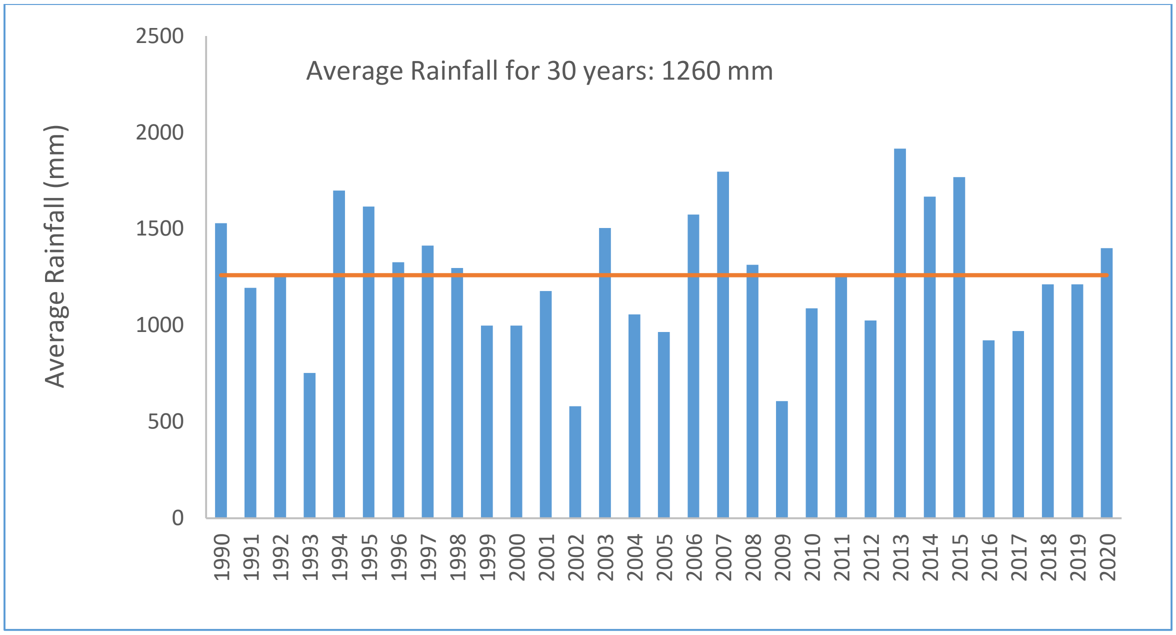

Figure 3: Rainfall Data of Rawalpindi

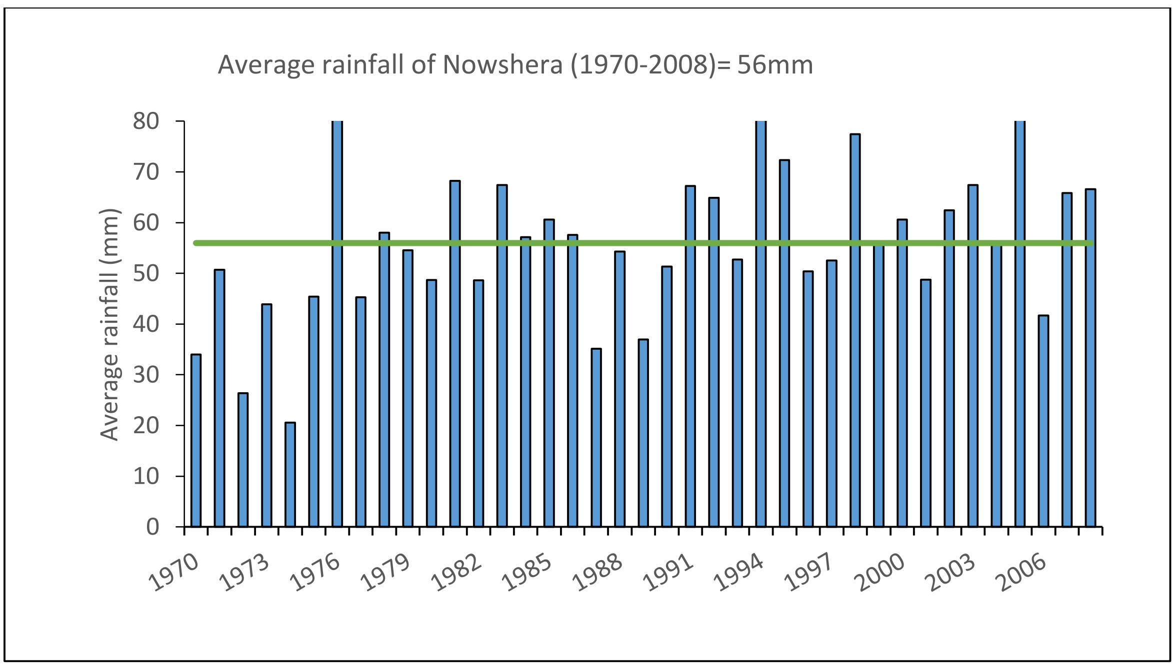

Figure 4: Rainfall Data of Nowshera

Note: Datasets presented in the figure are presented only for the basic understanding of the users for the purpose of designing rainwater harvesting system.

