Prospects, Principles and Practice of Urban Rainwater Harvesting in Bangladesh

A Guidebook for Professionals, Practitioners and Students

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developed by
ITN-BUET

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Contents

1.0 Introduction

Rainwater harvesting is a widely used term covering all those techniques whereby rain is intercepted and used ‘close’ to where it first reaches the earth. The typical uses of this intercepted rainwater are drinking and domestic use (after proper treatment), garden irrigation, water closet flushing, etc. Often the rainwater is just redirected to a deep pit for percolation (artificial groundwater recharge). Rainwater harvesting is an old technology; it has been practiced in different cultures and societies in different parts of the world from ancient times. Yet, a renewed interest regarding this technology among modern day engineers and water practitioners has been observed mainly due to the following reasons:

- RWH can be considered as a probable solution of drinking water crisis in areas where there is no possibility of providing safe water cheaply within a reasonable distance of homes, because the ground conditions are unsuitable and surface waters are polluted or absent. For example, the ground may be impermeable (rock/stony layers precluding tubewell construction), groundwater may be over-mineralized by fluorides, iron or even heavy metals (e.g. Arsenic contamination in Bangladesh), or the aquifer may have saline zones, such as in the coastal areas. The aquifer may be too deep to reach or groundwater table may be rapidly declining. In these situations the harvested rainwater can be a valuable alternate water supply option. The rainwater is free from arsenic and other impurities. The physical, chemical and bacteriological characteristics of harvested rainwater usually represent a suitable and acceptable standard of potable water.
- In the context of urban environment, adopting rainwater harvesting technology can reduce the pressure on municipal water supply. In recent years, rainwater harvesting has been adopted in developed nations to reduce runoff and to provide supplemental water for garden irrigation and water closet flushing. It is widely recognized that rainwater can replace potable water for several less quality-demanding water uses such as house toilet-flushing, terrace cleaning or private garden watering. It has been estimated that 30% of the water consumed in houses are typically used for toilet-flushing. Therefore, use of rainwater for water closet flushing is a simple and practical method of reducing the demand on both the public water supplies and waste treatment facilities.

- In urban areas, rapid population growth may collide with constraints on expanding water supplies from traditional sources. Often the expansion of existing centralized water infrastructure may require huge investments which may not be immediately available. In such cases, gradually moving towards a decentralized water supply system such as rainwater harvesting can be thought of as a useful strategy.

The advantages of using rainwater are the following:

- Rainwater is a safe source of drinking water and naturally free from bacteria and harmful chemicals. The physical and chemical properties of rainwater may be superior to those of groundwater or surface waters that may have been subjected to pollution, sometimes from unknown sources.
- The end use of harvested water is located close to the source, eliminating the need for complex and costly distribution systems.
- Rainwater harvesting provides a source of water at the point where it is needed. It is owner-operated and managed. The system is independent and suitable for scattered settlements.
- It provides an essential reserve in times of emergency and/or breakdown of public water supply systems, particularly during natural disasters.
- The construction of a rooftop rainwater catchment system is simple, and local people can easily be trained to build one, minimizing its cost.
- The technology is flexible. The systems can be built to meet almost any requirements. Poor households can start with a single small tank and add more when they can afford them.
- Running costs are low, and construction, operation, and maintenance are not labor-intensive. Since it is primarily a household technology, it usually does not require communal or commercial management.
- The zero hardness of rainwater helps prevent scale formation on appliances, extending their life; no water softener is required to treat the water.
- Rainwater is sodium-free, which is important for persons on low-sodium diets.

Some disadvantages are:

- The initial cost may prevent a family from installing a RWHS.
- Mineral free rainwater has a flat taste, which may not be liked by many. It may also cause nutrient deficiencies of trace minerals among users.
- Since the distribution of rainfall is not equal throughout the year, large capacity tank is needed to store requisite amount of water to serve during dry period.
- Unavailability of suitable catchment of adequate capacity for harvesting rainwater can be an issue. This could be the case of most poor people in rural areas who cannot afford to install the roofs which are suitable rainwater catchments.
- Due to lack of proper maintenance of catchment and storage system, bacterial contamination may occur.
- The success of rainfall harvesting depends upon the frequency and amount of rainfall; therefore, it is not a dependable water source in times of dry weather or prolonged drought.
- Where treatment of water prior to potable use is infrequent, due to a lack of adequate resources or knowledge, health risks may result. Further, cisterns can be a breeding ground for mosquitoes.

In urban areas, most buildings have a water demand based on the purpose of the building. Activities or facilities in a building requiring water include bathrooms, kitchens, manufacturing processes, fire suppression, cooling towers and so forth. The necessary task is to determine what percentage of that building’s demand can be met by site collected water. For practical reasons and to meet limited budget requirements, replacing all of a building’s water consumption with roof-collected rainwater is not necessarily the end goal. Alternatively, the design goal is to provide as much of the necessary water supply from rainwater or alternative water sources, thus reducing the demand on the municipal water system.

2.0 Elements of a Rainwater Harvesting System

The fundamental elements of a rainwater harvesting system include:

- **Collection/Catchment Surface:** The collection surface from where the rainfall runs off.
- **Conveyance:** Roof runoff is typically conveyed to a rainwater collection system via gutters with downspouts or roof area drains with leaders. Filtration devices are often used to remove particulate contaminants en-route to storage. In some systems, a first-flush method is used to completely bypass an initial amount of roof runoff so that it cannot enter storage.
- **Storage:** Tanks or cisterns are used to store harvested rainwater which may be placed in various locations. A number of processes automatically occur within the tank itself such as settlement, flotation and pathogen die-off. Finally, some technique of disinfection (such as chlorination, solar disinfection or use of a ceramic filter) may be employed to the water after it is drawn from the tank.
- **Distribution/delivery system (in buildings) :** Using harvested rainwater to fulfill designated uses in building of urban areas normally requires pressurizing, filtering, treating, controlling flow to end use, monitoring storage tank levels, and/or controlling the need for switching to backup/bypass/makeup water.

Figure 1, Figure 2 and Figure 3 show a schematic of the different components of a typical RWHS, a typical RWHS in buildings and process diagram of domestic RWHS, respectively.

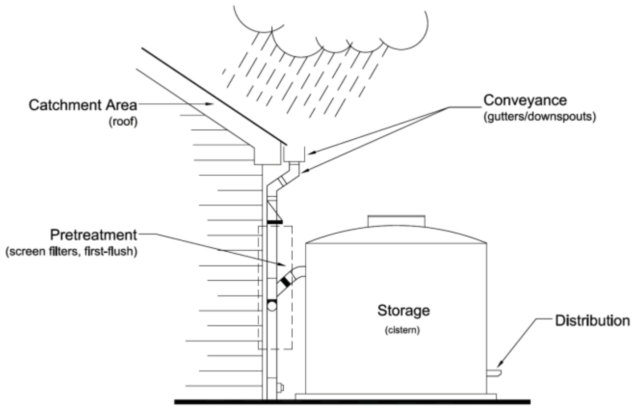


Figure 1: Different components of a typical RWHS
(adapted from: Waterfall, 2004)

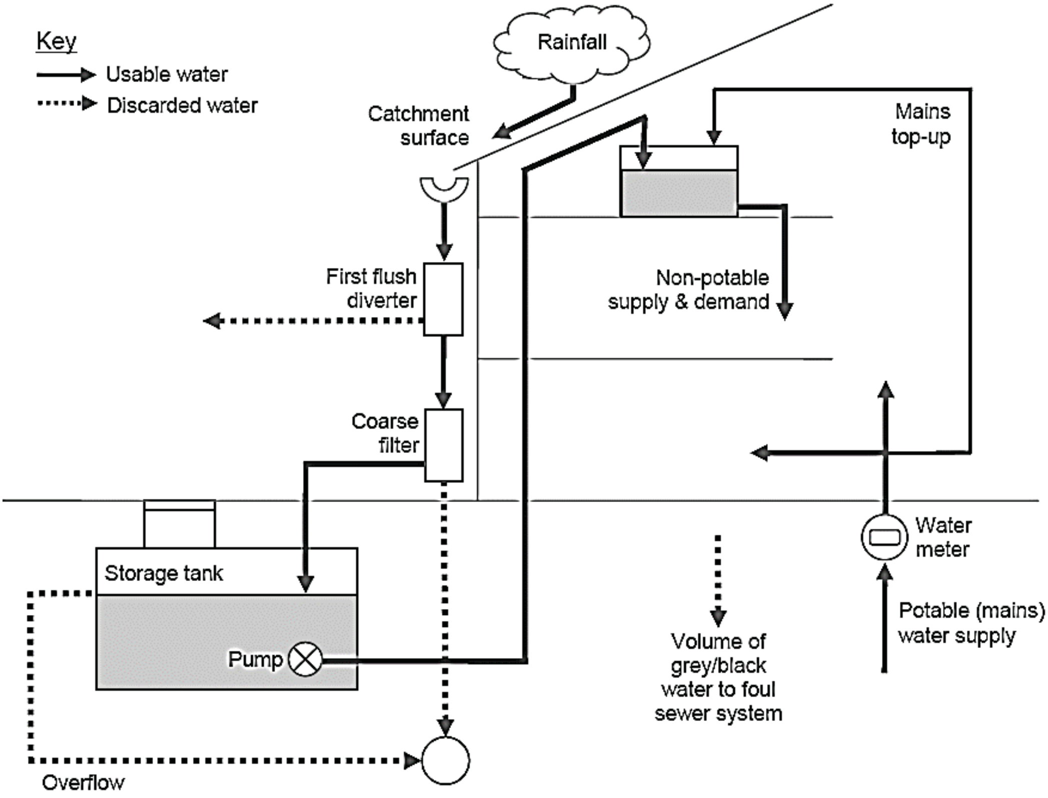


Figure 2: Different components of a typical RWHS in a building (urban context) (Roebuck 2007)

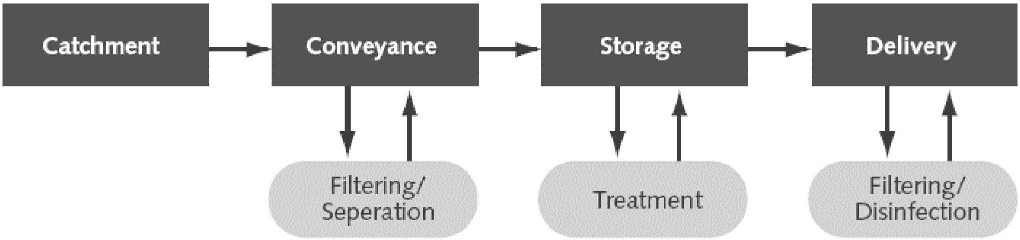


Figure 3: Process Diagram of domestic RWHS (Thomas and Martinson, 2007)

2.1 Collection/ Catchment Surface

A catchment is an extent of exposed surface area on which precipitation falls and flows towards a draining point. The volume and rate of rainwater runoff are functions of catchment area, intensity and duration of rainfall, slope of the surface, and type of surface material. Roofs are considered as the first and most effective choice for catchments. In buildings, besides the roof, verandahs and balconies, sunshades and cornices, car porch and part of any side walls can also be considered as part of the rainwater catchment.

Water quality from different roof catchments is a function of the type of roof material, climatic conditions, and the surrounding environment. Thin metal sheets (Galvanized iron, mild steel etc.), often corrugated, are the most commonly used roofing material in rural areas. Because of the smooth texture, the rainwater collection is very efficient. Some caution must be exercised regarding roofing surface paints. Asbestos sheeting or lead-painted surfaces should be avoided by all means. Rainwater collected from roofs with copper flashings may cause discoloration of porcelain fixtures. Roofs made of clay or concrete tiles deliver rainwater which are suitable for both potable and non-potable use, but may contribute as much as a 10 percent loss due to rough texture, obstacles in flow, evaporation and porosity. Bacterial growth is encouraged in rough surfaces and dirt may be accumulated on the corner of the tiles. To reduce water loss and prevent growth of microorganisms, tiles are painted or coated with a sealant. In this case, special sealants should be used containing little or no toxic materials. Roofing materials made of asphalt shingles (tar-like hydrocarbon speckled with colored small ceramic granules) are prone to leaching of toxins from colored shingles and the harvested water may not be appropriate for direct consumption as potable water.

The roof runoff coefficient (*f*), which is the ratio between the amount of rainwater received from a rain event and the actual rainwater delivered via the gutters and downpipes, varies significantly based on roof material, slope of the roof, etc. This parameter varies in between 0.75 - 0.85. For general purpose, a value of *f* = 0.80 is typically used.

Various factors in the building program influence roofing material choices, including the client's preferred aesthetics, budget, code requirements, energy efficiency goals, and so forth. Existing construction design may also be the determining factor influencing roofing choices.

Determining Catchment Area

For flat surface, the catchment area is its plan area plus 50 per cent of the adjoining vertical wall contributing rainwater accumulation on the concerned catchment. Let us consider a building having a flat roof at different levels as shown in Figure 4. In the topmost level, the area ABDC of terrace T1 is the catchment area contributing to the rainwater downpipe RDP1. In level 2, horizontal area EFHG and 50 percent of the vertical wall surface area AFHM are the catchment area for the rainwater downpipe RDP2. For the rainwater downpipe RDP3, the catchment area will be the terrace at levels 2 and 3 as well as 50 percent of the adjacent walls AFHM, GIJH and MJLC.

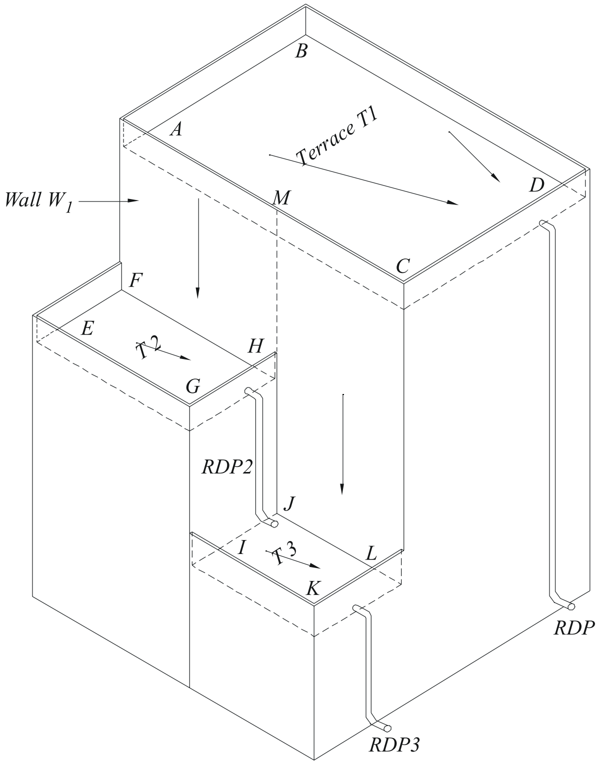


Figure 4: Catchment area of flat roof and surface wall. (Haq, 2006)

Problem 1: For the roof configuration as shown in Figure 4, if the areas ABDC, EFHG, AFHM, MJLC, GIJH and IJLK are 35 m^2, 8 m^2, 12 m^2, 18 m^2, 8 m^2 and 6 m^2 respectively, what would be the total contributing catchment areas corresponding to rainwater downpipes RDP1, RDP2 and RDP3?

