Potential of Rainwater harvesting by using different rooftop material in urban areas: A case study

Talat Farid Ahmed[1]*, Hashim Nisar Hashmi[2], Ashfaq Ahmed Sheikh[3], Muhammad Azeem Afzal[4], Shamim-ul-Sibtain Shah[5]

1. Principal Scientific Officer, Farm Operations & Services, National Agricultural Research Centre, Islamabad, Pakistan.
2. Professor, Civil Engineering Department, University of Engineering & Technology, Taxila, Pakistan
3. Additional Registrar, Pakistan Engineering Council, Islamabad, Pakistan.
4. Technical Officer, Farm Operations & Services, National Agricultural Research Centre, Islamabad, Pakistan.
5. Principal Scientific Officer, Farm Operations & Services, National Agricultural Research Centre, Islamabad, Pakistan.

*For Correspondence: tafa367@gmail.com

Novelty Statement:

The reliability in rainwater harvesting investigations is of great importance due to associated infrastructure and protection of human lives. Generally the rainwater harvesting methods developed up till now involve various parameters and coefficients. The relationship between catchment characteristics and intensity of rainfall vary from region to region as they show the composite effect of all other characteristics which are not even considered in the relationships. The scope of the study is vast and reducing our reliance on municipal water to some extent. The novelty in the study is to know the harnessed water potential on rooftop catchments and to determine its runoff co-efficient under different rooftop material.

Abstract:
The water resources are under enormous stress due to increased in agricultural expansion, population rate linked with urban and industrial growth. The gap between water demand and supply is expanding rapidly. In view the importance of water for various aspects, a study is designed to estimate runoff potential of rooftop catchment's under different rooftop material. It will provide a relationship of rainfall-runoff for better designing of an efficient rainwater harvesting (RWH). It will also give estimate of RWH potential and rainwater quality. The output of this study will help us for effective and efficient rooftop RWH for urban condition.

Key words: Rainwater harvesting, varying rooftop material, automatic rain gauge, Runoff Coefficient, Urban Catchment

1. INTRODUCTION

Water scarcity has been predicted as one of the major issues fronting many countries, it has become a scare resource; it constitute only 2.5 % of total water volume on Earth with largest deposits underground. Fresh water demand is continuously rising with the increase in population, economic development, land use and climate change. The growing demand is met by the increasingly exploited groundwater resource due to which it is declining at an alarming rate all around the world. Urbanization is the most extreme land use change induced by humans which lead to greater pressure on fresh water resource as the people became more concentrated in one area. Keeping in view the importance of fresh water and its depleting resource in urban areas rain water harvesting is extremely important to minimize our reliance on groundwater the study identify the behavior of different types of rooftop materials for rain water harvesting in urban areas.

The most common catchment area for rainwater harvesting systems is the roof. The preferred surfaces are those, which are chemically inert such as slates. Metal roof coverings are acceptable but slightly acidic nature of rainwater can produce some dissolution of metal ions from the surface. Water collected from roofs with bituminous surfaces may be discolored and have a distinct odour [1].

Rainwater collected from paved areas surrounding the building can be used but is likely to be more heavily polluted and require extra treatment. Permeable paving systems are an exemption because they provide some filtration in their sub-base and allow biogradation of oils the quality of rainwater collected via permeable paving is particularly suited to irrigation [2].

Green and planted roofs can also be used as a catchment area for rainwater harvesting systems. However, this type of roofing system can retain in excess of 50 percent of the incident rainfall but it capable of filtering the rainwater depending upon the composition of its substrata [3].