2.2 Rainfall Runoff Estimation

Surface runoff is generated when the rainfall intensity exceeds the infiltration capacity of soil for a period of time enough to get the soil surface saturated and puddled. Runoff is a function of many interrelated factors, such as soil type, slope, soil moisture content, topography, land cover, and rainfall characteristics (intensity-time distribution). Rainfall-runoff relationship is explained by Rational method for a drainage area less than 200 acres. This method determines peak runoff most accurately where catchment is mostly impervious. In this regarding, this method is very useful for estimating peak runoff in urban areas, i.e., roof top, small catchments, run off from paved roads and embankments. The following equation is used:

$$Q = CiA$$

Where:

Q = Peak discharge in cubic feet per seconds (cfs) or cubic meters per seconds (cms). Value of runoff is directly proportional to rainfall intensity.

C = Surface runoff coefficient based on the characteristics of soil/land surface from where the runoff is generated. Its values range between 0.1 (for an un improved area) to 0.9 (an impervious area). Values of runoff coefficient are estimated standards (Annexure I).

I = Rainfall intensity is defined as the maximum depth of rainfall over unit period of time (mm/hr). When the rainfall intensity is higher, duration of rainfall is generally low and peak flow is generated. Low intensity rainfall however generates less runoff and spans over longer duration.

A= Area of the catchment and determined in (square meters or hectares). Rational method gives accurate estimate of runoff for a catchment area less than 80 hectares.

2.3 Rainfall Storage Design

Rational method gives an estimate of peak discharge for designing a surface rainwater harvesting system both for surface storage and groundwater recharge. However, in order to design a domestic or commercial storage, following method is used:

$Y = \sum Ai \times hi \times ei \times \eta i$ ....[1]

[1] On-site non-potable water systems. Part 1: Systems for the use of rainwater. Tanzania Bureau of standards.

Y = Total volume of rainfall collected over a period of time. For design purpose, this period may be taken as total volume of rainfall received on a given area during 24 hours.

A_i = A particular horizontal area from where the total rainfall is collected and determined in terms of square meters.

h_i = Average annual rainfall (mm)

e_i = Runoff coefficient for a particular soil/land surface from where a rainfall volume is collected (Annexure II).

η_i = This is a coefficient of hydraulic treatment efficiency which is ratio of flow collecting into treatment system prior to storage to the flow coming out of the treatment system into the storage.

3. Classification of Rainwater Harvesting in Urban Areas

Impervious layers with limited vegetative cover are very common features of urban areas. These surfaces include concrete and marble lined as well as earthen rooftop areas. In public and private buildings, rainwater may also be harvested from the ground surface and impervious parking areas. There are various techniques to harvest rainwater within the premises of public and private buildings, from the landscape of urban, rural and semi urban areas, parks and greenbelts. These techniques are also tested and demonstrated by PCRWR on a wide variety of locations. Some of these techniques and the potential uses are discussed in the following sections.

3.1 Rooftop Rainwater Harvesting

Harvesting of rainwater can be from roofs of private, public or commercial buildings (e.g. greenhouses, offices, schools). The effective area of the roof and local annual rainfall will determine the volume of the rainwater that can be captured. Between 80 – 85 percent of rainfall can be collected and stored (Oweis et al., 2012). Harvested rainwater from the rooftop may be consumed for non-potable purposes, such as; horticulture, washing of home, car washing and artificial groundwater recharge through soak way pits. A schematic concept of rooftop rainwater harvesting system is provided in Figure 5.