Solution:

Catchment area for RDP1 = Area ABDC = 35 m^2

Catchment area for RDP2 = area EFHG + 0.5× area AFHM = 8+0.5×12
= 14m^2

Catchment area for RDP3 = area IJLK + 0.5× area (MJLC+GIJH)
+ catchment area for RDP2
= 6 + (18+ 8)×0.5 +14 = 33 m^2

In determining the total effective catchment area of a building having inclined roof, the contributing catchment will be the total inclined area of the roof. The roof footprint of various roof configurations is shown in the following Figure 5.

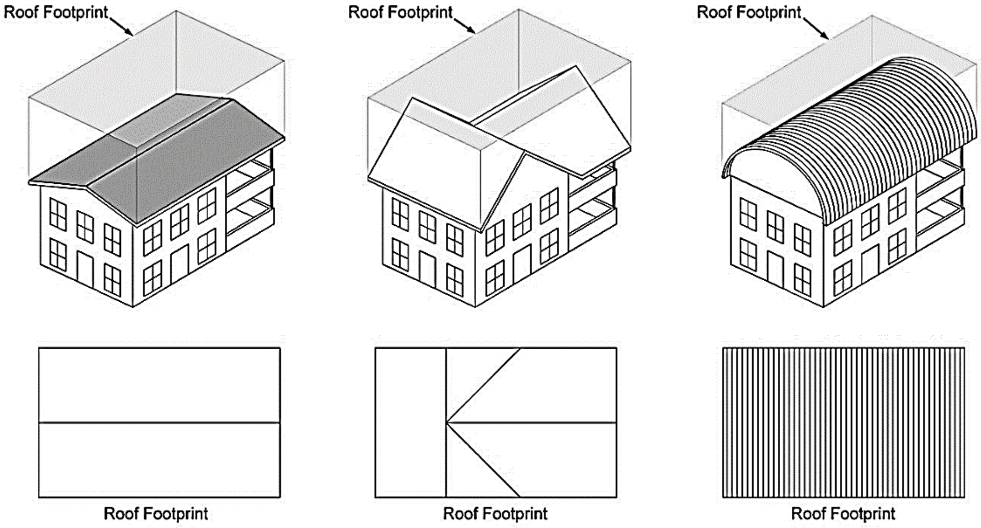


Figure 5: Roof footprint for rainwater harvesting for various roof configurations (image source: rainwaterharvesting.tamu.edu)

2.2 Rainwater Conveyance

Rainwater is typically conveyed from the collection surface (roof) to a storage tank or cistern in two ways (Figure 6):

1. A sloped roof typically drains to gutters and downspouts at the outer edges of the building envelope. Scuppers, oversized gutters, and other methods are employed for overflow protection.
2. A flat or semi-flat roof may use roof area drains that connect to leaders (downspouts/ rainwater downpipes). These leaders penetrate the roof, and flow either overhead to the exterior or down and then under the floor to the building's exterior. Siphonic and gravity-drained pipes then convey the water down to the storage vessel. Particularly for horizontal surfaces, there shall be parapet around the surface to prevent freefall of rainwater.

Gutter comes in a wide variety of shapes and forms, ranging from the factory made PVC type to homemade gutter using bamboo or folding metal sheet. 'V' shaped gutters from galvanized steel sheet can be simply made by cutting and folding flat galvanized steel sheet. The gutter can easily be hung along the edge of the roof with hanger. The hanger can be made easily with MS rod of 6mm diameter or MS flat bar.

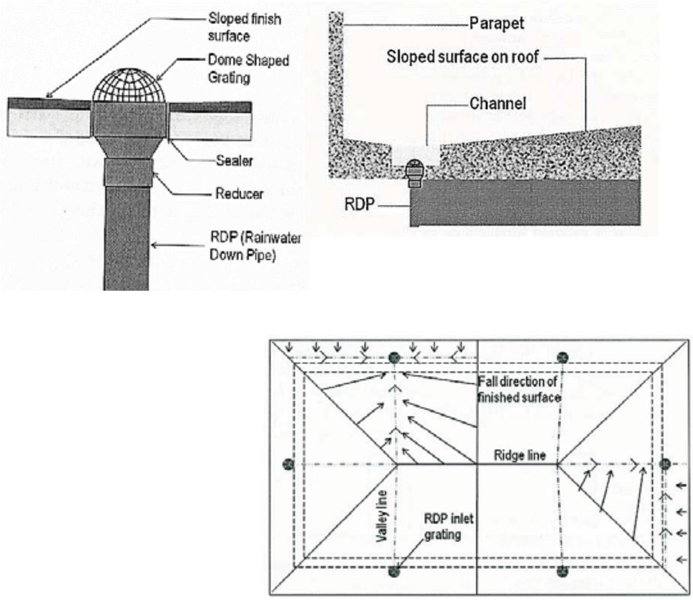


Figure 6: Configurations of gutters and rainwater downpipes on roofs (image source: *Rainwater harvesting in buildings* (unpublished manuscript) by Syed Azizul Haque, used with permission)

Designing the gutter for buildings

To find the design and size of the gutter, it is necessary to calculate the rainwater discharge rate from the roof which requires assessing the rainfall rate and the effective catchment area from where the rainfall is collected. The gutter has to be designed to provide sufficient capacity for the predicted discharge rate. The following design considerations may be adopted:

- The slope of the gutter should be less than 1:350.
- The gutter should have uniform cross-section.
- The outlets should be large enough so that the gutter discharges freely
- The depth of water in the gutter will vary from a maximum at the upstream end to a minimum of "critical depth" at the outlet, depending on the gutter shape and slope. For gutters with rectangular section, the maximum water depth equals twice the depth at the outlet.
- The dimensions from a stop end to outlet should be less than 50 times the maximum water depth.
- The dimensions between outlets should be less than 100 times the maximum water depth.
- Freeboard should be provided to allow for splashing and wave action. The recommended minimum freeboard depth varies between 25 mm and 0.3 times the total gutter depth up to a maximum of 75 mm. A minimum freeboard of 50 mm is often considered a good practice.

The sizing of a semi-circular gutter shall be based on the maximum projected roof area and slope of the roof as per Table 1 (BNBC 2015)

Table 1: Size of Semicircular Roof Gutters*

Dia of Gutter (mm)	Maximum Projected Roof Area for Gutter of Various Slopes							
	5 mm per m		10 mm per m		20 mm per m		40 mm per m	
	m^2	L/min	m^2	L/min	m^2	L/min	m^2	L/min
75	61	25	87	36	123	51	174	73
100	130	55	185	77	260	110	370	155
125	227	96	320	136	455	192	645	273
150	350	148	495	210	700	296	1010	425
175	503	210	710	300	1000	425	1420	600
200	725	307	1020	430	1300	610	2040	862
250	1300	555	1850	785	2610	1110	3650	1540

* Based upon a maximum rainfall of 25 mm per hour for 1-hour duration. The catchment area may be calculated based on the recommendations in the previous section.

Sizing of Rainwater Down Pipe (RDP)

The size and number of vertical leaders or Rainwater Down Pipe (RDP) shall be based on the maximum projected roof area according to the following Table 2 (BNBC 2015). Minimum two drains and vertical leaders shall be provided for any independent roof surface. Minimum diameter of RDP shall not be less than 50 mm.

Table 2: Size of vertical leaders*

Size of Leader** (mm)	Maximum projected roof area (m^2)	Flow (l/min)
50	202	87
65	367	155
75	598	253
100	1287	544
125	2336	986
150	3790	1602
200	8180	3450

* Based upon a maximum rainfall of 25 mm per hour for 1-hour duration. The figure for drainage area shall be adjusted to local conditions

** The equivalent diameter of square leader will be the diameter of that circle which can be inscribed within the cross-sectional area. The equivalent diameter of the rectangular leader will be the short dimension of the rectangular leader. However, the ratio of width to depth of rectangular leader shall not exceed 3:1.

Rainwater downpipe can rarely be installed vertical. In majority cases keeping the inlet vertical the pipe is offset either at top or at bottom. Sometimes at an intermediate level, the rainwater downpipe is needed to be made offset. So it is wise to consider the capacity of rainwater downpipe having both horizontal and vertical alignment. Diameter of a horizontal rainwater conveying pipe shall be based on the maximum projected roof area, slope of roof and intensity or rainfall as in the case of the design of semi-circular gutters (see Table 2). Slope of horizontal portion of pipe is considered to be 100:1. Rainwater downpipes should be proportionately distributed along all the sides of the building.

2.3 Rainwater Storage

While the tank is the largest component of storage, there are numerous supporting components that are fundamental to the functioning of this element. The components of a storage system include the following (Figure 7): (1) Tank, (2) Rainwater Inlet from Conveyance (may enter the tank from top, side, or bottom via riser), (3) Calming Inlet (minimizes disturbance of sediment at bottom of tank by reducing agitation from the incoming water), (4) Intake (provides extraction of water from a location below top surface. Generally, higher water quality is found below the top surface and above the very bottom of the tank. A floating screen inlet reduces vortexing and the introduction of air into the pumping system. An alternative is to provide a fixed intake with a screen to reduce vortexing placed at a minimum of

6-8 inches above the bottom of the tank.) (5) Water Level Indicator (device to monitor water level in tank and communicate with components in distribution, floating or electronic-based) (6) Overflow (excess water flows out of tank to grade, stormwater sewer, stormwater control devices, or other appropriate path as per local requirements/system goals) (7) Vent (provides ventilation for stored water and pressure relief from incoming water) (8) Tank Access (should be secured to prevent unauthorized access, access from belowground tanks should be minimum 4 inches above surrounding grade).

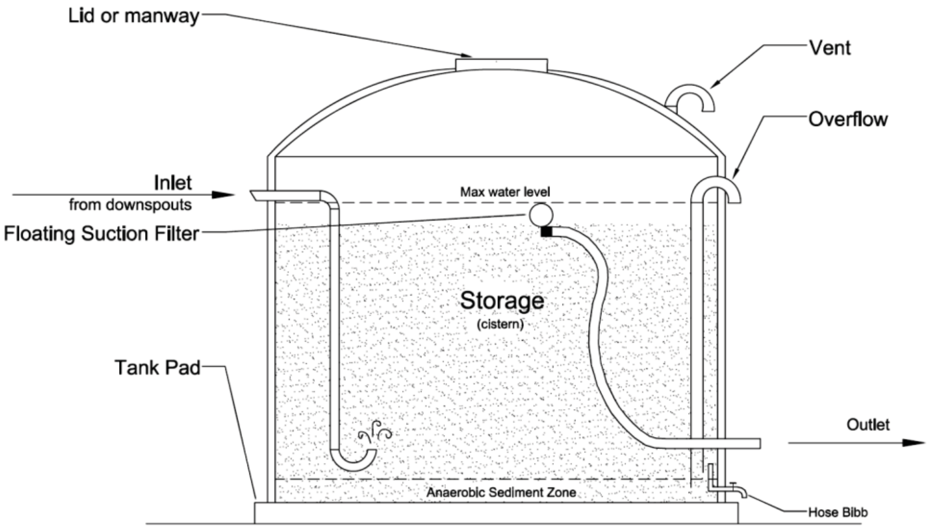


Figure 7: Different components of a rainfall cistern

While some of the above components (e.g. electronic water level indicator, floating intake) may be too sophisticated for rural RWHS, the other basic components can be installed with locally available materials and indigenous methods consistent with the best management practices to reduce contamination.

In nearly all instances, the storage tank will at some point overflow. The overflow must be at least equal to the inlet in terms of pipe size. Failing to plan for this important part of a storage tank will result in the water backing up into the conveyance pipe or out of the top of the tank. The open end of all pipes shall be covered with mosquito (insect) proof wire net. Storage tank shall be kept covered and lights must be excluded to prevent growth of algae and microorganisms. The tank is to be placed in such a way so that the water temperature is kept as low as possible to limit bacterial and algal growth. The inner surface of the tank shall be finished very smooth having no cracks or holes and no paints having toxic materials should be used. Regular cleaning at least once a year, preferably at end of dry periods, should be done. Disinfection of tankwater should be done after cleaning operation. Sizing of the tank must be done based on its intended water use. Storage will vary in size and can be aboveground, belowground, outside, or inside the building structure. Materials differ in appearance and application. Numerous factors influence the most appropriate size, type, materials, and location of a tank or cistern.

Location of Storage tanks

Rainwater can be stored at various locations of a building (Figure 8) depending upon the technological suitability, safety and economy. In buildings, the general preference is to store inside; the usual locations of the reservoirs are either on the top or the bottom level of the building but it can also be at intermediate locations. Intermediate locations are preferred particularly in high-rise buildings, when the static water pressure in the piping at any intermediate level exceeds the maximum allowable limit of pressure (>100 psi). For buildings having sufficient space outside for the purpose, the storage tanks can also be placed there. The factors that can affect the location of a tank are:

- Space requirement: exterior storage tank would be preferred if sufficient space is available within the property boundary.
- Conveyance strategies to tank location: If the tank is located on the top of the building, the length of inlet collection pipe will be smaller; in some cases rainwater can be collected directly without collection pipes.
- Conveyance to the end-use location: Required connectivity to various conveyances and distribution routes may be more readily achieved using certain types of tanks. If the tank is located outside the building, the requirement of piping would be more to convey the water to the end-use location. Exterior tank or tanks located at the bottom of the building would also require pumping to convey water to the end-use point, whereas in other options the conveyance would have been by gravity.
- Site constraints: Conflicts with utilities and future expansion plans might dictate the location of the tank. Potential conflicts for interactions

between subsurface utilities and conveyance piping must be assessed early in the design process to prevent costly consequences.

