Estimation of Rooftop Rain Water Harvesting Potential by Water Budgeting Study

M. Manikandan[1*], M. V. Ranghaswami[1] and G. Thiyagarajan[2]

[1]Department of Soil & Water Conservation Engineering, Agricultural Engineering College & Research Institute, Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu (641 003), India
[2]Agricultural Research Station, Tamil Nadu Agricultural University, Bhavanisagar, Tamil Nadu (638 451), India

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Correspondence to

*E-mail: muthiahmanikandan29@gmail.com

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Abstract

In the present era of acute water shortage both in rural areas for agriculture and urban areas for drinking and industrial water needs, rainwater harvesting seems to be feasible solution to provide for considerable storage of water during rains. The water budgeting study was conducted to know the rainwater harvesting potential for office/departments buildings in TNAU campus by considering rainfall as the only source of supply of water. The weekly water demands and water supplies by rain water were worked out. The period of surplus or deficit of water can be found out by comparing the total supply and the total demands for any week. From the water budgeting calculation, the total annual water requirement was found to be 306.15 ha cm and water harvesting potential was calculated as 255.59 ha cm. The potential period for rainwater harvesting was found to exist from 37th to 47th week. Temporary surplus water which can be stored in rainwater harvesting structure during rainy season were estimated as 146.29 ha cm. It was also found that seasonal water demand was more than seasonal rainwater supply in the first and third season whereas in second season the demand was very less compared to rainwater supply in office/departmental areas due to north east monsoon. The annual water demand was more than the annual water supply by rain water. The additional water required to overcome these deficit has to be managed through external water supply and groundwater pumping. The water harvesting potential, which was calculated from water budgeting analysis, can be effectively stored in water harvesting structures and beneficially used for supplemental irrigation, scientific lab purpose, drinking water needs of human beings and animals and other categories of water usage within the campus.

1. Introduction

Water is a nature's gift that is available through rain, snowmelt and as groundwater. The quantity and quality of water available for human use is linked to the ecosystem, sustainable management of natural resources and giving priority of water uses between different sectors. Factors like deforestation, disruption of hydrological cycle, surface runoff, over extraction of groundwater, pollution of water sources, silting of lakes and tanks, etc. contribute mainly to the scarcity of water. The demand for fresh water is constantly increasing every day with the rapid increase in population and the development of industry and agriculture in the country. Agriculture has always remained a gamble with monsoon and the situation is further assuming precarious levels due to non-adherence of implementing water-harvesting strategies.

The available sources of good quality water are in the form of precipitation only, which is more or less a constant. Water harvesting systems for runoff water collection and storage represent an attractive solution for resolving water scarcity in various parts of the world (Frot et al., 2008). Rainwater harvesting is the practice of collection and storage of rainwater, either runoff or creek flow, for beneficial use (Myers, 1975). It can be sliced into different sub-components such as Rooftop Water Harvesting, Micro Catchment Water Harvesting, Roaded Catchment Water Harvesting, and Runoff Water Harvesting. Rainwater harvesting remains only feasible option to meet out the minimal irrigation needs of the crops (Rana and Gupta, 2010).

The central idea behind any water harvesting strategy is to store the excess water available during rainy season for use during post-rainy season. Rooftop rainwater harvesting is one of such techniques. Rooftop area provides ample scope to harvest the rainwater in humid and sub-humid areas (Ray et al., 2009). It has been estimated that about 11.44 km^3 of rainwater could be harvested through rooftops in India, which is approximately 30% of the domestic water requirement of the country (Taneja and Aggarwal, 2004).

Irrigation in TNAU campus is mainly dependent on groundwater and rainfall. As it is feared that over exploitation of groundwater is being done, a water budgeting study is necessary to know the present situation of the study area. Indiscriminate use of groundwater may lead to serious situations and may cause excessive drawdowns or mining of aquifers. There is an urgent need for harvesting every drop of rainwater, since this is the major source of replenishment of groundwater (Vashisht, 2008). The present study aims to assess the rainwater harvesting potential through water budgeting (water availability and usage) method.

