www.arpnjournals.com

DOMESTIC ROOFTOP WATER HARVESTING- A CASE STUDY

Arun Kumar Dwivedi[1] and Sudhir Singh Bhadauria[2]
[1]Department of Civil Engineering, SSVPS BSD College of Engineering, Dhule (MS), India
[2]Department of Civil Engineering, Rajiv Gandhi Technological University, Bhopal (MP), India
E-Mail: akd321@gmail.com

ABSTRACT

Although water is as important for survival of human being as much as food, air etc, but hardly any attention is paid for its economical use and conservation of this precious resource. Due to indiscriminate pumping of ground water, the water table is going down abnormally and if the problem is not given a serious look, then the future generations may have to face severe crisis of water. Rains are the main source of water and if rain water is harvested, the scarcity of water can be eliminated altogether. This is an ideal solution of water problem where there is inadequate groundwater supply quantitatively and qualitatively and surface sources are either lacking or insignificant. Rain water is bacteriologically pure, free from organic matter and soft in nature. In urban areas, rain water available from rooftop of buildings, paved and unpaved areas goes waste. This water can be stored in tank and can be used directly and also indirectly by diverting to recharge the aquifers through existing GW tapping arrangements and thereafter can be utilized gainfully at the time of need. The paper aims towards the development of the framework for domestic rooftop harvesting for drinking water. The paper is based on the analysis of survey record of around 50 houses of different rooftop areas of peri-urban area of Dhule city. The estimation of the appropriate size of the water tanks and their costs required to fulfill the annual drinking water demands through Domestic Rooftop Water Harvesting (DRWH) from rooftop of different areas are done. A mathematical equation expressing the relationship between the required size of water tank and different rooftop areas is developed. The DRWH systems for all houses are designed considering the existing rain water outlets and cost estimation for each individual house is done. A cost model expressing the relationship between rooftop area and cost of DRWH system is developed.

Keywords: cost model, direct roof top water harvesting system, rain water harvesting, unit cost.

INTRODUCTION

Water is the most common or major substance on the earth, covering more than 70% of its surface. Out of the total volume of water available on the surface of the earth, only 2 percent (over 28,000,000 km^3) is fresh water. The fresh water is used for the purpose of human use, industries and agriculture. The different forms of fresh water in which it is available on earth are given in Table-1 [2].

Table-1. World wide Distribution of Fresh Water.

#	Water type	Volume (1000 km^3)	% of total global volume
1	Glaciers	24,000	85.000
2	Ground Water	4,000	14.000
3	Lakes & Reservoirs	155	0.600
4	Soil Moisture	83	0.300
5	Atmospheric Water	14	0.050
6	River Water	1.2	0.004
		28,253.20	**100.00**

In India, the water availability per capita is declining. The per capita availability of water at the national level is reduced from about 5,177 m^3 in the year 1951 to the present level of 1,869 m^3. The prominent reasons behind are the increasing demand for water due to the increasing population and extensive use of water by agricultural sector, which continues to be the single largest consumer of water [2, 3].

In fact India is blessed with adequate rainfall as a whole, yet there are large swathes of dry and drought prone area. In many places the quality of groundwater is not good. In such places rainwater harvesting may provide lifeline for survival.

Rainwater harvesting

The human civilization, entirely depend upon rivers, lakes and ground water to fulfill their water demands. However rain is the ultimate source that feeds all these sources. The implication of rainwater harvesting is to make optimum use of rainwater at the place where it falls i.e. to conserve it without allowing it to drain away. Rainwater harvesting is an ancient technique enjoying a revival in popularity due to the inherent quality of rainwater. Rainwater is valued for its purity and softness. It has a nearly neutral pH, and is free from impurities such as salts, minerals, and other natural and man-made contaminants. Archeological evidence attests to the capture of rainwater as far back as 4,000 years ago. The concept of rainwater harvesting in China is as old as 6,000 years. Ruins of cisterns built as early as 2000 B.C. for storing runoff from hillsides for agricultural and domestic purposes are still standing in Israel [3].

Need for rainwater harvesting

Due to over population and higher usage levels of water in urban areas, water supply agencies are unable to cope up demand from available surface sources especially during summer seasons. This has led to digging of individual tube wells by house owners. Even water supply agencies have resorted to ground water sources by digging tube-wells in order to augment the water supply.