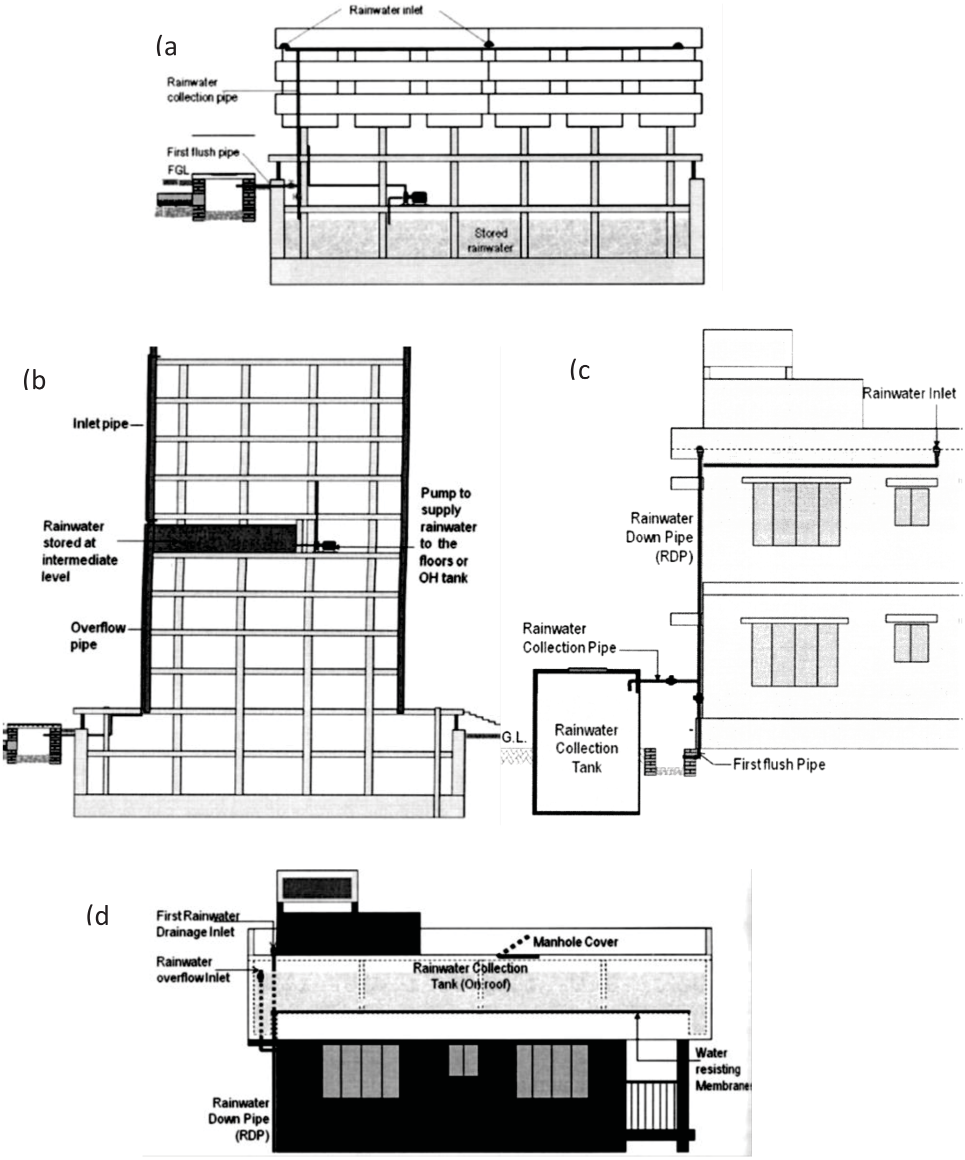


Figure 8: Different locations of Rainwater storage (a) storage inside the building below ground level (b) storage inside a high-rise building at an intermediate level (c) storage outside the building (d) storage just under the roof on top of a building (image source: *Rainwater harvesting in buildings* (unpublished manuscript) by Syed Azizul Haque, used with permission)

- Structural Design Considerations: Storing water outside or at the bottom of the building will not impose any extra load on the building. Building code may not allow top of the building storage tank in some countries/ areas due to earthquake considerations. Besides, where there is restriction in height of building, the extra height for storage may not be allowable. Again, if proper protection is not taken, leakage from underground storage reservoirs can cause deterioration of load-bearing properties of soil that support the building foundation as well as capacity of load-bearing structural elements.
- Aesthetics: Tank outside the building will occupy valuable space. Visibility of the tank outside the building may be aesthetically unpleasant in some instances. The architect may consider the tank as an essential part of the building's architecture and devise ways to accommodate it without affecting the aesthetics.

The designer should think about all the factors affecting the function, aesthetics, and costs (initial and long-term) of all the elements in a rainwater harvesting system. Finding the best storage tank and supporting components for a particular application would be the key to a successful system.

Figure 9: Rooftop rainwater storage tank arrangements at BUET cafeteria (left) and Independent University Bangladesh (IUB) (right)

Tank Sizing

The capacity of the storage tank is an important determinant of the RWHS as it will dictate how much of the mains water (i.e., supply water) may be conserved (i.e. water saving efficiency), how much will be the installation cost, how much rainwater can be retained (affects the quality of water) and how much water is overflown into the surface drains. The tank needs to be large enough to ensure that:

- The required volume of water can be collected by the tank, and
- The volume of water in the tank is sufficient to meet demand during the drier months or through periods of low or no rainfall.

In general, it is found that storage capacity cannot be standardized, being markedly influenced by site-specific variables such as local rainfall, roof area, potable water demand and number of people in the household. There are numerous methods available for predicting the performance of RWH systems or to determine the storage capacity of a RWH tank to satisfy a given demand for a certain pattern of precipitation conditions and these ranges from the relatively simple, such as "rule-of-thumb" approaches to the more complex, such as statistical methods and sophisticated computer programs. The following sizing methodologies can be used to size rainwater tanks:

(a) Dry season demand vs. supply
(b) Simple Water Budget
(c) Computer-based Simulation Methods

(a) Dry Season Demand vs. Supply: This methodology is generally well suited for arid climates, which have a distinct dry season. In this case, the water demand during the dry season is estimated and the cistern is sized to store enough water to sustain the dry season. According to this method,

Size of storage tank, $V = n \times d \times q$

Where n : no. of water users
d : no. of dry days / scarcity period
q : per capita demand

BNBC recommends the number of dry days/ scarcity periods to be 90 days for drinking, cooking, utensils cleansing, bathing and ablution purposes; 210 days for other purposes. Also typically, 10% extra volume is provided as freeboard.

Problem 2: If the number of people in a family = 6 and per capita consumption of water per day = 10 liters, determine the required volume of the storage tank based on minimum requirements assuming a 100 day dry-period.

Solution: Tank volume = $n \times q \times d = 6 \times 10 \times 100 = 6{,}000$ liters
For Free board, add 10 per cent volume = 600 liters.
A storage of 6,600 liters (6.6 m^3) can be built

The dry season demand volume should also be compared to the potential rainfall capture associated with the rainy season to confirm that the cistern has the potential for being full at the start of the dry season. If not, the cistern may be considered to be reduced in size for cost savings. An example problem for such a case is given below:

> ***Problem 3:*** If the number of people in a family = 5 and per capita consumption of water per day = 60 liters, average total dry-period rainfall = 250 mm, catchment area = 100 m^2 and runoff coefficient = 0.8, determine the required volume of the storage tank based on minimum requirements assuming a 100 day dry-period.
>
> ***Solution:***
>
> Total demand for dry period = 5 × 60 ×100= 30,000 liters
>
> Rainfall supply = runoff coefficient × catchment area × average rainfall = 0.8 ×100 m^2 × 250 mm = 20,000 liters
>
> Since rainfall supply < total demand for water, tank volume = 20,000 liters
>
> For Free board, add 10 per cent volume = 2000 liters.
>
> A storage of 22,000 liters (22 m^3) can be built

Features of the method:

- Simplest approach to system design but is relevant only in areas where distinct dry seasons exist.
- Provides a rough estimate of storage volume requirements.
- This method does not take into account variations between different years, such as the occurrence of drought years. It also entirely ignores rainfall input and the capacity of the catchment to deliver the runoff necessary to fill the storage tank.
- This technique can be used in the absence of any rainfall data and is easily understandable to the layperson. These issues can be particularly relevant when designing systems in the remote areas of developing countries where obtaining reliable rainfall data can be difficult.

Sometimes, if the monthly mean rainfall data is available, it can be used to determine the storage tank size. If the total rainfall supply over the year is lower than the yearly demand of water, supply side would govern (as in the previous example) and the demand has to be modified to utilize the limited amount of water available. A mass curve method may be applied to arrive at the size of the tank necessary to meet this demand. The following example depicts the calculation procedure:

Problem 4: For a medical dispensary, the following data is available:
Demand:

- Number of staff: 7
- Staff water consumption: 45 litres per day
- Patients: 40
- Patient water consumption : 10 litres per day

Supply:

- Roof area: 190m^2
- Runoff coefficient (for new corrugated GI roof): 0.9
- Average annual rainfall: 1056 mm per year

The distribution of rainfall is as follows:

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rainfall (mm)	114	101	136	214	75	3	5	15	47	88	124	134

Determine the size of the rainwater storage tank for this facility

Solution:

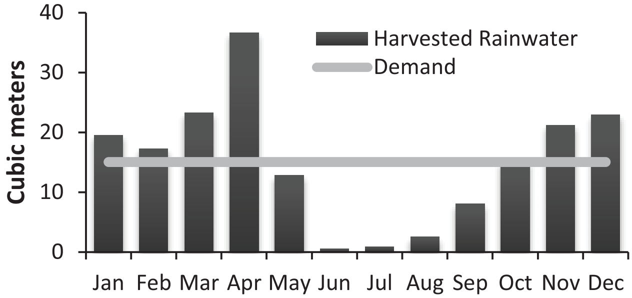
Total demand: 7×45 + 40×10 = 715 litres per day or 21.75 cubic metres per mean month

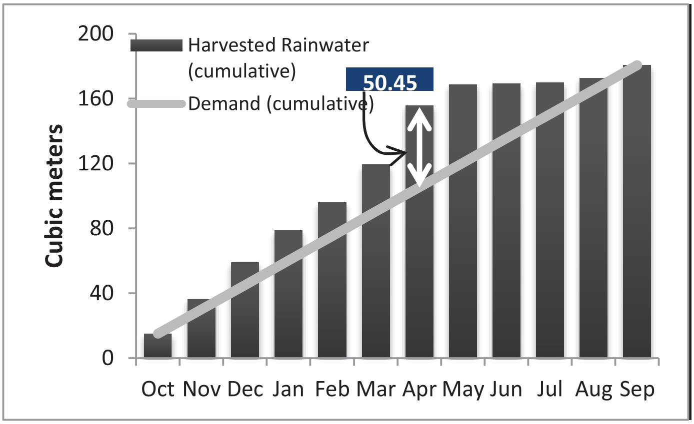
Annual available rainwater (assuming all is collected) = 190 × 1.056 × 0.9 = 180.58m^3

Daily available water = 180.58 / 365 = 0.4947 m^3 / day or 494.7 litres per day or 15.05 cubic metres per mean month

So, if we want to supply water all the year to meet the needs of the dispensary, the demand cannot exceed 494.7 litres per day. The expected demand cannot be met by the available harvested water. Therefore, the tank has to be sized based on a compromised demand of 15.05 cubic metres per mean month

The following figure shows the comparison of water harvested and the amount that can be supplied to the dispensary using all the water which is harvested. It can be noted that the first month that the rainfall on the roof meets the demand is October. If we therefore assume that the tank is empty at the end of September we can form a graph of cumulative harvested water and cumulative demand and from this we can calculate the maximum storage requirement for the dispensary.





The following table shows the spreadsheet calculation for sizing the storage tank. It takes into consideration the accumulated inflow and outflow from the tank and the capacity of the tank is calculated as the greatest excess of water over and above consumption. This occurs in April with a storage requirement of 50.45 cubic meters. All this water will have to be stored to cover the shortfall during the dry period.

Month	Rainfall (mm)	Rainfall harvested (cubic metres)	Cumulative rainfall harvested (cubic metres)	Demand (based on total utilization)	Cumulative demand (cubic metres)	Deficit (cubic meters
Oct	88	15.05	15.05	15.05	15.05	0.00
Nov	124	21.20	36.25	15.05	30.10	6.16
Dec	134	22.91	59.17	15.05	45.14	14.02
Jan	114	19.49	78.66	15.05	60.19	18.47
Feb	101	17.27	95.93	15.05	75.24	20.69
Mar	136	23.26	119.19	15.05	90.29	28.90
Apr	214	36.59	155.78	15.05	105.34	**50.45**
May	75	12.83	168.61	15.05	120.38	48.22

Jun	3	0.51	169.12	15.05	135.43	33.69
Jul	5	0.86	169.97	15.05	150.48	19.49
Aug	15	2.57	172.54	15.05	165.53	7.01
Sep	47	8.04	180.58	15.05	180.58	0.00
Totals		180.58		180.58		

(b) Simple Water Budget: This methodology considers the inputs (supply) and output (demand) on a monthly basis based on average (or median) monthly precipitation and user estimated monthly water demands. The analysis summarizes the entire month's supply and subtracts the entire month's demand at the end of each month. First, the average monthly precipitation depth is used to calculate the monthly rainwater capture volume based on the area and collection efficiency of the catchment area. Then the estimated monthly demand is subtracted from this value to determine the end-of-month storage. For the second month, the end-of-month storage from the previous month is added to the second month's rainwater capture volume and monthly demand subtracted to estimate the second month's end-of-month storage, and so on.

(c) Computer-based Simulation Methods: Probably the most accurate method for sizing rainwater cisterns is using computer-based simulation models. These models can be proprietary, but some are also available online for free for academicians and researchers. Computer-based models apply different algorithms of mass conservation [such as Yield Before Spillage (YBS) and Yield After Spillage (YAS)] and typically perform simulation of the estimated daily demand using historic daily precipitation records over a number of years. It can be used to test a range of cistern sizes for a given reliability of the system. A continuous simulation can be used to determine the most efficient cistern sizes, especially in humid climates where precipitation occurs frequently. Conversely, this model can be used to determine the reliability of existing rainwater harvesting systems with a given storage size and demand characteristics. The application of these tailor-made computer programs have so far been mostly for academic and research purpose.

