ROOF-TOP RAIN WATER HARVESTING: PROSPECTS FOR SHIMLA

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ABSTRACT: This paper talks about the possibilities of rain water harvesting for a city like Shimla where rainfall has seen a drastic change in the past 109 years. Now it is a well known fact that during summers there is scarcity of water in this region so the efforts have been made to design a roof top rain water harvesting system to meet the demand in this period. Two dimensionless less quantities storage fraction and demand fraction have been taken to find some alternative. The results clearly show that if we can store the rain water not only in the summers but round the year then a huge quantity of water will be stored without any significant loses. The demand of water for toilet flush for four persons living in a family can be fulfilled for two months with the storage of rain water of even one month only. The design of the houses will not be altered much because the roofs are already sloped and we have to find ways for the efficient storage. The non-dimensional design can be applied for the metropolitan cities and those places also where scarcity of water is always there.

INTRODUCTION

The world faces escalating demands for good quality water as current usage from surface and ground is outstripping supply. Even in those areas of the world that appear to have adequate water supplies, there are constant needs to balance existing supplies with ever growing demands. Cycles of droughts bring into sharp contrast the need to conserve, protect and supplement existing water supplies. The collection and storage of rainwater to supplement existing water supplies could alleviate some of these problems. Rainwater utilization may be one of the best available methods for recovering natural hydrological cycles and aiding in sustainable urban development. (Kim R-H, Lee S, Et al., 2005)

Water scarcity demands the maximum use of every drop of rainfall. (M. Abu-Zreig et al, 2000). Rainwater harvesting system has been regarded as a sound strategy of alternative water sources for increasing water supply capacities. **(**Hatibu N, Et al. ,1999**).** Rainwater harvesting systems intercept rainwater in hydrologic cycle through either natural landforms or artificial facilities. The small scale RHS does not involve the existing water right. And it has become one of the economical and practical measures for providing supplementary water supplies with its easy system installation. It can be a supplementary water source in urbanized regions for miscellaneous household uses such as toilet flushing, lawn watering, landscape and ecological pools, and cooling for air conditioning **(**Handia L et al, 2003**).**

HISTORY OF RAIN WATER HARVESTING

Water harvesting like many techniques in use today is not new. It is practiced as early as 4500 B.C. by the people of Ur and also latest by the Nabateans and other people of the Middle east. While the early water harvesting techniques used natural materials, 20th century technology has made it possible to use artificial means for increasing runoff from precipitation. Evenari and his colleagues of Israel have described water harvesting system in the Negve desert. The system involved clearing hill sides to smooth the soil and increase runoff and then building contour ditches to collect the water and carry it to low lying fields where the water was used to irrigate crops. By the time of the Roman Empire, these runoff farms had evolved into relatively sophisticated systems. The next significant development was the construction of roaded catchments as described by the public works Department of Western Australia in 1956. They are so called because the soil is graded into ditches. These ditches convey the collected water to a storage reservoir. Lauritzan, USA has done pioneering work in evaluating plastic and artificial rubber membranes for the construction of catchments and reservoirs during 1950's. In 1959,Mayer of water conservation laboratory, USA began to investigate materials that caused soil to become hydrophobic or water repellent. Then gradually expanded to include spray-able asphalt compounds, plastic and metal films bounded to the soil compaction and dispersion and asphalt fiber glass membranes. Early 1960, research programmes in water harvesting were also initiated in Israel by Hillal and at the University of Arizana by Gluff. Hillal's work related primarily to soil smoothing and runoff farming. Cluff has done a considerable amount of work on the use of soil sealing with sodium salt and on ground covered with plastic membranes. Water harvesting was practiced more than 1000 years back in South India, by way of construction of irrigation tank, ooranis, temple tanks, farm ponds etc, but the research in India on this subject is of recent one. Work is taken up at ICRISAT, Hyderabad, Central arid Zone Research Institute, Jodhpur, Central Research Institute for dryland Agriculture (CRIDA), Hyderabad, State Agricultural Universities and other dry land research centers throughout India.

