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RESEARCH PAPER

Study on technical feasibility and economic viability of rooftop rainwater harvesting systems suitable for residential premises

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Abstract : An investigation was carried out to study the technical feasibility and economic viability of rooftop rainwater harvesting systems suitable for residential premises in Tamil Nadu Agricultural University, Campus. Coimbatore. The technical feasibility and economic viability of rooftop rainwater harvesting systems revealed that among individual residential blocks and all residential blocks combination, the all residential blocks combination was found to be more feasible for installation of rooftop rainwater harvesting structure with a benefit cost ratio of 2.27 and pay back period of 1.78 years. Hence, this combination was more suitable than any other individual blocks for rooftop rainwater harvesting systems. All the residential blocks combination can generate 40,92,611 liters of water per annum. Due to rooftop rainwater harvesting a sum of Rs. 1,22,778 per annum would be saved from all residential blocks combination which otherwise could be incurred from transporting water from tanker to these buildings combinations. The recharge pit can be constructed for all those residential blocks which are having surplus water.

Key Words : Rainwater harvesting, Rooftop rainwater harvesting, Technical feasibility, Cost analysis, Pay back period

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INTRODUCTION

In recent years, due to rapid urbanization and industrialization water demand in urban areas has increased manifold. Competing demands of water for agriculture, industrial and other urban usage have created a tremendous pressure on natural water resources *viz,* surface and groundwater. The technology of water harvesting is as old as our civilization. It is in practice in order to augment groundwater by artificial recharge and to drinking water resources for rural areas. The demand for water is realized from different fronts such as water for domestic purposes, civic or public purposes, fire fighting purposes, The central idea behind any water harvesting strategy should be such that the excess water available during rainy period should be collected and stored for a compensative usage during non-rainy periods (Boers, Th.M *et al.*, 1982).

MATERIALS AND METHODS

Study was conducted to study the technical feasibility and economic viability of rooftop rainwater harvesting systems suitable for residential premises based on rainfall analysis, at Tamil Nadu Agricultural University, Campus in Coimbatore.

Experimental site :

For designing roof top rainwater harvesting structures, residential buildings 'B' C' and 'D' type were selected and the area was located in the southern side of the TNAU campus. The TNAU campus was located at latitude of 11° N, longitude of 77 °E

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Table A : Particulars of persons and roof areas of the buildings in different blocks in TNAU Campus, Coimbatore

Sr. No.	Blocks	Buildings	No. of persons	Total roof area m^2
1.	I	Quarters: B 6-7	10	397
2.	II	Quarters: B 8-9	12	397
3.	III	Quarters: B 10-11	10	397
4.	IV	Quarters: C 8-13	24	856
5.	V	Quarters: C 14-19	25	856
6.	VI	Quarters: C 40-45	24	856
7.	VII	Quarters: C 46-51	28	856
8.	VIII	Quarters: D 1-8	22	812
9.	IX	Quarters: D 17-24	21	812
10.	X	Quarters: D 25-32	20	812
11.	XI	All residential	194	7051

and altitude of 426.72 m (above MSL). The average annual rainfall of TNAU campus was 677.8 mm (35 years average).

Description of the study area :

To provide rainwater harvesting structures some houses of 'B', 'C' and 'D' type residential blocks were selected. The residential blocks were located just beside of P.G hostel building. All these buildings have same structural framework which is in the form of gabled type, provided with Mangalore tiled roof with a slope of 35^o . The description of buildings is given in Table A.

Cost benefit analysis :

The total initial cost incurred in the installation process of the rooftop rainwater harvesting for individual residential blocks, combination of all buildings were calculated and the expected life of all structures were taken as 25 years (Ravikumar *et al.,* 2000). The total savings after the installation of these systems were also calculated per year. To examine the economic feasibility of investment in rooftop rainwater harvesting the pay back period, benefit cost ratio and net present worth methods were used.

Pay back period :

The pay back period is the length of time required to recover the initial cash outlay of the project and it was calculated as:

$$\text{Pay back period} = \frac{\text{Initial cash outlay or investment}}{\text{Constant annual cash inflow}}$$

According to this pay back criterion, the shorter the pay back period, the more desirable the project would be.

Benefit-cost ratio :

This ratio was calculated by dividing present worth of the discounted benefit to the present worth of the discounted cost.

$$\text{BC ratio} = \frac{\sum_{t=1}^{n} Bt\ (1+i)^{-t}}{\sum_{t=1}^{n} Ct\ (1+i)^{-t}}$$

where,

Bt = benefit in t^{th} year

Ct = cost in t^{th} year

i = discount rate.

Net present worth :

This is the present worth incremental net benefit or incremental cash flow stream and it was calculated as :

$$NPW = \sum_{t=1}^{n} Bt\,(1+i)^{-t} - \sum_{t=1}^{n} Ct\,(1+i)^{-t}$$

Water budgeting studies :

For the water budgeting analysis, residential blocks of 'B' 'C' 'D' type were selected and the weekly demand and supplies for these buildings were arrived at during the study period (Omwenga 1984).