The replenishment of ground water is drastically reduced due to paving of open areas. Indiscriminate exploitation of ground water results in lowering of ground water table (GWT) rendering many bore-wells dry, which has led to drilling of bore wells of greater depth. This further lowers the water table such frequent fluctuations in GWT results in presence of higher concentration of salts in ground water. In coastal areas, over exploitation of ground water results in seawater intrusion thereby rendering fresh ground water bodies' saline [4].

In rural areas also, government policies on subsidized power supply for agricultural pumps and piped water supply through bore and open dug wells are resulting into decline in GWT. The solution to all these problems is to replenish ground water bodies with rainwater by man made means [3].

Benefits of rainwater harvesting

The rainwater's environmental advantage and purity over other water alternatives makes it the sustainable option, even though the precipitation cycle may fluctuate from year to year. The collection of rain water not only leads to conservation of water but also energy since the energy input required to operate a centralized water system designed to treat and pump water over a vast service area is bypassed. Rainwater harvesting also lessens local erosion and flooding caused by runoff from impervious cover such as pavement and roofs, as some rain water is captured and stored. Rain water quality almost exceeds that of ground or surface water as it does not come into contact with soil and rocks where it dissolves salts and minerals and it is not exposed to many of the pollutants that often are discharged into surface waters such as rivers, and which can further contaminate groundwater. However, rainwater quality can be influenced by characteristics of area where it falls, since localized industrial emissions affect its purity. Thus, rainwater falling in non-industrialized areas can be superior to that in cities which are dominated by heavy industry or in agricultural regions where crop dusting is prevalent [5].

Rooftop water harvesting

Rooftop water harvesting is a process of collecting of runoff during rains from impermeable surfaces on houses or close to houses, its storage in water proof vessels and its subsequent use for the inhabitants of the houses. The use may be temporary (with in a day or so following a rainstorm), seasonal (throughout the rainy season) or permanent (throughout the year) except in years of exceptionally low rainfall. The rain water from the roof may also be used for recharging the ground water through near by water sources such as open dug wells or bore wells. It may be achieved in the case of storing the harvested water from roof by diverting the excess water for ground water recharge and in absence of storing vessel by diverting all the water for ground water recharge.

Rooftop rainwater harvesting for household purpose only represent a small part of the total water balances. In areas with significant variations in the annual rainfall pattern, the matching of water supply and water demand may be difficult. However, in terms of economic and human welfare it has a crucial role to play. Rainwater in many cases is the easiest to access, most reliable, and least polluted source. It can be collected and controlled by the individual household or community as it is not open to abuse by other users [1, 6].

PROPOSED DRWH-A CASE STUDY FOR DHULE CITY

The Dhule town

Dhulia (Dhule) latitude $21^{o}10'$ and longitude $75^{o}20'$ is the chief town of the district as the headquarter, lying 57 km. north of Chalisgaon on the Bombay-Nagpur route of the central railway, with which it is connected by a broad gauge line. It is well connected by road network and is located at the crossings of NH-3, NH-6 and NH-211. It is situated on the southern bank of the Panzara River on the outer side of the bend of the river near the extremity of the easterly course just before it turns northwards to join the river Tapi. The town and its suburbs, covering an area of nearly 26.68 km^2 are well shaded by avenues of fine trees. The town area is developing in all directions. Many villages around the town have developed and constitute the peri-urban characteristics and are deprived of basic amenities such as water supply and drainage.

Rainfall data for Dhule town

A rain gauge station is located in the central part of the city. The daily rainfall records from 1996 to 2006 is made available and used for the purpose of analysis (Table-2).

ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

Table-2. Monthly Average Rainfall Data 1996-2006.