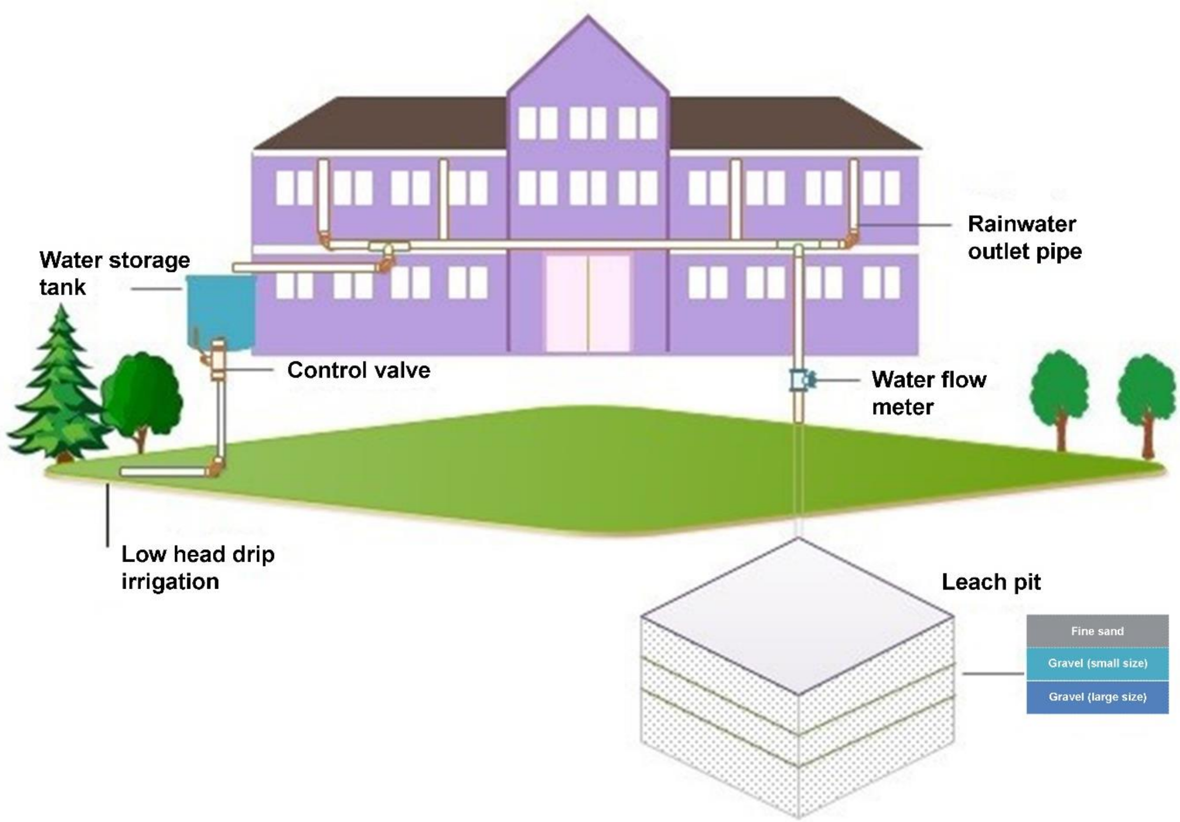

Figure 5: Schematic Diagram of Rooftop Rainwater Harvesting

This system may have the following components:

Catchment Area: It should be of suitable size that can meet domestic and small-scale irrigation requirements.

Gutter Pipe: This pipe is used to collect rooftop rainwater and convey to the storage tank. Its size depends upon roof size, rainfall intensity and water to be collected.

Screen: A screen is attached with the gutter line to prevent small leaves and other material from entering the pipes.

Flush Valve: A flush valve may be installed at the bottom of collector pipe to drain off the first few minutes rainfall so that clean water is collected in the tank.

Filter: Depending on the intended uses, a filter may be installed to the pipe above the storage tank to remove silt, sand, dust, leaves and other organic material.

Storage Tank: It can be designed either based on the maximum single rainfall event or the total accumulated rainfall during a year.

Overflow Pipe: It is used to drain off extra water from the tank and may be linked to an underground tank or to a storm drain.

Valve: It is attached at the outlet of storage tank to have water for use.

Soak way pit: A soak way pit is an earthen unimproved soil surface enabling artificial groundwater recharge controlling runoff into the streets.

Harvested rainwater from the rooftop is a readily available source of water that may be stored in tanks for later uses. It reduces the need for groundwater abstraction and offer a good quality alternate to many other sources of supply. The surplus water from the rooftop may be used for artificial groundwater recharge through soak way pit (Figure 6).

Figure 6: A surface View of Soak Way Pit

A rooftop rainwater harvesting system may be designed using following step-wise methodology:

i. Determining design rainfall (mm), a designer may also take maximum rainfall value to design the storage requirement, section 2.1.1
ii. Estimation of rooftop area (square meters)
iii. Coefficient of runoff impervious surface such as rooftop is taken as 0.9
iv. Determine storage requirement using relationship;
Design volume (gallon) = {Max daily Rainfall (mm) × Catchment/rooftop (m^2) × 0.9 (runoff coefficient)} / 3.785

Once the design volume is finalized, rooftop rainwater harvesting may be designed after selecting appropriate pipe and storage sizes (Figure 7).

Figure 7: Rooftop Rainwater Harvesting Storage Tanks Installed at PCRWR

3.2 Courtyard Water Harvesting

In the premises of public and private buildings, not all water is collected from the rooftop. Grassy and unimproved soil surfaces act as soak ways and help in the infiltration of rainfall moisture into the root zone. However, water that flows over impervious surfaces such as granite, asphalt and concrete tiles of parking areas and passages triggers the runoff. This water may be stored into subsurface storage system and alternatively used for artificial groundwater recharge.

3.2.1 Components of Groundwater Recharge System

Bore Wells

Bore wells serve as booster to invert rainwater into underground. However, these wells require pre-filtration system to eject the debris and sediments from runoff and to allow only silt free water into the bore to avoid the choking of wells. The pre-filtration is provided by making a pit and filling it with different natural filtering material in layers such as gravel, stone crush and sand etc. This filter acts both way i.e. remove sediments from runoff as well as enhance the recharge rate from surface.

Filtration

For filtration process, vertical gravity head filter technique is used. A pit is excavated around borehole depending upon the catchment size and rainfall history of the area. After excavation of pit, a manhole is constructed in the bottom of pit to collect filtered water. A horizontal pipe is connected from the center of manhole to the recharge well. Top of manhole is covered with an iron mesh which is generally made from angle iron and reinforcement bar. Once the construction of manhole is completed, filter material is filled into the pit layer by layer. Generally, a layer of 0.6 m loose boulder (38-76 mm) is provided in bottom on top of an iron mesh, 0.6 m crushed stone (13 – 19 mm) as middle layer, topped with an organza mesh and finally 0.6 m top layer filled by coarse sand. The organza mesh protects the sand to mix with stone crush and protects from choking of the system. A schematic diagram for groundwater recharge well is given in (Figure 8).

