Rainwater harvesting, a measure to meet domestic water requirement; a case study Islamabad, Pakistan.

O Rashid¹, F M Awan¹, Z Ullah¹, and I Hassan¹

¹Department of Civil Engineering, Capital University of Science and Technology, Islamabad, Pakistan

Email: saami.avon@gmail.com

Abstract. Pakistan is located in the semi-arid region of the world where water scarcity is a major issue. In such areas, rainwater harvesting (RWH) is considered to be the best alternate source of domestic water supply. Rainwater harvesting is being considered as an integral part of the sustainable water management in many parts of the world. Rainfall patterns in arid areas are typically highly variable, both spatially and temporally. Hence, there is always a need to evaluate rainwater harvesting keeping in view the seasonal variations for a specific area. In rainwater harvesting, a mechanism is designed to collect surface runoffs effectively during rainfall events from residential rooftops. In this paper, it has also been analyzed that rainwater has a great potential to be taken as a source of water demands in residential colonies of major cities like Islamabad being our study area. Here, 116 m² (five marlas) housing pocket has been considered as a model site for which various water demands have been calculated depending upon residential needs and horticulture requirements of the study pocket. Rainwater from rooftops has been used to reduce freshwater needs of the houses. As a result, residential water demands for fresh water have reduced by almost 22% average.

Keywords. Rainwater harvesting, rooftop collection, residential water demand, Islamabad.

1. Introduction

Pakistan has been facing rapid climate change since last few years and the water resources of the country are at extremely vulnerable state. Water scarcity is the principal issue in most of the developed cities of Pakistan. The Capital Islamabad has been prone to a major migration of people since last decade which incredibly increases the water demand. The city is growing at the rate of 5.7% per year. According to the Capital Development Authority (CDA) [1] the average water demand within the city is 800 Million Liters/day (L/d), whereas average 481 Million L/d water shortage has to be encountered by the city every year. Islamabad relies on Simly dam and Khanpur dam to meet the water demand, tube wells and bores are also a key source of water in the surrounding areas of the capital city. The two major sources contribute 381 Million L/d collectively to meet the water demand. The city has to face acute water shortage in summer and pre-monsoon period. In June 2017 the Simly and Khanpur dams found drying at the rate of 50mm/d, as a result, the water supply was cut down further to 86 Million L/d from 109 Million L/d by the authorities [1]

Inappropriate usage of local resources has also led to water scarcity in the city. Low water prices, little amount of water bills and easy access to water allows the user to misuse water without concerning the vulnerability of water resources. Moreover, unplanned and miserable domestic water supply lines led to the leakages of water. There are less appropriate rules and regulations to monitor the water usage, and less awareness ultimately reduces the supply and increases the demand. According to UN-Habitat report [2] the groundwater level in Islamabad city is depleting at an alarming rate of 1.7 m/year. The groundwater level was observed to drop by 20m in various sectors of the city. This extreme drop links to the amplified extraction of water and reduced percolation of water into the soil because of urbanization and population growth within the city.
2. Rainwater harvesting

Rainwater Harvesting (RWH), a famous technique that has been practiced for hundreds of years. It is a method for accumulating and saving rainwater from various elements such as rooftops, surface runoff, and other catchments. Most of the time water downpour is so intense that a sufficient amount of water can be saved by simple harvesting techniques for a few months. To ensure a sustainable urban future, society must adapt effectual application behavior towards water usage. RWH has a very contributing role to minimize the risk of scarcity. Furthermore, in an urban environment, RWH is a scheme that carries certain profits and it may help to overcome water scarcity issues, degradation of land and flooding. Harvested water can be used for all domestic purposes like drinking water, cooking and washing etc. Moreover, this harvested water has a potential to meet agricultural and crop’s water needs according to the available economy, the storage can be managed either on-surface or sub-surface.

UNESCO [3] reported in 2008 there were one billion people who don't approach protected and safe drinking water. Food and Agriculture Organization (FAO) also demonstrated almost 840 million people still encounters the evil impacts of undernourishment. According to the UN [4] that urban water demand will become double from 2007 to 2050. The climate of Pakistan is uneven and almost two-thirds of the country demonstrate arid type climate. Groundwater table in the Potohar region (Rawalpindi district and its surroundings) has depleted by 116m in the last 30 years as reported by Water and Sanitation Agency (WASA), Rawalpindi [5] Per capita availability of water is running out on a fast pace as it dropped to 850 m² in 2013 as compared to 5,300 m² in 1951. Pressure on water assets is increasing day by day with developing demand but water resources are getting limited and this expanding demand decreases sources of freshwater [7] Asian Development Bank (ADB) placed Pakistan in red zone declared it as a water-stressed country and is likely to face an acute shortage of water in the next five years [5] In Rawalpindi, precipitation regularly changes in a scope of 900-1000 mm per year but in case of potential evapotranspiration, there is a fluctuation of 1200-1400 mm [8] All these facts and figures emphasize the need to adjust water administration to natural and modern techniques. RWH, among different choices, may assume a focal part for providing freshwater even with increasing water shortage and raising interest.