2.4 Rainwater Distribution System

Distribution system is the element responsible for delivering water with the appropriate quality and pressure. All the components in distribution system must be chosen carefully for compatibility and application. Distribution is affected by factors such as location of the tank and the water supply expected from the rainwater system. In the rural context, at the household level water can be collected and used from the storage tank directly which may undergo a certain form of treatment/ disinfection (UV, chlorination, etc.) in a separate container (see Figure 20). When the collected rainwater is to be supplied to buildings, a distribution system has to be designed which may have the following typical components:

Pressurization: A pump is used to provide pressurization on the downstream side of storage. For belowground tanks a submersible pump in the storage tank is the preferred type of pump. With careful planning, a suction-lift pump may be used in some applications. When choosing aboveground tanks, a flooded-suction pump located outside of the storage tank is recommended. The design of the system must prevent air from entering the piping, thus damaging the impellers.

Filtration: The main post-storage filter types used in rainwater harvesting systems are fine-mesh screen filters, bag filters, cartridge filters, and membrane filters. The purpose is to remove particles in the water including silts, clays, organic particles, microorganisms, and various compounds that may have formed in storage. Removing these contaminants is important due to their possible negative effects on human health and/or equipment and materials in the system. It is also very important to remove the particulates so they do not interfere with other downstream processes such as disinfection. Filters must be chosen that are appropriate for removing unwanted contaminants. Consideration of pre-storage filtration practices will lessen expenses and maintenance problems in both the storage tank and post-storage filtration.

Disinfection: Disinfection is primarily achieved by the following methods:

- Exposure to UV light: Water flows in a sealed chamber containing UV light bulbs. The UV light disinfects the water by applying a certain light intensity over a period of time.

- Exposure to chlorine: Chlorine is introduced to the water and it kills microorganisms. The water maintains a residual amount of the chemical that helps to maintain water quality in the distribution system.
- Exposure to ozone: Ozone is injected into the water for disinfection.

Controller: Multiple relationships between various components on the pressure side of storage must be managed in an operating rainwater system. Simpler systems may employ a control station that only has on/off pressure switches, motor starters, and float switches. Larger systems usually have setups that are more sophisticated.

Automatic Protected Bypass**:** For all systems that use rainwater for critical uses in the building, an automatic bypass strategy may be employed. In the event of low cistern water levels or mechanical failure, a means of allowing water to flow from the backup source (usually the municipal water supply) to the end use is mandatory. This should happen seamlessly so that there is no interruption to the end use. *Solenoid valves, three-way valves,* and *non-electrically controlled pressure valves* may be used to serve this purpose. The alternate water feed is to be controlled by a smart system which would allow the backup water to pass only when the water level in the tank drops below a critical level detected by a change in static pressure inside the tank (Figure 10).

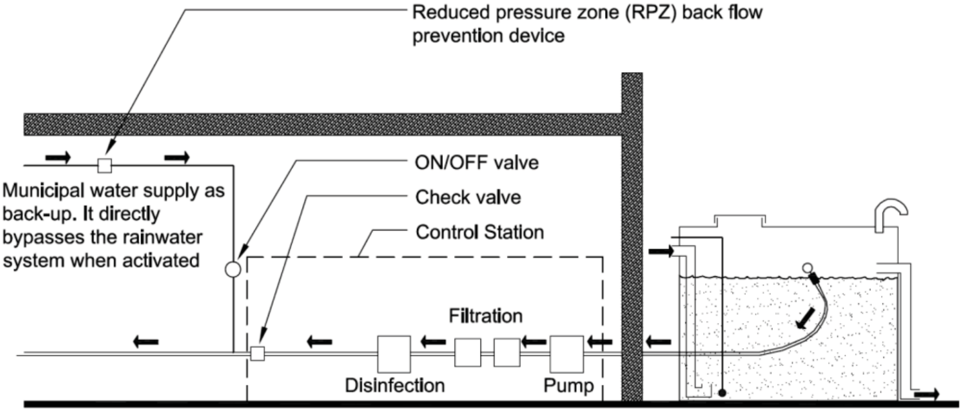


Figure 10: Automated Protected Direct Bypass to end use after disinfection
(Image source: Novak et al 2014)

A direct bypass is useful because it utilizes the inherent energy in the municipal water supply as opposed to requiring the municipal water to be released back to the atmospheric pressure and then re-pressurizing the water again. This is very energy-intensive and can be avoided when the bypass water is directly connected to the outgoing water supply downstream. Additionally, these types of bypass systems reduce the need for duplicate booster pumps (for re-pressurizing the water), which can provide significant cost savings for the owner.

In the event that the automatic measures fail to operate as planned and the owner desires the system to operate regardless, a manual bypass must be designed so that, with the turn of a valve or two, flow can be restored to the end use. It must be kept in mind that this manual setup only bypasses the control portion of the mechanism and not around the backflow preventer. The backflow preventer must never be circumvented, as it is the device that protects the quality of the municipal water supply from the intrusion of non-potable water.

Modality of the Makeup Supply: The term "makeup supply" implies the refilling of a tank or vessel. There are basically two ways of supplying makeup water to the rainwater system. Either the municipally supplied makeup water is directed to the main storage tank (Figure 11) or it is directed to a buffer tank (Figure 12). Generally, supplying municipal water to the main storage tank is a strategy used on smaller residential systems. Trickle top-type fill valves can top up the system when water levels are low. In this case, the inherent energy (pressure) and water quality of the municipal water are lost due to the mixing with untreated rainwater in a non-pressurized tank (as mentioned earlier).

The other method is to supply the municipal water to the buffer/day tank. A buffer/day tank is a tank smaller than the main storage tank, which holds a particular quantity of water. It can also serve as a vessel for receiving makeup municipal supply for the system. In this case, the quality of make-up water is not compromised since day/buffer tank stores water treated suitably for end use. In either instance, the makeup water (potable) supply is protected via an air gap. An air gap keeps the water in the tank from siphoning back into the potable water supply in a potential backflow situation. This is because the overflow on the tank or buffer tank is below the pipe supplying the makeup water to the system.

Booster pumps are a necessity for systems employing a make-up water supply via buffer/day tank since the inherent pressure of the municipal water is lost flowing through the air gap. In such cases, when these booster pumps fail, the system is out of commission until the pumps are repaired. Therefore additional pumps are usually installed in the system to provide redundancy.

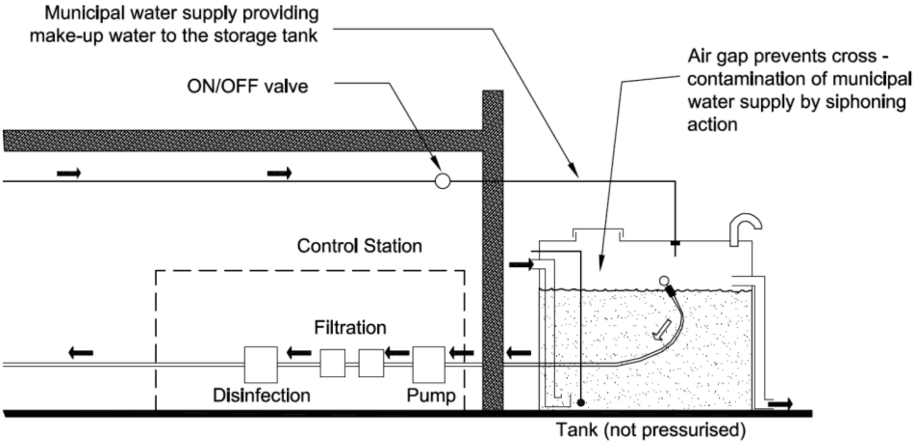


Figure 11: Make-up supply to main tank with air-gap protection
(Image source: Novak et al 2014)

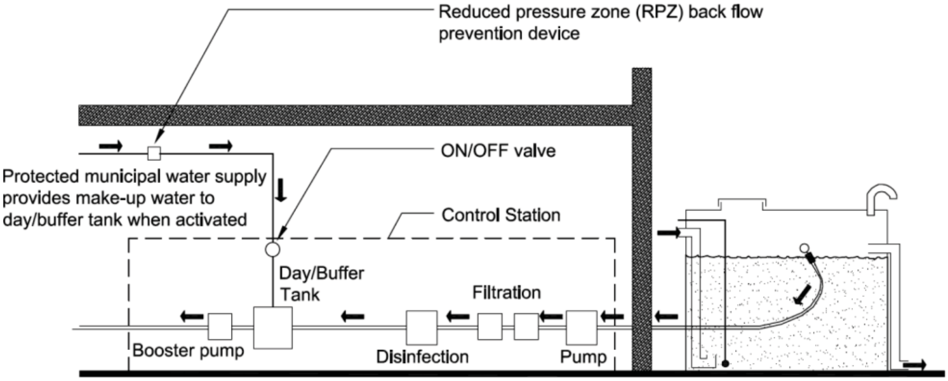
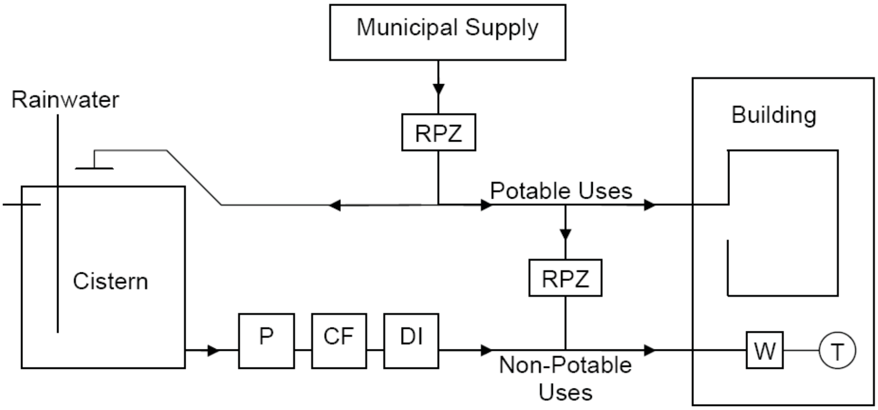


Figure 12: Make-up supply to day/buffer tank with air-gap protection
(Image source: Novak et al 2014)

3.0 Rainwater Harvesting in Buildings

There are numerous examples around the world where rainwater harvesting is being promoted to conserve water and help reduce the demand on municipal water systems. When used in conjunction with public water systems, harvested rainwater can be used for outdoor (landscape) watering and indoor non-potable uses such as washing machines and toilets. Toilets and washing machines could consume about 40 percent of the water that is used inside homes (Vickers, 2001). If those two uses can be served with rainwater, a significant saving will result to the homeowner. A typical schematic recommended for rainwater used in conjunction with a public water supply is shown in Figure 13.



P=Pump; CF=Cartridge Filtration; DI = Disinfection; W=Washing Machine; T=Toilets; RPZ = Reduced Pressure Zone Back Flow Preventer.

Figure 13: A schematic showing the conjunctive use of public water systems for potable uses, and rainwater for non-potable uses (washing machines and toilets).

Public water systems serve as a backup source for the cistern, with an air gap to prevent any cross-contamination. If at any time the cistern, pump, or other equipment becomes nonfunctional, the public water system could also serve the non-potable needs through a reduced pressure zone back-flow preventer valve. A dual plumbing system used for rainwater harvesting in conjunction with a public water system in Australia is shown in Figure 14.

Piping and Labeling

If a rainwater harvesting system is used in conjunction with a public water system at any facility, the Texas Rainwater Harvesting Evaluation Committee recommends that the rainwater pipe be labeled for non-potable uses. The pipe should be painted in black lettering “RAINWATER – DO NOT DRINK” on a bright orange background. The lettering should be in bold and clearly visible. The label should be painted at two-foot intervals throughout the length of the pipe. If rainwater is mixed with other sources, such as air conditioning condensate or reclaimed water, purple pipe should be used. Every toilet, urinal, hose bib, irrigation outlet, or other fixture that uses rainwater should be permanently identified as non-potable rainwater by the above labeling. Since rainwater is slightly acidic, contains little dissolved minerals and can be corrosive, plastic delivery pipes, and fixtures made with non-corrosive materials are often recommended.

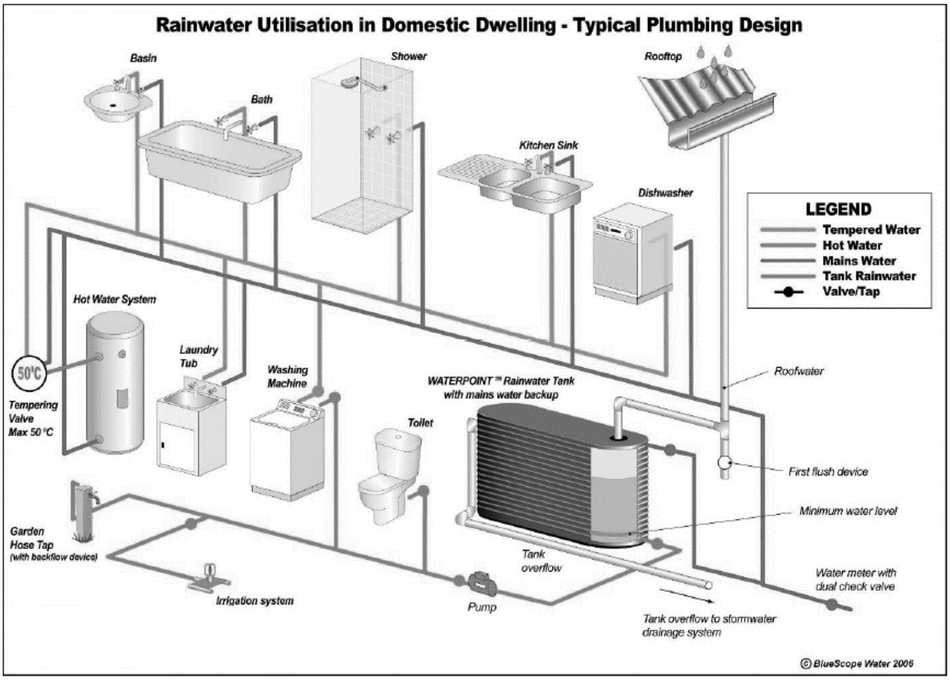


Figure 14: An example of a dual plumbing system used in Australia (TWDB 2006)

4.0 Water Quality and Treatment

Rainwater is generally considered pure and the physicochemical quality of rainwater in terms of colour, odour and taste, turbidity, pH, total dissolved solids (TDS) and total hardness generally meets the drinking water quality standards. But there are several ways a large number of anthropogenic and natural contaminants may find their way into rainwater and compromise the water quality. The chemical and microbiological water quality in RWHS might not be a pressing issue if the purpose of collected rainwater is to recharge groundwater or to supplement the water demand for non-potable uses (e.g., water closet flushing or garden irrigation). However, if the water is intended for drinking purpose, then the physicochemical and microbiological quality of harvested water certainly warrants close attention.

