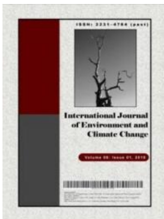

International Journal of Environment and Climate Change

8(1): 1-17, 2018; Article no.IJECC.2018.001
Previously known as British Journal of Environment & Climate Change
ISSN: 2231–4784

Probabilistic and Economical Design of Roof Top Rainwater Harvesting Tank by Simulation Technique

J. Ramachandran[1*] and V. Ravikumar[1]

[1]*Department of Soil and Water Conservation Engineering and Agricultural Structures, Agricultural Engineering College and Research Institute, Tamil Nadu Agricultural University, Kumulur, Trichy, India.*

Authors' contributions

This work was carried out in collaboration between both authors. Author VR designed the study and guided. Author JR performed the statistical analysis, wrote the protocol and drafted the manuscript. Both authors read and approved the final manuscript.

Article Information

DOI: 10.9734/IJECC/2018/v8i127099

Received 4th October 2017
Accepted 9th December 2017
Published 10th March 2018

Original Research Article

ABSTRACT

Introduction: Rainwater harvesting is the collection of rainwater directly from the surface(s) it falls on. Rainwater harvesting through collection tank is an effective method. Numerous methods are available for determining the size of the storage capacity required to satisfy a given demand. These methods vary in complexity and sophistication.
Methods: The tank design method includes general thumb rule (5% of annual runoff), sequential peak analysis (simulating twice the length of the record), optimization (best one that suits objective criteria), simulation, probabilistic and economical design. Simulation water balance model which works on daily basis, normal probability distribution and economics are used in designing the capacity of tanks and it is presented in a graphical form. The tanks are designed for two different purposes like domestic use and toilet flushing only.
Place and Data: Trichy city daily rainfall records from 1951-2011 is used. If a person living in Trichy city wants to construct a rainwater harvesting tank for toilet flushing purpose (6 Nos * 25l = 150l demand per day), the graphs can used.
Results: At a chosen exceedance probability (EP) of failure (how much time the tank fails to supply water), the engineer can decide the storage size under a preset deficit rate and also the cost of each tanks (per 1000 l) from the curves generated in this study. These relationships can be used by engineers in the design process.

Keywords: Rainwater harvesting; tank design; simulation; probability; economics.

**Corresponding author: E-mail: eeesurya.tnau@gmail.com;*

ABBREVIATIONS

DR : Annual Deficit Rate
CDF : Cumulative Probability Functions
EP : Exceedance Probability
FRP : Fiber Reinforced Plastic Tanks
pdf : Probability Density Functions
RWH : Rainwater Harvesting Systems

1. INTRODUCTION

Rainfall is the most directly accessible water supply source. In the past several decades, due to population increases and concentration, rainwater tank systems have become a significant source of water supply in regions of Africa, Asia and South America [1].

The techniques for rainwater collection can be classified into three categories, namely: roof collection, ground collection and dam collection. The roof collection system is the simplest method for rainwater collection. The major components of the system are the roof, gutter and tank. The roof is the collection area for rainwater. The gutter or guide pipe is for conveying water to storage, and the tank is for water storage.

Ground collection can be attempted in a large earth area with a suitable depression. Banks to divert runoff into storage must be constructed. The main disadvantage of ground cisterns is that the water supply is easily contaminated. Moreover, the water can only be stored below the ground surface, which is less convenient for withdrawal.

Dam collection requires that runoff be restrained by concrete embankments. They are small-scale dams on non-perennial streams, and/or sub-surface dams constructed below ground level to arrest flow in an aquifer. In general, dam collection is not feasible because adequate geological and geomorphic sites are limited to natural watersheds. Roof collection or ground collection is relatively convenient to set up.

As far as roof top rainwater harvesting is concerned, either the harvested water is used for the recharge of aquifers or for the direct consumption by storing water in a sump (Fig. 1) or in plastic containers (Fig. 2) or in a surface pit with a plastic sheet lining (Fig. 3) to prevent infiltration. Direct consumption is one of the most economic ways of rainwater harvesting [2].

Determining an appropriate tank size is crucial for establishing an effective cistern system. Rainfall records and information for water demand are required to determine the tank size. Numerous methods are available for determining the size of the storage capacity required to satisfy a given demand. These methods vary in complexity and sophistication.

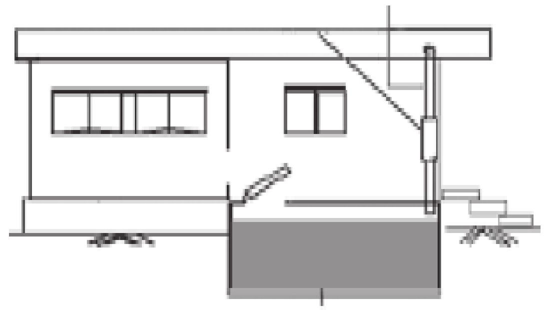

Fig. 1. Rain water harvesting in sumps for direct consumption

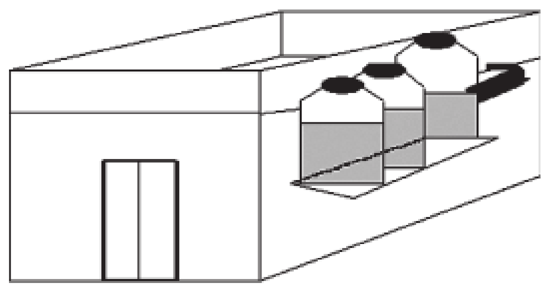

Fig. 2. Rain water harvesting in tanks for direct consumption

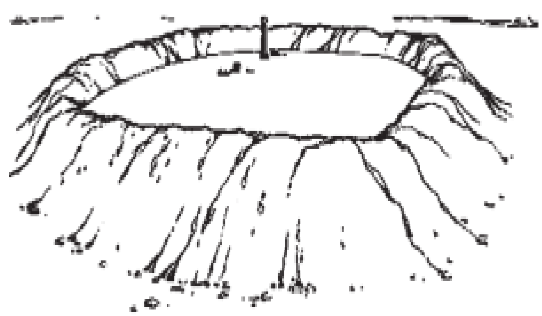

Fig. 3. Harvesting in small ponds with plastic sheets underneath

General simple thumb rules are also available. One of the thumb rules is, sizing the tank is 5% of total annual runoff collected [3]. If the historical record is not long enough to be used with sufficient confidence, the record is usually repeated up to twice its total length i.e., sequential peak analysis [4]. Optimization methods are used to provide the 'best' values of system design. Simulation is done using historical data for sizing the tank with the inputs such as daily rainfall, daily demand, roof area and a specified tank volume.

Natural precipitation is a random process and has some probabilistic characteristics. Therefore a continuous probabilistic relationship exists between storage capacities and supply deficits in designing a rainwater harvesting system. And so probability of failure for water supply will be considered in determining the tank size [1,5]. The key to the success of water harvesting techniques in a region is the acceptance by the beneficiaries and their full support. The beneficiaries will accept if the designed tank is economical [6].

Trichy is the 2nd largest city in Tamil Nadu, India in terms of land area and ranks 4th in population. Trichy is located along the Cauvery river delta and is the district headquarters. River Cauvery is the major source of water supply for Trichy. Sometimes the residents in city face scarcity of water and shell out more for getting water from the Trichy Corporation. The rainwater harvesting systems (RWH) will definitely be an alternative solution for domestic use of residents and for increasing the groundwater table in Trichy city.

Here, the main objective is to design the storage capacity of the rainwater harvesting tank for the roof top rainwater harvesting system. The combination of simulation model, probabilistic model and economic analysis is done on the historical daily rainfall records. The results are represented in the graphical form. These graphs are useful for the engineers in designing the rainwater harvesting tanks and also check the economic practicability of the rainwater harvesting tanks.