2. Materials and Methods

2.1. Study area

Water budgeting study was conducted to know rainwater harvesting potential for office/department buildings in Tamil Nadu Agricultural University (TNAU) campus, Tamil Nadu, India. Office/departmental areas includes various buildings like RI building, Ramasamy Sivam building, Ramasamy Sivam PG block, Golden Jubilee building, Freeman building, Library, AEC & RI, Horticultural College and Basic Science building which have various departments and laboratories. The data regarding roof area, lawn area, number of persons working, number of labs in departments were collected under these groups and given in Table 1.

Table 1: Abstract of office/departmental areas

Roof area (m^2)	Lawn area (m^2)	Number of persons	Number of Labs
52,442.75	30,529	2,207	87

2.2. Water supply

Weekly rainfall data and evaporation was obtained from the meteorological station of the university. Rainfall for standard week was worked out by weekly rainfall data for the recent 25 years (1978-2002). During I, II and III season total number of rainy days are 9, 20 and 21, respectively. Effective rainfall can be determined by the evapotranspiration and precipitation ratio method given by USDA SCS (Dastane, 1977). At present for office/departments water is supplied by groundwater pumping and municipal (Siruvani) water supply through estate office.

Water budgeting study was carried out by considering rainfall is the only source of water supply. The volume of rainwater that can be collected from the rooftops can be calculated by the following formula:

$$Vr = Dr \times A \times C$$

Where, Vr = Rainwater harvested from roof $week^{-1}$ (liter)

Dr = Depth of rainfall received during the standard week (mm)

A = Area of the roof surface (m^2)

C = Runoff coefficient

The runoff coefficient ranges from 0.7 to 0.9 for different roof surfaces. For example, it is 0.7 in concrete, 0.75 in tile, 0.8 in asbestos, and 0.9 GI sheet. However, in this study, most of the roof surfaces are RCC roofs. So the value 0.7 was taken for C (Michael, 1999).

2.3. Water demand

The water demand for each building (office/department) was assessed by assuming the appropriate quantity of water for laboratory/lavatory needs in each department/office. During the observations, the average number of persons working in each office was obtained. The weekly drinking water demand was estimated by multiplying the water requirement for drinking $person^{-1}$ $week^{-1}$, and the number of persons present in the building. The assumed values for drinking, toilet and lab use are 5, 10 and 300 l day^{-1}, respectively. Evapotranspiration of lawn (ET crop) was calculated by multiplying weekly pan evaporation and crop factor (Allen et al., 1998). Irrigation water requirement (mm) of lawn was calculated by deducting the weekly effective rainfall from weekly evapotranspiration of crop. Weekly total water demand (ha cm) is obtained by multiplying the water requirement (mm) by lawn area (ha). By adding all the different demands, the total water demand has been worked out for office/department buildings.

2.4. Water budgeting

Water budgeting study was assessed by comparing the weekly demands and supplies of water for office/department buildings. The period of surplus or deficit of water can be worked out by deducting the total water demands from the total water supply for any week. Surplus water, if any, can be effectively stored by rainwater harvesting structures and used during the period of deficit.

2.5. Rain water harvesting potential

To calculate the rainwater harvesting potential of the roof areas of office/departments in TNAU campus, the rainwater harvestable from office/departmental areas was estimated. The quantity of water harvested has to be effectively stored in the rainwater harvesting structures (RWHS). The capacity of rainwater harvesting systems was calculated from surplus water.

3. Results and Discussion

Preparing the water budget is similar to operating the bank account with debits and credits. Here the credit part involves the total amount of water applied out of storage by way of irrigation and net contribution of rainfall. The debit side involves expending water by ET from crop canopy, runoff and deep percolation losses, and soil moisture storage changes. This water balance is an integral part of water budgeting over a specified period of time, which may be over a week/month, season or a full year. Supply demand analysis is the essence of water budgeting.

Weekly water demand, water supply and the rainwater harvesting potential of office/departmental areas in TNAU campus was studied through water budgeting techniques by considering rainfall as the only source of supply of water.