Rainwater catchment systems are open to environmental hazards and the quality of rainwater may deteriorate during the process of harvesting and unsanitary practices in storage and consumption. There are numerous sources of pollutants that can affect the quality of harvested rainwater. Potential sources include atmospheric deposition, roofing materials, overhanging vegetation, fauna, residue from delivery and distribution piping, storage tank materials, and sediments that have accumulated within the storage tank. The quality of the rainfall falling onto a given surface is a key factor influencing the quality of rainwater leaving the catchment surface. The chemical composition of rainwater is influenced by a multitude of factors, such as geographic location and influences, prevailing meteorological conditions, and anthropogenic activities (agriculture, industry, motor vehicle emissions, and the like) and thus varies greatly by location, season, and even storm type.

4.1 Factors Affecting Water Quality

pH

As a raindrop falls and comes in contact with the atmosphere, it dissolves naturally occurring carbon dioxide to form a weak acid. The resultant pH is about 5.7, whereas a pH of 7.0 is neutral. If rainwater absorbs sulfur and nitrogen oxides from the atmosphere, the pH decreases and the rain becomes acidic. The presence of sulfur and nitrogen oxides can be attributed to fossil fuel combustion (specific sources include motor vehicle emissions, combustion in building heating systems, coal-fired power plant and industrial processes). Acid rain is prominent in regions characterized by high vehicle traffic volumes, high-density residential development, and industry. In some areas of the world the pH of rainwater can be as low as 5.25 due to atmospheric pollution and regional geography. Although pH is not considered a pollutant, it affects the fate and transport of other contaminants which affect the quality of rainwater.

Particulate matter through wet deposition

Particulate matter refers to smoke, dust, and soot suspended in the air. Fine particulates can be emitted by industrial and residential combustion, vehicle exhaust, agricultural controlled burns, and sandstorms. As rainwater falls through the atmosphere, it can incorporate these contaminants. Various hydrocarbons and lead (adsorbed on particulate matter) may be introduced into rainwater from the atmosphere.

Catchment surface through dry deposition

Dry deposition, a process by which particulates in the atmosphere that are generated via automobile emissions, industrial processes, and fertilizer applications settle out and accumulate on surfaces, can be a contributor of nutrients, sediment, and heavy metals in rooftop runoff. Constituents that have been linked to atmospheric deposition include total suspended solids (TSS), lead (due to heavy traffic or industrial emissions), chloride (Cl^-) (due to application of de-icing salts in the winter), copper, nitrates (due to agricultural fertilizer applications), nitrites, zinc, aluminum, Fe, and Ca. Constituents contributed by dry deposition undergo rapid decrease in concentrations as rainfall continues. The type of roofing surface can have substantial impacts on roof runoff. Roofing surfaces such as asphalt shingles trap and retain particles and pollutants more so than smooth materials. When it rains, the trapped particulate matter is transferred to the runoff water and can have a detrimental effect on water quality.

Leaching from rainfall collection system

Rainwater, being slightly acidic and aggressive, has a tendency to dissolve heavy metals and other impurities from the catchment. Elevated levels of zinc and lead in rainwater have sometimes been reported, which could be from leaching of metallic roofs. Also, paint coatings on roof can get oxidized through weather action and eventually washed out through rain. If these paint coatings are lead or lead-copper based, then that can result in elevated levels of heavy metals in collected rainwater. In addition to the roofing materials, uncoated gutters can contribute significant amounts of heavy metals to roof runoff, especially zinc and aluminum. Distribution piping can be another significant contributor of contaminants within rainwater collection systems. In addition to piping, plumbing fixtures such as faucets, fittings, valves, pumps, and pressure tanks may be a direct source of metal loads to water during passage. Nickel plating and solder can increase nickel and lead concentrations, respectively, in water, especially in standing tap water. Aging galvanized iron piping can also contribute to elevated iron concentrations in tap water. It may be mentioned that the presence of these dissolved metals may not adversely affect the use of rainwater for non-potable applications. Nevertheless, contamination of rainwater by toxic metals has been reported in a limited number of cases and serious chemical contamination of stored rainwater is rare.

Storage Tank

After leaving the roof surface, rainwater enters the storage tank of the collection system. The storage tank provides an opportunity to improve water quality via increasing pH, the settling of sediment particles (sedimentation) that may have made their way through the pre-filtration devices, and the precipitation of heavy metals. Sedimentation plays a primary role in the reduction of contaminant loads within the tank, as particulates settle out rather quickly once water enters the storage tank (though the long-term removal of sediment particles from stored water depends on quiescence being maintained within the tank). In addition to sedimentation, water quality improvement occurs via the settling-out of heavy metals, especially when the pH is neutral or alkaline. These treatment processes are most likely the cause of a generally better quality of stored water compared to roof runoff. The storage tank material can substantially influence water quality. Storing rainwater in concrete or plaster tanks can increase the pH of the water, thus facilitating precipitation and removal of heavy metals. Metal tanks can potentially leach metals into collected water, while plastic tanks may leach organic compounds if they are not manufactured to specific standards.

Despite the numerous opportunities for water quality improvement during storage, some studies have reported poor water quality in rainwater storage tanks. Long retention times (ranging from two or three weeks to several months) of stored water can be detrimental to water quality, especially if there is a large amount of organic matter being introduced into a system (such as pollen or leaf debris). The decomposition of this organic matter can deplete oxygen from water in the tank and result in an offensive odor and/or color to the harvested rainwater. This is one of the reasons that careful attention to pre-storage filtration and tank venting is so important. The precipitation and settling processes occurring within rainwater storage tanks in areas with heavy atmospheric pollution may lead to the accumulation of sediments in the bottom of the tanks. These sediments are often comprised of heavy metals such as copper, nickel, zinc, and lead. Heavy metal contamination in sediments, although rare, can be severe enough to result in the sediments being classified as "contaminated" or "hazardous."

Microbial Contamination

Microbial contamination at the point of use is the main health concern in a rainwater harvesting system. A variety of microorganisms can be present throughout rainwater harvesting systems. These organisms range from indicator bacteria (such as enterococci, fecal coliform, and fecal streptococci) to pathogens (*E coli*, Salmonella, Giardia, Cryptosporidium, and the like) and even viruses. While some of these organisms may be harmless, others warrant considerable concern with respect to human health. A primary source of bacteria and pathogens in collected rainwater is fecal matter from wildlife such as insects, birds, small mammals (bats, possums, squirrels, rats, and so forth), and small reptiles or amphibians (lizards, frogs) that is washed into the rainwater storage during rain events. The presence of overhanging trees and significant animal activity on roof surfaces can greatly increase microbial concentrations within collected rainwater. Animals that have been specifically linked to bacteria and pathogens (such as Campylobacter, Giardia, Cryptosporidium, Salmonella, and *E coli*) in roof runoff include birds, possum, rats, hedgehogs, rabbits, ferrets, and mice. Microbial concentrations can vary based upon the contributing roof surface. Roofing materials with rougher textures (for example, asphalt shingle, wooden shingle) allow flora and organic matter to accumulate on the roof surface, which can harbor bacteria and pathogens. Metal roofs often produce roof runoff with lower microbial concentrations due to the smooth surface, relatively high temperatures at the roof surface, and the concentration of UV light on the metal.

The high microbial counts are found in the first flush of rainwater and the level of contamination reduces as the rain continues. A significant reduction of microbial contamination is found in the rainy season when flush washing of the catchment is frequent. Long storage of rainwater is associated with the growth of algae, aquatic organisms and breeding of vectors (e.g. dengue mosquito) inside the storage tanks.

The different pathways for microbial and chemical contamination of rainwater are shown in Figure 15.

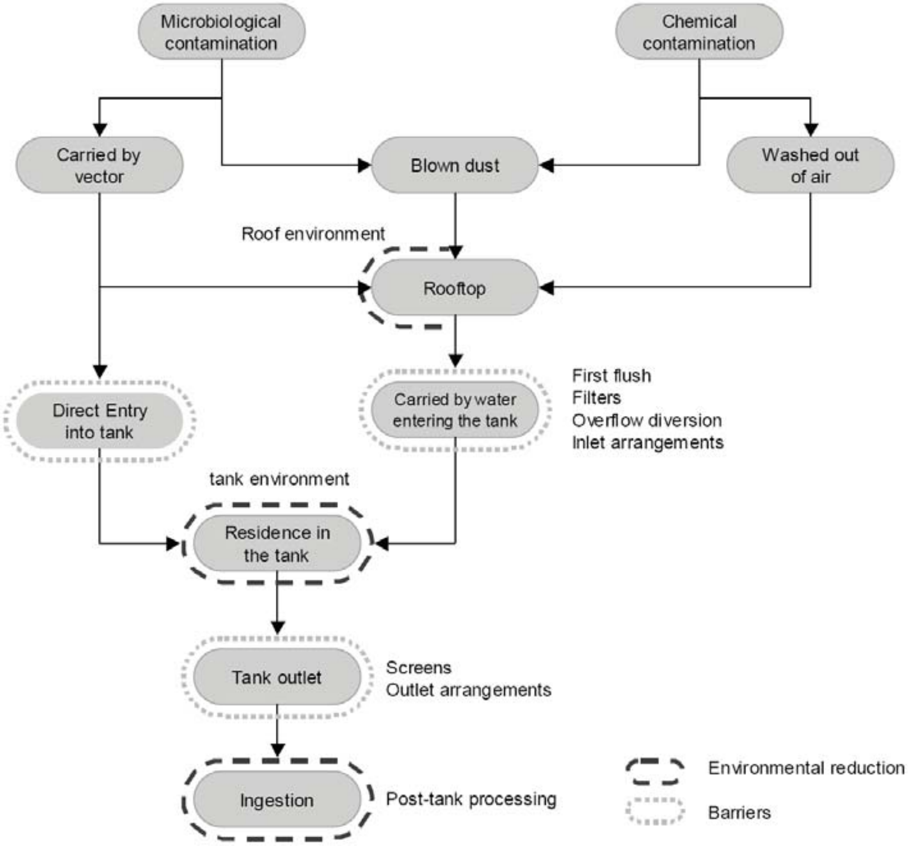


Figure 15: Contamination pathways for rooftop rainwater harvesting (Martinson and Thomas 2003)

Mineral Content

The rainwater lacks in minerals, while some minerals like calcium, magnesium, iron, and fluoride in appropriate concentrations are considered essential for health. It is now recognized that there is an inverse relationship between death from heart disease and the concentration of calcium and magnesium in drinking water (WHO, 2005). Although most of the essential nutrients are derived from food, the lack of minerals in water may cause nutrition deficiencies in people who are already on mineral deficient diet. The mineral salts in natural ground and surface waters sometimes impart pleasing taste to water. The lack of mineral content may affect acceptability of rainwater for its lack of taste.

4.2 Water Quality Management in RWHS

The potential of water quality contamination throughout a rainwater harvesting system necessitates the use of intervention options to produce water of suitable quality for potable and non-potable uses. Potential intervention options for rainwater collection systems include improved design features (positioning of inlet, altering the location of collection systems), pre-storage measures (debris screens and filters and first-flush diversion), and post-storage measures (post-storage filtration and disinfection).

4.3 Design features of the RWHS and maintenance

Positioning the tank inlet in the center of the tank, instead of adjacent to the wall, may minimize the re-suspension of sediments that have already collected at the bottom of the tank. More effectively, a "calming inlet" design can be used in which the inlet pipe enters the storage tank and extends to the bottom of the tank where a U-shaped fitting directs water flow upward into the tank. This calming inlet maybe positioned anywhere in the tank and minimizes turbulence of the stored water, thus reducing the agitation of sediments that have collected on the bottom and the likelihood of releasing pollutants into the stored water, as shown in Figure 16.

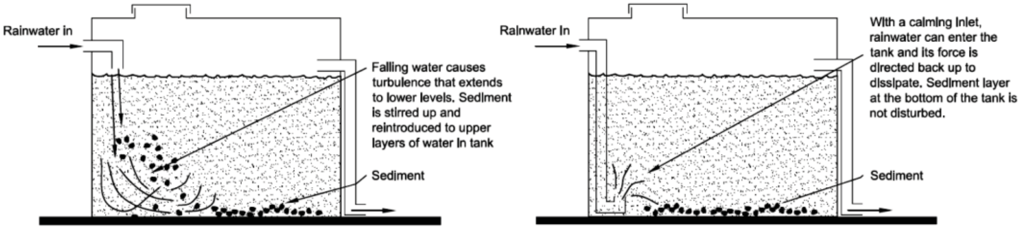


Figure 16: Operation of a storage tank with a 'calming inlet'
(image source: Novak et al 2014)

To minimize the potential for microbial contamination, a system should be located such that overhanging vegetation is avoided or minimized, either through design modification or pruning. This would reduce tree litter and deny access to the roof by rodents and lizards. Other structures that would facilitate the perching of birds and other animals should also be avoided. A filtration system can be as simple as installing an angled mesh screen over the tank opening or gutters to divert leaves and large debris away from the main storage tank. It could also incorporate a finer mesh in the outflow pipe to reduce the volume of suspended particles exiting the tank. Often both a pre-filtration unit prior to the entry into the storage tank and a post-filtration at the point of use is practiced for improved water quality. For particulate settling, a separate chamber is sometimes installed prior to reaching the storage tank or a separate spigot may be installed several inches below the level of the tap inside the storage tank to collect the debris. Cleanliness of catchment and storage tank is critical in maintaining good quality of rainwater. Regular cleaning of the catchment surfaces, gutters and down-pipe to remove accumulated dirt, etc. are very important to ensure better quality of rainwater.

4.4 Diversion of the first flush

The first portion of a rainfall event produces the dirtiest runoff, as it washes off the material that has accumulated on a roof surface since the last rainfall. This dirtier portion of runoff is known as the first flush. As with most pollutants, concentrations of bacteria and pathogens are notably higher in roof runoff during the first flush. Pre-storage first-flush diversion can significantly improve the quality of collected rainwater and this technology can easily be incorporated into small-scale systems with a limited number of downspouts and a strict maintenance regime. Diverting the first flush can retard the buildup of particulates and sediments within storage tanks, prevent odor and aesthetic problems (e.g., coloration, visible organic matter), and improve overall water quality. Two different configurations of first flush device are shown in Figures 17 and 18.

A recent study analyzing the first flush measurements showed that there was an exponential decrease in turbidity and conductivity with increasing cumulative runoff depth (Doyle and Shanahan 2010). It was also found that diverting the first millimeter of rain halves the contaminant load from the roof with a negligible reduction in storage reliability. (Martinson and Thomas, 2005; Doyle and Shanahan, 2010).