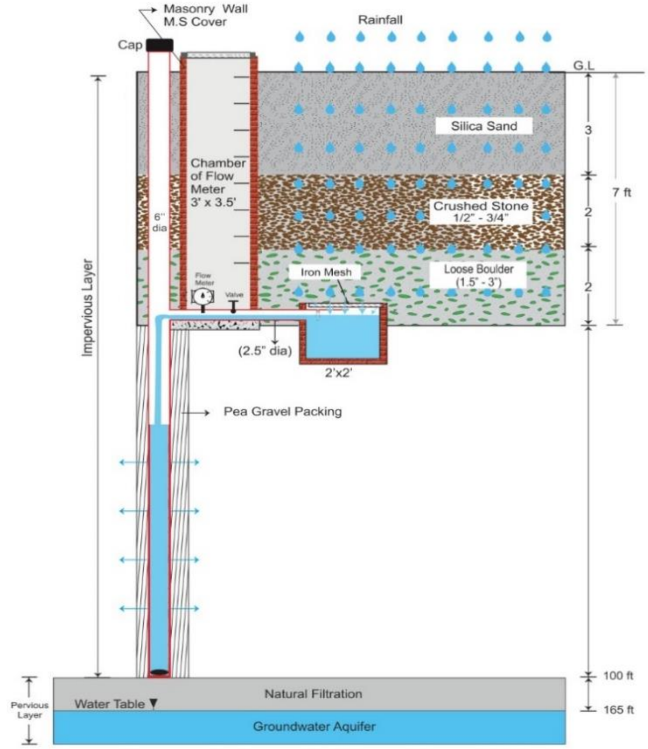

Figure 8: Perspective View and Schematic Drawing of Artificial Recharge Well for Court Yard Rainwater Harvesting

3.2.2 Step-wise approach to designing a surface RWH system for groundwater recharge

i. Identify open and impervious catchment area,

ii. Identify slope of the impervious flood to plan the construction of a recharge well.

iii. Identify a spot where runoff from courtyard accumulates, this is a site for artificial groundwater recharge if it is not located near the foundation of a building. Most suitable place for such spot is back yard of a building where stagnant rainwater does not harm the building.

iv. Artificial recharge well has two components *viz*. a soak way pit that accommodates slow sand filtration prior to artificial groundwater recharge and a bore.

v. In order to develop artificial groundwater recharge system, depth to water table must be known.

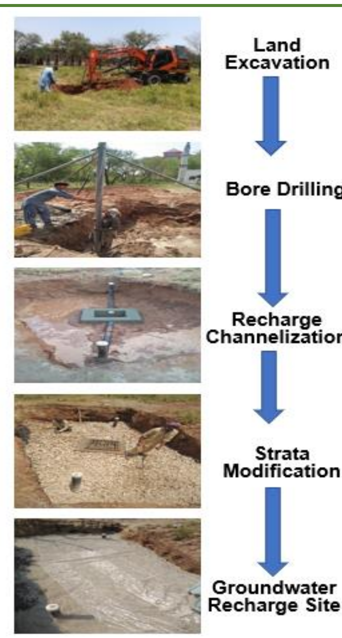

Figure 9: A step-wise process of developing

vi. A borehole is made generally 10-15 meters above the groundwater table allowing for natural filtration before recharge.

vii. Depth to water table and perimeter of soaking pit containing the filtration medium may vary according to location.

viii. The design shown in Figure 8 is of a 2 m × 2 m × 2 m soaking pit with filtration medium of sand on top surface, followed by organza mesh, crushed stones, loose boulders and iron mesh in descending order.

ix. This filtration system is a physical system that operates under the force of gravity without external sources of energy and compatible with natural process of artificial recharge.

x. Once water is filtered through loose boulders, it is then collected into a basin beneath soaking pit.

xi. The small basin when over flows, flushes filtered water through the borehole where recharged water needs to pass through natural filtration medium before entering into the groundwater.

xii. Rainwater harvested from courtyard and surplus from rooftop runoff is free of chemical impurities, therefore slow sand and natural filtration process cleanse it from natural impurities.

xiii. Such artificial recharge system in the premises of the building not only reducees the volume of urban flooding but also helps in replenishing the groundwater.

3.3 Surface Rainwater Harvesting

Surface rainwater harvesting is similar to rooftop and yard scale rainwater harvesting. Flood water from catchment area is collected mostly unimproved and modified to enable rainwater harvesting through construction of small ponds, leaky structure, inverted wells in natural drainage passages. Surface rainwater harvesting may have two purposes; development of small storage ponds along the natural terrain, reducing the speed of flood water and diverting it for groundwater recharge. In urban areas, surface rainwater harvesting for surface storage ponds is not possible due to the limited area. However, surface rainwater harvesting for catchment management particularly in natural rainfall runoff drains may be practiced to cut the slope of flooding. In the following sections, design of surface rainwater harvesting will be discussed.

3.3.1 Surface Rainwater Harvesting for Hilly Terrain and Natural River Channels

Natural rain channels are essential elements of the topography of Nowshera, Rawalpindi and Islamabad districts. Natural rain channels are also prevalent in plain areas. In hilly areas, natural drains take the form of several reaches and each reach represent a different catchment area. Generating urban flooding in such reaches are easy and it is also equally easier to manage. Following is the step-wise strategy for developing surface run off system in marginal lands of hilly terrain:

i. Topographic survey of natural river channels and its catchment areas to determine the area of sub catchment, and slope of the drainage basin forming a channel reach.
ii. Using historical rainfall data and characteristics of local soil determine peak discharge using Rational Method.
iii. Design gabion structures according to mouth of drainage basins of each sub catchments of a watershed.
iv. Gabion/check structure obstruct the natural flow of water creating a pond at the upstream of check structure wall. The gabion walls are loose structure and does not act as weir.
v. In case of high potential of flooding a gabion, structure may also be designed along with an inverted well/artificial groundwater recharge well.
vi. In order to design an inverted well on the hilly slope, identify depth to water table to ensure the presence of groundwater aquifers. In most reaches of rainwater channels groundwater aquifer is absent. Therefore, it will be of no use to design an inverted well.
vii. An alternate approach for harvesting rainwater through steep valleys is the construction of leaky structures on cascade approach (a number of structures in a series to allow maximum recharge time).
viii. A leaky structure does not store water on upstream rather allows water to reduce its velocity and travels on downstream through body of the leaky structure. Inverted wells in the downstream area facilitate the process of recharge.
ix. Leaky structures are constructed utilizing the similar methodology of topographic survey, historical rainfall records, run off potential of the local soil, catchment area, and properties of groundwater aquifer
x. Inverted wells are designed by constructing a pit covered with river sand on the top layers, gradually increasing gravel size to enable standing water at the downstream of gabion structure to percolate in groundwater aquifer.