3.1. Water budgeting and rainwater harvesting potential of office/department buildings

Weekly rainwater supply (ha cm) was calculated by multiplying the roof area with weekly rainfall and runoff coefficient (which is taken as 0.7). The weekly water demand for drinking, toilet, laboratory, lawn was calculated for each zone. Finally surplus and deficit was calculated by deducting the water demand from rainwater supply.

Table 2 gives the details of water budgeting calculation for office/department buildings in TNAU campus. The total rainwater supply was calculated by multiplying the total roof area 52,442.75 m^2 by rainfall and runoff coefficient (0.7). The water requirement for lawn was computed by multiplying the area 30,529 m^2 by the ET crop (ET_C) (K_C=0.65) (Doorenbos and Pruitt, 1975).

The departmental areas have 87 laboratories for which water demand was calculated by multiplying the number of labs with the daily demand (300 l day^{-1}). The water demand for human beings was worked out by multiplying the total number of persons (2207) working in office with their daily demand of 5 l day^{-1} $person^{-1}$ for drinking and 10 l day^{-1} $person^{-1}$ for toilet. The total water demand (ha cm) was calculated by adding the water requirement for lawn areas, water requirement for laboratory and human beings.

From Table 2, the total annual water requirement was found to be 306.15 ha cm, while we can harvest 255.59 ha cm of rainwater. The annual deficit was estimated to be 50.56 ha cm of water. Nearly 84% of the annual water demand can be met by annual supply by rain water by implementing rainwater harvesting structures. Remaining 16% of annual water demand can be met by external pumping and municipal water supply.

Figure1 shows the water budgeting study of office/departmental buildings. Form Figure, it can be noted that the water demand curve showed a trend well above the water supply curve up to 37th week and then declined until 47th week and gradually raised towards the last. The potential period for rainwater harvesting was found to exist from 37th week to 47th week. Since rainwater harvesting can be implemented, the total volume of water that can be stored during rainy season was worked out to be 146.29 ha cm. Water harvesting structures are designed based on the quantity of water collected from the roof areas of office and departmental buildings.

In Tamil Nadu region, a major share is taken by north-east monsoon towards the supply of rainwater. In the study area (TNAU campus), 52% of rainfall is available during this season extending from October to January. In this period, the excess water can be collected and stored effectively in the rainwater harvesting structures like farm pond, percolation pond, etc. and used for supplemental irrigation for agricultural areas and lawn and to recharge the ground water.

Table 3 gives the details of seasonal water demand and rainwater harvesting potential in office/department buildings. From Table, it is found that the seasonal water demand was more than seasonal rainwater supply in the first and third season whereas in second season the demand was very less compared to rainwater supply in office/departmental areas due to north-east monsoon. The annual water demand was more than the annual water supply. The excess demand can be met by external water supply and round water pumping.

It is often observed that rainwater draining down from rooftop surface is simply disposed off through sewage network or stream network wastefully. This often leads to poor ground water recharge due to runoff. The concept of water harvesting is very much the need of the hour in order to narrow down the supply-demand gaps of water. That is the supply-demand gap during non-rainy season can be brought down by supplemental usage of harvested water. The rooftop water harvesting techniques helps to meet the local needs of community.

Rooftop surfaces offer greater scope for domestic storage of relatively pure water and in addition, augmentations of ground water table *in-situ*. Urban areas where a lot of housing colonies and commercial complexes are coming up, rainwater harvesting from roof top is the only feasible solution to develop water resources in order to meet the local needs of water with self-sustainability.

The foregoing analyses explored the potential of rainwater harvesting by water budgeting study in office/departmental areas. The water harvesting potential, which is calculated from water budgeting analysis, can be beneficially used for supplemental irrigation, scientific lab purpose, drinking water needs of human beings and animals and other categories of water usage within the campus.