MONTHS	RAINFALL RECORD IN DIFFERENT MONTHS YEARS 1996 - 2006 (mm)											AVG
	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	
January	14.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.27
February	0.00	0.00	0.00	16.00	0.00	0.00	14.00	0.00	0.00	0.00	0.00	2.73
March	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.00	0.36
April	0.00	40.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.68
May	0.00	0.00	0.00	18.00	14.00	0.00	0.00	0.00	20.00	0.00	0.00	4.73
June	77.10	88.55	116.00	115.00	94.00	173.00	129.50	224.50	192.00	53.00	85.50	122.56
July	137.25	104.05	152.70	62.00	137.00	36.00	14.00	176.55	311.00	85.00	149.50	124.10
August	115.30	124.05	167.80	32.00	30.00	115.00	108.00	179.00	154.00	37.00	229.00	117.38
September	169.05	74.00	158.00	50.00	27.00	68.00	147.00	155.00	140.00	137.00	169.00	117.64
October	146.50	87.50	134.00	230.00	0.50	63.00	0.00	0.00	7.00	0.00	32.00	63.68
November	0.00	12.00	18.00	0.00	0.00	0.00	2.00	0.00	0.00	0.00	0.00	2.91
December	0.00	45.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.09
ANNUAL	659.20	575.65	746.50	523.00	302.50	455.00	414.50	735.05	824.00	312.00	669.00	**565.13**

METHODOLOGY

Around 50 houses having different rooftop area are surveyed. The DRWH potential for different sizes of rooftop is estimated. The annual rainfall quantum in Dhule town is less and hence the gross demand of a family can not be fulfilled by DRWH and at the same time number of days of rainfall is another constraint. The estimation of the size of the water tanks to fulfill drinking and cooking water demand @ 8.00 LPCD & their costs required to fulfill the annual drinking water demand through DRWH from rooftop of different areas are done. A general mathematical equation expressing the relationship between the size and cost of water tank and rooftop areas of different houses is developed.

The cost estimations of proposed DRWH system for all houses are doe and a cost model expressing the relationship between rooftop area and cost of DRWH system is developed. The flowchart as shown in Figure-1, presents the overall procedure of the work.
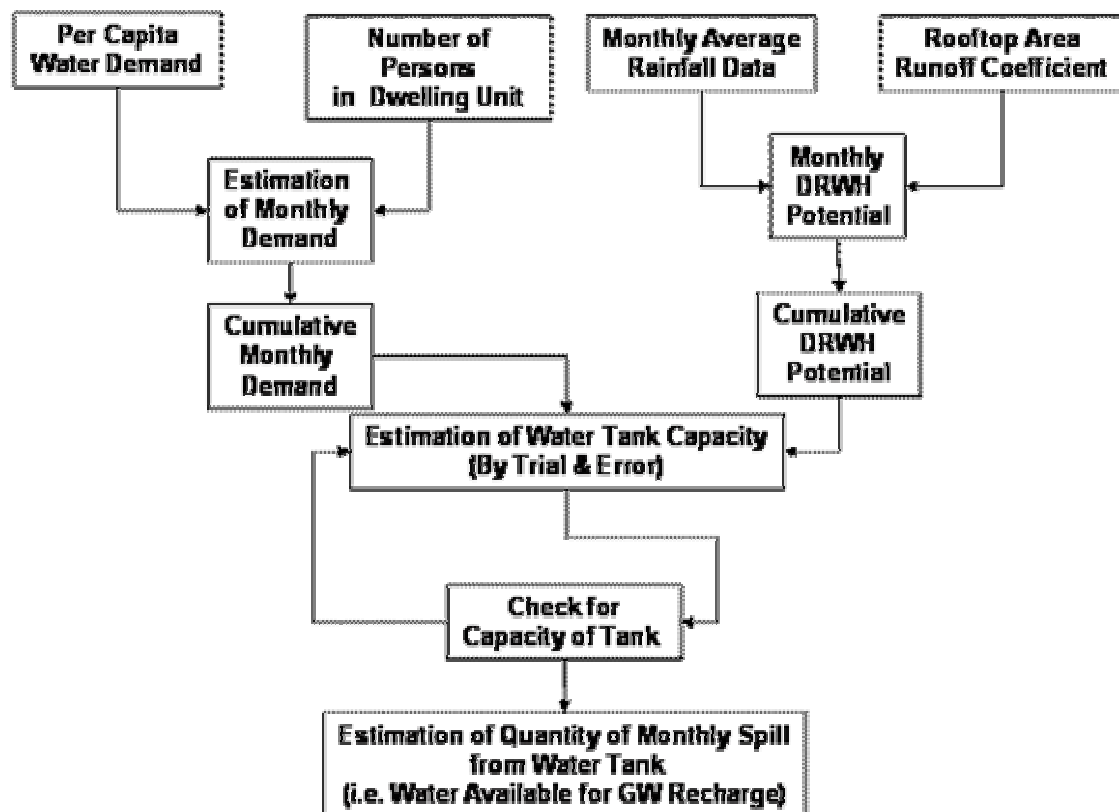
Figure-1. Flow chart showing overview of methodology.