RESULTS AND DISCUSSION

Design of different components involved in rooftop rainwater harvesting structure.

Residential block :

As the roof areas of all the blocks were same, the design of the components involved in the rooftop harvesting was also same. The detailed design of one block is given below.

Gutter design :

Projected rooftop area of one side larger section of the block = 270.3 m^2

Assuming runoff co-efficient = 0.9

Maximum discharge (Q) = rooftop area x rainfall intensity x runoff co-efficient :

= 270.3 x 0.0000161 x 0.9

= 0.003915 m^3/s

Q = A x Vm

$$0.003915 = \left(\frac{\Pi r^2}{2}\right) \times \frac{1}{0.016} \times \left(\frac{\frac{\Pi r^2}{2}}{\Pi r}\right)^{2/3} \times (0.005)^{1/2}$$

Radius, r = 0.0719 m ≅ 0.075 m

The required radius of the semicircular gutter for larger section was 7.5 cm.

Projected rooftop area of one side smaller section of the block = 132.5 m^2

Maximum discharge = 132.5 x 0.0000161 x 0.9

= 0.001919 m^3/s

$$0.001919 = \left(\frac{\Pi r^2}{2}\right) \times \frac{1}{0.016} \times \left(\frac{\frac{\Pi r^2}{2}}{\Pi r}\right)^{2/3} \times (0.005)^{1/2}$$

Radius, r = 0.055 ≅ 0.06 m

The required gutter radius for the smaller section roof was 6 cm.

Down pipe :

Projected rooftop area of one side larger section of the block = 270.3 m^2

Assuming runoff co-efficient = 1

Maximum discharge (Q) = rooftop area x rainfall intensity x runoff co-efficient

= 270.3 x 0.0000161 x 1

= 0.00435 m^3/s

Q = A x Vm

$$0.00435 = \left(\frac{\Pi d^2}{4}\right) \text{ x } \sqrt{\frac{2 \times d \times 9.81}{2 \times 0.009 \times 2}}$$

Diameter, d= 0.035m ≅ 0.04m

The required diameter of the down pipe for one side roof area was 4 cm.

The diameter for the smaller section of the roof area was also taken as 4 cm.

P.V.C pipe :

Assuming runoff co-efficient = 1

Maximum discharge (Q) = rooftop area x rainfall intensity x runoff co-efficient.

= 812 x 0.0000161 x 1

= 0.01307 m^3/s

Q = A x Vm

$$Q = \left(\frac{\Pi d^2}{4}\right) \times \left(\frac{1}{n} \times \left(\frac{d}{2}\right)^{2/3} \times S^{1/2}\right)$$

$$0.01307 = \left(\frac{\Pi d^2}{4}\right) \times \left(\frac{1}{0.009} \times \left(\frac{d}{2}\right)^{2/3} \times 0.015^{1/2}\right)$$

Diameter, d= 0.0962 m ≅ 0.1m

The required diameter of the P.V.C pipe was 10 cm.

Detention basin :

Q = A x Vm

The vertical distance through which the particle falls, taken as 1 m

$$T = \frac{0.03 \text{ x } 0.016 \text{ x } 1}{(2.65-1) \text{ x } 4 \text{ x } (0.001)^2}$$

T = 73 s

The time required for settling the particle of depth 1 m was 73 seconds.

$$Vf = \frac{0.01176}{\frac{L \times L}{1.5}}$$

$$Vf = \frac{0.0176}{L^2}$$

Length of the basin (L) = maximum flowing velocity x time of settling.

$$L = \frac{0.0176}{L^2} \text{ x } 73$$

Length, L = 1.088 m ≅ 1.5 m

$$\text{Breadth, } B = \frac{L}{1.5} = \frac{1.5}{1.5} = 1\text{m}$$

The dimensions required for the detention basin

Length of the basin = 1.5 m

Breadth of the basin = 1 m

Depth of the basin = 1 m

Filtration tank :

Assuming runoff co-efficient = 0.9

Maximum discharge per min = 812 x 0.000967 x 0.9

= 0.7065 m^3/min

Taking the rate of filtration for the flowing media of depth 1 m = 0.2 $m^3/min\text{-}m^2$

$$\text{Total area required (A)} = \frac{\text{Maximum discharge}}{\text{Rate of fitration}}$$

$$= \frac{0.7065}{0.2} = 3.533 \text{ m}^2$$

Area of rectangular basin, A = L x B

assuming L = 1.5 times the breadth = 1.5 B

3.533 = 1.5 B x B

B = 1.534 m ≅ 2 m

$L = 1.5 \times 2 = 3$ m

The dimensions required for the filtration tank

Length of the tank = 3 m

Breadth of the tank = 2 m

Depth of the tank = 1 m

Storage tank :