In Pakistan, in the mountainous and dry province of Balukhistan, bunds are constructed across the slopes to force the runoff to infiltrate. In China, with its vast population is actively promoting rain and stream water harvesting. One very old but still common flood diversion technique is called 'Warping' (harvesting water as well as sediment). When

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water harvesting technique are used for runoff farming, the storage reservoir will be soil itself, but when the water is to be used for livestock, supplementary irrigation or human consumption, a storage facility of some kind will have to be produced. In countries where land is abundant, water harvesting involves; harvesting or reaping the entire rainwater, store it and utilize it for various purposes.

In India, it is not possible to use the land area only to harvest water and hence water harvesting means use the rain water at the place where it falls to the maximum and the excess water is collected and again reused in the same area. Therefore the meaning of water harvesting is different in different area/ countries. The methods explained above are used for both agriculture and to increase the ground water availability.
The water harvesting for household and for recharging purposes are also in existence for long years in the world. During rainy days, the people in the villages used to collect the roof water in the vessels and use the same for household purposes including drinking. In South East Asian countries people used to collect the roof water (thatched roof by providing gutters) by placing 4 big earthen drums in 4corners of their houses. They use this water for all household purposes and if it is exhausted only they will go for well water. The main building of the Agricultural College at Coimbatore was constructed 100 years ago and they have collected all the roof water by pipes and stored in a big underground masonry storage tanks by the sides of the building. These rainwater are used for all labs, which require pure and good quality of water. In the same way the rainwater falling on the terrace in all the building constructed subsequently are collected and stored in the underground masonry tanks Even the surface water flowing in the Nalla's in the campus are also diverted by providing obstructions, to the open wells to recharge ground water. Hence Rainwater harvesting is as old as civilization and practiced continuously in different ways for different purposes in the world The only thing is that it has not been done systematically in all places. Need has come to harvest the rainwater including roof water to solve the water problems everywhere not only in the arid but also in the humid region. (Dr. R. K. Sivanappan, 2006)

Collecting rainwater as it falls from the sky seems immensely sensible in areas struggling to cope with potable water needs. Rainwater is one of the purest sources of water available as it contains very low impurities. Rain water harvesting systems can be adopted where conventional water supply systems have failed to meet people's needs. (Dr. K. A. Patil, Et al. 2006)

OUR AREA OF DISCUSSION

Rainwater harvesting (RWH) is recognized as one of the tools of Sustainable Urban Drainage Systems (SUDS) which aim at restoring the natural hydrologic cycle in the urban environment. RWH limits the demand for potable water and, at the same time, rainwater storage controls storm water runoff at the source (Elliott and Trowsdale, 2007). Various methodologies for the design of rainwater harvesting systems are documented in the literature (Mitchell, 2007 etal.,) and generally include simplified approaches based on user-defined relationships (e.g. Ward et al., 2010), continuous mass balance simulations , non-parametric approaches based on probability matrix methods and statistical methods . The most common methodology is the behavioral analysis that uses continuous simulation to assess the inflow, outflow and change in storage volume of the rainwater harvesting system according to a mass balance equation.

Same has been done here. The study has been carried out on the recorded data on average monthly rainfall for the time period of 109 years i.e. from 1900 to 2009 at Shimla, Himachal Pradesh, India.(10).

GEOGRAPHY OF SHIMLA

The geography of Shimla is most diverse and multifaceted as the city is located on the verge of subtropical regions and higher Himalayas. The pleasant weather, sometimes steep, sometimes perpendicular landscape of most of the geographical locations of Shimla India is a sure proof of that. The average elevation of the city of Shimla is 2397 meter or 7866 ft. above the sea level and Shimla is located on the ridge and in the north western portion of Himalayas.

METHODOLOGY ADOPTED

Schematic illustration of the rainwater harvesting system used in this work is reported in Fig. 1

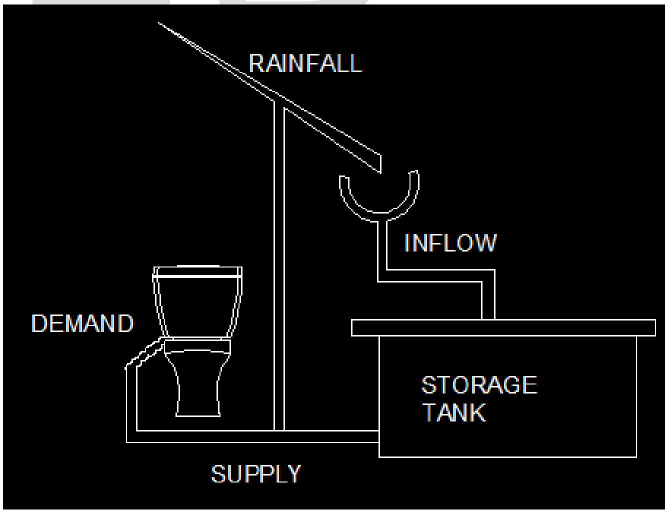

Fig. 1. Configuration of the rainwater harvesting system

This figure clearly explains the following equation:

Equation 1.
Max Supply (or) outflow = Water stored in tank + Inflow ;
where inflow(Q) depends on the precipitation (R), Area of roof (A) and Runoff Coefficient(K).

Equation 2.
$$\mathbf{Q = K * R * A}$$

The rainfall–runoff process is therefore interpreted by assuming a constant runoff coefficient and no quality aspects are taken into account thus neglecting the occurrence of the first flush phenomenon. As widely documented in the literature (Gnecco et al., 2006) the impact of pollutant load associated with urban paved surfaces is significant thus requiring at least to divert the first flush volume. As examples, in order to account the first flush effect, Khastagir and Jayasuriya (2010) subtracted the first 0.33 mm of daily rainfall while Basinger et al. (2010) assumed 0.4 mm of first flush occurring after 3 dry days. However, in the present configuration it is assumed that rainwater is only collected from rooftops since the pollutant load washed-off from such surfaces is limited compared to road runoff (Gnecco et al., 2005).

The runoff coefficient is taken as the average of the two limits for the runoff coefficient as stated in table 1, i.e. 0.85 (16).

TABLE 1: **Runoff Coefficient Table**

Area Description	**Runoff Coefficient K**
Business	
Downtown	0.70-0.95
Neighborhood	0.50-0.70
Residential	
Single-Family	0.30-0.50
Multiunits, detached	0.40-0.60
Multiunits, attached	0.60-0.75
Residential (suburban)	0.25-0.40
Apartment	0.50-0.70
Industrial	
Light	0.50-0.80
Heavy	0.60-0.90
Parks, cemeteries	0.10-0.25
Playgrounds	0.20-0.35
Railroad yard	0.20-0.35
Unimproved	0.10-0.30
Character of surface	**Runoff Coefficient K**
Pavement	
Asphaltic and concrete	0.70-0.95
Brick	0.70-0.85
Roofs	**0.75-0.95**
Lawns, sandy soil	
Flat, 2 percent	0.05-0.10
Average, 2-7 percent	0.10-0.15
Steep, 7 percent	0.15-0.20
Lawns, heavy soil	
Flat, 2 percent	0.13-0.17
Average, 2-7 percent	0.18-0.22
Steep, 7 percent	0.25-0.35

The water demand to be supplied by rainwater is limited in this study to toilet flushing and is assumed to occur at a constant rate. This assumption is reasonable because the demand time series generated by WC usage does not exhibit excessive daily variances. (Fewkes, 2000).

The average monthly rainfall for different time intervals is stated in table 2 & combined average monthly rainfall for time duration of 109 years i.e. from 1900 to 2009 is stated in table 3.(10)

TABLE 2**: Average monthly rainfall for different time interval s.**

TIME INTERVAL	1900-1930	1930-1960	1960-1990	1990-2009
MONTH				
JANUARY	41.04	41.39	35.84	37.49
FEBRUARY	39.03	42.49	41.9	52.21
MARCH	31.79	33.94	45.67	36.83
APRIL	28.39	29.95	32.71	35.47
MAY	36.61	34.57	40.96	42.27
JUNE	129.01	130.59	122.54	108.9
JULY	246.38	285.33	282.79	177.22
AUGUST	246.6	227.57	240.1	175
SEPTEMBER	148.76	140	140.21	113.73
OCTOBER	15.55	23.74	21.86	10.04
NOVEMBER	12.88	9.75	10.62	11.97
DECEMBER	16.05	15.84	17.66	12.49

TABLE 3: **Combined average monthly rainfall for time duration of 109 years.**

MONTH	1900-2009
JANUARY	39.19
FEBRUARY	42.86
MARCH	36.73
APRIL	31.5
MAY	37.55
JUNE	125.13
JULY	253.99
AUGUST	226.51
SEPTEMBER	138.31

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OCTOBER	18.4
NOVEMBER	11.14
DECEMBER	15.58

Percentage of population using different ways for toilet purposes in Shimla is stated in Table 4 as per the data set available on (18).