www.arpnjournals.com

Tank size and GW recharge from different rooftop areas

The estimations of tank sizes to fulfill the drinking and cooking water demands @ 8.00 LPCD are done. The sizes of water tanks and the overflow from tanks for GW recharge are estimated. The month wise status of quantity of water available in the water tanks of different capacities are estimated. A sample calculation for 50 m^2 rooftop area is shown in Table-3. The cumulative water demand and cumulative DRWH versus time (for 2 cycles of months) and month wise status of quantity available in the water tank of (as estimated 7650 litres capacity for 50.00 m^2 rooftop areas) are shown in Figures 2 and 3.
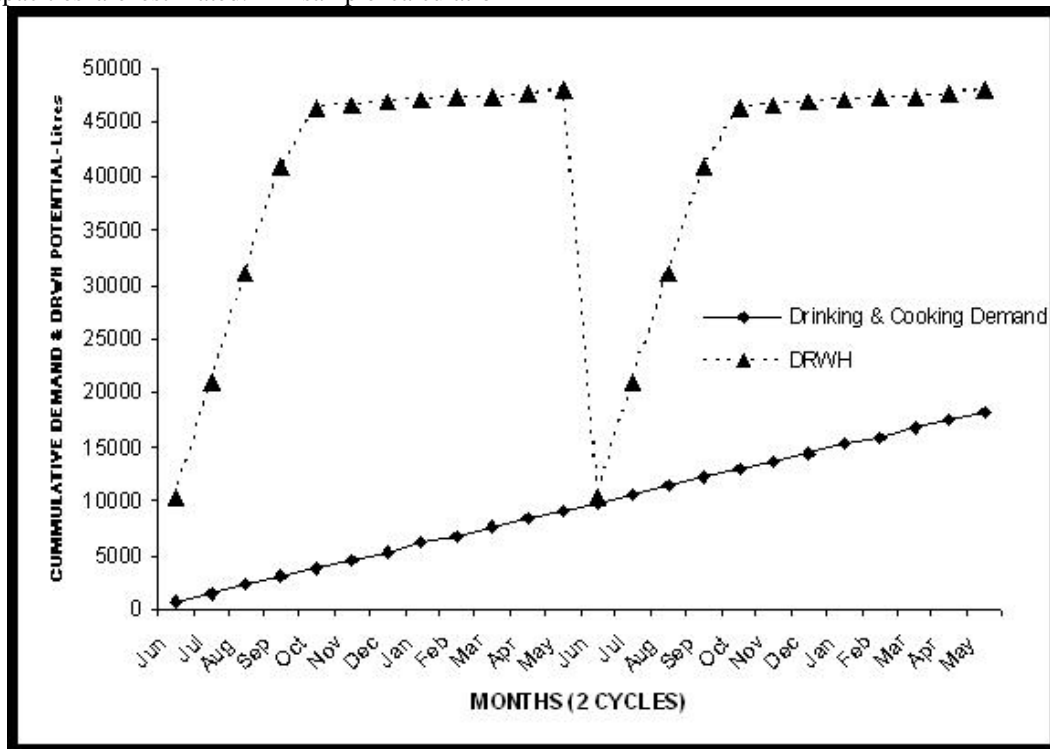

Figure-2. Cumulative drinking and cooking water demand and cumulative DRWH
from 50.00 m^2 rooftop area versus time (2 cycles of months).