RWH is a technique in which water is collected from rooftops and then used for flushing, washing and different household purposes. The aim of the study is to apply this technique to meet the daily water demand. The rainwater harvesting has various advantages such as water is free; its direct collection and storage near the place of use eliminates need of distribution system and its maintenance cost; good quality for various applications; it reduces need for fresh potable water for uses other than drinking; it decreases the costs of utility bills and helps to recharge the groundwater [5] RWH decreases the requirement for mains water and rainwater discharge also decreases and henceforth may add to lessening flood dangers and the load on storm drainage and sewer frameworks [9] Burkhard [10] claimed that due to more softening of rainwater, it reduces the usage of washing powders.

“Sant Cugat del Vallès” a town in Spain, RWH from housetop could conceivably meet around 16% of the aggregate residential water demand of that town and in Jordan, RWH saved 0.270 % to 16.6% [11] In the case of south-eastern Brazil, RWH saves 41%, average running from 12% to 80% varies with the study area [12] Hassan [5] suggested [12] that in Rawalpindi, 110 m² houses with flat roof have sufficient size to accommodate 2 persons and 4 persons at the most. According to a study on RWH in Amman and Irbid, rainwater meets the WHO standards chemically and physically but when it comes to biological tests, it does not meet with WHO guidelines [13] Chang [14] stated that the quantity of pollutants in roof rainwater depends upon surface, atmosphere and pollutants properties.

According to Alpaslan [15] rainwater quality and its collection efficiency greatly depend upon roof area and construction material and best roof for RWH are tiled and Cement roofs in terms of durability, economy and water quality. Saozakli [7] investigated that water from housetops, by and large, meets the universal rules of drinking water. Helmreich [15] claimed that the quality of rainwater in a rural area is far better than the urban area due to their climate. Kahinda [17]
concluded that for RWH, it is not right to expect that the harvested water achieves the drinking water standard.

Fewster [18] stated that there are various choices to achieve rainwater of good quality like the washing of rooftop, avoiding the primary flush from rooftops and chlorine must be used for cleansing of the tank. Slow sand filtration is a modest strategy to enhance the bacteriological nature of water. Wegelin [19] concluded that pasteurization by sun-oriented innovation is otherwise called a cheap disinfection method. This Sunlight technique is good for small families as it only gives us the 100L of water on an area of 1 Square meter of sunlight. According to Kim [20] rapid Sand Filter is also used to remove suspended particles from the water.

Domenech [21] suggested for the single-family system, the tank limit extended from 2 to 20 m³ and was by and large of 12 m³. A promising end-use for water which is especially engaging in single-family houses is flushing. The water-powered reenactment display demonstrates that a tank of 17 m³ can completely take care of flushing demand in a standard single-family house. The most proficient tank for flushing is 11 m³ which empowers to take care of 97.9% of the demand and can spare 28.4 m³ of drinking water every year or 25.9 LCD. In the case of a single family, where water utilization per capita is high, water displayed an essential potential to diminish per capita drinking water utilization. If there is a low precipitation in any year, little tanks could take care of 100% of the demand for those utilizations with a steady request, for example, latrine flushing, and laundry requirements. According to Sazakali [7] RWH seems by all accounts, to be a standout amongst the most encouraging choices for providing freshwater even with expanding water shortage and raising interest.

RWH technique is very commonly used in the Northern part of Pakistan where the climate is very humid and often rainy. Residents of Northern cities of Khyber Pakhtunkhwa like Nathiagali, Ayubia, Batgram, some parts of Abbottabad and Mansehra rely on RWH as the main source of portable water in these cities are from perennial streams and seasonal streams. The roofing system of houses in these areas are sloping, made of steel sheets which minimize the absorption and other roof losses. In said areas, the maximum amount of water could easily be harvested without any additional loss. The system is designed as the harvested water enters a primary tank (flash tank) first where sedimentation takes place and clean water enters into the secondary tank from where water is drawn for domestic use. Moreover, in some remote areas of Azad Jammu and Kashmir RWH is the main source for domestic water utilization. In these hilly areas like Khabli, Ghari Dupatta, Peer Hasimaar and Majhoi, there is no proper municipal water supply system and due to hard soil strata, bore-holes are near to impossible. The residents of these areas face difficulty in getting water to meet their daily requirements. Due to the economic status of these areas people cannot afford water tankers from private dealers as the cost is too high for them to afford. In order to meet their water need, they mostly rely on RWH.