2. MATERIALS AND METHODS

2.1 Simulation Model

The simulation model is a water balance model which works on daily basis [2]. It is assumed that the first 2 mm of any day's rainfall is not collected in the tank. This 2 mm rainfall may be lost for washing the surface or lost in the initial wetting of the surface. The runoff coefficient is assumed as 0.95. The equation used for computing runoff Q_t on any day t is

$$Q_t = 0.95\,(P_t - 2)\,A \rightarrow 1$$

where, P_t is rainfall on day t and A is roof top area. On any day, rainfall may occur at any time and may occur either in short spell or for a longer duration. But the demand of water is mostly during morning time for a small length of time. Therefore, it has been assumed that any rainfall occurring on a day cannot be used for meeting the same day's demand. To get a conservative estimate of the usable water from rainwater harvesting, rainfall on any day is assumed to occur after the daily withdrawal of the water has occurred. Withdrawal from the tank (R_t) on any day t:

$$R_t = D_t \text{ if } S_{t-1} > D_t \rightarrow 2$$

$$R_t = S_{t-1} \text{ if } S_{t-1} < D_t \rightarrow 3$$

where R_t is the withdrawal; D_t is the demand; and S_{t-1} is the water available in tank on the previous day t-1. If the previous day storage in the tank (S_{t-1}) is more than the demand on day t (i.e., D_t), withdrawal is equal to R_t. If the previous day storage (S_{t-1}) in the tank is less than the demand, withdrawal is equal to the storage in the tank. Then, the sum of spill from the tank (SP_t) and the storage in the tank at the end of period t (S_t) is calculated as

$$[SP_t + S_t] = S_{t-1} + Q_t - R_t \rightarrow 4$$

Then the spill alone is calculated as,

$$SP_t = [SP_t + S_t] - V \text{ if } [SP_t + S_t] > V \rightarrow 5$$

$$SP_t = 0 \text{ if } [SP_t + S_t] \leq V \rightarrow 6$$

To compute the available water in the tank (S_t),

$$S_t = S_{t-1} + Q_t - R_t - SP_t \rightarrow 7$$

2.1.1 Annual deficit rate

The entire demand may not always be fulfilled in simulation model. Deficit may occur whenever the release R_t is smaller than demand D_t. The deficit at day t, Def_t, can be determined by the difference between D_t and R_t. The annual deficit rate (DR) can be defined as the ratio of total deficit volume to total demand as shown in the following equation,

$$DR = \frac{\Sigma Def_t}{\Sigma D_t} = \frac{\sum(D_t - R_t)}{\Sigma \mathrm{D_t}} \rightarrow 8$$

The probabilistic relationships between storage capacities and deficit rates can be developed from the simulation results based on the historical rainfall records [5].

2.2 Probabilistic Model

Natural precipitation is a random process and has some probabilistic characteristics. The annual deficit rate will be a random variable since it was generated from the simulation with natural rainfall which is a continuous random variable. The probability of failure for the water supply was considered in determining the tank size. There exists some probability distribution, for example, the normal distribution [7,8] or the lognormal distribution [8,9] for deficit rate under a specific design tank storage.

Probability density functions (pdf) of deficit rate can be established for each design storage capacities from the simulation results (Fig. 4). The cumulative probability functions (CDF) of deficit rates can then be constructed by integrating the pdf. The CDFs can then be transformed into the exceedance probability (EP) curves as shown in Fig. 5. And for a specific exceedance probability EP_i, a curve like the one shown in Fig. 6 can be established to describe the relationship between the design storage capacity and the corresponding deficit rate. These relationships can be used by engineers in the design process. At a chosen exceedance probability of failure, the engineer can decide from the curve on the storage size under a preset deficit rate. This more comprehensive perspective of the design storage—deficit rate is more realistically applicable than traditional presentation of deficit rate distribution under specific design storage [5].

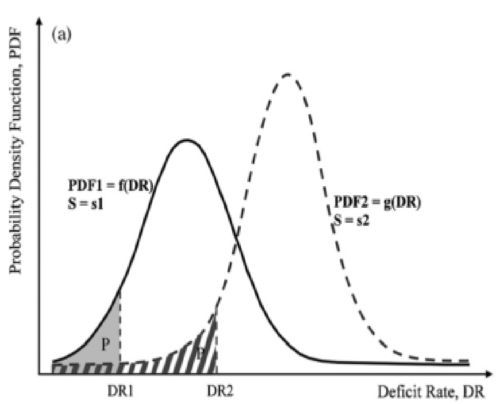

Fig. 4. Fitted pdfs of deficit rate distribution under different design storages

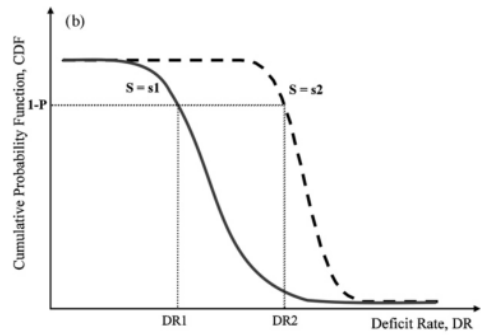

Fig. 5. Exceedance probability curves for deficit rates under different storage capacities

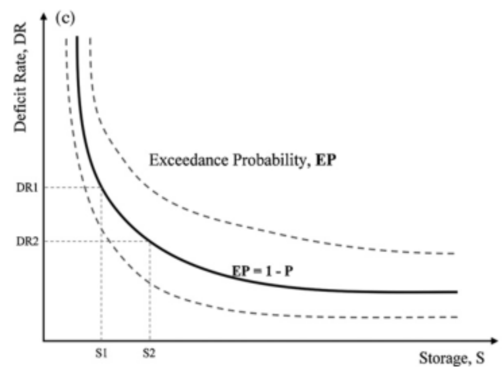

Fig. 6. Relationships between storage capacities and deficit rates

2.2.1 Chi square test

Chi-square test was used to examine the goodness-of-fit of the distribution fittings. The main aim of the test is to decide how good the distribution fits between the observed frequency of occurrence in a sample and the expected frequencies obtained from the hypothesized distributions. The goodness-of-fit test between observed and expected frequencies is based on the chi-square quantity (eq. 9), which is expressed as,

$$\chi^2 = \sum_{i=1}^{k} \frac{(O_i - E_i)^2}{E_i} \rightarrow 9$$

where χ^2 is a random variable whose sampling distribution is approximated very closely by the chi-square distribution, O_i and E_i represent the observed and expected frequencies, respectively, for the i^{th} class interval, k represents the number of class intervals.

If the observed frequencies are close to the corresponding expected frequencies, the χ^2 value will be small, indicating a good fit; otherwise, it is a poor fit. A good fit leads to the acceptance of null hypothesis, whereas a poor fit leads to its rejection. The critical region will, therefore, fall in the right tail of the chi-square distribution. For a level of significance equal to α, the critical value is found from readily available chi-square tables.

2.3 Economic Analysis

Rainwater harvesting methods are site specific and hence it is difficult to give a generalized cost. But first of all, the major components of a rainwater harvesting system –rain and catchment area (roof) are available at free of cost. A good proportion of the expenses would be for the pipe connections and the construction of the storage tank.

Economic analysis for using three different types of storage tanks, namely, fiber reinforced plastic tanks (FRP), ferro-cement tanks and pond with plastic sheet lining is explained [2]. A comparison is made between the equivalent average tariff slabs of corporation water and annualized capital cost of rainwater harvesting system. The cost of different types of storage tanks is given in Table 1. The cost of installation of tanks and rainfall collection pipes irrespective of volume of tanks is assumed as Rs. 1000 per installation.

Table 1. Cost of storage tanks

Sl. no.	Tank Type	Cost per liter
1	Fiber Reinforced Plastic Tanks (FRP)	4.00
2	Ferro – Cement Tanks	1.70
3	Pond (with Plastic Sheet Lining)	0.25

Table 2 shows, the different tariff slabs adopted from year 2013 by the Trichy City Corporation. It is assumed that the tariff increases annually at rate of 5% per year. The service life of the rainwater harvesting project is taken as ten years.

The investment for rain water harvesting (RWH) is done initially. The water tariff slabs are subjected to increase every year. Therefore, in order to compare the alternatives, the tariff slabs are also converted into annual equivalent average tariff slabs. Then the capital investments for RWH's are converted into annualized expenditure assuming that the capital is borrowed at the time of investment.