While the recommendation for including first-flush diversion is universal, the diversion volume recommendation varies greatly. The exact volume that can be considered as first-flush at any given time is dependent upon several factors, including the number of preceding dry days, amount and type of debris present on roof surface, season, catchment area, and quality and type of roof surface. Some examples of recommended first-flush amounts are: 40 L per 80 to 90 m^2 of rooftop, 200 L per 100 m^2 of rooftop, and 50 L per 100 m^2 of rooftop. The American Rainwater Catchment Systems Association (ARCSA) recommends the diversion of the first 0.002 to 0.03 inches (0.05 mm to 0.75 mm) of rainfall. In areas where there are frequent, low-intensity precipitation events, the lower end of these spectrums can be used. In some instances the use of first flush diversion may be impractical or unnecessary. Areas with less frequent, high-intensity rainfall patterns should use the upper end of these ranges. Table 3 shows the recommended duration of first flush diversion as per BNBC (2015).

Table 3: Recommended duration of first flush diversion for various regions in Bangladesh (BNBC 2015)

Location	Time
Dhaka metropolitan area	15 min
Other urban areas	10 min

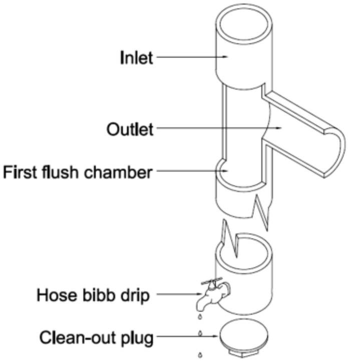


Figure 17: A PVC standpipe first-flush diverter arrangement. The diverter fills with water first, backs up, and then allows water to flow into the main collection piping. These standpipes usually have a cleanout fitting at the bottom, and must be emptied and cleaned out after each rainfall event. A pinhole drilled at the bottom of the pipe or a hose bib fixture left slightly open (shown) allows water to gradually leak out.

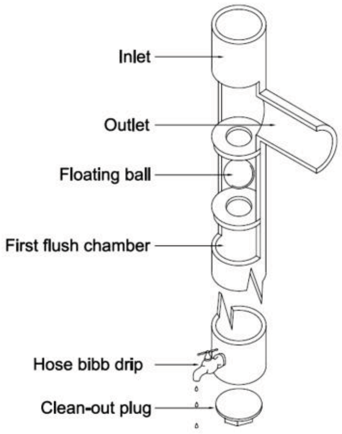


Figure 18: A PVC standpipe with ball-valve first-flush diverter arrangement. As the chamber fills, the ball floats up and seals on the seat, trapping first-flush water and routing the balance of the water to the tank.

4.5 Filtration

Debris screens and filters can be used between the roof surface and the storage tank to prevent particulate matter (and contaminants adsorbed in particulate matter) from entering the tank. Debris filters should include a coarse filter to exclude leaves, and other large debris, as well as a fine screen to exclude smaller particulates (such as asphalt shingle grit). Regardless of filter style (self-cleaning, basket-shaped), the following characteristics should be employed to maximize the effectiveness of debris screens:

- Filter should be easy to clean or largely self-cleaning
- Filter should not clog easily and clogging should be easy to detect and rectify
- Filters should be located at a position/height that is easy for system users to see and clean
- Filters should not provide an entrance for additional contamination (e.g., corrodible materials, openings large enough to allow animals to access the system, and so forth).

Particulate filtration (sediment filters, sand filtration, and other types of filters) can effectively remove particles and heavy metals and lower the turbidity of stored water. The level of filtration needed for a particular system is often dictated by the requirements of equipment or a system's designated uses. For example, irrigation sprinkler heads will get clogged if water is not filtered to a certain level and large particles can damage moving parts of pumps. When using harvested rainwater for tasks such as vehicle washing, it is necessary to remove a sufficient amount of particles in the water to avoid damaging painted surfaces. The filtration level should also be appropriate for any subsequent treatment techniques. For example, if ultraviolet (UV) light treatment is being employed, particulate filtration to 5 microns is required, as particles larger than 5 microns may prevent the UV rays from disinfecting the water.

Figure 19: A sedimentation-filtration system (with rainwater storage tank) installed above ground at UITS, Dhaka.

4.6 Disinfection by Chlorination

Chlorination is an inexpensive and effective form of disinfection. Chlorine must be present in a concentration of 0.5 - 1 ppm to achieve disinfection. Liquid chlorine, in the form of laundry bleach, usually has 6 percent available sodium hypochlorite. For disinfection purposes, 2 fluid ounces (¼ cup) must be added per 1,000 gallons of rainwater. A purer form of chlorine, which comes in solid form, is calcium hypochlorite, usually with 65 - 70 percent available chlorine. At that strength, 0.85 ounces by weight in 1,000 gallons of water would result in a level of 1 ppm. An appropriate contact time should be selected which depends on pH and water temperature. Chlorine contact times are shown in Table 4.

Table 4: Recommended contact time with Chlorine (Ref: BNBC 2015 *t*)

Water pH	**Water temperature**		
	50 ºF or warmer	**45 ºF**	**40 ºF or colder**
	Contact time in minutes		
6.0	3	4	5
6.5	4	5	6
7.0	8	10	12
7.5	12	15	18
8.0	16	20	24

Higher chlorine doses will effectively reduce microbial contamination. Regrowth may occur within 4 to 5 days if there is high organic contamination. Since rainwater is not typically heavily contaminated with organic compounds, higher chlorine doses (~ 2 mg/L) will not be necessary. Higher dose of chlorine (> 1 mg/L) creates smell which is not acceptable to consumers. If adequate disinfection is to be done, chlorine should be applied on a regular basis with careful monitoring of water quality.

Some parasites and protozoa have demonstrated resistance to chlorine. Microorganisms such as Giardia or Cryptosporidium, which are cysts protected by their outer shells, cannot be eliminated by chlorine. So filtration may need to accompany chlorination to ensure removal of all microorganisms. A drawback to using chlorine is the formation of undesirable and hazardous byproducts (e.g. trihalomethanes) when the chlorine reacts with organic matter present in the storage tank. This can be 'avoided by applying chlorine after water is extracted from the tank, thereby reducing contact with organic matter. Alternatively, chlorine dioxide or silver nitrate may be used in lieu of chlorine when byproduct formation is a significant concern. Some find the use of chlorine unacceptable due to taste and odor issues, in which case other forms of disinfection should be used. To address this concern, an activated carbon filter may be used to help remove chlorine. It needs to be mentioned that the presence of turbidity causing substances (e.g. suspended solids, finely divided organic matter, clay and silt) reduces the effectiveness of disinfection by chlorination. Therefore removal of turbidity is necessary. It is found that maintaining turbidity levels below 10 NTU improves disinfection effectiveness (AWWA, 2006).

4.7 Solar/UV disinfection

Under normal circumstances, if storage tank is clean and nutrients are absent, bacteria would be expected to die off naturally in stored water tanks. Direct sunlight accelerates the bacterial die-off rate and solar water disinfection (SODIS) or UV disinfection have been proposed as a good water treatment method for stored drinking water provided that nutrients are absent in the water and that algal growth is inhibited (Appan, 1997; Wegelin and Sommer, 1998). UV light of 254 nanometers wavelength will inactivate organisms that can contaminate rainwater such as viruses and bacteria. Specialized UV chambers for treating rainwater are designed to provide a dosage of UV light for a given flow rate. UV light systems require relatively low maintenance and have the advantages of being chemical free and impossible to overdose. UV light is most effective when the water is clear and free of particles and this is effectively achieved with 20 micron filters installed between the pump and UV chamber. This is because pathogens can be shadowed from the UV light by suspended particles in the water. A second stage of filtration before the chamber should be a 1 micron filter to reduce parasitic cysts such as *Cryptosporidium* and *Giardia* that are resistant to UV light. If Activated Carbon filters are added to the pipe system downstream of the UV lamps, the media must be bacteriostatic so that bacteria and viruses do not colonize the media and re-contaminate the rainwater.

If UV light irradiation is used, it is important to install a system incorporating a sensor that indicates when the device is or is not operational. UV lamps have a limited effective life and most need to be replaced after 12 months. UV lights are benign; they disinfect without leaving behind any disinfection by-products. They use minimal power for operation.

Figure 20: Application of solar-powered UV disinfection of harvested rainwater in a rural RWH unit in Bangladesh supported by CAFOD and DFID and implemented by ITN-BUET

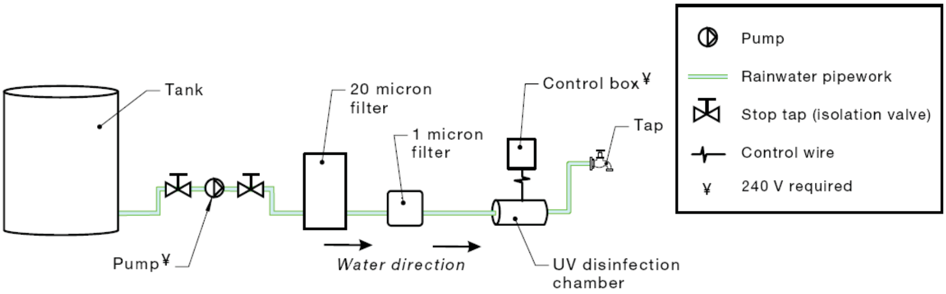


Figure 21: Schematic Diagram of a post-storage filtration with UV-disinfection system (MPMSAA 2008)

The end use of a system dictates the treatment options necessary to achieve a desired quality of water. Some water quality requirements for specific end uses are instigated by healthy and safety concerns, while others simply address aesthetic issues. Applicable regulations, cost, taste/odor preferences, and equipment requirements will also dictate which treatment options of those discussed herein are most appropriate for a given system. When used for potable applications, it is imperative that the harvested rainwater be treated appropriately to conform to applicable drinking water standards and guidelines so that the water does not pose a short- or long-term threat to human health.

4.8 Monitoring Water Quality for Drinking

If the rainwater is intended for potable use, the water quality should satisfy the national drinking water standard or guidelines set by WHO. It has been observed in the field that there is no contamination in rainwater if it is properly collected (as prescribed) and stored in a clean reservoir even after 6 months after the collection of water. Rainwater is usually free from minerals and organic compounds, but susceptible to bacteriological contamination. pH level, Total coliform and fecal coliform of stored water should be monitored, tested and recorded on a regular basis. If bacteriological contamination is found in the stored water during the rainy season, the water can be disinfected (e.g., with chlorine) or alternatively, since rainfall is abundant during the season, the whole water maybe drained out and the storage reservoir should be washed properly to collect rainwater again. In the dry season, water may be disinfected (e.g., with chlorine solution). Table 5 summarizes the different measures in order to minimize contamination of rainwater (MPMSAA 2008):

Table 5: Minimizing Contamination in Rainwater Tanks

Health hazard	Cause	Preventative measure	Monitoring	Corrective action
Fecal contamination from birds and small animals	Overhanging branches on roof	Prune tree branches	Check tree growth every six months	Prune branches
	Animal access to tank	Protect all inlets, overflows and other openings to prevent entry by small animals and birds	Check access covers are kept closed. Check inlets, overflows and other openings every 6 months	Repair gaps. Secure access cover. If animal access is suspected, disinfect tank using chlorine
		Maintain integrity of tank roof and body to prevent access points	Check structural integrity of tank	If a dead animal is found, empty and clean tank. If this has to be delayed, remove remains and disinfect with chlorine
Mosquitoes	Access to stored water	Protect all inlets, overflows and other openings with mosquito-proof mesh	Inspect water for presence of larvae at least every 6 months	Repair screening of inlets and openings to prevent access and, if larvae are present, to prevent escape of mosquitoes.
Lead contamination	Lead-based paints and primers on roofs	Do not collect rainwater from roofs painted with products containing high lead concentrations. When painting roof, check suitability with paint retailer		

Health hazard	Cause	Preventative measure	Monitoring	Corrective action
	Increased corrosion of metals due to low pH from long periods of contact between rainwater and leaves	Keep gutters clean. Install leaf protection devices on gutters	Inspect gutters every 6 months	Clean gutters. If large amounts of leaves detected on regular inspection, clean more often
Airborne pollutants	Industry and vehicles	Do not collect rainwater if in a known high air pollution area, or ensure a first flush diverter is installed	Assess functionality of first flush diverter every 6 months. Check water quality for a range of commonly found airborne pollutants	Install and monitor first flush diverters
Sulphide/ rotten egg/ sewage odours	Anaerobic growth in accumulated sediment at the bottom of tanks	Regularly clean tank to remove accumulated sediment	Inspect tank every year	Clean tank if required. If cleaning not practical disinfect tank with chlorine and flush chlorinated water through all pipework
	Slime and stagnant water in pipework	Avoid u-bends or underground pipework that can hold stagnant water. Install drainage points on pipework		

Health hazard	Cause	Preventative measure	Monitoring	Corrective action
Musty or vegetable type tasted and odours (no light penetration)	Accumulated on roofs and gutters. Possibly including pollen	Remove overhanging branches from trees. Keep gutters clean. Install leaf protection devices on gutters	Inspect gutters at least every 6 months	Clean gutters. If large amounts of leaves (or pollen) are detected on regular inspections, clean more often
Colored water	Accumulated damp leaves in gutter	Keep gutters clean. Install leaf protection devices on gutters	Inspect gutters at least every six months	Clean gutters. If large amounts of leaves (or pollen) are detected on regular inspections, clean more often
Colored water, particularly after rain (tiled roof)	Re-suspension from sediments when fresh intake	Regularly clean tank to remove accumulated sediment	Inspect water after rainfall	Remove sediment by cleaning the tank
Musty, vegetable or fishy type taste and odours (light penetration)	Algal growth due to light penetration into tank or pipework	Make sure tank is completely roofed and is impervious to light	Inspect water every six months	Repair roof
		Ensure pipework, including inlets to tanks, are impervious to light (while pipes can allow light penetration)		Paint pipework with dark color
Insects/water boatmen/bees etc.	Access to stored water	Protect all inlets, overflows and other openings with insect- proof mesh	Inspect water for presence of insects and/or larvae every six months	Repair screenings of inlets and openings to prevent further access. Use simple

Health hazard	Cause	Preventative measure	Monitoring	Corrective action
				coarse filter to remove remaining insects
Small while flakes in water	Microbial growth	Keep gutters clean. Growth encouraged by nutrients contained in plant and soil material accumulated in gutters or at the bottom of tanks. Install leaf protection devices on gutters	Inspect gutters at least every six months. Inspect tank every 2-3 years	Clean gutters and tank if necessary. Disinfect tank using chlorine
Slime on the inside of tanks	Microbial growth	All containers that continuously hold water will develop biofilms on surfaces below the water level	None required	None required. These are naturally occurring and not harmful to the general population

4.9 Qualifying Rainwater for Harvesting

The level of treatment that rainwater should undergo depends on its intended use. Typically for indoor use, treatment system consists of filtration and disinfection systems in series before distribution into the plumbing system. The BNBC guidelines (2015) state the following requirements for treatment of rainwater:

(a) For using rainwater in drinking, cooking, washing utensils, bathing and ablution it shall be disinfected along with filtration.