The major concern of municipal authorities of Islamabad is the speedy decline of the groundwater table which is an alarming threat to the future of the city. Increasing the growth rate of the city’s population and deforestation are setting new environmental challenges for the municipal authorities. This study aims to promote an alternative source of water for the inhabitants so that the dependency on conventional sources could be minimized. RWH system proved to be an efficient system to meet the partial water demand of inhabitants plus it minimizes the reliance and conventional water sources. This study would also suggest the sectors where harvested water could be utilized effectively.

3. Study area
The study area is in the vicinity of Islamabad (Zone V) and it is highlighted in figure 1. This site is accessible only from Islamabad Highway through Japan Road at a distance of 6.1 Km’s. The site is surrounded by Gulberg Greens, Japan Road, Naval Anchorage Block F and OPF Housing Society from North, South, West, and East respectively. This site consists of 500 houses. The plot size for each house is 116 m² and effective roof size of each house is 94 m² as by building bye-laws.
4. Water availability survey and demand

A reconnaissance survey has been conducted in the surrounding of the study area in a village named “Dadoo Maira” which consists of 50-60 houses. The aim of this survey is to know about the condition of water sources. Figure 1 shows the localities which were surveyed to find various facts about water in the surroundings of the study area.

Statistics show a shortage of water in the surrounding areas which ask for development of RWH as an alternative source of water to meet the water demand of the society. Different questions that were asked from the people about the source of their water supply, water depth, water level, change in water level in past few decades, problems about their water demand and quality of water. The water availability survey data is presented in the table 1.

![Figure 1. Location map of the study and survey Area.](image)

| No | Name of Person | Main Source | Water Level (m) | Depletion in Summer (m) | Depletion in past decades (m) | Availability issue during | Quality |
|----|----------------|-------------|----------------|------------------------|-------------------------------|--------------------------|---------|
| 1  | Shabbir        | Bore        | 52             | Dry                    | 12-15                         | Full Year                | Good    |
| 2  | Abdul Irfan    | Bore        | 49             | 15-18                  | 14-15                         | Summer                   | Good    |
| 3  | Raja Abrar     | Bore        | 43             | 6                      | 10-14                         | Summer                   | Good    |
| 4  | Imran          | Bore        | 37             | 1.5-3                  | 10-12                         | Summer                   | Good    |
| 5  | M. Saeed       | Bore        | 61             | Dry                    | 17                            | Full Year                | Good    |
| 6  | Mujtaba        | Bore        | 55             | 21-24                  | 13-17                         | Summer                   | Good    |
| 7  | M. Aslam       | Bore        | 46             | 15                     | 14-17                         | Summer                   | Good    |
| 8  | M. Aslam       | Bore        | 20             | 00                     | 6-8                           | Summer                   | Good    |
| 9  | Tahir          | Bore        | 33             | 18-20                  | 9-12                          | Summer                   | Good    |

4.1 Water demand analysis

According to CDA [23] water requirement per capita per day is 227 LPCD. When we apply this figure to our 116 m² (5 marlas) house having 4 people living in it, what we got for our monthly water demand for a single house is 27,240 L and 326,880 L for the whole year. Half of this demand is used for the summer season and another half for the winter season as roof absorption losses are different for each season. Table 2 shows the water demand of a single house having 4 persons in it.
Table 2. Water demand for a single house having 4-person accommodation.

| Water demand          | Quantity (liters) |
|-----------------------|-------------------|
| CDA Standard          | 227 Liters/person/day |
| Daily                 | 908               |
| Monthly               | 27,240            |
| Seasonally (6 Months) | 163,440           |
| Yearly                | 326,880           |

5. Weather data analysis
In this section we will discuss and analyze the precipitation, and evaporation data. The number of wet days, effective rainfall losses, and roof absorption losses is also discussed in the following paragraphs.

5.1 Precipitation data analysis
Precipitation data was taken from the World Bank Group’s official website [22] suggest an average yearly precipitation of 1,063 mm which is sufficient to harvest down water and to use it in many effective ways. Minimum precipitation was observed in the months of October and November whereas maximum was in the months of July and August with an average of 89 mm per month. For a 116 m$^2$ (5 marlas) house with an effective roof size of 94 m$^2$, total rainfall generated during a year is 98,700 L which is more than 30% of yearly water demand. Figure 2 shows average monthly precipitation that Islamabad receives per year. This data will be used to carry out a study to find out how much rainwater can be harvested and how much daily water requirements can be fulfilled using that harvested rainwater.

5.2 Calculation of evaporation losses
As per Nestle Pakistan report [8] the average evapotranspiration per day has been picked which was further processed to calculate average evaporation per day. According to Herbst and Lodger [24] determined evaporation loss as 35.65% of evapotranspiration. Jasechko S [25] worked out evaporation loss as 42.5% in evapotranspiration. This study is based on taking average 40% evaporation losses from the roof. On the basis of these values, it is estimated that yearly evaporation losses are 11,059 L of rainfall. The average evaporation per day for each month of a year is presented graphically in figure 3.