For converting the tariff slabs into equivalent average tariff slabs during the service life of ten years following formula is used.

$$C_p = F_p \times T_A \rightarrow 10$$

where, C_p is equivalent average tariff per 1000 l; T_A , the value of the tariff slab during the first year; F_p is the equivalent factor for accounting the rise of tariff every year and found out using the following formula,

$$F_p = \frac{((1+e)^N - (1+r)^N)}{((1+e) - (1+r))}\left(\frac{r}{(1+r)^N - 1}\right) \rightarrow 11$$

where e is the tariff rise per year, r is interest rate on the borrowed capital; and N is service life of the project. Following formula is used for annualizing the capital investment,

$$C_c = f_c \times I \rightarrow 12$$

where, C_c is annualized capital cost; I is capital investment and f_c is capital annualizing factor found out using the following equation,

$$F_c = \frac{r\,(1+r)^N}{(1+r)^N - 1} \rightarrow 13$$

where, r is interest rate on the borrowed capital. This is assumed as 12%, because the present rate of interest for house construction is approximately 12%. N is service life of the project.

3. RESULTS AND DISCUSSION

In Trichy city, sixty one years of daily rainfall data from 1951 to 2011 have been used. The annual average rainfall during these sixty one years is 799 mm. The annual rainfall occurred during 1951 to 2011 is shown in Fig. 7.

3.1 Storage Size of Tank

A single house of roof area 100 m^2 is considered. Number of persons living in the house is taken as six. Simulations were done for two scenarios. One scenario is for the assumption that the rainwater is used for all the uses and the water used per person per day is taken (twadboard.gov.in) as 110 l. Another scenario is that the rainwater is used for only toilet flushing and the water used per person per day are taken as 25 l.

The second scenario has been selected because the water can be collected at a little higher elevation as in Fig. 2 and toilet flushing can be done without use of any electric power. Socially also, it is possible to motivate the people to adopt this kind of structures. A sample calculation for the scenario 1 and 2 is shown in Tables 3 and 4 respectively.

A graphical representation is made between the amount of water that is withdrawn or the annual water used for domestic purpose (Fig. 8) and toilet flushing purpose (Fig. 9) and the amount of water spilled for different storage tank sizes (500, 1000, 1500, 2000, 2500, 5000, 7500, 10000, 15000 and 20000 l).

Table 2. Different tariff slabs

Criteria	Purpose	Cost per 10000 L (Rs.)	Present payment slab Rs. /1000 L
UPTO 10000	Domestic	125	12.5
10000 - 20000	Domestic	250	25.0
20000 - 30000	Domestic	375	37.5
30000 - 40000	Domestic	500	50.0
UPTO 10000	Non drinking	600	60.0
UPTO 10000	Industrial	850	85.0

Table 3. Sample water balance computation – domestic purpose

Day t	Rainfall P_t (mm)	Runoff Q_t (l)	Tank Content S_{t-1} (l)	Withdrawal R_t (l)	Spill S_t (l)	Tank Content S_t (l)	Deficit D_t (l)
05-08-11	0.0	0.00	0.00	0.00	0.00	0.00	660.00
06-08-11	7.5	522.50	0.00	0.00	0.00	522.50	660.00
07-08-11	0.0	0.00	522.50	522.50	0.00	0.00	137.50
08-08-11	0.0	0.00	0.00	0.00	0.00	0.00	660.00
09-08-11	9.3	693.50	0.00	0.00	0.00	693.50	660.00
10-08-11	0.9	0.00	693.50	660.00	0.00	33.50	0.00
11-08-11	0.4	0.00	33.50	33.50	0.00	0.00	626.50
12-08-11	0.0	0.00	0.00	0.00	0.00	0.00	660.00
13-08-11	0.0	0.00	0.00	0.00	0.00	0.00	660.00
14-08-11	0.0	0.00	0.00	0.00	0.00	0.00	660.00
15-08-11	0.0	0.00	0.00	0.00	0.00	0.00	660.00
16-08-11	21.3	1833.50	0.00	0.00	0.00	1833.50	660.00
17-08-11	0.0	0.00	1833.50	660.00	0.00	1173.50	0.00
18-08-11	23.6	2052.00	1173.50	660.00	0.00	2565.50	0.00
19-08-11	0.0	0.00	2565.50	660.00	0.00	1905.50	0.00
20-08-11	0.0	0.00	1905.50	660.00	0.00	1245.50	0.00
21-08-11	5.6	342.00	1245.50	660.00	0.00	927.50	0.00
22-08-11	0.1	0.00	927.50	660.00	0.00	267.50	0.00
23-08-11	0.0	0.00	267.50	267.50	0.00	0.00	392.50
24-08-11	0.0	0.00	0.00	0.00	0.00	0.00	660.00
25-08-11	39.4	3553.00	0.00	0.00	0.00	3553.00	660.00
26-08-11	4.4	228.00	3553.00	660.00	0.00	3121.00	0.00
27-08-11	0.0	0.00	3121.00	660.00	0.00	2461.00	0.00
28-08-11	0.0	0.00	2461.00	660.00	0.00	1801.00	0.00
29-08-11	0.0	0.00	1801.00	660.00	0.00	1141.00	0.00
30-08-11	0.0	0.00	1141.00	660.00	0.00	481.00	0.00
31-08-11	0.0	0.00	481.00	481.00	0.00	0.00	179.00

Data assumed: Roof Top Area = 100 m^2 ; Demand /day = 660 l; Tank Volume = 20000 l