(b) For cloth washing, floor washing, fountain, water fall cascade, etc. rainwater shall be filtered.

(c) For using in sprinkler firefighting, air conditioning, etc. sedimentation of suspended particles will be required.

(d) For toilet flushing, gardening, cleaning artificial ground, parking lots, etc. screening floating materials are needed.

Where rainwater is used for non-potable use such as hand-watering, vehicle washing, etc., and for non-critical operations, such as irrigation and wash down, a high level of filtration may not be necessary. However, some filtration will likely be needed to prevent clogging sprinklers, or drip irrigation emitters.

However, according to the TWDB (2005), disinfecting non-potable rainwater for indoor use is desirable to control microbial growth, which could cause fowling and affect the operation of plumbing fixtures. Even though bacterial contamination of water for indoor non-potable use is not as critical as that used for potable purposes, total coliform and fecal coliform sampling can be used to evaluate a general level of acceptable microbial contamination for non-potable water. The acceptable level of total coliform for non-potable water should be less than 500 cfu/100 ml, and fecal coliform levels should be less than 100 cfu/100 ml (Lye, 2005).

5.0 Tank Maintenance

The success and overall usefulness of a RWH system will be largely determined by how a system is maintained. Downspout filters should be installed at a location easily seen and accessed by system users to facilitate frequent inspection and cleaning. Pump filters and treatment filters should be easily accessed and cleaned as well. Storage tanks should have access ways and drawdown valves should be installed to make tank cleaning and sediment removal easier. It is recommended to always isolate each tank within a system with a ball valve so that the tank may be taken "offline" for cleaning and maintenance without impacting the rest of the system.

Tasks that should be performed regularly include cleaning the catchment surface, gutters, and storage tank; cleaning filters, first-flush diverters, and debris screens; and inspecting the system for possible points of entry for mosquitoes and vermin. These tasks are described further in the Table 6.

The importance of maintenance to the overall success of a rainwater collection system should be conveyed to property/house owners during the entire design process, from the initial design concepts to the installation. Design choices should be made to make maintenance as easy as possible to increase the likelihood that a system owner will follow proper maintenance protocols.

Establishing a maintenance contract between the owner and the system provider (wherever applicable) can reinforce the necessity of timely and thorough maintenance practices and protect the designer from system problems that arise due to lack of maintenance. Additionally, an owner's manual should accompany every rainwater collection system and should include detailed troubleshooting guidance, maintenance tasks and frequency, and replacement part component details. A water safety plan may be developed for effective risk management.

Table 6: Maintenance Tasks for a RWHS and Recommended Frequency (Novak et al 2014)

Task	Description/Details	Frequency
Clean roof surface and gutters	Manually clean rooftops, gutters, and downspouts by hand, with hand tools, brooms, and rakes, pressurized air, or gas-powered blowers. If using water to flush rooftops, gutters, or downspouts, be sure to divert this debris-laden water to flow into downspouts, filters, or the tank. Inspect gutters for leaks and holes; repair as needed.	A minimum of once per month. For sites with over hanging vegetation, after each significant rainfall event. This is especially important after leaf fall during the winter season.

Task	Description/Details	Frequency
Inspect and clean debris filter(s) and first-flush diverter(s)	Disassemble, clean, and replace screens on all inlet filters as needed. Disassemble and clean as needed. Inspect all downspouts, clear any obstructions. Inspect all inlets and overflow pipe assemblies to ensure they are unobstructed and working properly. Check screens for holes/tears and repair as needed. Disassemble and clean as needed. Disassemble and clean the first-flush diverter; ensure the weep hole is open .and unclogged.	After each significant rainfall event
Check all piping and valves for leaks; inspect all openings in storage tank	Check all piping and valves for cracks, holes, or leaks. Repair as needed. Inspect all openings in the storage tanks for leaks and gaps.	Annually
Clean/change pump filters and particle filtration filters/media	Clean/replace filters in inline pump filters and all particle filtration assemblies. Replace media in granulated carbon filters and/or sand filtration units.	Annually or as needed
Remove tank sediments	Remove sediments that have accumulated in the bottom of the tank. Be sure that all safety regulations are followed with respect to confined space entry. Dispose of sediment in the manner deemed appropriate by the local regulating authority.	Every 5 to 10 years, or as needed

6.0 Artificial Groundwater Recharge

Artificial recharge systems are engineered systems where surface water is put on or in the ground for infiltration and subsequent movement to aquifers to augment groundwater resources (Bouwer 2002). Artificial recharge is one of many techniques used to manage water resources and is being promoted as a significant solution to water scarcity in many nations. Aquifers (groundwater) can be recharged in two basic ways – naturally and artificially. In natural recharge, the rainwater or surface water get percolated into shallow and deep aquifer by itself through uncovered (unpaved) soil surfaces and fissures on the rock mass. This is a slow process and depends on the surface geology and topography. In urban settlements, the natural recharge to ground water has diminished considerably due to shrinkage of open (unpaved) land as a result of urbanization activities. This along with loss of wetlands and overexploitation of groundwater (e.g., in Dhaka) has created undesirable effects which include lowering of groundwater table and an increase of urban flooding. Therefore, in order to ease the process of recharge, artificial recharge is being practiced mainly in urban environment nowadays. Artificial recharge to the aquifer is the process of draining the rain water or surface water into the aquifer by constructing simple civil structures.

Modifying the natural movement of surface water by constructing recharge structures has the following objectives:

(a) Enhancement of sustainable yield in areas where there is over development and depletion of the aquifers.
(b) Conservation and storage of excess underground water in the aquifers.
(c) Improvement of the quality of the existing ground water through dilution.
(d) Maintaining the natural balance of the ground water and its usage as the rain-water is a renewable supply source.
(e) Minimizing urban flooding.
(f) Revitalize the wells which are dried up or have reduced water level considerably compared to the past.
(g) Prevent salinity intrusion in coastal aquifers. (in many coastal areas, freshwater aquifer layer is available at very shallow depths; harvested rainwater can be stored here for dry season use and push back the salinity front)

6.1 Recharge structures

The basic form of recharge system involves connecting either the rainwater downpipe from the roof directly or the overflow pipe of a rainwater storage tank to a recharge structure. Where large basin area is available and aquifers are unconfined without impervious layer above it, surface spreading methods such as flooding, basin and percolation tanks, ditch and furrow systems, etc. may be employed. The conditions that permit surface spreading (e.g., high permeability, homogeneous aquifer, no impending layers between land and water table) are relatively rare. In urban environments, there is scarcity of unpaved lands which preclude the use of such methods. The following are the types of recharge structures commonly adopted for the purpose of artificial recharge of harvested rainwater:

- Recharge/injection wells
- Recharge pits and trenches
- Dried up/ abandoned dugwells or tube wells converted into recharge structures

Where permeable soils and/or sufficient land area for surface infiltration is not available (e.g. urban areas), groundwater recharge can be achieved through vertical infiltration systems such as trenches and wells. Direct recharge wells are used if vadose zones are not suitable for trenches or wells and aquifers are deep and/or confined. Recharge wells can be of two types - (a) Injection well, where water is “pumped in” for recharge and (b) Recharge well, where water flows under gravity.

The Injection wells are similar to a tubewell. This technique is suitable for augmenting the ground water storage of deeper aquifers by “pumping in” rainwater. The recharge through this technique is comparatively costlier and requires specialized techniques of tubewell construction and maintenance to protect well from clogging.

There are three levels of aquifer where harvested rainwater can be potentially released, these are:

- ○ Dry part of the soil strata, above the water-bearing aquifer,
- ○ Unsaturated part of the aquifer layer, and

  - Saturated part of the aquifer layer (from where the water is typically pumped for supply)

Selection of the location of artificial recharge depends on hydrogeological conditions, groundwater levels and objective of use of recharge. For example, if the objective of recharge is to augment the groundwater of the deeper (>50 m) dupitila aquifer of Dhaka city, recharging the dry or unsaturated part of the soil strata might not be the ideal option. Recharging the dry part of the soil strata will mostly help the spreading of water horizontally over the huge dry sand formations before reaching the lower water-bearing strata. In case of recharging the unsaturated zone, though it can help restoring the depleted groundwater level, it will not be useable immediately after recharge as the pumping aquifer part is at a much deeper depth.

If there are dugwells/ abandoned tubewells that have gone dry due to decline of water levels or currently not in use because of being contaminated, these can be used for the purpose of recharge. A recharge pit very similar to that of the injection wells may need to be built and a desilting unit may need to be constructed to treat the water before recharge. Also in such cases, it must be ensured that the recharge water does not contain any contaminant that might interfere with the quality of the groundwater.

Before designing recharge/injection well it must be kept in mind that there are some basic differences between production well and injection well, as listed below:

Production well	**Recharge/Injection well**
Application of force mode/suction mode pump is required.	No pumping is required for recharging the unconfined and semi-confined aquifer.
Screens are located only at the saturated part of the aquifer.	Screen depth and location depends on the intended recharge location (i.e. level of the aquifer).
The inside opening of the slot is larger than the outside opening for "V"-shaped slot arrangement.	The screen slot opening should be the same in both inside and outside.
Groundwater quality is a major consideration in installing a well.	Groundwater quality is not a consideration for recharge wells.
Well spacing should be maintained as required by guidelines which depends on drawdown, well interference, pumping schedules, etc.	No requirement for maintaining spacing as for production wells.
Usually large diameter housing pipes are required to accommodate for the convenient placement of pumps.	No large diameter housing pipe required, since pumps are not placed there.

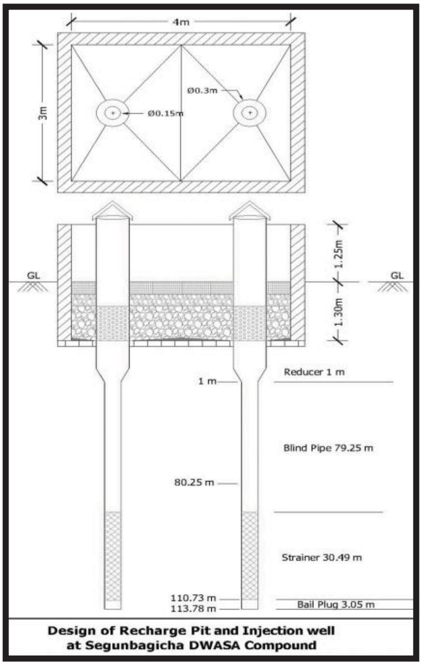


Figure 22: Layout of the artificial groundwater recharge structure installed by DWASA in Segunbagicha (image source: IWM, 2011)

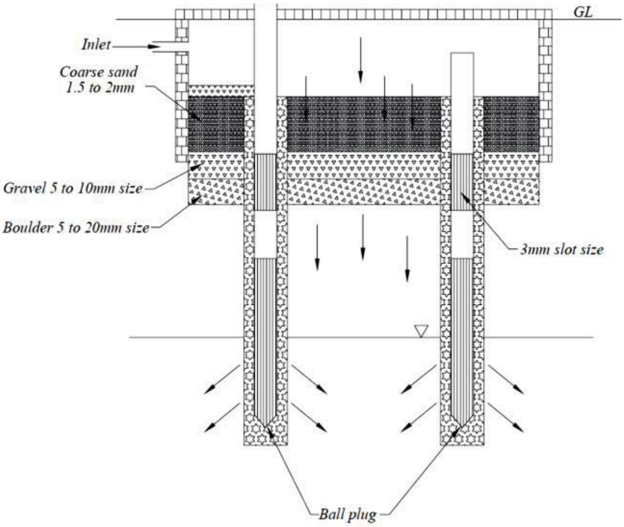


Figure 23: Layout of an artificial groundwater recharge structure without a reducer in the wells and having the well cover at two different elevations. The well cover may be extended only upto a point below the ground level if there is no risk of flooding which might cause contaminated water to enter the aquifers (image source: BNBC 2015)

6.2 Clogging of Infiltration Layer and its Control

The main problem in infiltration systems for artificial recharge of groundwater is clogging (mainly caused by rain-washed suspended inorganic sediments, accumulation of microorganisms) of the infiltrating surface and the resulting reduction of infiltration rates (Bouwer 2002). The following options can be adopted to control the clogging of infiltration layer:

- Pre-sedimentation of clay, silt and other suspended solids by passing through a dedicated pre-sedimentation basin before recharge (see Figure 24)
- Disinfection with chlorine reduces biological activity and hence reduces clogging
- Regular pumping of recharge wells and periodic redevelopment delays the process of clogging.
- Periodic removal of clogging layer (typically at the end of a drying period) manually or mechanically.

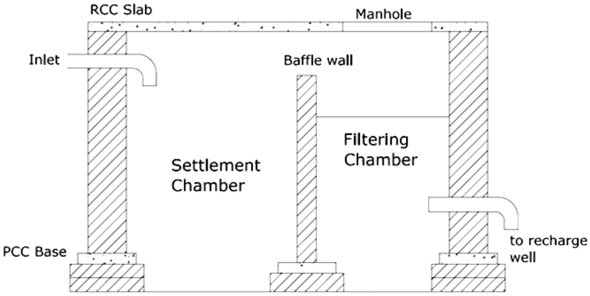


Figure 24: Cross-section of a desilting chamber used before the recharge well.

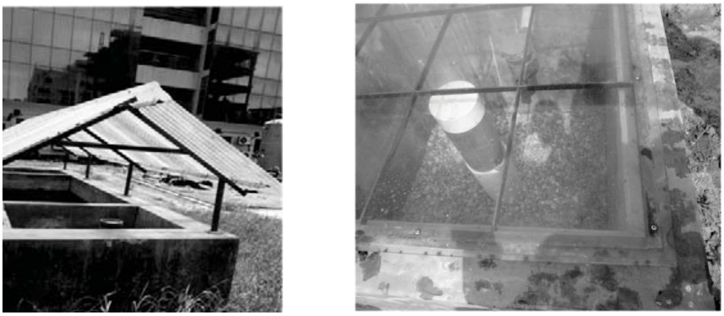


Figure 25: Artificial groundwater recharge systems installed at Independent University Bangladesh (IUB) (left) and UITS (right). Recharge systems consist of filter beds to reduce bacteriological contamination, recharge down pipes and flow meter to record the amount of water being recharged.