Similarly the size of tanks, ground water recharges and cost of tanks for different rooftop top areas e.g. 100.00, 150.00, 200.00 and 250.00 m^2 are estimated.
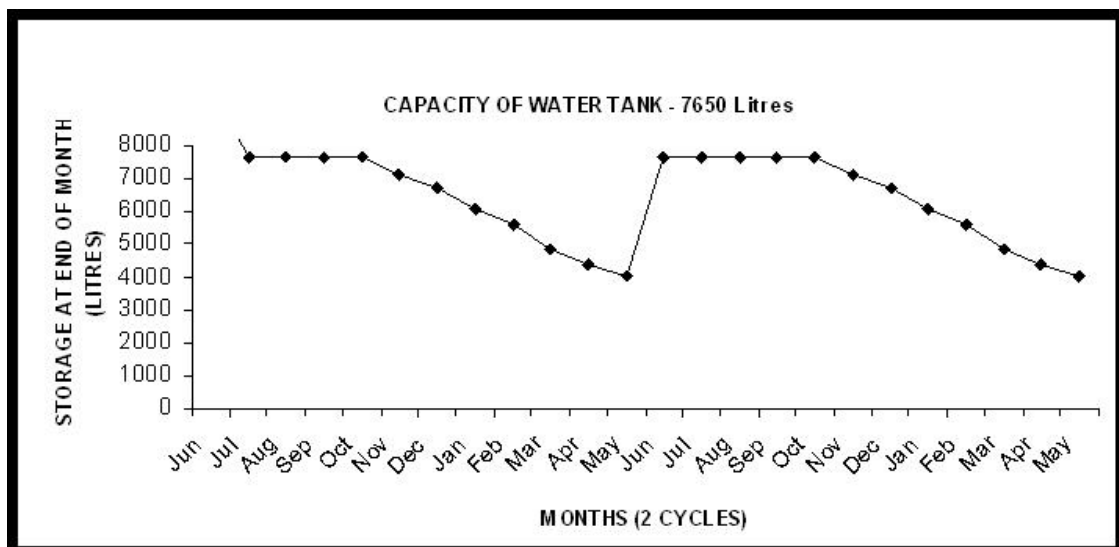

Figure-3. Month-wise availability of water in water tank of capacity 7650 litres
for 50.00 m^2 rooftop area (2 cycles of months).

www.arpnjournals.com

RESULTS AND DISCUSSIONS

Sizes and costs of water tanks

The general mathematical equation expressing the relationship between the required size of water tank and rooftop area is

$$V = -16.8 \cdot A + 8502 \ \ldots\ldots\ldots (1)$$

Where; V = Volume of Water Tank Required to fulfill the Drinking and Cooking Demand in Litres and A = Rooftop Area in m^2

The costs of the water tanks of all five sizes required to fulfill the drinking and cooking water demand through DRWH are estimated as per DSR-2007-08 of Maharashtra Jeevan Pradikaran, Nashik Region.

The general mathematical equation expressing the relationship between the cost of water tank and the roof top area size of water tank in litres is

$$C_T = 1.0022 \cdot V + 4332.80 \ \ldots (2)$$

Where; C_T = Cost of Water Tank in Rupees, V = Size of Water Tank in Litres

As the non monsoon rainfall is almost negligible in Dhule town, hence it is not feasible to fulfill the gross water demand throughout the year from DRWH.
Even during the monsoon period this demand can not be met from rooftop area less than 125 m^2. It is evident from Table-4 that the gross water demand for four monsoon months can be met from roof top area 125 m^2 and above.

Table-4. Percent of water demand fulfilled by DRWH from different roof-top area.

Month	Rooftop area in m^2				
	50	100	150	200	250
	% of total demand fulfilled from DRWH				
Jan	0.44	0.88	1.31	1.75	2.19
Feb	1.04	2.07	3.11	4.14	5.18
Mar	0.13	0.25	0.38	0.50	0.63
Apr	1.31	2.61	3.92	5.22	6.53
May	1.62	3.24	4.86	6.48	8.10
Jun	43.41	86.82	130.23	173.63	217.03
Jul	42.54	85.07	127.60	170.14	212.67
Aug	40.23	80.47	120.69	160.93	201.15
Sep	41.67	83.33	125.00	166.66	208.33
Oct	21.83	43.65	65.48	87.31	109.14
Nov	1.03	2.07	3.09	4.13	5.16
Dec	1.40	2.81	4.21	5.61	7.02