Runoff coefficient is generally used to quantify rainwater collection losses. It represents a comparison between proportions of rainwater collected from roof under study as compared to an idea roof with no losses. Runoff coefficient of different roof types and configuration are, Pitched roof covered with tiles or slates (total flow type) 0.75-0.95, Flat roof covered with impervious membrane 0-0.5, Flat green roof incorporating plants and growing medium 0-0.5, [4]

Roofs are the first candidates for rainwater harvesting in urban areas. This research integrates quantitative and qualitative data of rooftop storm water runoff in an urban Mediterranean-weather environment. The objective of this study was to provide criteria for the roof selection in order to maximize the availability and quality of rainwater. Four roofs was selected for a period of 2 years i.e. three sloping roofs – clay tiles, metal sheet and polycarbonate plastic – and one flat gravel roof. Great differences in the runoff coefficient (RC) were observed, particularly on slope and roughness of the roof. Results indicated that sloping smooth roofs (RC > 0.90) harvest up to about 50% more rainwater than flat rough roofs (RC = 0.62). Physicochemical runoff quality appears to be generally better than the average quality found in the literature review. It was suggested that inclusion of criteria related to the roof's slope and roughness in city planning may be useful to promote rainwater as an alternative water supply while preventing flooding and water scarcity [5].

As performance of the Rooftop Rainwater harvesting Systems is responsive to the runoff coefficient, a field experiment was conducted to determine the runoff coefficient more precisely for various types of roofs. A simulation model was used was elucidated of four major identified rooftop rainwater harvesting parameters. It also estimates the most cost effective combination of the roof area and the storage capacity which could be best supplies a specific volume of water. The criteria established here formulate an efficient utensil for preliminarily estimating the most satisfactory storage capacity of any specific roof area and for determining the rational reliability of a corresponding water supply [6].

This study deals with two small scale rain water harvesting systems, buildings with corrugated iron roofs were selected with Runoff coefficient of 0.85. The rainwater harvesting design and required storage capacities can be identified on the basis of investigation results and on physical condition. The local socio-economic conditions were also assessed in the feasibility of system proposed. The results showed that decentralize methods of Rainwater harvesting is most economical in terms of rooftop catchment system [7].

Physical feasibility, scope and economical viability of roof top rainwater harvesting system were studied across classes and under different physical and socio-economic situation which debated that the rainwater harvesting systems are not alternative to the public systems in urban and rural area which receive low rainfall as the system is least reliable and is subjected to the availability of rainfall. Most houses had concrete roof with runoff coefficient 0.70 these rainwater harvesting system cannot replace the existing public systems however can be used as an additional resource. To implement these system a subside scheme by the government must be initiated [8].

Water scarcity has been predictable as one of the major issues fronting many countries. Plenty of rainfall is available in Ireland to overcome future shortage of water in urban areas. The water ingestion per capita per day in Ireland is one of the highest in Europe and increasing due to population growth and standard of living of their inhabitants. A study was initiated to use domestic rainwater harvesting and greywater treatment systems to know the potential of domestic water supply of Irish households. The results reveal that it can supply nearly 94% of domestic water for their households if a well-designed roof normally having a runoff coefficient between 0.7 and 0.9. It also helps Irish householders in achieving major water savings and avoids the domestic water bills; it also helps take pressure off from centralized domestic water supply [9].

Runoff coefficient is a dimensionless factor that is used to convert the rainfall amounts to runoff. It represents the integrated effect of catchment losses and hence depends upon the nature of land surface, slope, degree of saturation, and rainfall intensity. It is also affected by the proximity to water table, degree of soil compaction, porosity of soil, vegetation, and depression storage. Some of its probable values for different land use [10],[11]. The joint committee of the American Society of Civil Engineers and Water Pollution Control Federation has recommended values of runoff coefficient for a variety of land uses, soil types, and surface slopes [12].
In addition to various catchment factors as mentioned above, runoff coefficient also varies for different storm events (from nearly zero [for small storms] to a relatively high value [for a major storm]) depending upon the initial moisture conte [13]

In Islamabad, Pakistan, water table ranges between 150 and 400 ft on the average. It is further depleting day-by-day and exploitation of groundwater is becoming comparatively expensive. Supplies from two reservoirs, Simily and Rawal are not sufficient to meet demands for growing population. Islamabad is among the few cities in Pakistan those receive per annum precipitation in the range of 950-1100 mm. Rainwater can successfully supplement water supplies in this city and many other similar areas. This source of water is free from harmful environmental effects and may help in sustainable development. So it will be a nice place for experimentation regarding rooftop rainwater harvesting. In addition to this, water demand has considerably increased because of improvement in living standards. This resulted in an increasing pressure on underground water resources which lead to an alarming depletion of aquifers. This has emphasized the need to explore new water resources in Islamabad and Rawalpindi.