Table 2: Water budgeting of office/departmental areas in TNAU campus

Stan-dard wk	Rainfall		Water supply		ET			Water demand (l)				Total (ha cm)	Deficit	Sur-plus
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	4.77	3.68	175033	1.75	26.60	22.61	14.70	336323	55175	110350	130500	6.32	-4.57	0.00
2	0.57	0.44	20925	0.21	27.30	23.21	15.08	447044	55175	110350	130500	7.43	-7.22	0.00
3	4.87	3.76	178777	1.79	29.40	24.99	16.24	381109	55175	110350	130500	6.77	-4.98	0.00
4	0.00	0.00	0.00	0.00	32.20	27.37	17.79	543126	55175	110350	130500	8.39	-8.39	0.00
5	0.00	0.00	0.00	0.00	35.70	30.35	19.72	602162	55175	110350	130500	8.98	-8.98	0.00
6	1.25	1.14	45887	0.46	32.90	27.97	18.18	520130	55175	110350	130500	8.16	-7.70	0.00
7	3.72	3.41	136561	1.37	37.80	32.13	20.88	533479	55175	110350	130500	8.30	-6.93	0.00
8	4.82	4.45	176942	1.77	33.60	28.56	18.56	430886	55175	110350	130500	7.27	-5.50	0.00
9	3.84	3.57	140966	1.41	39.90	33.92	22.04	564016	55175	110350	130500	8.60	-7.19	0.00
10	7.97	7.97	292578	2.93	42.00	35.70	23.21	465109	55175	110350	130500	7.61	-4.69	0.00
11	4.40	4.40	161524	1.62	42.70	36.30	23.59	585905	55175	110350	130500	8.82	-7.20	0.00
12	1.30	1.30	47723	0.48	47.60	40.46	26.30	763194	55175	110350	130500	10.59	-10.11	0.00
13	3.97	3.97	145738	1.46	47.60	40.46	26.30	681682	55175	110350	130500	9.78	-8.32	0.00
14	7.00	7.00	256969	2.57	43.40	36.89	23.98	518337	55175	110350	130500	8.14	-5.57	0.00
15	16.46	16.46	604245	6.04	44.80	38.08	24.75	253146	55175	110350	130500	5.49	0.00	0.55
16	14.31	14.31	525319	4.03	46.20	39.27	25.53	443754	55175	110350	130500	7.40	-3.36	0.00
17	10.99	10.99	403442	4.03	46.20	39.27	25.53	443754	55175	110350	130500	7.40	-3.36	0.00
18	19.19	19.19	704463	7.04	42.00	35.70	23.21	122574	55175	110350	130500	4.19	0.00	2.86
19	11.33	11.33	415923	4.16	40.60	34.51	22.43	338918	55175	110350	130500	6.35	-2.19	0.00
20	12.49	12.49	458507	4.59	53.20	45.22	29.39	516032	55175	110350	130500	8.12	-3.54	0.00
21	7.67	7.67	281565	2.82	47.60	40.46	26.30	568725	55175	110350	130500	8.65	-5.83	0.00
22	8.05	8.05	295515	2.96	44.10	37.49	24.37	498088	55175	110350	130500	7.94	-4.99	0.00
23	7.04	6.94	258438	2.58	49.00	41.65	27.07	614625	55175	110350	130500	9.11	-6.52	0.00
24	8.84	8.67	324516	3.25	49.00	41.65	27.07	561810	55175	110350	130500	8.58	-5.33	0.00
25	7.74	7.61	284135	2.84	48.30	41.06	26.69	582364	55175	110350	130500	8.78	-5.94	0.00
26	9.67	9.44	354985	3.55	49.00	41.65	27.07	538303	55175	110350	130500	8.34	-4.79	0.00
27	8.66	7.48	317908	3.18	42.70	36.30	23.59	491876	55175	110350	130500	7.88	-4.70	0.00
28	16.35	13.82	600207	6.00	42.00	35.70	23.21	286515	55175	110350	130500	5.83	0.00	0.18
29	7.44	6.43	273122	2.73	46.90	39.87	25.91	594774	55175	110350	130500	8.91	-6.18	0.00
30	9.34	8.07	342871	3.43	39.90	33.92	22.04	426635	55175	110350	130500	7.23	-3.80	0.00
31	6.90	5.97	253298	2.53	48.30	41.06	26.69	632431	55175	110350	130500	9.28	-6.75	0.00
32	7.00	6.20	256969	2.57	40.60	34.51	22.43	495531	55175	110350	130500	7.92	-5.35	0.00
33	8.59	7.59	315338	3.15	39.90	33.92	22.04	441289	55175	110350	130500	7.37	-4.22	0.00
34	10.19	8.19	374074	3.74	44.10	37.49	24.37	493814	55175	110350	130500	7.90	-4.16	0.00
35	9.39	8.29	344706	3.45	35.70	30.35	19.72	349076	55175	110350	130500	6.45	-3.00	0.00