Figure 10: Gabion/Check Structure to Reduce the Speed of Flash Flooding

Figure 11: Inverted Well with Gabion/Check Structure

Figure 12: A Perspective View of Leaky Dam

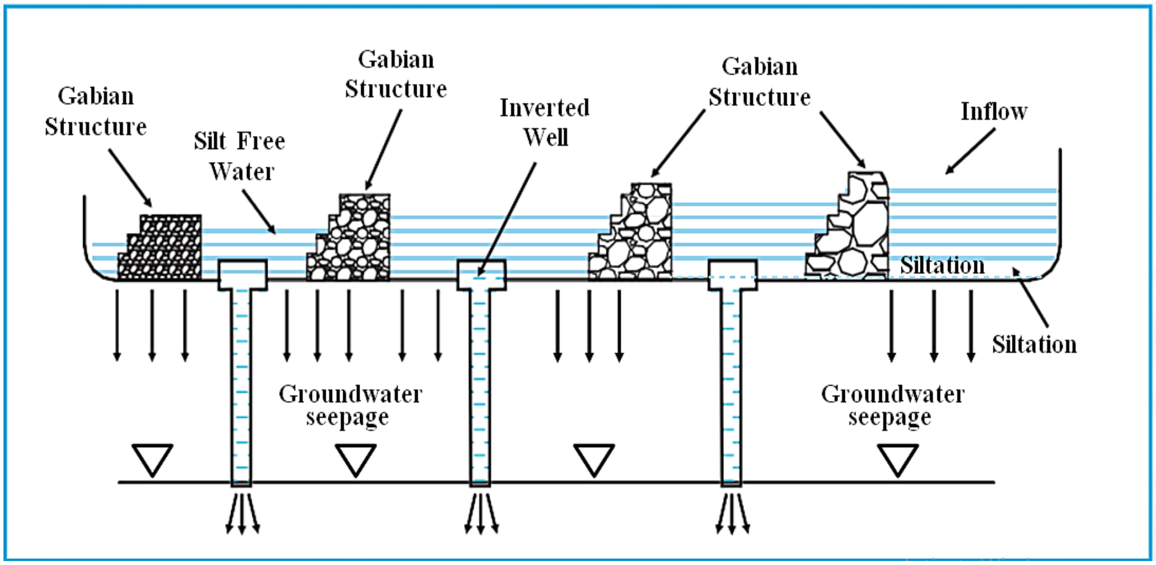

Figure 13: Schematic Concept of Leaky Structures

3.3.2 Surface Rainwater Harvesting in Cities for Artificial Groundwater Recharge

In urban settlements, rainfall accumulates in parks, green belts and road sides creating puddles and an enabling environment for water borne diseases. These puddles of water may be brought into productive use if harvested for artificial groundwater recharge. In urban areas, it is also essential to maintain the aesthetics of environment. In order to design surface runoff in urban areas following step-wise methodology is adopted:

i. Topographic survey of the catchment area for selecting a suitable natural slope to accumulating rainfall runoff followed by recharge through inverted well.
ii. Using historical rainfall data and characteristics of local soil determine peak discharge using Rational Method.
iii. Identify depth to water table for designing soaking pit and recharging shaft for the inverted well.
iv. If the runoff potential is high, the surface water harvesting is done in a lake like structure, directing the flow to an artificial recharge well.
v. In urban landscape where catchment area is small, a simple recharge well with soaking pit may serve the purpose of recharge.

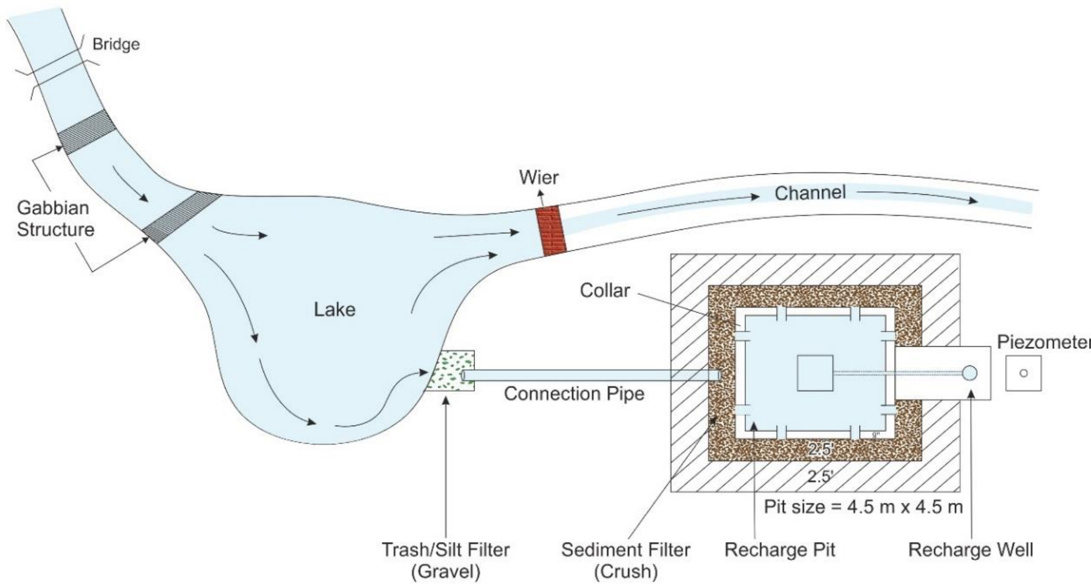

Figure 14: Surface Rainwater Harvesting Options in Urban Areas[2].