Keeping in view of its importance a study is designed to estimate runoff potential of rooftop catchment's under different rooftop material. This study will provide basic and proper relationship of rainfall-runoff for better designing of an effective and efficient rainwater harvesting system. It also will give estimate of rainwater harvesting potential and quality of rainwater. This will also be reducing stress on our available resources, significant reduction in water bills and controlling wastage of storm water. It will help to evaluate its suitability for supplement water supply and other miscellaneous uses such as ground water recharge and control flooding. Which in turn to overcome water demand to some extent, recharge of our depleting ground water resources and development of an additional source of water within the available ground water source.

2. MATERIALS AND METHODS

2.1 Site description

Study area is located in one hydrological region. Five catchments selected under this study are located in Model Village Chak Shahzad, Islamabad, Pakistan. The study area is situated between Latitude: 33.67272 and Longitude: 73.140124 with catchment area 100 square feet's (Table 1). The average annual rainfall in this area varies from 40 to 50 inches. Maximum rain occurs in the months of May to September. Maximum summer precipitation occurs as a result of seasonal low encountered by south eastern and western disturbances along with the effect of south eastern monsoons. Severe winter and mild summer temperature with summer dust storms takes place over low lands.

S. No.	Catchment Type	Catchment Area (Sq.ft)
1	Concrete rooftop	100
2	GI Iron Sheet rooftop	100
3	Asbestos Sheet rooftop	100
4	Terrazzo rooftop	100
5	Fiberglass Sheet rooftop	100

Table 1. Physiographic Features of Catchments

2.2 Methodology

An experimental study was imitated with the specific objectives; Testing different rooftop material to estimate runoff volume and to find out runoff coefficient values for different types of rooftop materials. For this a site in the urban areas of Islamabad with five rooftop catchment having different type of roof material was selected. The roof area of all five rooftop catchment under this experiment was considered 100 ft^2 .The roof material of all five catchment under testing include concrete, asbestos, fiber glass, Terrazzo and Corrugated iron sheets. The runoff from individual rooftop was collected in a storage Bucket attached with each catchment for measurement at various storm. The Rainfall will be observed using recorded rain gauge during the entire experiment. Runoff data will be collected at various intensities of a storm under different rooftop material conditions. Runoff co-efficient at various intensities of a storm under different rooftop catchment's material will be developed from this study, which leads rainfall-runoff relationship for effective and efficient designing of a domestic rooftop rainwater harvesting system.

2.2.1 Setup

Under this experiment, five rooftop catchments were developed; Concrete, Corrugated GI Iron sheet, Corrugated Asbestos sheet, Terrazzo and Fiber glass sheet rooftop, all had equal area of 100 sq.ft. Different rooftop materials under study are shown in Figures 1 to 5. Four water bucket and one water tank were used for volume measurement. Volume of water at various intensity of rainfall was collected through PVC pipes from individual catchment to these water buckets and water tank. Stop watch was used for volume collection time interval from a catchment. An automatic recorded rain gauge as shown in figure 5 was used during entire experiment for knowing observed rainfall.