1: RF (mm); 2:EF (mm); 3:RTWH (l); 4: Supply (ha cm); 5: E_P (mm); 6: ET_0 (mm); 7: ET lawn (mm); 8: IR of lawn; 9: Drinking; 10:Toilet ; 11: Lab; 12: Total (ha cm); 13: Deficit; 14: Surplus

Table 2: Water budgeting of office/departmental areas in TNAU campus (in continuation)

Standard wk	Rainfall		Water supply		ET			Water demand (l)				Total (ha cm)	Deficit	Surplus
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
36	6.02	5.92	220994	2.21	39.20	33.32	21.66	480465	55175	110350	130500	7.76	-5.55	0.00
37	14.84	13.93	544775	5.45	37.10	31.54	20.50	200507	55175	110350	130500	4.97	0.00	0.48
38	20.16	18.35	740072	7.40	38.50	32.73	21.27	89183	55175	110350	130500	3.85	0.00	3.55
39	27.24	24.12	999978	10.00	40.60	34.51	22.43	-51548	55175	110350	130500	2.44	0.00	7.56
40	29.84	23.31	1095424	10.95	32.90	27.97	18.18	-156698	55175	110350	130500	1.39	0.00	9.56
41	34.44	26.46	1264290	12.64	30.10	25.59	16.63	-300092	55175	110350	130500	-0.04	0.00	12.68
42	37.06	28.19	1360470	13.60	25.90	22.02	14.31	-423750	55175	110350	130500	-1.28	0.00	14.88
43	45.73	33.32	1678745	16.79	24.50	20.83	13.54	-603978	55175	110350	130500	-3.08	0.00	19.87
44	50.18	35.56	1842104	18.42	21.70	18.45	11.99	-719591	55175	110350	130500	-4.24	0.00	22.66
45	54.68	33.57	2007299	20.07	19.60	16.66	10.83	-694260	55175	110350	130500	-3.98	0.00	24.06
46	40.06	27.00	1470600	14.71	21.70	18.45	11.99	-458263	55175	110350	130500	-1.62	0.00	16.33
47	28.86	21.34	1059448	10.59	18.20	15.47	10.06	-344505	55175	110350	130500	-0.48	0.00	11.08
48	10.27	7.70	377011	3.77	23.80	20.23	13.15	166368	55175	110350	130500	4.62	-0.85	0.00
49	7.86	5.81	288540	2.89	24.50	20.83	13.54	235875	55175	110350	130500	5.32	-2.43	0.00
50	12.59	9.14	462178	4.62	27.30	23.21	15.08	181441	55175	110350	130500	4.77	-0.15	0.00
51	3.08	2.21	113067	1.13	25.20	21.42	13.92	357586	55175	110350	130500	6.54	-5.41	0.00
52	7.18	5.29	263577	2.64	29.40	24.99	16.24	334399	55175	110350	130500	6.30	-3.67	0.00

1: RF (mm); 2:EF (mm); 3:RTWH (l); 4: Supply (ha cm); 5: E_P (mm); 6: ET_0 (mm); 7: ET lawn (mm); 8: IR of lawn; 9: Drinking; 10:Toilet ; 11: Lab; 12: Total (ha cm); 13: Deficit; 14: Surplus