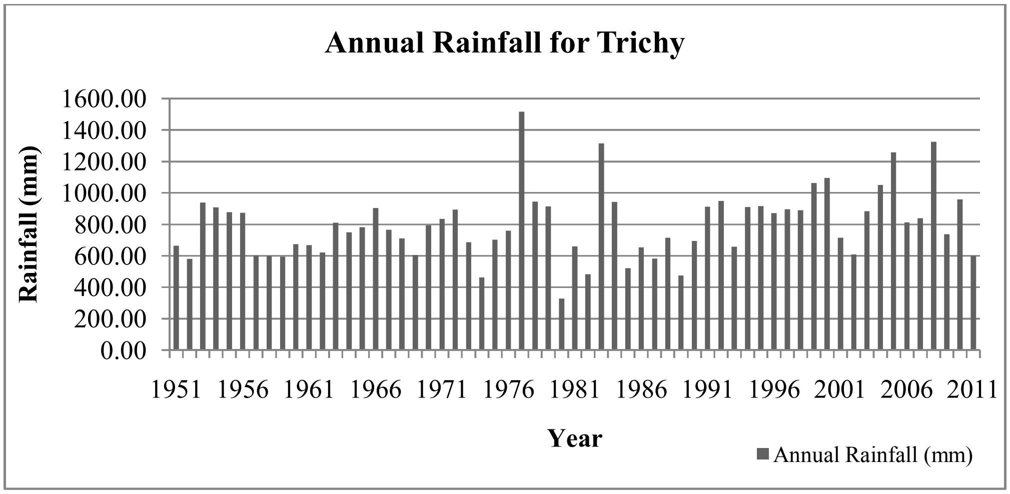

Fig. 7. Annual Rainfall in Trichy

Table 4. Sample water balance computation – toilet flushing

Day t	Rainfall P_t (mm)	Runoff Q_t (l)	Tank Content S_{t-1} (l)	Withdrawal R_t (l)	Spill S_t (l)	Tank Content S_t (l)	Deficit D_t (l)
05-08-11	0.0	0.00	0.00	0.00	0.00	0.00	150.00
06-08-11	7.5	522.50	0.00	0.00	0.00	522.50	150.00
07-08-11	0.0	0.00	522.50	150.00	0.00	372.50	0.00
08-08-11	0.0	0.00	372.50	150.00	0.00	222.50	0.00
09-08-11	9.3	693.50	222.50	150.00	0.00	766.00	0.00
10-08-11	0.9	0.00	766.00	150.00	0.00	616.00	0.00
11-08-11	0.4	0.00	616.00	150.00	0.00	466.00	0.00
12-08-11	0.0	0.00	466.00	150.00	0.00	316.00	0.00
13-08-11	0.0	0.00	316.00	150.00	0.00	166.00	0.00
14-08-11	0.0	0.00	166.00	150.00	0.00	16.00	0.00
15-08-11	0.0	0.00	16.00	16.00	0.00	0.00	134.00
16-08-11	21.3	1833.50	0.00	0.00	0.00	1833.50	150.00
17-08-11	0.0	0.00	1833.50	150.00	0.00	1683.50	0.00
18-08-11	23.6	2052.00	1683.50	150.00	0.00	3585.50	0.00
19-08-11	0.0	0.00	3585.50	150.00	0.00	3435.50	0.00
20-08-11	0.0	0.00	3435.50	150.00	0.00	3285.50	0.00
21-08-11	5.6	342.00	3285.50	150.00	0.00	3477.50	0.00
22-08-11	0.1	0.00	3477.50	150.00	0.00	3327.50	0.00
23-08-11	0.0	0.00	3327.50	150.00	0.00	3177.50	0.00
24-08-11	0.0	0.00	3177.50	150.00	0.00	3027.50	0.00
25-08-11	39.4	3553.00	3027.50	150.00	0.00	6430.50	0.00
26-08-11	4.4	228.00	6430.50	150.00	0.00	6508.50	0.00
27-08-11	0.0	0.00	6508.50	150.00	0.00	6358.50	0.00
28-08-11	0.0	0.00	6358.50	150.00	0.00	6208.50	0.00
29-08-11	0.0	0.00	6208.50	150.00	0.00	6058.50	0.00
30-08-11	0.0	0.00	6058.50	150.00	0.00	5908.50	0.00
31-08-11	0.0	0.00	5908.50	150.00	0.00	5758.50	0.00

Data assumed: Roof Top Area = 100 m^2; Demand /day = 660 l; Tank Volume = 20000 l

The total volume of water needed annually for the household considered is 240.9 m^3 (i.e. 660*365). If the household uses 2500 l tank, they would harvest the rain of 43 m^3 annually. Therefore they will make use of rainwater for 18% of the total demand.

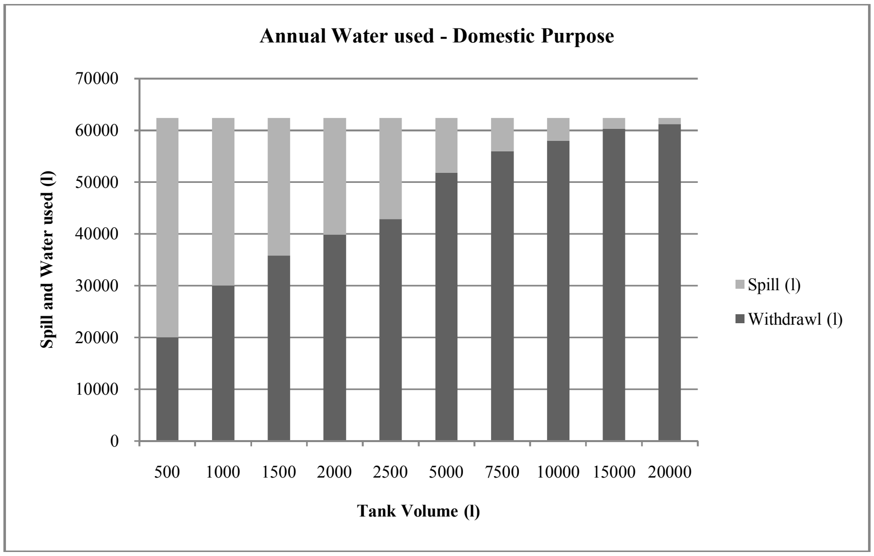

Fig. 8. Annual water used for all the household uses against tank volume

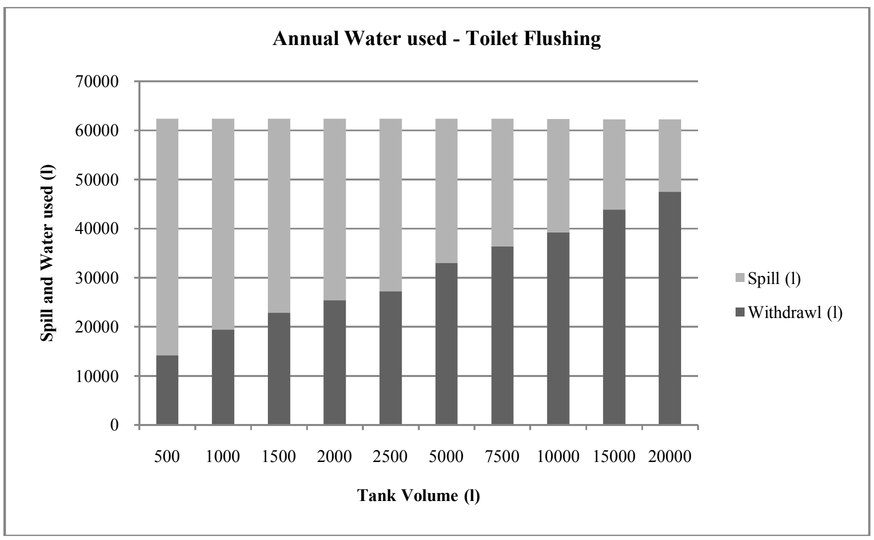

Fig. 9. Annual water used for only toilet use against tank volume

For toilet flushing, the use of rainwater can be encouraged. Total volumes of water needed for flushing annually for the household considered is 54.75 m^3. (i.e. 150*365). If the household uses 2500 l or 5000 l tank, they will harvest rain of 27 and 33 m^3 respectively. Therefore, they will make use of rainwater for 50 - 60% of total demand in toilet flushing.

3.2 Probability Distribution of Deficit Rate under Specific Storage Size

Normal distribution curves were fitted to the resulting deficit data to describe its probabilistic characteristics in this study. The fitted PDFs were shown in Figs. 10 and 11 for domestic and toilet flushing purpose respectively. It was observed from the figure that the average water supply deficit decrease as the design storage gets bigger. But it should also be noted that the variations of deficit rate also become a little wider.

For example in case of domestic water use, the water supply deficit for 500 l capacity tank is 0.92 whereas for 2500 l capacity tank the water supply deficit is 0.82. And the water supply deficit range of 500 l tank varies from 0.86 to 0.96 whereas for 2500 l capacity tank 0.71 to 0.92.

Table 5. Distribution fittings for deficit rate at specific design storage

Volume (l)	Chi square test values	
	Scenario 1	Scenario 2
500	1.86	0.62
1000	0.96	0.80
1500	1.02	0.47
2000	1.71	0.53
2500	0.50	0.72
5000	0.73	0.39
7500	0.98	0.25
10000	1.00	0.52
15000	0.95	0.23
20000	0.98	1.13

Chi square table value: At α = 0.05%, χ^2 = 12.592. At α = 0.95%, χ^2 = 1.635.

Chi-square test was used to examine the goodness-of-fit of these distribution fittings (Table 5). It is seen from the table that all the data fit the distribution at a level of significance *α = 0.05%* ($\chi_{cal}{}^2 < \chi_{table}{}^2$). 500 l and 2000 l tank capacity under scenario 1 fails the goodness of fit test at a level of significance *α = 0.95%* ($\chi_{cal}{}^2 > \chi_{table}{}^2$). Since exceedance probability have continuous value between 0 and 1, five relationship curves of EP of 50%, 75%, 80%, 90% and 95% are shown respectively in Figs. 14 and 15.

The storage–deficit relationships under different exceedance probabilities for domestic and toilet flushing purpose are shown in Figs. 11 and 12 respectively. For specific design storage and exceedance probabilities, the corresponding deficit rates were estimated. If the design failure level is set as 0.5, the relationship between storage and deficit rate can be depicted from the graph for that particular probability of failure set by the engineers.

3.3 RWH Tank Design Cost Analysis

For the tariff rise of 5% per year, r =12% and N =10 yr, the value of F_p works out to 1.20. The present payment slabs of the corporation (Table 2) is converted into equivalent slabs for the 10 years service life of RWH and are presented in Table 6. In annualizing the capital investment, capital annualizing factor works out to 0.176. For instance, if the cost of 5000 l tank is Rs 5000 and installation cost is Rs 1000 and useful project life is ten years, then the annualized capital cost works out to Rs 850. If 30 000 l are collected by RWH annually, then the equivalent cost per 1000 l is Rs 28.33. The Table 7 present the equivalent cost of RWH water for domestic uses and toilet flushing alone respectively.