6.3 Recharge structure capacity estimation

Construction of the recharge pit includes two components; e.g. civil structure and filter bed. Fixing size of the recharge pit depends on the availability of the area and facility for storing maximum water at a time.

Volume of recharge pit can be calculated on the basis of maximum intensity of rainfall in a shorter period of at least 15 minutes. It is about one fourth peak hourly rainfall.
Capacity of recharge tank = $A \times I_s \times f / p$
Where

A = Catchments area
I_s= Intensity of rainfall in 15 minutes = 0.25 × peak hourly rainfall
f = Runoff co-efficient and
p = Porosity of filter bed = 0.5

In this method, the capacity of the pit is considered to be sufficient to retain the runoff occurring from conditions of peak rainfall intensity. The rate of recharge in relation to runoff is a critical factor. However, since accurate recharge rates cannot be made available without detailed hydro-geological studies, the rates have to be assumed. The capacity of the recharge pit is therefore designed to retain runoff from at least 15 minutes of rainfall of peak intensity, which is about one-fourth of peak hourly rainfall. Pit is filled with porous materials so a factor of loose density of the media (void ratio or porosity) has to be applied in designing the pit size. Though the void ratio of the filler material varies with the kind of material used, for commonly used materials like brickbats, pebbles and gravel, a void ratio of 0.5 may be assumed here. The following worked out example illustrates the capacity calculation of a recharge structure:

Problem 5: If the one hour rainfall intensity is 120 mm/hr, calculate the capacity of the recharge pit from the run-off from the following catchment areas (assume a porosity of 0.5 for pit filter material):

Type of catchment	Area (m^2)	Runoff coefficient
Roof top	100	0.85
Paved Area	25	0.75
Semi- Paved	20	0.6
Unpaved	30	0.2

Solution:

The following table summarizes the recharge pit capacity calculation:

Type of Catchment	Area, A (m^2)	Runoff Coefficient, *f*	Total RWH potential (liters) = 0.25× 120× area × runoff coefficient / porosity	Recharge pit capacity (m^3)
Roof top	100	0.85	5100	5.1
Paved Area	25	0.75	1125	1.125
Semi- Paved	20	0.6	720	0.72
Unpaved	30	0.2	1440	1.44
Total			8385	8.385

6.4 Precautions for Artificial Recharge

Some precautions need to be exercised before installing an artificial recharge structure:

- In the absence of financial incentives, laws, or other regulations to encourage landowners to maintain drainage wells adequately, the wells may fall into disrepair and ultimately become sources of groundwater contamination.
- There is a potential for contamination of the groundwater from injected surface water runoff, especially from agricultural fields and road surfaces. Recharge structures can provide the means for unethical practice of industry owners to dispose their untreated industrial wastewater and thereby causing groundwater contamination.

- Recharge can degrade the aquifer unless quality control of the injected water is adequate. The vulnerability of the aquifer needs to be assessed beforehand. The data on the chemical quality of native water and the changes which take place during the artificial recharge schemes should be collected by regular sampling from observation well network. The composition of native water in the aquifer and the recharged water is important to prevent clogging of well and aquifer due to excessive precipitation of salts.
- Unless significant volumes can be injected into an aquifer, groundwater recharge may not be economically feasible.
- The hydrogeology of an aquifer should be investigated and understood before any future full-scale recharge project is implemented. This might always not be possible for the case of individual/ household recharge structures. Therefore, a degree of uncertainty would still remain regarding the effectiveness of the recharge.
- During the construction of water traps, disturbances of soil and vegetation cover may cause environmental damage to the project area.

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Annex I: Drinking Water Quality Standards and Guidelines

Sl. No.	Parameter	Unit	Bangladesh Standards (ECR 1997)	World Health Organization Guidelines (WHO, 2011)
1	Aluminum	mg/l	0.2	--
2	Ammonia (NH_3)	mg/l	0.5	--
3	Arsenic	mg/l	0.05	0.01
4	Barium	mg/l	0.01	0.7
5	Benzene	mg/l	0.01	0.01
6	BOD_5 20°C	mg/l	0.2	--
7	Boron	mg/l	1.0	2.4
8	Cadmium	mg/l	0.005	0.003
9	Calcium	mg/l	75	--
10	Chloride	mg/l	150-600	--
11	Chlorinated alkanes			
	Carbontetrachloride	mg/l	0.01	0.004
	1,1- Dichloroethylene	mg/l	0.001	--
	1,2- Dichloroethylene	mg/l	0.03	0.05
	Tetrachloroethylene	mg/l	0.03	0.04
	trichloroethylene	mg/l	0.09	0.02
12	Chlorinated phenols			
	Pentrachlorophenol	mg/l	0.03	0.009
	2,4,6- Trichlorophenol	mg/l	0.03	0.2
13	Chlorine (residual)	mg/l	0.2	5
14	Chloroform	mg/l	0.09	0.3
15	Chromium (hexavalent)	mg/l	0.05	--
16	Chromium (total)	mg/l	0.05	0.05
17	COD	mg/l	4	--
18	Coliform (fecal)	Nos/100 ml	0	0
19	Coliform (total)	Nos/100 ml	0	0
20	Color	Hazen unit	15	--
21	Copper	mg/l	1	2
22	Cyanide	mg/l	0.1	--
23	Detergents	mg/l	0.2	--
24	Dissolved Oxygen	mg/l	6	--

Sl. No.	Parameter	Unit	Bangladesh Standards (ECR 1997)	World Health Organization Guidelines (WHO, 2011)
25	Fluoride	mg/l	1	1.5
26	Hardness ($CaCO_3$)	mg/l	200-500	--
27	Iron	mg/l	0.3-1.0	--
28	Kjeldahl Nitrogen (total)	mg/l	1	--
29	Lead	mg/l	0.05	0.01
30	Magnesium	mg/l	30-35	--
31	Manganese	mg/l	0.1	--
32	Mercury	mg/l	0.001	0.006
33	Nickel	mg/l	0.1	0.07
34	Nitrate	mg/l	10	50 (as NO_3^-)
35	Nitrite	mg/l	<1	3 (as NO_2^-)
36	Odor	mg/l	Odorless	--
37	Oil and grease	mg/l	0.01	--
38	pH	mg/l	6.5-8.5	--
39	Phenolic compounds	mg/l	0.002	--
40	Phosphate	mg/l	6	--
41	Phosphorous	mg/l	0	--
42	Potassium	mg/l	12	--
43	Radioactive materials (gross alpha activity)	Bq/l	0.01	--
44	Radioactive materials (gross beta activity)	Bq/l	0.1	--
45	Selenium	mg/l	0.01	0.04
46	Silver	mg/l	0.02	--
47	Sodium	mg/l	200	--
48	Suspended particulate matters	mg/l	10	--
49	Sulfide	mg/l	0	--
50	Sulfate	mg/l	400	--
51	Total dissolved solids	mg/l	1000	--
52	Temperature	°C	20-30	--
53	Tin	mg/l	2	--
54	Turbidity	JTU	10	--
55	Zinc	mg/l	5	--

Annex II: Bangladesh 1-hr Rainfall Map (BNBC 1993)

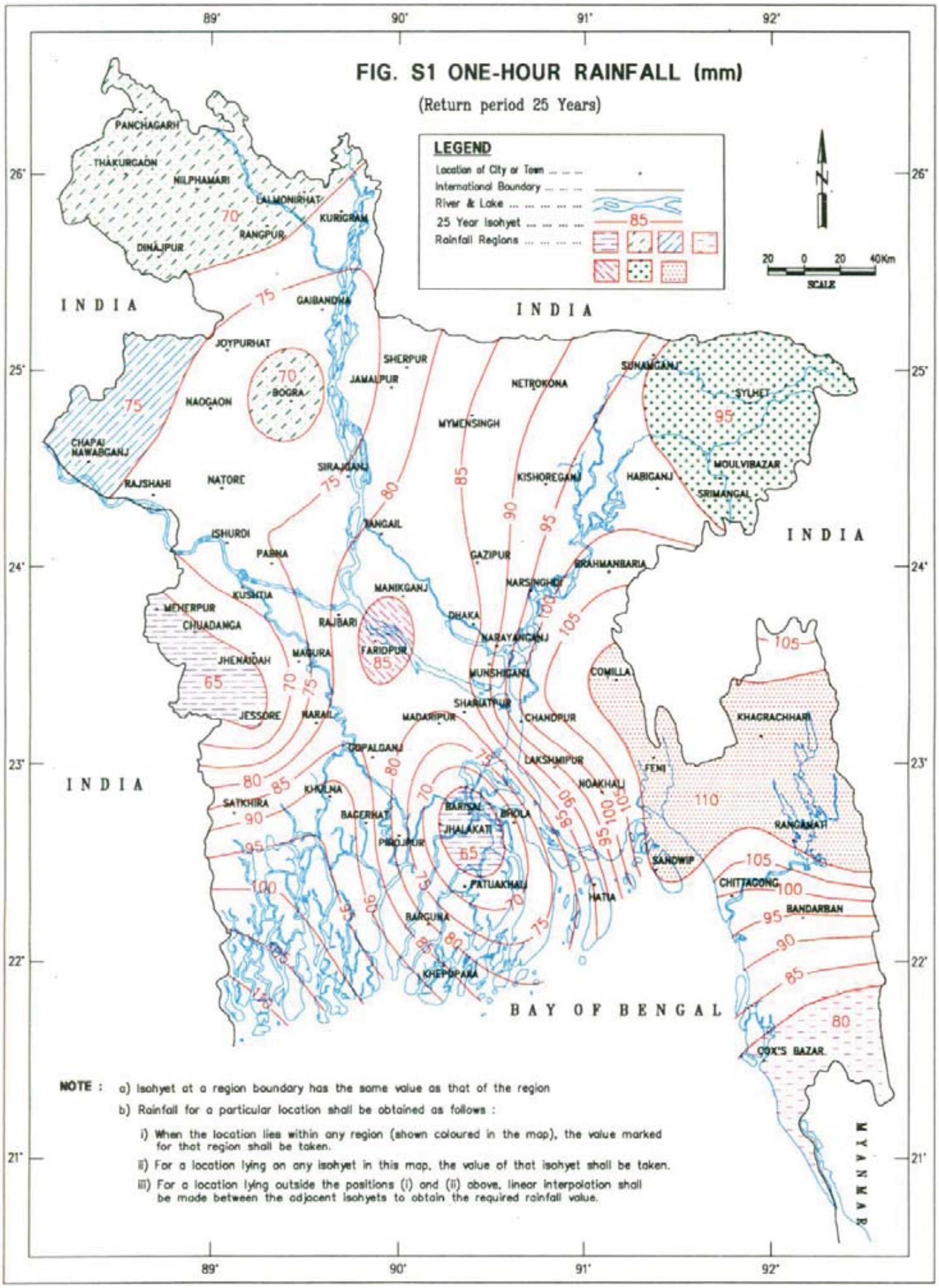

FIG. S1 ONE-HOUR RAINFALL (mm)

(Return period 25 Years)

LEGEND
Location of City or Town ... ...
International Boundary ... ...
River & Lake ... ...
25 Year Isohyet 85
Rainfall Regions ... ...

NOTE : a) Isohyet at a region boundary has the same value as that of the region

b) Rainfall for a particular location shall be obtained as follows :

i) When the location lies within any region (shown coloured in the map), the value marked for that region shall be taken.

ii) For a location lying on any isohyet in this map, the value of that isohyet shall be taken.

iii) For a location lying outside the positions (i) and (ii) above, linear interpolation shall be made between the adjacent isohyets to obtain the required rainfall value.

Annex III: Average Monthly Rainfall Data (in mm) of Some Selected Rainfall Stations in Bangladesh for the years 2001-2013

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Octo	Nov	Dec
Dhaka	4	14	42	111	226	368	388	304	310	163	19	10
Tangail	6	11	52	77	243	313	306	279	250	181	25	7
Barisal	8	11	33	73	207	387	421	319	337	212	29	4
Bhola	4	9	21	64	254	407	469	361	330	225	25	4
Mymensingh	5	12	34	142	289	419	417	340	242	193	14	5
Faridpur	8	19	33	74	174	308	354	260	237	142	30	8
Khepupara	13	11	26	57	279	505	654	449	463	350	44	5
Patuakhali	6	13	30	55	225	509	586	402	399	289	16	1
Chandpur	6	12	39	83	259	374	384	311	302	192	28	4
Teknaf	5	2	11	54	370	1015	1193	882	490	331	45	20
Madaripur	6	12	29	70	222	332	381	275	285	182	30	2
Srimangal	4	24	61	227	484	468	346	342	221	163	27	9
Sylhet	2	28	105	388	574	776	709	605	411	223	31	6
Bogra	5	8	20	82	167	304	289	308	248	168	7	3
Chittagong	7	3	27	91	364	688	656	477	259	269	33	11
Comilla	6	9	47	101	298	420	363	288	269	175	26	5
Cox's Bazar	4	11	21	85	423	898	924	733	409	269	46	8
Feni	4	11	27	96	345	566	613	466	346	247	25	6
Dinajpur	6	11	14	77	203	438	405	296	269	214	7	3

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Octo	Nov	Dec
Ishurdi	6	7	29	59	135	242	268	229	244	139	15	6
Rajshahi	6	6	25	48	145	244	263	228	220	131	10	4
Rangpur	6	10	28	131	272	478	440	312	324	239	3	4
Syedpur	6	7	35	109	264	477	455	301	323	211	7	4
Chuadanga	9	12	29	50	151	225	318	203	297	162	18	6
Jessore	12	12	37	54	184	297	393	248	318	165	25	5
Khulna	13	14	36	50	187	318	357	324	356	184	32	3
Mongla	10	12	28	46	178	362	410	332	342	201	30	4
Satkhira	12	18	34	60	170	294	346	308	299	175	28	4

(Data source: Bangladesh Meteorological Department)

It is estimated that if 60%
rainfall from roof top in Dhaka City
can be harvested, then about
200 MLD can be made
available

approximately 15%
of the **ANNUAL DEMAND**
of Dhaka City can be met from
HARVESTED RAINWATER

ITN-BUET
Centre for Water Supply and Waste Management

WaterAid