TABLE 4: **Percentage of population using different ways for toilet purposes in Shimla.**

Type	Percentage
Individual Toilets	85.15
Open Defecation	2.31
Public Toilets	12.42

Optimum design of the roof top rainwater harvesting system may vary with the local specific constraints & conditions which would directly or indirectly influence the analysis of performance and the conclusions drawn on the reliability of the system.
Thus, the design of RHS under different environmental conditions such as amount of rainfall, water demand etc. and system characteristics like water storage capacity, is examined as a function of two non-dimensional parameters:
1. Demand fraction
2. Storage fraction.
The demand fraction is defined as the ratio D/Q between the average monthly water demand D [L3] and the average monthly inflow Q [L3] while the storage fraction is defined as the ratio S/Q between the storage capacity of the storage tank S [L3] and the average monthly inflow Q [L3].

Demand depends solely upon the type of water closet being used. In a home with older toilets, an average flush uses about 3.6 gallons (13.6 liters), and the daily use is 18.8 gallons (71.2 liters) per person per day. In a home with ultra-low-flow (ULF) toilets, with an average flush volume of 1.6 gallons (6 liters), the daily use is 9.1 gallons (34.4 liters) per person per day. A family of four using an older toilet will use approximately 26,000 gallons (98.4 m3) per year in toilet flushes, while a family with a ULF toilet will use approximately 11,000 gallons (41.6 m3) per year in toilet flushes, achieving a savings of 15,000 gallons (56.7 m3) per year. New, High Efficiency Toilets (HETs) use 1.3 gallons (5 liters) per flush (gpf). With an HET, a family of four will use approximately 9,000 gallons (34 m3) per year in total toilet water use. (19).

CALCULATIONS & OBSERVATIONS:
Assumptions:
1. Area of roof : 150 m^2
2. 53% population in Shimla is using old toilets, 28% is using ULF & remaining 17% using HETs. As stated in table 5.
3. Storage tank capacity is 12 m^3 be [3m * 2m * 2m]

Figure 2: Pictorial representation of percentage of population using different ways for toilet purposes as stated in table 4.

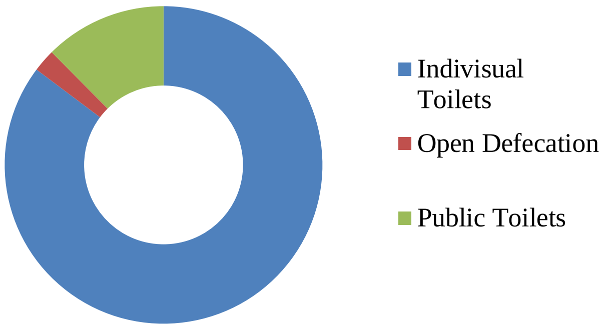
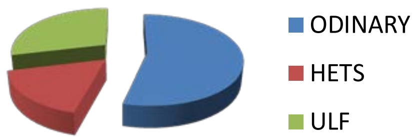


Table 5: showing the percentage of population using different types of toilets.

Type of WC	Percentage
ODINARY	52.793
HETS	16.6775
ULF	28.0995

Figure 3: Pie diagram on the basis of table 5.