Volume of water collected from roof

= roof area x depth of rainfall

= 812 x 0.0454

$= 36.86 \text{ m}^3 \cong 36.9 \text{ m}^3$

Runoff over the tiled slope terraces accounting 15% losses

= 36.9 x 0.85

$= 31.365 \text{ m}^3 \cong 31.4 \text{ m}^3$

Assuming D, depth of the tank as = 2 m

Assuming L, length = 1.5 times the breadth

$31.4 = 1.5 B \times B \times 2$

$B = 3.23 \text{ m} \cong 3.5 \text{ m}$

$L = 1.5 \times 3.5 = 5.25 \text{ m} \cong 5.5 \text{ m}$

The dimensions required for the storage tank

Length of the tank = 5.5 m

Breadth of the tank = 3.5 m

Depth of the tank = 2 m

Abstract of design specifications for different structures :

The abstract of detailed design specification are presented in Table 1.

d = diameter, m L = length, m

B = breadth, m D = depth, m

* diameter of downpipe was same as in case of all hostels,

** length of downpipe was same as in case of all hostels,

*** diameter of gutter was same as in case of all residential blocks,

● - diameter of downpipe was same as in case of all residential blocks

Table 1: Abstract of design specifications for different buildings

Components	B block (6-7, 8-9 and 10-11)				C block (8-13, 14-19, 40-45 and 46-51)				D block (1-8, 17-24 and 25 - 32)				All residential blocks combination			
	d	L	B	D	d	L	B	D	d	L	B	D	d	L	B	D
Gutter																
larger	0.12	-	-	-	0.16	-	-	-	0.15	-	-	-	***	-	-	-
smaller	0.1	-	-	-	0.12	-	-	-	0.12	-	-	-	***	-	-	-
Down pipe	0.03	2	-	-	0.04	2	-	-	0.04	2	-	-	•	••	-	-
P.V.C pipe	0.075	12	-	-	0.1	15	-	-	0.1	15	-	-	0.21	183	-	-
Detention basin	-	1	1	1	-	1.2	1	1	-	1.5	1	1	-	3	2	2
Filtration tank	-	2.5	1.5	1	-	3	2	1	-	3	2	1	-	7.5	5	1
Storage tank	-	4	2.5	2	-	5.5	3.5	2	-	5.5	3.5	2	-	10.5	7	4

Table 2: Recharge pit specifications for different blocks

Sr. No.	Blocks	Circular recharge pit		Rectangular recharge pit		
		Depth (m)	Diameter (m)	Length (m)	Breadth (m)	Depth (m)
1.	B (6-7, 8-9, 10-11)	4	2.5	3.1	2.1	3.1
2.	C (8-13, 14-19, 40-45, 46-51)	6.1	3	3.9	2.6	4.3
3.	D (17-24, 25-32)	6	3	3.9	2.6	4

Table 3: Pay back period, BC ratio and net present worth for different buildings

Sr. No.	Building	Pay back period	BC ratio	Net present worth (Rs)	Investment (Rs)	Benefit from RTRWH (Rs)
1.	B 6-7	5.59	1.18	8424.88	16513	6917
2.	B 8-9	5.59	1.18	8424.88	16513	6917
3.	B 10-11	5.59	1.18	8424.88	16513	6917
4.	C 8-13	3.47	1.49	38636.59	28205	14906
5.	C 14-19	3.47	1.49	38636.59	28205	14906
6.	C 40-45	3.47	1.49	38636.59	28205	14906
7.	C 46-51	3.47	1.49	38636.59	28205	14906
8.	D 1-8	3.45	1.55	39383.23	28581	14134
9.	D 17-24	3.45	1.55	39383.23	28581	14134
10.	D 25-32	3.45	1.55	39383.23	28581	14134
15.	All residential	1.78	2.27	538334	153009	122778

●● - length of downpipe was same as in case of all residential blocks,

●●● - diameter of P.V.C pipe was same as in case of all individual buildings

Recharge pit design :

The recharge pit can be constructed for those buildings which were having surplus water (Romani Saleem *et.al* 2000). The recharge pit designs were made for the different buildings such as blocks B 6-7, B 8-9, B 10-11, C 8-13, C 14-19, C 40-45, C 46-51, D 17-24 and D 25-32. For these blocks it was observed from water budgeting tables that there was surplus amount and this excess water can be stored or recharged. The design specifications required for the above blocks are given in Table 2.

Cost analysis :

The total quantity of different materials required and total costs for the installation of the structure for individual buildings B block, C block and D block, the total investment required were Rs. 16,513, Rs. 28,205 and Rs. 28,581, respectively. For combination of all residential blocks the investment required was Rs. 1, 53,009 (Table 3).

Benefit cost ratio :

From the Table 3, it was observed that the benefit cost ratios for the individual residents in B blocks, C blocks and D blocks were 1.18, 1.49 and 1.55, respectively. For the combination of all residential blocks the ratios was 2.27. It was observed that the benefit cost ratio was higher in case of combination of all residential blocks compared to individual residential blocks.

It was found that as the benefit cost ratio increased the pay back period decreased. The pay back periods for B blocks, C blocks and D blocks were 5.59, 3.47 and 3.45 years, respectively. For combination of all residential blocks the pay back period was obtained as 1.78.

Similar to present investigation a research study on the quality of roof harvested rain water for domestic use in developing countrees was conducted by Michaelides (1990).

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