Figure 1. Catchment with concrete rooftop

Figure 2. Catchment with Asbestos rooftop

Figure 3. Catchment with Fiber Glass rooftop

Figure 4. Catchment with Corrugated iron sheets rooftop

Figure 5. Catchment with Terrazzo rooftop

Figure 6. Automatic Recorded Rain Gauge

3. RESULTS

The results were calculated by application of the rational method based on formula which relates to runoff producing potential of the watershed, watershed drainage area and the time of concentration. The formula is as under.

$$Q = CiA$$

$$C = Q/iA$$

Where

Q = volume collected (cusec)
C = runoff coefficient
i = rainfall intensity (inch/hr)
A = Catchment area (acres)

This study catchment considered a 100 sq.ft area for all five catchments with different rooftop material. The study results showed that high volume of rainwater harvested was observed from fiber glass rooftop catchment i.e.116 liters in 5 minutes duration at rainfall intensity 1mm/min while it was 11.6 liters at rainfall intensity 0.1 mm/min as shown in Table No.1 as compared to other four rooftop catchments. The study results also showed the calculated average value of runoff coefficient is 1.54 if fiber glass roof top selected for rainwater harvesting as shown in Table No.2 and 5.

The study results showed that volume of rainwater harvested from Terrazzo rooftop catchment as compared to fiber glass rooftop catchment was less but more as compared to asbestos, GI iron sheet and concrete rooftop catchment i.e.108 liters in 5 minutes duration at rainfall intensity 1mm/min while it was 10.8 liters at rainfall intensity 0.1 mm/min as shown in Table No.1. The study results also showed the calculated average value of runoff coefficient, which was 1.43 if Terrazzo roof top selected for rainwater harvesting as shown in Table No.3 and 5.

The study results showed that volume of rainwater harvested was observed from Asbestos rooftop catchment i.e.80.6 liters in 5 minutes duration at rainfall intensity 1mm/min while it was 8.3 liters at rainfall intensity 0.1 mm/min as shown in Table No.1, which is less as compared to Terrazzo and fiber glass rooftop respectively. The study results also showed the calculated average value of runoff coefficient, which was 1.09 if asbestos roof top selected for rainwater harvesting as shown in Table No.3 and 5.

The study results showed that volume of rainwater harvested from GI iron sheet rooftop catchment as compared to asbestos, Terrazzo, fiber glass rooftop catchment was less but more as compared to concrete rooftop catchment i.e.75 liters in 5 minutes duration at rainfall intensity 1mm/min while it was 7.5 liters at rainfall intensity 0.1 mm/min as shown in Table No.1. The study results also showed the calculated average value of runoff coefficient, which was 0.99 if Galvanized Iron Sheets roof top used for rainwater harvesting as shown in Table No.3 and 5.

The study results showed that volume of rainwater harvested was observed from Concrete rooftop catchment i.e.58 liters in 5 minutes duration at rainfall intensity 1mm/min while it was 5.8 liters at rainfall intensity 0.1 mm/min as shown in Table No.1, which is least value of volume harvested as compared to other four roof top catchments. The study results also showed the calculated average value of runoff coefficient, which was 0.77 if asbestos roof top selected for rainwater harvesting as shown in Table No.3 and 5.

Duration (minutes)	Rainfall intensity (mm/min)	Volume Collected (Liters)				
		Type of rooftop material				
		Concrete	GI Iron Sheet	Asbestos Sheet	Terrazzo	Fiberglass Sheet
5	1	58	75	80.6	108	116
5	0.9	52.2	67.5	72.5	97.2	104.4
5	0.8	46.4	60	64.4	86.4	92.8
5	0.7	40.6	52.5	58.1	75.6	81.2
5	0.6	34.8	45	49.8	64.8	69.6
5	0.5	29	37.5	41.5	54	58
5	0.4	23.2	30	33.2	43.2	46.4
5	0.3	17.4	22.5	24.9	32.4	34.8

ISSN 2229-5518

5	**0.2**	**11.6**	15	**16.6**	**21.6**	**23.2**
5	**0.1**	**5.8**	7.5	**8.3**	**10.8**	**11.6**

Table No.1 Rainfall Potential at different at different rainfall intensity under different rooftop material