Cost model for DRWH system

A survey of around 50 individual houses in peri-urban area of Dhule town is conducted, out of which 43 single story houses are selected for study. The DRWH is planned for these houses considering the existing roof's drainage system. The minimum size of the drainage pipe is taken as 63 mm. The quantity of pipe and other relevant items are measured as on actual up to the boundary limit of the plot of the house, in such a way that the harvested water can be used for purpose of ground water recharging or and for direct use or for both. The filter box's cost is taken for the size of 1.16 x 1.16 x 0.90 m. The cost of filter box for roof top area more than 70.00 m^2 & less than 100.00 m^2 is considered as 1.25 times more than the cost of basic size and 1.50 times more in case, if area exceeds 100.00 m^2. The cost estimation of DRWH for the surveyed houses is shown in Table-5. The plot of cost of DRWH versus the area of rooftop of 43 houses surveyed is shown in Figure-4.
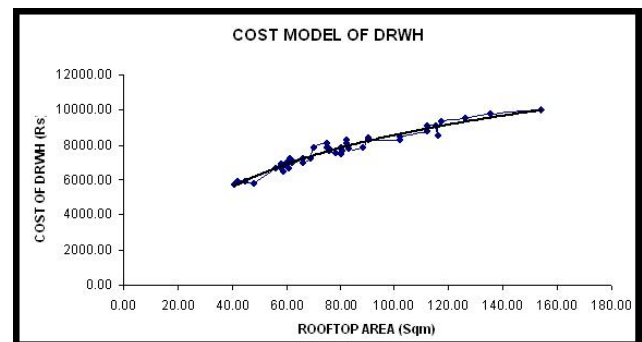

Figure-4. Cost model of DRWH system.

The general mathematical equation for finding out the cost of DWRH system of dwelling units of different sizes required to fulfill the drinking water demand is developed.

$$C_D = 3265 \cdot \mathrm{Ln}\,(A) - 6462 \ \ldots (3)$$

Where; C_D = Cost of DRWH System in Rupees and A = Rooftop Area in m^2.

Unit cost of water

The unit cost of the water which can be harvested from rooftop area is calculated by considering the 30 years of serviceable life of DRWH system and water tank and 7% rate of interest. The salvage value of the DRWH system is assumed 25% and annual maintenance and repair cost is taken as 0.5% of the capital cost. The plot of cost of water in Rs./kL vs. rooftop area is shown in Figure-5 and calculations are shown in Table-5.
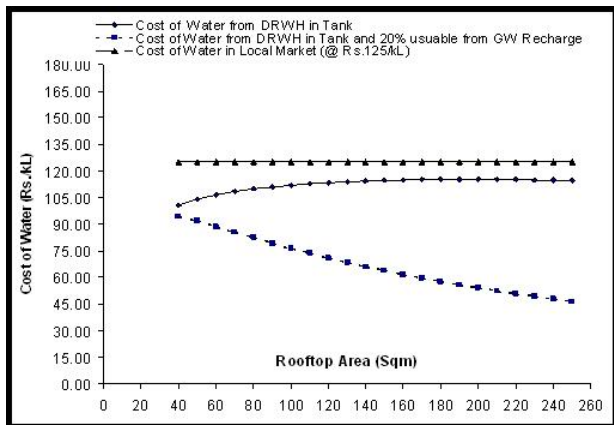
www.arpnjournals.com

Figure-5. Cost of water (Rs./kL) vs. rooftop area.

The horizontal line shows the market cost of water i.e. Rs.125.00/kL. The DRWH cost is less than the market cost of water and is constant after 150 m^2 rooftop area (Rs.115.00/kL). If it is considered that the 20% quantum of the water recharged into ground can be reused by means of the existing GW tapping arrangements, then the cost is convincingly less than the market cost.

LIMITATIONS AND FUTURE SCOPE OF STUDY

The size of the water tank required to fulfill the drinking and cooking water demand of a family from DRWH from rooftop area of different sizes, as expressed by mathematical equations is exclusively for area of study. Similarly by using same procedure the sizes and costs of water tanks for different areas having different rainfall may be estimated. All such calculations are based on the mean rainfall however the calculations on the basis of median rainfall may give more realistic output. In planning of DRWH system for different houses, the rainfall intensity is not taken into account. The inclusion of rainfall intensity in planning and design process may give more scientific basis for design of DRWH system. The cost of the DRWH system as estimated is based on the existing outlets provided in the rooftop. This is the main reason of the higher cost of system. The cost of DRWH system may be appreciably less if the planning of the houses is done bearing in mind the DRWH system.