3.3.3 Effectiveness of Surface Water Harvesting for Groundwater Recharge

Effective utilization of surface areas for the harvesting and routing of rainwater has a strong potential for recharging an aquifer. This harvesting techniques in urban catchments has the potential to bring viable results to curtail the impact of urban flooding. The assessment of rainfall versus recharge at PCRWR's Lahore and Islamabad offices identifies that a rainfall event of 20 mm or less has the potential to recharge up to 2,000 gallons in urban catchments of Lahore and Islamabad. Figure 14 & 15 show trends of artificial recharge at both of these locations;

[2] Figure 13 shows a plan of surface rainwater harvesting in Kachnar Park, Islamabad followed by artificial groundwater recharge through a recharging pit. The lake has gabion and weirs allowing rainfall runoff to stay in the lake enabling discharge while allowing surplus water to pass over to natural drain.

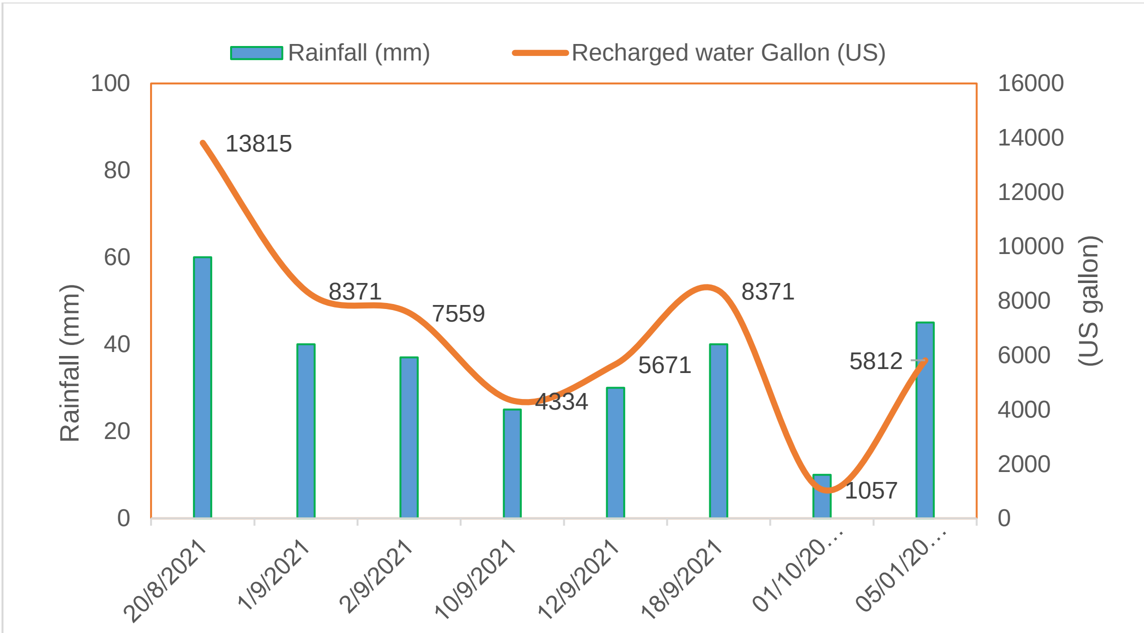

Figure 15: Rainfall vs Groundwater research at PCRWR Regional office, Lahore

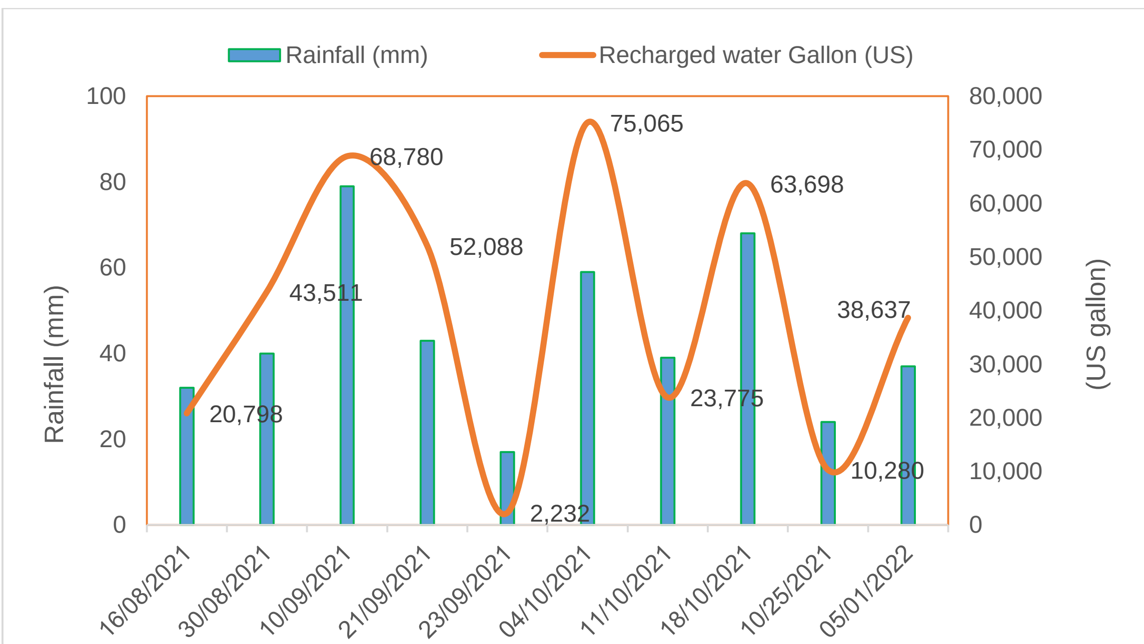

Figure 16: Rainfall vs groundwater recharge at PCRWR head office, Islamabad

Data shown in figures 14& 15 reveals a maximum daily recharge up to 75,000 gallons during a rainfall event of 59 mm in Islamabad. The recharge potential is also dependent on the characteristics of individual rainfall events. A low intensity longer duration rainfall event enables higher recharge whereas and vice versa. In this situation, in urban areas prone to more intensive and short duration rainfall there is a need to develop multiple artificial surface rainwater harvesting and recharge techniques to avoid the situation of urban flooding.

Example 1:

Design a rooftop rainwater harvesting system for a flat concrete roof if its size is 25 m × 15 m and maximum rainfall in a single event is 100 mm.

Given:

Roof surface area = 25 m x 15 m

Maximum rainfall in a single event = 100 mm

Calculate roof surface area = 25 x 15 = 375 m^2

Select runoff coefficient = 0.8 (it varies with roof material and slope)

Calculate runoff (mm) = rainfall x runoff coefficient =100 x 0.8 = 80 mm

Calculate volume of runoff (m^3) = roof area (m^2) x runoff (m) = 375 x 80/1000 = 30 m^3

Determine runoff generated in a single event (liters) = 30x1000 = 30,000

liters (1 m^3 = 1,000 liters) or 6,667 gallon (1 gallon = 4.5 liters).

Option 1: Arrange a tank of required capacity (say 7000 gallons).

Option 2: Construct a storage tank of the required capacity say 30 m^3 (3 m x 3 m x 3.3 m).

The size of the tank can be adjusted according to the situation/need. The tank should preferably be placed at least 1.5 m above the ground surface.

This will eliminate requirement of pumping. If an underground tank is constructed, it should be deep enough to reduce surface area to minimize the evaporation losses.

Example 2:

Design a storage tank for an inclined rooftop with a surface area of 60 m^2 and rainfall event of 80 mm.

Given:

Surface area = 60 m^2

Maximum rainfall in a single event = 80 mm

Select runoff coefficient = 0.9

Calculate runoff (mm) = rainfall x runoff coefficient = 80 x 0.9 = 72 mm