Fiberglass Rooftop					
liter/5min	l/min	cfs	iA	C=Q/iA	C
116	23.2	0.014	0.0035	3.8665	1.55
104	20.9	0.012	0.0032	3.857	1.54
92.8	18.6	0.011	0.0028	3.8452	1.54
81.2	16.2	0.01	0.0025	3.8706	1.55
69.6	13.9	0.008	0.0021	3.8571	1.54
58	11.6	0.007	0.0018	3.8382	1.54
46.4	9.28	0.006	0.0014	3.8805	1.55
34.8	6.96	0.004	0.0011	3.8568	1.54
23.2	4.64	0.003	0.0007	3.8103	1.52
11.6	2.32	0.001	0.0004	3.9515	1.58

Table No.2 Calculated run off coefficient values for fiberglass rooftop

Asbestos Roof						**Terrazzo Roof**					
liter/5min	l/min	cfs	iA	C=Q/iA	C	liter/5min	l/min	cfs	iA	C=Q/iA	C
80.6	16.1	0.01	0.0035	2.681	1.072	108	21.6	0.013	0.0035	3.584	1.43
72.5	14.5	0.009	0.0032	2.665	1.066	97.2	19.4	0.011	0.0032	3.575	1.43
64.4	12.9	0.008	0.0028	2.681	1.072	86.4	17.3	0.01	0.0028	3.598	1.44
58.1	11.6	0.007	0.0025	2.742	1.097	75.6	15.1	0.009	0.0025	3.588	1.44
49.8	9.96	0.006	0.0021	2.775	1.11	64.8	13	0.008	0.0021	3.575	1.43
41.5	8.3	0.005	0.0018	2.766	1.106	54	10.8	0.006	0.0018	3.612	1.44
33.2	6.64	0.004	0.0014	2.752	1.101	43.2	8.64	0.005	0.0014	3.598	1.44
24.9	4.98	0.003	0.0011	2.728	1.091	32.4	6.48	0.004	0.0011	3.575	1.43
16.6	3.32	0.002	0.0007	2.822	1.129	21.6	4.32	0.003	0.0007	3.528	1.41
8.3	1.66	0.001	0.0004	2.822	1.129	10.8	2.16	0.001	0.0004	3.669	1.47

Table No. 3 Calculated run off coefficient values for Asbestos and Terrazzo rooftop

Concrete Roof						**Galvinized Iron Roof**					
liter/5min	l/min	Q=cfs	iA	C=Q/iA	C	liter/5min	l/min	cfs	iA	C=Q/iA	C
58	11.6	0.0068	0.0035	1.9191	0.77	75	15	0.0088	0.0035	2.48356	0.9934
52.2	10.4	0.0061	0.0032	1.9128	0.77	67.5	13.5	0.0079	0.0032	2.47727	0.9909
46.4	9.28	0.0055	0.0028	1.9402	0.78	60	12	0.0071	0.0028	2.50467	1.0019

ISSN 2229-5518

40.6	8.12	0.0048	0.0025	1.9353	0.77	52.5	10.5	0.0062	0.0025	2.49975	0.9999
34.8	6.96	0.0041	0.0021	1.9285	0.77	45	9	0.0053	0.0021	2.493	0.9972
29	5.8	0.0034	0.0018	1.9191	0.77	38	7.5	0.004	0.0018	2.48356	0.9934
23.2	4.64	0.0027	0.0014	1.905	0.76	30	6	0.0035	0.0014	2.4694	0.9878
17.4	3.48	0.002	0.0011	1.8814	0.75	23	4.5	0.003	0.0011	2.44579	0.9783
11.6	2.32	0.0014	0.0007	1.9757	0.79	15	3	0.002	0.0007	2.54022	1.0161
5.8	1.16	0.0007	0.0004	1.9757	0.79	7.5	1.5	9E-04	0.0004	2.54022	1.0161

Table No. 4 Calculated run off coefficient values for Concrete and GI iron rooftop