It can be seen that 500 and 1000 l FRP tank is economical for users having equivalent tariff slab of Rs. 30 per 1000 l. Similarly 1500, 2000 and 2500 l FRP tanks are economical for the users having equivalent tariff slab of Rs. 60 per 1000 l. The FRP tank having capacity 10000 l and above is not economical as the highest equivalent tariff Rs. 102 per 1000l.

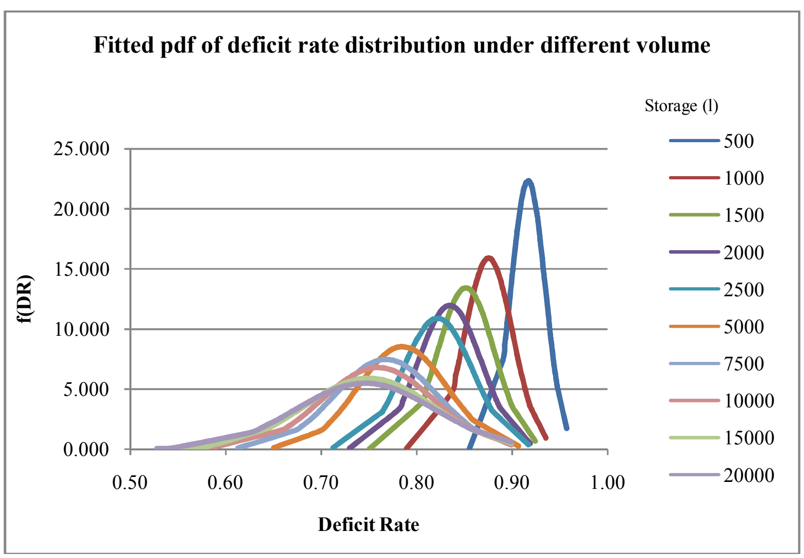

Fig. 10. Fitted pdfs of deficit rate distribution under different design storages for domestic purpose

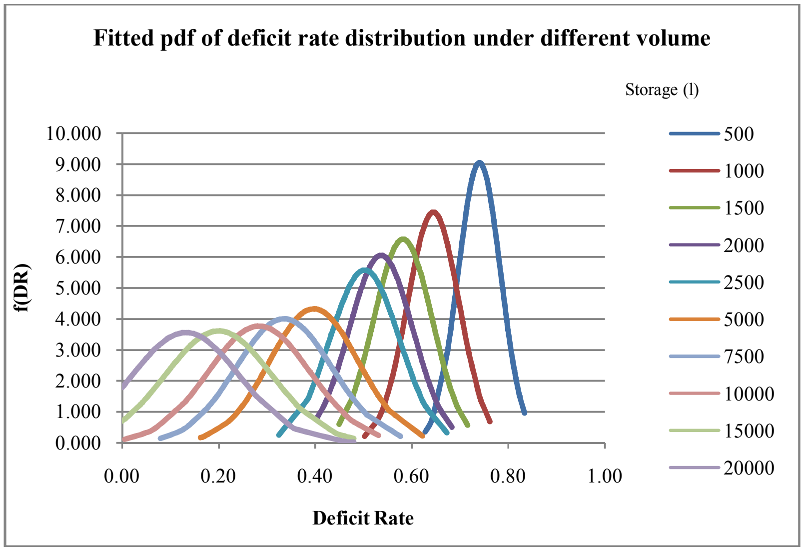

Fig. 11. Fitted pdfs of deficit rate distribution under different design storages for toilet flushing

Table 6. Equivalent slabs for the 10 years service life of RWH

Criteria	Purpose	Present Payment Slab Rs. /1000 L	Eq. Slab for 10 years (Rs.)
UPTO 10000 l	Domestic	12.5	15
10000 – 20000 l	Domestic	25.0	30
20000 – 30000 l	Domestic	37.5	45
30000 – 40000 l	Domestic	50.0	60
UPTO 10000 l	Non drinking	60.0	72
UPTO 10000 l	Industrial	85.0	102

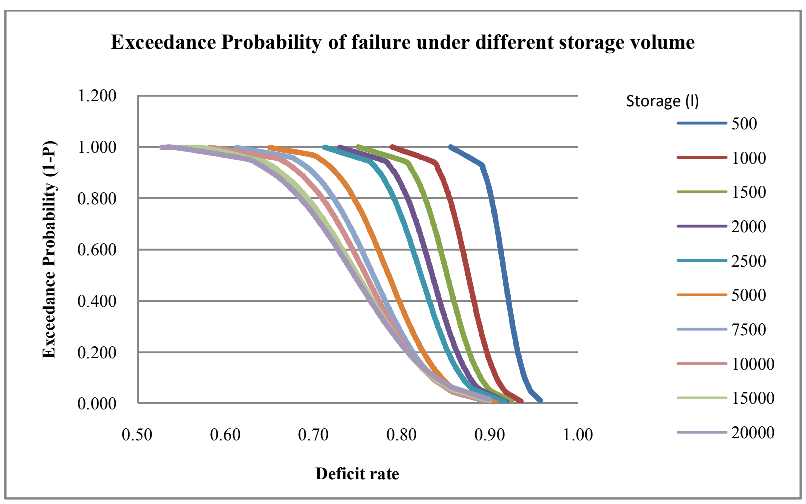

Fig. 12. Exceedance Probability of failure under different storage volume for domestic purpose

The 500 l to 10000 l capacity ferro-cement tanks are economical for the user having equivalent tariff slab of Rs 72 per 1000 l. Also 15000 l to 20000 l capacity ferro-cement tanks are economical for the user having equivalent tariff slab of Rs 102 per 1000 l. Constructing a pond with plastic sheet lining is economical for all the users provided the area for water harvesting pond is available.

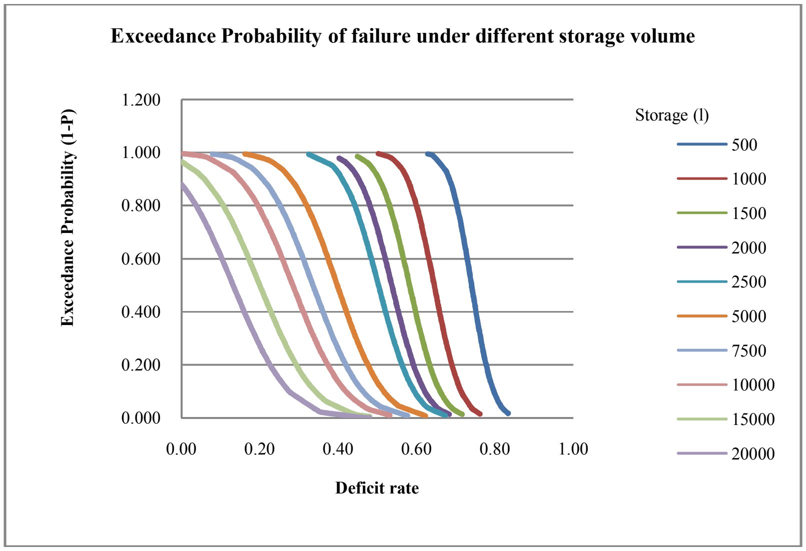

Fig. 13. Exceedance Probability of failure under different storage volume for toilet flushing purpose

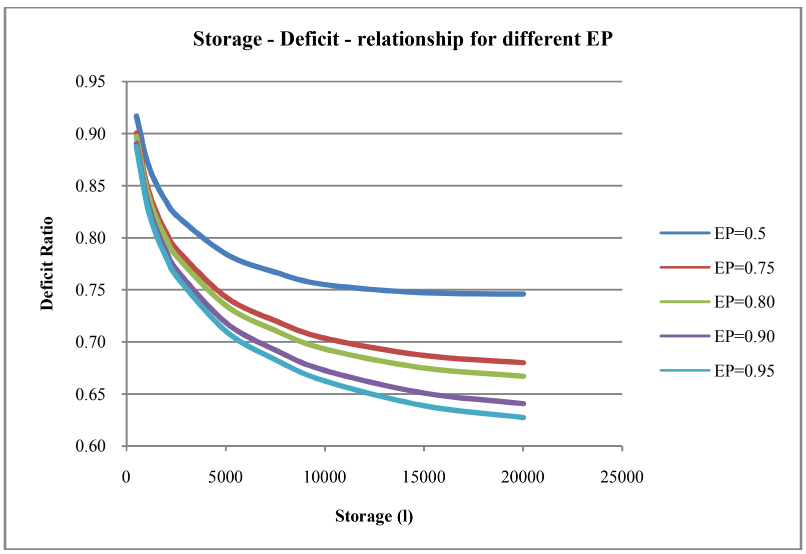

Fig. 14. Storage – Deficit relationship for different EP (Domestic use)