Calculate volume of runoff (m^3) = roof area (m^2) x runoff (m) = 60 x 72/1000 = 4.32 m^3

Calculate runoff generated in a single event (liters) = 4.32x1000 = 4320

liters (1 m^3 = 1000 liters) or 960 gallons (1 gallon = 4.5 liters). Therefore, one tank of 1,000 gallons capacity will be enough.

4. Water Quality Management in Community Water Harvesting Systems

In urban system designs for rainwater harvesting, only water from rooftop or sub surface storage tanks may be brought in direct use, except for drinking after necessary treatments. Quality of rainwater is generally good; it becomes turbid and contaminated by the interaction with catchment areas. There is a general perception that surface water harvested for the recharge of artificial aquifer has the potential of contaminating groundwater aquifers. This however is not true, as the rainwater generally carries no chemical impurities and the filtration pit further clears any physical contaminants. Moreover, the design of leaving the recharge well above groundwater table making way for natural filtration to take place as well. PCRWR has installed artificial groundwater recharge well at its Islamabad and Lahore offices and regularly monitors the quality of rainwater being collected in the recharge pit and the quality of water passing through the filtration process;

Table 1: A comparison of rainwater water quality at different stages of harvesting, PCRWR Lahore Office

		Rain Gauge		Surface Runoff		Recharge Well	
		EC (dS/m)	pH	EC (dS/m)	pH	EC (dS/m)	pH
1-Aug-21	22	75	6.8	157	7.3	298	7.1
2-Aug-21	30	100	6.7	217	7.3	447	7.1
3-Aug-21	34	92	6.6	163	7.5	327	7.3
6-Aug-21	48	100	6.7	228	7.8	450	7.7
20-Aug-21	60	117	6.9	220	7.7	417	7.5
1-Sep-21	40	103	6.9	150	6.8	217	7.7
2-Sep-21	37	53	6.6	108	7.0	260	7.5
10-Sep-21	25	32	6.8	150	7.3	347	7.3
11-Sep-21	30	40	6.6	147	7.1	345	7.2
12-Sep-21	40	37	6.8	145	7.0	353	7.0

Water quality data at different stages of rainwater harvesting shows that the quality of harvested water remains fresh after passing through the filtration. The recharge well releases harvested rainwater at least 12 meters above the groundwater table allowing for natural recharge the impervious layers of soil above the aquifer. Likewise, the table 2 reveals similar facts about the quality of recharged groundwater in Islamabad;

Table 2: A comparison of rainwater water quality at different stages of harvesting, PCRWR Islamabad Office

Rainfall event	Rainfall depth (mm)	Rainfall Water Quality		Recharge Well Water Quality	
		EC (µS/cm)	pH	EC (µS/cm)	pH
4-Sep-20	7	47	6.9	380	7.0
19-April-21	21	61	6.9	369	7.0
23-April-21	13	57	6.9	257	6.9
17-May-21	28	92	6.9	292	7.0
31-May-21	6	62	6.9	269	7.0
10-Sep-21	79	38	7.2	240	7.4
06-March-22	25	95	6.8	225	7.0
15-Jun-22	32	105	6.9	390	6.9
10-Sep-22	18	58	6.8	387	7.1

However, rooftop rainwater stored in tanks may develop microbiological contamination with the passage of time. In order to manage the quality of rainwater following options may be opted;

4.1 Clean Catchment Areas

As domestic level roof top is the main catchment area that collects rainwater in storage tank, it is essential to keep rooftop clean. Rooftop drains needs to be checked occasionally for any blockage due to dirt and debris.