S.No.	Type of Roof material	Average runoff coefficient
1	Concrete Roof	0.77
2	Galvanized Iron Roof	0.99
3	Asbestos Roof	1.09
4	Terrazzo Roof	1.43
5	Fiberglass Roof	1.54

Table No. 5 Average Runoff Coefficient of different Rooftop materials

5. CONCLUSION

The study relieved the following conclusion:

1. Based on the volume of water collected by using different rooftop materials at different rainfall intensity, the results show that Fiberglass Sheet has maximum rainfall harvesting potential as shown in figure. 7 as compared to other four rooftop material types.
2. Result relieved that Fiberglass rooftop material has the highest runoff coefficient value as compared to Terrazzo rooftop, Corrugated Asbestoses rooftop, Corrugated GI iron rooftop and Concrete rooftop respectively shown in figure. 8.

I

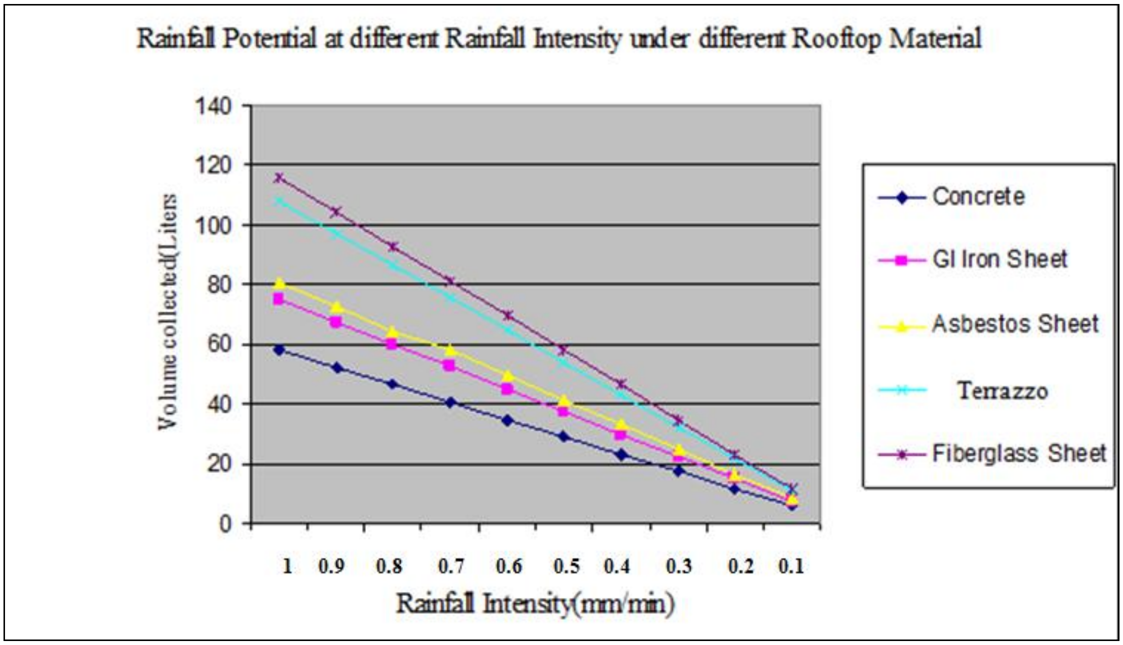

Figure 7. Trend of rainfall volume at variable rain intensity under different Rooftop Materials