Table 7. Equivalent cost of RWH water for domestic uses

Volume (l)	Withdrawal (l)	Cost of RHW /1000 L (Rs.)		
		FRP	Ferro cement	Plastic sheet for pond
500	20085	26	16	10
1000	30041	29	16	7
1500	35787	35	18	7
2000	39863	40	20	7
2500	42934	45	22	7
5000	51798	72	32	8
7500	55997	98	43	9
10000	58051	125	55	11
15000	60288	179	78	14
20000	61217	234	101	17

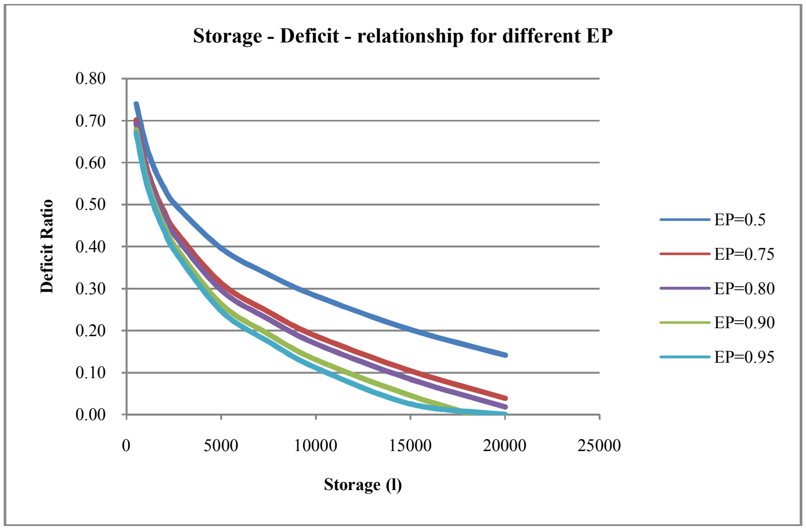

Fig. 15. Storage – Deficit relationship for different EP (Toilet flushing use)

As shown in Table 8, for toilet flushing purpose 2500 l FRP tank is economical for users having equivalent tariff slab of Rs. 102 per 1000 l and less. The FRP tank having capacity 5000 l and above is not economical as the highest equivalent tariff Rs. 102 per 1000l.

The 500 l to 7500 l capacity ferro-cement tanks are economical for the user having equivalent tariff slab of Rs 72 per 1000 l. Also 15000 l to 20000 l capacity ferro-cement tanks are not economical for any users as highest equivalent tariff slab is Rs 102 per 1000 l. Constructing 500 l to 7500 l capacity pond with plastic sheet lining is economical for the users having minimum tariff slabs provided the area for water harvesting pond is available.

Finally using the probabilistic and economical design concepts the RWH tank design graphs are presented. The Figs. 16a-16e and 17a-17e shows the Storage - Deficit - Cost relationships at different level of exceedance probability for domestic purpose and toilet flushing purpose respectively.

For example (Fig. 18), if a person living in Trichy city wants to construct a rainwater harvesting tank for toilet flushing purpose alone (6 No. of persons * 25 l = 150l demand per day), the following graph can used.

Step 1: First the exceedance probability level (how much time the tank fails to supply water) is chosen (say EP = 80%).

Step 2: Then from the chosen exceedance probability graph, the person can decide the storage size of the tank under a preset deficit rate (say 0.5).

Step 3: Finally the cost of three different types of tanks (per 1000 l) for the decided storage size of the tank is determined from the curves.

Table 8. Equivalent cost of RWH water for toilet flushing

Volume (l)	Withdrawal (l)	Cost of RHW /1000 l (Rs.)		
		FRP	Ferro cement	Plastic sheet for pond
500	14237	37	23	14
1000	19465	45	25	11
1500	22905	54	27	11
2000	25396	63	31	10
2500	27255	71	34	11
5000	33018	113	51	12
7500	36411	151	67	14
10000	39237	185	81	16
15000	43843	246	107	19
20000	47577	301	130	22

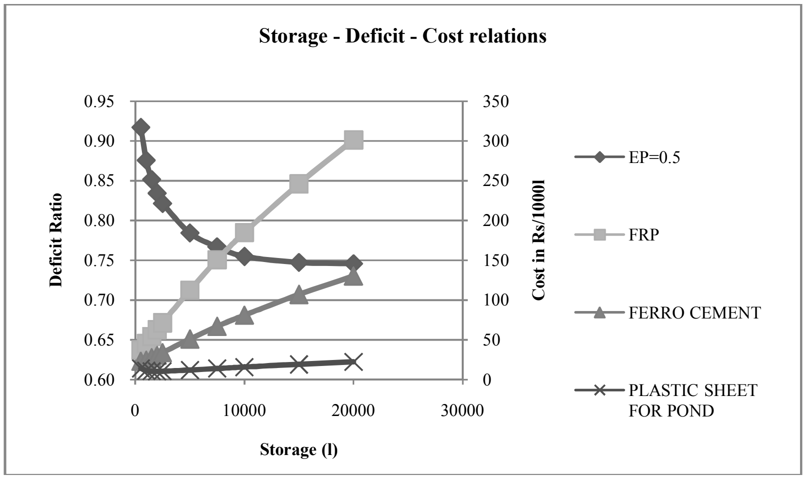

Fig. 16a. Storage - Deficit - Cost relationships at 50 % exceedance probability for domestic use

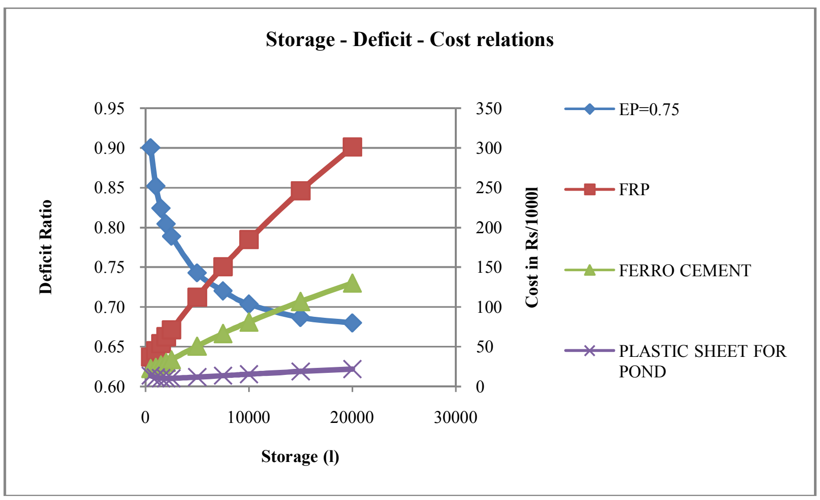

Fig. 16b. Storage - Deficit - Cost relationships at 75 % exceedance probability for domestic use

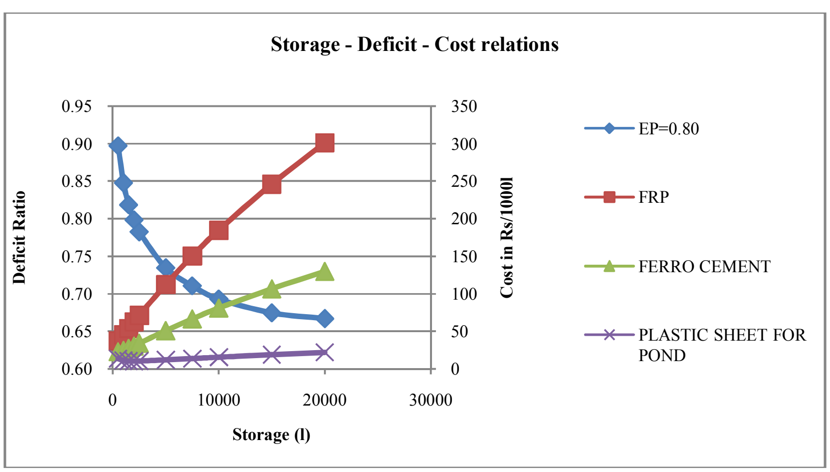

Fig. 16c. Storage - Deficit - Cost relationships at 80 % exceedance probability for domestic use