ACKNOWLEDGEMENTS

REFERENCES

[1] BIS-1742-1983 1983 Sizing of RW Pipes for Roof Drainage Bureau of Indian Standards, New Delhi.

[2] CGWB. 2000. Guide on Artificial Recharge to Ground Water prepared by Central Ground Water Board, Ministry of Water Resources, Government of India, New Delhi. May.

[3] IE-NLC. 2006. Rain Water Harvesting and Water Management Proceedings of 22nd National Convention of Environmental Engineers, 11-12 November 2006, Organized by Institution of Engineers (India) Nagpur Local Centre, November.

[4] LRHF. 2001. A Report Domestic Roof Water Harvesting and Water Security in the Humid Tropics prepared by Lanka Rainwater Harvesting Forum under Domestic Roof Water Harvesting in the Humid Tropic, June.

[5] Mudrakartha and Chopade. 2002. Srinivas Mudrakartha and Shashikant Chopade Closing the Demand Supply gap through Rain Water Harvesting- A Case Study of Sargasan, Gujrat, India, Paper Submitted to-International Symposium on Artificial Recharge (ISAR-4), Adelaide, Australia, September.

[6] T.W.D.B. 2005. A Manual prepared by Texas Water Development Board Texas Manual on Rainwater Harvesting Texas Water Development Board, Austin, Texas, Third Edition.

www.arpnjournals.com

Table-3. Estimation of water tank's capacity to fulfill the drinking and cooking water demand by DRWH from rooftop area 50 m².

MONTHS	DAYS	AVERAGE RAINFALL (1996-2006) (mm)	DEMAND (DRINKING & COOKING) @ 8 LPCD (for 5 Soul)	Cummulative DEMAND (DRINKING & COOKING)	DEMAND (OVERALL) @ 80 LPCD	Cummulative DEMAND (OVERALL) @ 80 LPCD	DRWH VOL	CUM DRWH	(8) - (4)	(9) - (5)	COMMENT	End of Month Storage	DRWH avaialble for GW Recharge	% OF TOTAL DEMAND CAN MET FROM DRWH
							Litres	Litres	Litres	Litres		Litres	Litres	
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Jun	30	122.56	1200	1200	12000	12000	5209	5209	4009	4009	The drinking & cooking demand can be met from DRWH. The size of the storage tank = 7637~7650 Liters. The surplus water for GW Recharge = 9423 Litres.	4009	0	43.41
Jul	31	124.10	1240	2440	12400	24400	5275	10484	4035	8044		7650	394	42.54
Aug	31	117.38	1240	3680	12400	36800	4989	15473	3749	11793		7650	3749	40.23
Sep	30	117.64	1200	4880	12000	48800	5000	20473	3800	15593		7650	3800	41.67
Oct	31	63.68	1240	6120	12400	61200	2707	23180	1467	17060		7650	1467	21.83
Nov	30	2.91	1200	7320	12000	73200	124	23304	-1076	15984		6574	0	1.03
Dec	31	4.09	1240	8560	12400	85600	174	23478	-1066	14918		5508	0	1.40
Jan	31	1.27	1240	9800	12400	98000	55	23533	-1185	13733		4323	0	0.44
Feb	28	2.73	1120	10920	11200	109200	116	23649	-1004	12729		3319	0	1.04
Mar	31	0.36	1240	12160	12400	121600	16	23665	-1224	11505		2095	0	0.13
Apr	30	3.68	1200	13360	12000	133600	157	23822	-1043	10462		1052	0	1.31
May	31	4.73	1240	14600	12400	146000	201	24023	-1039	9423		13	0	1.62
									-7637	9423			9410	
Jun	30	122.56	1200	1200	12000	12000	5209	5209	4009	4009		4022	0	43.41
Jul	31	124.10	1240	2440	12400	24400	5275	10484	4035	8044		7650	407	42.54
Aug	31	117.38	1240	3680	12400	36800	4989	15473	3749	11793		7650	3749	40.23
Sep	30	117.64	1200	4880	12000	48800	5000	20473	3800	15593		7650	3800	41.67
Oct	31	63.68	1240	6120	12400	61200	2707	23180	1467	17060		7650	1467	21.83
Nov	30	2.91	1200	7320	12000	73200	124	23304	-1076	15984		6574	0	1.03
Dec	31	4.09	1240	8560	12400	85600	174	23478	-1066	14918		5508	0	1.40
Jan	31	1.27	1240	9800	12400	98000	55	23533	-1185	13733		4323	0	0.44
Feb	28	2.73	1120	10920	11200	109200	116	23649	-1004	12729		3319	0	1.04
Mar	31	0.36	1240	12160	12400	121600	16	23665	-1224	11505		2095	0	0.13
Apr	30	3.68	1200	13360	12000	133600	157	23822	-1043	10462		1052	0	1.31
May	31	4.73	1240	14600	12400	146000	201	24023	-1039	9423		13	0	1.62
									-7637	9423			9423	