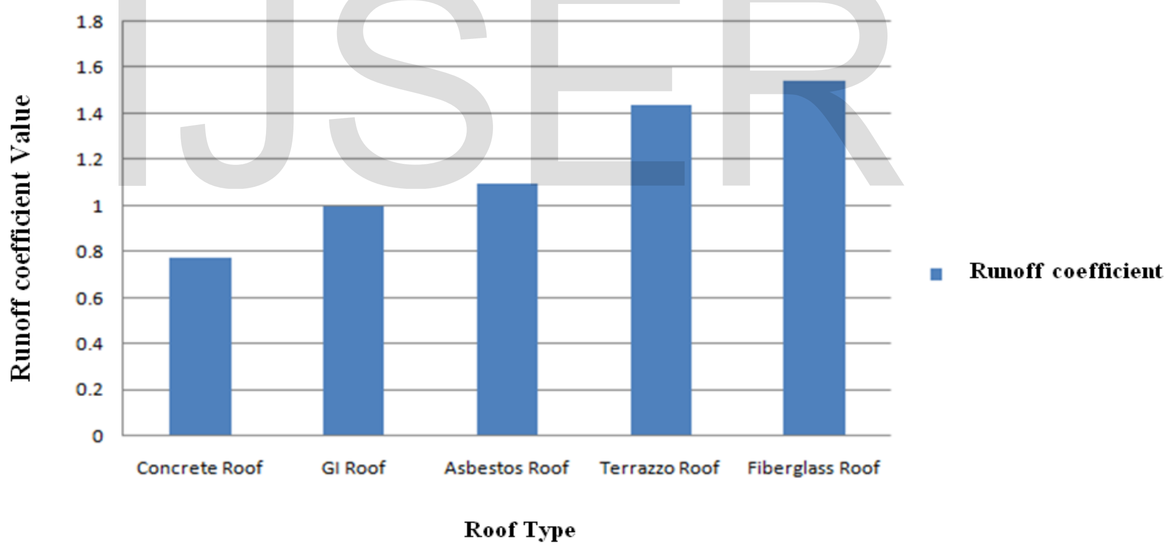

Figure 8. Runoff Coefficient of different Rooftop Materials

References

1. Konig, K.W., "The rainwater technology handbook: Rainwater harvesting in building"., Wilo-Brain, Germany (2001).
2. Pratt,C. J., Use of Permeable, reservoir pavement construction for storm water treatment and storage for re-use. Water Science & Technology., (1999), 39(5) 145-151
3. Fewkes, A., and Warm,P., "Method of Modeling: The performance of rainwater collection system in the United Kingdom. Building Services Engineering Research and Technology .,(2000), 2(4),257-265.

ISSN 2229-5518

4. Fewkes, Alan. "The technology, design and utility of rainwater catchment systems." Water demand management (2006): 27-51.
5. Farreny, Ramon, et al. "Roof selection for rainwater harvesting: quantity and quality assessments in Spain." Water research 45.10 (2011): 3245-3254.
6. Liaw, Chao, Hsien, and Yao Lung Tsai. "Optimum storage volume of rooftop rain water harvesting systems for domestic use 1." JAWRA Journal of the American Water Resources Association 40.4 (2004): 901-912.
7. Sturm, M., et al. "Rainwater harvesting as an alternative water resource in rural sites in central northern Namibia." Physics and Chemistry of the Earth, Parts A/B/C 34.13-16 (2009): 776-785.
8. Kumar, M. Dinesh. "Roof water harvesting for domestic water security: who gains and who loses?" Water International 29.1 (2004): 43-53.
9. Li, Zhe, Fergal Boyle, and Anthony Reynolds. "Rainwater harvesting and greywater treatment systems for domestic application in Ireland." Desalination 260.1-3 (2010): 1-8.
10. Mutreja, K. N., 1990. *Applied Hydrology*. New Delhi: Tata McGraw-Hill.
11. Subramanya, K., 1991. *Engineering Hydrology*. New Delhi: Tata McGraw-Hill.
12. American Society of Civil Engineers and Water Pollution Control Federation, 1969. Design and Construction of Sanitary Storm Sewers. ASCE Manuals and Reports on Engineering Practice no. 37 and WPCF Manual of Practice no. 9.
13. Goel, Manmohan Kumar. "Runoff Coefficient." Encyclopedia of Snow, Ice and Glaciers. Springer Netherlands, 2011. 952-953.