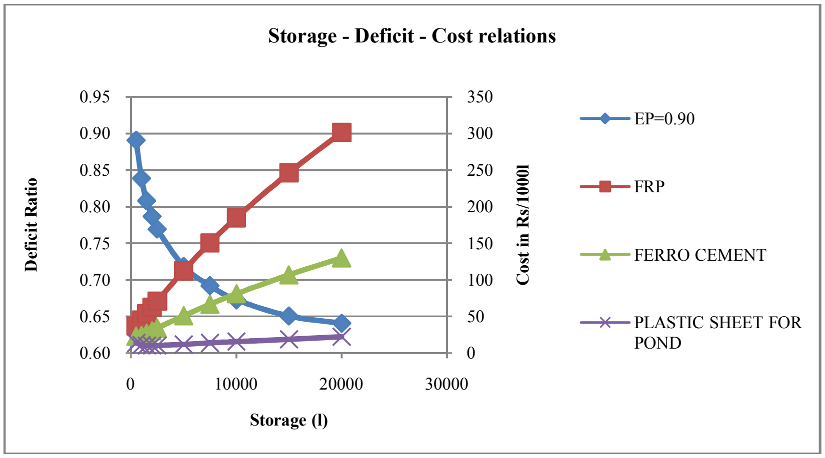

Fig. 16d. Storage - Deficit - Cost relationships at 90 % exceedance probability for domestic use

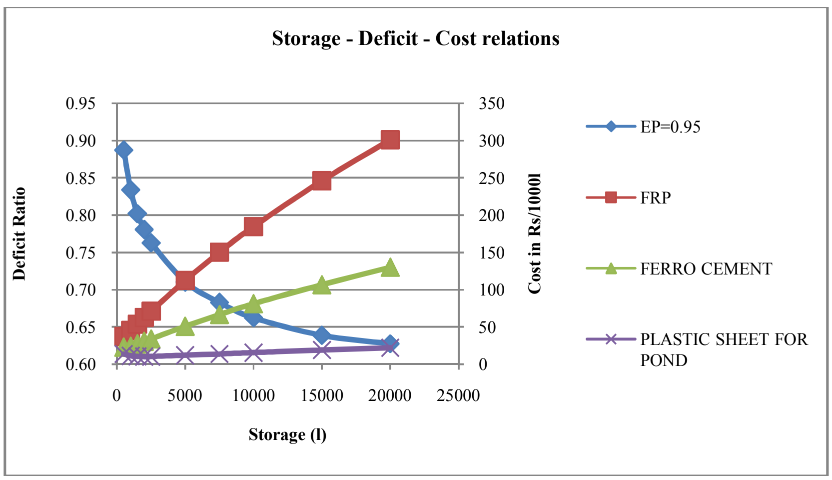

Fig. 16e. Storage - Deficit - Cost relationships at 95 % exceedance probability for domestic use

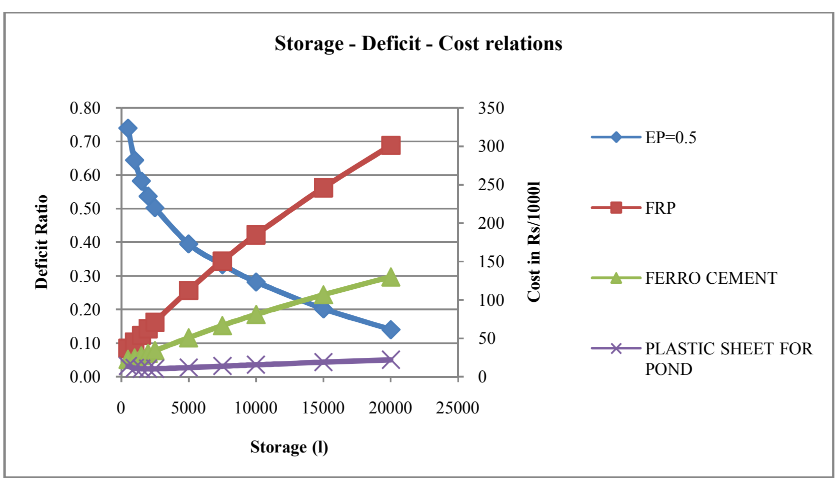

Fig. 17a. Storage - Deficit - Cost relationships at 50 % exceedance probability for toilet flushing purpose

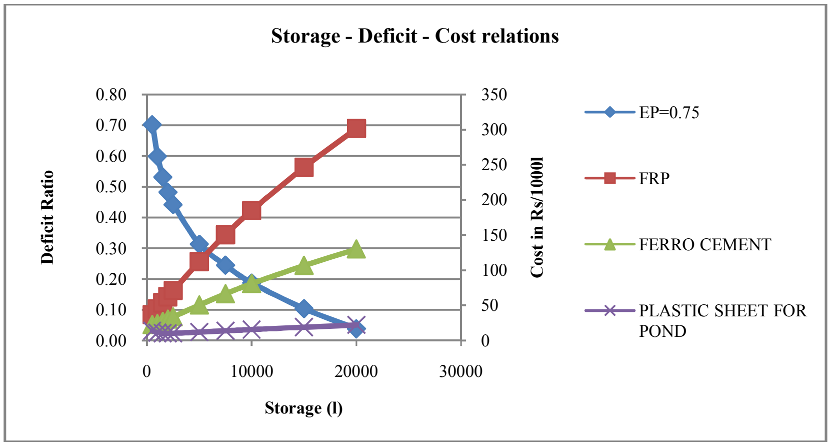

Fig. 17b. Storage - Deficit - Cost relationships at 75 % exceedance probability for toilet flushing purpose

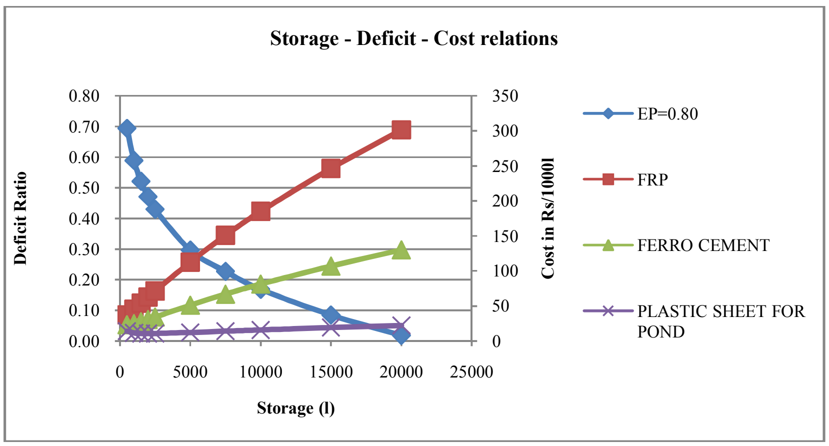

Fig. 17c. Storage - Deficit - Cost relationships at 80 % exceedance probability for toilet flushing purpose