5.3 Calculation of wet days
A number of average wet days in Rawalpindi region are collected from the weather sparks website [26] The minimum wet days are 2 in the month of November and maximum is in the month of August that is 14 with an average of 8 days. These wet days were multiplied with evaporation losses of that particular month then subtracted from the average precipitation of that month. All data about wet days is shown in figure 4.

5.4 Roof absorption losses
Alpaslan N [15] claims that the roof losses during an event of a rainfall are up to 20% of the total downpour. This study carries an average 12.5% (10%-15%) for winter season and 17.5% (15%-20%) for summer season [15] The winter span is from October – March and summer span is from April –
September in Pakistan. On the basis of facts explained above, roof absorption losses for a year are 15,490 Liters. Average roof losses percentage is shown in figure 5.

5.5 Effective rainfall analysis
Evaporation losses and roof absorption losses are subtracted from the actual amount of precipitation to get the effective precipitation that will generate the water flow. Effective average precipitation per day is shown in the figure 6.

For the plot size of 116 m² (5 Marla) with an effective roof size of 94 m² with evaporation losses and roof absorption losses, the amount of rainwater that can be harvested for each month is shown in figure 7. The total amount of rainwater that can be harvested is 72,154 Liters.
6. Result and discussion
According to CDA, the yearly water demand for a single house having four people accommodations is 326,880 L as given in table 2, and the maximum amount of water that can be saved using RWH is 72,154 L which is more than 22% of the yearly demand.

By considering all relevant factors like roof absorption losses, evaporation losses, and system inefficiencies, RWH still meets the 22% of the yearly water demand in this specific area. For water bifurcation, the percentage for different uses are shown in figure 8 from which quantity of water for different purposes is calculated. By utilizing water demand bifurcation, yearly water demand and yearly harvested rainwater are bifurcated into four different purposes. The drinking and cooking is 4%, black water is 16% of total water demand. The grey water demand is 36% while demand for all other usage is 44% of the total water demand. The amount of rainwater that can be used for different purposes like cooking and drinking, black water for flushing and the grey water for laundry, and washing is illustrated in the table 3.

![Figure 8. Water demand bifurcation.](image)

For blackwater usage like flushing, rainwater can meet 100% requirement annually and for grey water usage after appropriate treatment, rainwater can meet almost 17% of its requirements annually for laundry, washing floors, in the kitchen etc. For the months of July and August.

Rainwater can meet more than 50% of monthly water demand in which black water and grey water usage can be 100% accommodated at the same time. But in the months of May, June, and October to December, harvested rainwater is not enough even for flushing so we have to save some water from previous two months to meet grey water demand here. The monthly harvested rainwater analysis is presented in table 4.

| Purpose / Use         | Water demand (L) | Harvested Rainwater used (L) | Percentage met by RWH | Remarks          |
|-----------------------|------------------|------------------------------|-----------------------|------------------|
| Drinking and Cooking  | 13,075           | 0                            | 0%                    | Not suitable     |
| Black Water           | 52,300           | 52,300                       | 100%                  | Suitable without any treatment |
| Grey Water            | 117,677          | 19,853                       | 17%                   | Suitable with treatment |
| Purpose / Use                        | Water demand (L) | Harvested Rainwater used (L) | Percentage met by RWH | Remarks |
|------------------------------------|------------------|-----------------------------|----------------------|---------|
| Others                             | 143,827          | 0                           | 0%                   | -       |
| Total for Single House (4 persons) | 326,880          | 72,154                      | 22%                  | -       |

Table 4. Monthly harvested rainwater analysis

| Monthly | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sept | Oct | Nov | Dec |
|---------|-----|-----|-----|-----|-----|-----|-----|-----|------|-----|-----|-----|
| Harvested RW (L) | 5757 | 7355 | 6429 | 5298 | 2738 | 4045 | 14269 | 14514 | 6247 | 2184 | 1126 | 2193 |
| Water demand (L)  | 27240 | 27240 | 27240 | 27240 | 27240 | 27240 | 27240 | 27240 | 27240 | 27240 | 27240 | 27240 |
| Water demand % meet by RWH | 21.2 | 27.0 | 23.6 | 19.5 | 10.1 | 14.9 | 52.4 | 53.3 | 22.9 | 8.0 | 4.1 | 8.0 |
| Flushing demand % meet by RWH | 100 | 100 | 100 | 100 | 62.8 | 92.8 | 100 | 100 | 100 | 50.1 | 25.9 | 50.3 |

7. Conclusion
Rainwater Harvesting system incorporation at the household level is the need of the hour to meet water demand for sustainable development even in the capital city of Islamabad. The same concept should be studies in different cities and necessary amendments in building bye-laws be made to make it compulsory to construct a RWH system.

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