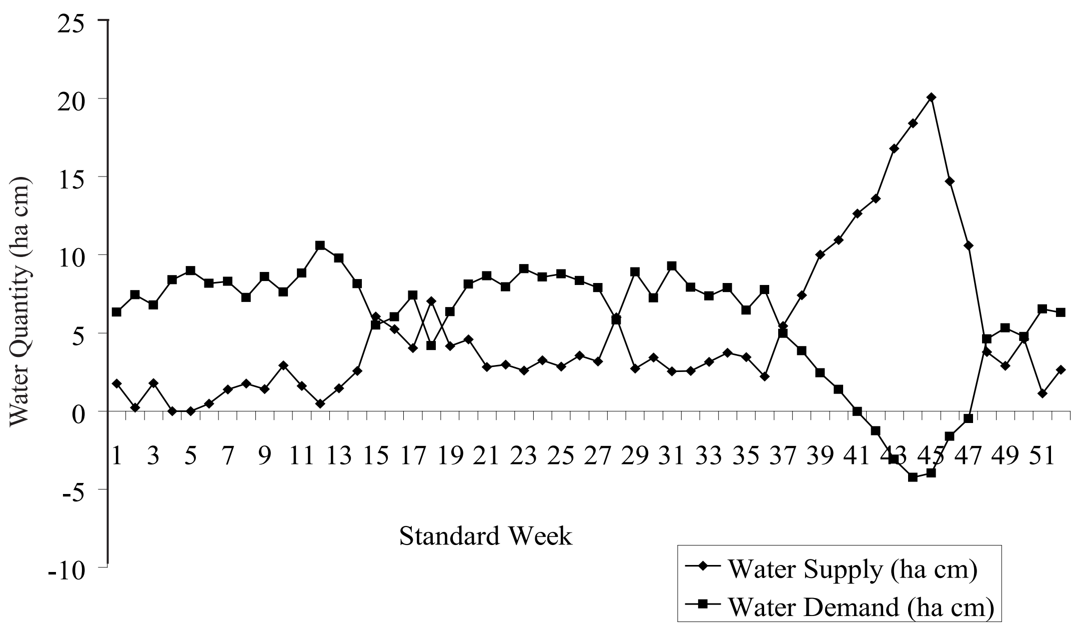

Figure 1: Water budgeting of office/ departmental buildings in TNAU campus

Table 3: Seasonal rain water harvesting potential (RWHP) and water demand			
Sl. No.	Season	RWHP (ha cm)	Demand (ha cm)
1	I Season	68.06	122.60
2	II Season	136.57	52.13
3	III Season	50.94	131.43
	Total	255.59	306.15

4. Conclusion

Water budgeting study for office/departmental areas was conducted to assess the water harvesting potential by considering rainfall as the only source of water supply. From the water budgeting study, the water harvesting potential in office/department areas was estimated to be 255.59 ha cm. However, the water demand was found to be 306.15 ha cm in order to meet the supplemental irrigation for lawns, human and laboratory needs in the departments. Hence the annual deficit was estimated to be 50.58 ha cm of water. It was also found that seasonal water demand was more than seasonal rainwater supply in the first and third season whereas in second season the demand was very less compared to rainwater supply. The potential period for rainwater harvesting was found to exist from 37th week to 47th week. Temporary surplus water from office/departmental areas which can be stored in rainwater harvesting structure during rainy season were estimated as 146.29 ha cm. The calculated quantity of rain water can be effectively stored in rain water harvesting structures and used to irrigate lawn area and recharging the groundwater during next season.

5. Further Study

All the surfaces ranging from agricultural areas to non-agricultural areas in entire TNAU campus can profitably be used to harvest rainwater. The capacity of rain water harvesting structures is designed by the water harvestable from the roof areas and runoff generated from surface areas. The proper location of rainwater harvesting structure, basic design of a suitable rooftop rainwater structure, its impact on ground water recharge and irrigation potential should be studied for the entire campus.

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