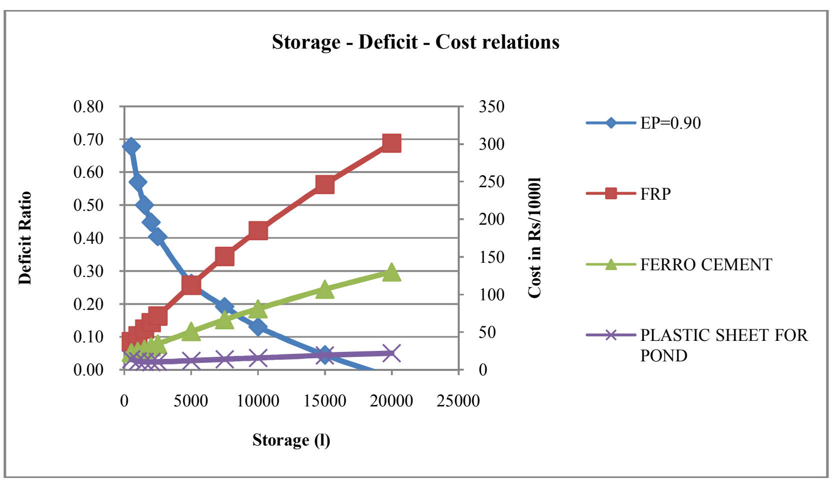

Fig. 17d. Storage - Deficit - Cost relationships at 90 % exceedance probability for toilet flushing purpose

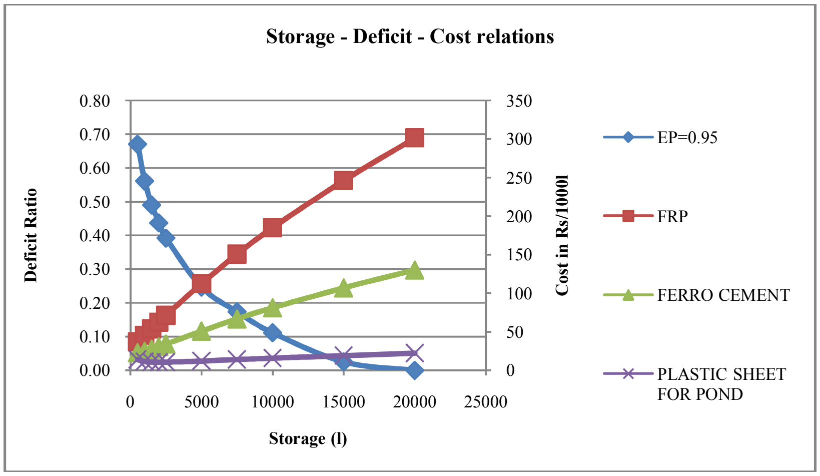

Fig. 17e. Storage - Deficit - Cost relationships at 95 % exceedance probability for toilet flushing purpose

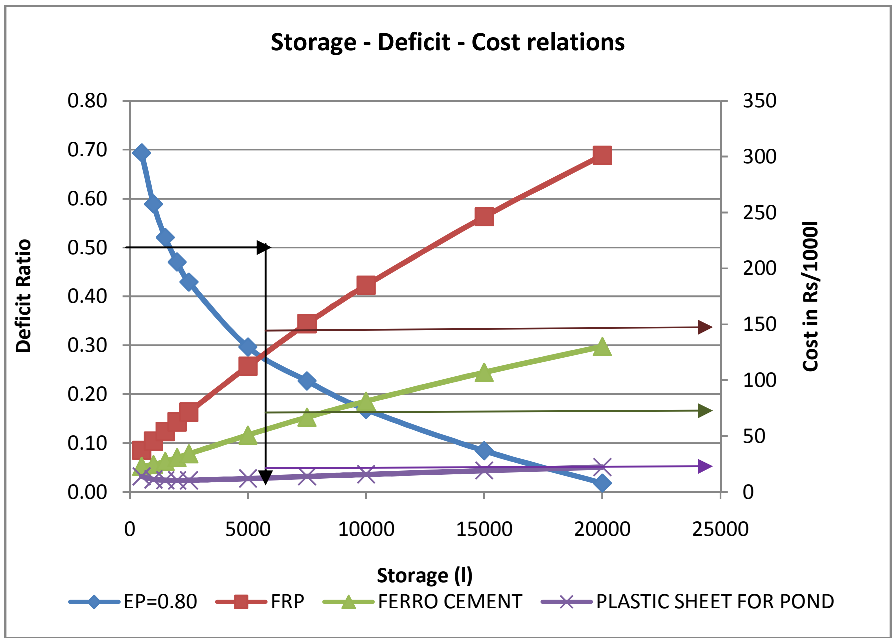

Fig. 18. Sample Design Chart at 80 % exceedance probability for toilet flushing purpose

4. CONCLUSION

Simulation of rain water harvesting through tanks on daily basis for different collection tank volumes and also for two different types of end uses, namely, full potable use and only toilet flushing use was done for the Trichy city. The annual harvestable volume of water as a function of volume of collection tank was found out.

The EP curves describing the continuous relationships between storage capacities and deficit rates were developed for describing the probabilistic relationships between storages and deficit rates. The probability density function was fitted and transformed into exceedance probability (EP) curve for reliability evaluations on RWH system designs which lead to a more effective RWH system design.

Economic analysis for using three different types of storage tanks, namely, fibre reinforced plastic tanks, ferro-cement tanks and pond with plastic sheet lining was done. The cost of the tank is found to be a crucial factor in the economic analysis. With the existing tariff slabs, it is only for some tariff slabs; rain water collection through tanks is economical.

If the corporation aims to increase the RWH, one possibility is to increase the tariff rates still higher so that the people start harvesting the rainwater. Or else with the lower tariff slabs the people may be given some kind of incentives to use rain water. The cost of RWH can also be reduced by providing RWH tanks at a subsidized rate.

Finally by combining the simulation, probabilistic and economical design concepts the RWH tank design graphs are presented. The Storage - Deficit - Cost relationships at different level of exceedance probability for domestic purpose and toilet flushing purpose is developed for Trichy city.

ACKNOWLEDGEMENTS

The author acknowledges Dr. V. Ravikumar for his guidance and support for the completion of work. Sincere thanks to the Agro Climatic Research Centre, Tamil Nadu Agricultural University, Coimbatore, India and Dept. of Applied Sciences and Engineering, Agricultural Engineering College and Research Institute, TNAU, Kumulur, Trichy, India for providing the meteorological data for the research work. My regards for Dr. K. Shanmugasundaram Professor (SWCE) and Dr. Sugunthakunthalambigai, Asst. Prof. (Maths) of Agricultural Engineering College and Research Institute, TNAU, Kumulur, Trichy, India for their support and guidance. Also Sincere thanks for the Faculty members of Department of Soil and Water Conservation Engineering and Agricultural Structures, Agricultural Engineering College and Research Institute, Tamil Nadu Agricultural University, Kumulur, Trichy, India.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Lee KT, Chin-Dee Lee, Ming-Sang Yang, Chih-Ching Yu. Probabilistic design of storage capacity for rainwater cistern systems. J. agric. Engng Res. 2000;77(3): 343-348
2. Ravikumar V, Raviraj A, Ranghaswami MV, Chellamuthu S. Volume of Tank and Economics for Roof Top Rain Water Harvesting. Journal of Environmental Engineering. 2010;91:1-5.
3. Environment Agency. 'Harvesting Rainwater for Domestic Uses: an Information Guide.' Environment Agency, Rio House, Bristol BS32 4UD. 2010.
4. Loucks DP, Stedinger JR, and Haith DA. Water Resource Systems Planning and Analysis, Chapter 4 & 5. Prentice-Hall, Inc., Englewood Cli!s, NJ 1981.
5. Su MD, Chun-Hung Lin, Ling-Fang Chang, Jui-Lin Kang and Mei-Chun Lin. A probabilistic approach to rainwater harvesting systems design and evaluation. Resources, Conservation and Recycling. 2009:53. 393–399
6. Machiwal D, Jha MK, Singh PK, Mahnot SC, and Gupta A. Planning and design of cost-effective water harvesting structures for efficient utilization of scarce water resources in semi-arid regions of Rajasthan, India. Water Resource Management. 2004:18 (3). 219–35.
7. Rahman M, and Yusuf FUAMS. Rainwater harvesting and the reliability concept. In: Proceedings of the 8th ASCE specialty conf. on probabilistic mechanics and structural reliability. 2000.
8. Surendran S, Tanyimboh TT, and Tabesh M. Peaking demand factor based reliability analysis of water distribution systems. Adv Eng Software 2005:36(11–12):789–96.
9. Xu C. and Goulter IC. Reliability based optimal design of water distribution networks. ASCE J Water Res Plan Manage. 1999:125(6). 352–62.