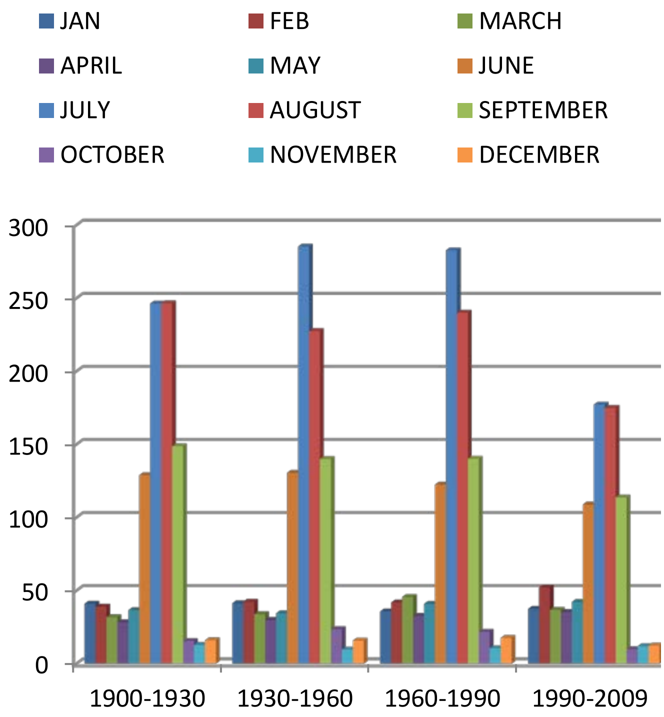


Since 53% population is using old toilets, 28% using ULF & remaining 17% using HETs (Assumption 2), total demand per year for a family of four is = 69.58 m^3

Thus,
Average water demand per month [D] = 69.58/12 =5.798 m^3
Runoff Coefficient = (0.75 + 0.95)/2 = 0.85 [from table 1].

Area of Roof = 150 m^2 (Assumption 1)

Fig 3: Pictorial representation of table 2



Average monthly rainfall [R] calculated from table 2 & table 3 is stated in table 6.

Table 6:

Time Interval	Average Monthly Rainfall
1900-1930	82.67mm
1930-1960	84.60mm
1960-1990	86.07mm
1990-2009	67.80mm
1900-2009	81.54mm

Using Equation 2 ‘Q’ is calculated and stated in table 7

Table 7: **Inflow value chart**

Time interval	Q (m3)
1900-1930	10.54
1930-1960	10.79
1960-1990	10.97
1990-2009	8.64
1900-2009	10.38

As

[D_f]Demand fraction= D/Q
[S_f] Storage Fraction= S/Q

Values are accordingly calculated and stated in table 8 & 9.

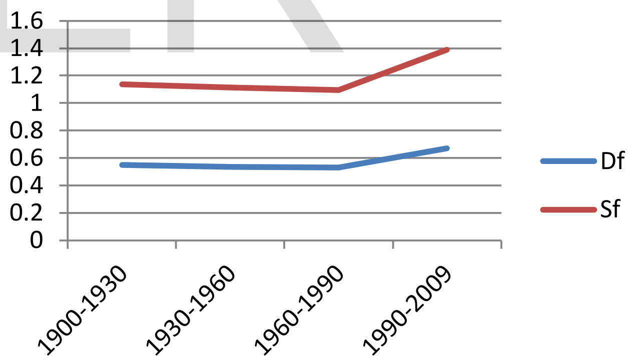
Table 8: **Demand fraction table.**

Time interval	D_f
1900-1930	0.55
1930-1960	0.537
1960-1990	0.528
1990-2009	0.671
1900-2009	0.559

Table 9: **Storage fraction table.**

Time interval	S_f
1900-1930	1.138
1930-1960	1.112
1960-1990	1.093
1990-2009	1.388
1900-2009	1.156

FIGURE 4: PICTORIAL REPRESENTATION OF TABLE 8 & 9



ANALYSIS

Volume stored in tank at beginning of the month = V
Rain water supplied from storage tank = Y
Now,
V = Q – D = 10.38- 5.789 = 4.591 m^3
Y = min (V, D) = 4.591 m^3

Performance assessment of the rainwater harvesting system is performed by means of a non-dimensional index called water efficiency [E]

E = Y / D

E= 4.591 / 5.789 = 0.793

The value of efficiency is very high even under the current circumstances when the rainfall data is taken for a mean value. Though the design parameters taken are random and capacities assumed are random but as per the demand the calculation show that supply of one month will be more than sufficient to meet the demand of one month. There can be variations in all the parameters taken but one thing is certain that it can meet the demand of present and future generations

CONCLUSIONS

- ✓ As per the observations the ground water level is depleting and annual rainfall is going down.
- ✓ Fresh water is everybody's need which will not be fulfilled if the current trend continues so we need a system which can meet the demand upto some extent.
- ✓ Rain water harvesting is a very good alternative for upcoming crises.
- ✓ The design shown here clearly suggests that roof rain water harvesting with the calculated parameters are very compatible in the current scenario.
- ✓ The design done is based on storage fraction and demand fraction which may vary and optimization will have to be done to make it more applicable.

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