Rooftop Area = 50 m², R.O. Coefficient = 0.85

www.arpnjournals.com

Table-5. Estimation of cost of water (Rs./kL) vs. different rooftop area (from cost model).

Area	Cost in Rs			Qty. Harvested Water (Annual)		Salvage Value (@25% of CC)	Equivalent Annual Cost (ACR)	Annual M&R Cost @0.5% of CC	Gross Annual Cost	Cost of Water from DWRH (in tank)	Cost of Water from DWRH (in tank) + 20% usuable from GW Recharge
	DRWH	Tank	Total (Capital Cost)	Drinking	GW Recharge						
(m²)	(Rs)	(Rs)	(Rs)	(Litres)	(Litres)	(Rs)	(Rs)	(Rs)	(Rs)	(Rs/kL)	(Rs/kL)
40	5582.19	12180.40	17762.59	14600	4859	4440.65	1384.41	88.81	1473.23	100.91	94.61
50	6310.76	12012.00	18322.76	14600	9723	4580.69	1428.07	91.61	1519.69	104.09	91.85
60	6906.03	11843.60	18749.63	14600	14587	4687.41	1461.34	93.75	1555.09	106.51	88.77
70	7409.34	11675.20	19084.54	14600	19450	4771.13	1487.45	95.42	1582.87	108.42	85.61
80	7845.32	11506.80	19352.12	14600	24314	4838.03	1508.30	96.76	1605.06	109.94	82.47
90	8229.88	11338.40	19568.28	14600	29177	4892.07	1525.15	97.84	1622.99	111.16	79.42
100	8573.88	11170.00	19743.88	14600	34041	4935.97	1538.83	98.72	1637.55	112.16	76.49
110	8885.07	11001.60	19886.67	14600	38905	4971.67	1549.96	99.43	1649.40	112.97	73.70
120	9169.16	10833.20	20002.36	14600	43768	5000.59	1558.98	100.01	1658.99	113.63	71.04
130	9430.50	10664.80	20095.30	14600	48632	5023.82	1566.22	100.48	1666.70	114.16	68.51
140	9672.46	10496.40	20168.86	14600	53495	5042.22	1571.96	100.84	1672.80	114.58	66.12
150	9897.72	10328.00	20225.72	14600	58359	5056.43	1576.39	101.13	1677.52	114.90	63.85
160	10108.44	10159.60	20268.04	14600	63223	5067.01	1579.69	101.34	1681.03	115.14	61.70
170	10306.38	9991.20	20297.58	14600	68086	5074.40	1581.99	101.49	1683.48	115.31	59.66
180	10493.00	9822.80	20315.80	14600	72950	5078.95	1583.41	101.58	1684.99	115.41	57.72
190	10669.53	9654.40	20323.93	14600	77813	5080.98	1584.04	101.62	1685.66	115.46	55.89
200	10837.01	9486.00	20323.01	14600	82677	5080.75	1583.97	101.62	1685.59	115.45	54.14
210	10996.31	9317.60	20313.91	14600	87541	5078.48	1583.26	101.57	1684.83	115.40	52.47
220	11148.19	9149.20	20297.39	14600	92404	5074.35	1581.97	101.49	1683.46	115.31	50.89
230	11293.33	8980.80	20274.13	14600	97268	5068.53	1580.16	101.37	1681.53	115.17	49.38
240	11432.29	8812.40	20244.69	14600	102131	5061.17	1577.87	101.22	1679.09	115.01	47.94