4.2 Chlorination

Chlorination is done either in the tank or after the water is collected. Chlorination may be done using a number of methods, liquid chlorination, tablets of sodium hypochlorite and elemental gas. House hold scale liquid bleach is the most readily available option for performing chlorination. If a 1,000 gallon storage tank is heavily contaminated it is recommended to use 1-2 gallons of liquid bleach for the treatment. However, for a freshly collected rainwater, 0.5 liters of liquid bleach is sufficient.

4.3 Filtration

Gravity filtration is the most cost effective but slow process of treating rainwater. If rainwater is immediately needed after the harvesting, it is recommended to use an automatic filter consisting of an assembly of turbidity filters, carbon filters and UV lamp.

4.4 Boiling

This is most conventional remedy for treatment of water at domestic level. Boiling is effective only for certain type of bacteria that does not survive on high temperatures.

5. Operation and Maintenance

5.1 Rooftop and Recharge Sites

It is extremely important to maintain the rainwater harvesting systems regularly for high quality performance. Following aspects should be taken care of:

- Just before the arrival of monsoon, the rooftop/catchment area has to be cleaned properly.
- The roof outlet on the terrace should be covered with a mesh to prevent entry of leaves or other solid waste into the system.
- The filter materials have to be either replaced or washed properly before the monsoon.
- The diversion valve has to be opened for the first 5 to 10 minutes of rain to dispose off the polluted first flush.
- All polluted water should be taken away from the recharge structures.
- The depth of bores (of recharge structures) shall be finalized depending on the actual site condition.

Table 3: Maintenance of Rainwater Harvesting Systems

Parts	Maintenance	Frequency
Roof	Wash off roof with water before arrival of monsoon diverting run-off away from tank inlet.	Monthly and especially after a long period of dry weather or heavy wind.
	Sweep off leaf litter	Regularly, especially after heavy winds and just before the rains set in, Check daily for leaf litter accumulation during the rainy season
	Trim and cut trees around roof	When required
	Fix damage to roof (broken tiles, cracked water-proofing, etc.)	At the earliest and definitely before the rainy season

	Paint if rust is present using lead-free paint	At the earliest and before the rainy season
Gutter and pipe	Clean and wash out bird droppings, leaves, etc., with water Check and repair gutter and down take pipes Ensure guttering /down take pipes are sloped to ensure steady flow and avoid pooling of water, collection of dirt, debris, etc. Repairs leaks at elbows	Check monthly and especially after a long period of dry weather or heavy wind. Check daily during rainy season When required During installation and after periods of heavy rain When required
Filters First-flush devices	Check and clean	Before and after rainy season Before and after the rainy season and after every rooftop cleaning session
Tank	Clean Repair leaks Cut nearby tree roots (if underground tank) Ensure lid is sturdy and secure Ensure there are no gaps where insects can enter or exit Securely fasten insect screen over the end of the overflow pipe/valve	Before and after rainy season At the earliest

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7. Appendix

Rainfall Intensity

Rainfall intensity is the quantity of rain falling in a given time over an area, and can be expressed in terms of cm/h or mm/h.

Rain duration

Rain duration is the period of time during which a rainfall event takes place, and can be expressed in hours or minutes depending upon the duration and purpose.

Rainfall frequency

Frequency of rainfall is the frequency within which a given amount of rain falls over a given period, e.g. once in four years, once in six years, etc.

Magnitude of rainfall is the total amount of rain falling at a point over a given period of time, i.e. daily, monthly, annually.

About PCRWR

PCRWR is an apex body of the Ministry of Water Resources and is mandated to conduct, organize, coordinate and promote research on all aspects of water resources including irrigation (surface and groundwater), drainage, soil reclamation, drinking water and wastewater. It has eight regional offices located at different agro-ecological zones and each centre conducts research on water-related issues of the respective zones. These Regional Offices are located at Lahore, Bahawalpur, Tandojam, Quetta, Peshawar, Karachi, Gilgit and Muzaffarabad. Besides these eight Regional Offices, PCRWR has a setup of 24 water quality testing and research laboratories in major cities of the country. This includes ISO-17025 accredited National Water Quality Laboratory having its own Laboratory Information Management System (LIMS). PCRWR has all types of infrastructure such as soil and water testing laboratories, groundwater assessment equipment, research farms to conduct and disseminate the research regarding water efficiency in agriculture. It is the only organization in Pakistan that owns drainage type lysimeters in Lahore, Tandojam, Quetta and Peshawar. PCRWR has done considerable work on crop water requirements, tile drainage, soil reclamation, on-farm water management technologies, rainwater harvesting, artificial groundwater recharge, groundwater assessment and management, skimming wells, drinking water, drinking water assessment and management alongwith indigenous development of drinking water testing and treatment technologies and indigenous development of salinity and moisture sensors. To help in developing the capacity of in-service professionals and fresh graduates, PCRWR has also a well-equipped National Capacity Building Institute in Islamabad.

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