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# Hydrologic Design of Roof Water Harvesting Tank for Urban Area of Junagadh

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**Abstract** The water is prime and compulsory requirement any living organism. There are lots of water need for domestic, irrigation and industry. It's can't replace with another resources. The average annual rainfall of Junagadh for last 30 year (1988-2017) is 950 mm, but standard deviation (SD) and Coefficient of Variability (Cv) of rainfall 350 mm and 34% respectively. The variability shows the rainfall pattern is not uniform in Junagadh. The Junagadh faces serious water scarcity in summer season even good rainfall occurs in monsoon season. Peoples brought water from outside of the city by water tanker which put extra burden on their expenses. The roof water harvesting system mitigates the demand of water in prevailing condition for particular summer season. The present approached were carried out for optimal design of roof water harvesting tank with probability distribution and probability analysis of rainfall. The best fit probability distribution was found Fisher Type III which was carried out by CUM freq program. The rainfall depth at 75% probability of exceedence was found 700 mm by probability distribution Fisher type III and probability analysis methods. This rainfall depth was used for hydrologic design of roof water harvesting tank. The probability distribution and probability analysis revealed the volume of rainfall could be stored 560 per square meter for Junagadh city. The length, width and height of roof water harvesting tank were calculated for assumed roof area 100 square meters for the optimal design of roof water harvesting tank. The result reveal that harvested volume of roof water can compensate the demand of water for 70 to 90 days and even up to 100 days in prevailing condition with full flushing system for four niumbers of family members for Junagadh city. This present approached can be used to optimal (i.e.minimum cost) hydrologic design of roof water harvesting tank for residential houses, corporate offices, schools, colleges and university campus on the basis of their requirement (i.e.drinking, domestic, kitchen gardening and toilet flushing) for any city.

**Keywords** Hydrologic design, Probability analysis, Probability distribution, Roof water harvesting system.

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## Introduction

Water is a precise gift of the God. Air, water and foods are prime requirement of human life. The God gives plenty of air and water. The distribution of fresh water is uneven. There is highest rainfall occurs in Cherrapunjee, a high-altitude town in the northeast Indian state of Meghalaya, drier place like the Rajasthan state and Kuchh in India. The North Gujarat and Shaurashtra fall in semi-arid region in Gujarat where water scarcity occurs in summer. The population increases continuously in urban in search of job and better livelihood and the availability of natural resources like water are decreasing day by day and result urban area face water scarcity in summer season for 2 to 3 months. The villages and urban area faces water scarcity in summer season for two to 3 months. Rain water harvesting is an old age practices since long time which are useful to minimize the scarcity of the problem.

The scarcity of water occur mostly all urban cities in India where plenty of rainfall occurs in monsoon season (i.e. Mumbai). There was time where distribution of water sufficient to compensate the demand of water for all. But, urbanization and continuous migration of people directly affect the natural resources. Present study is carried of Junagadh city for designing of efficient water harvesting tank based on probability distribution and analysis of rainfall. The main aim of this study is to design water harvesting tank with optimization of resources which stored water useful 2 to 3 months in summer season. The Junagadh city fall in the foot hill of the Girnar mount in Saurashtra. Peoples of Junagadh use domestic water from the municipal corporation supply, society bore well and own bore well. There is adequate water supply in city during the monsoon and winter season while scarcity of water occurs mostly in summer season. The some part of city faces serious scarcity of water for domestic purpose. As per Bureau of Indian Standard IS : 1172-1993, the minimum water requirement for urban population 1, 00, 000 and above should be provided per capita per day 150 l to 200 l with full flushing system and even reduced up to 135 l for Lower Income Groups (LIG), Economically Weaker Section of Society (EWS) and depending upon prevailing conditions. People need to extra expenses on water in summer season even good rainfall occurs in respective year. Traditional approached insufficient to manage water cycle due to urbanization (Raimondi and Becciu 2014). So, its variability shows the uneven distribution of rainfall. Probability analysis approached is help to reduce uncertainty of designing of water storage (Bacchi et al. 2008). Probability analysis will provide useful information for water resources planner, farmers and urban engineers to assess the availability of water and create the storage (Arvind et al. 2017).

Geographic information system (GIS)-simulation-based design system (GSBDS useful for harvesting (RWHS) which is systematically and cost-effectively for an innovative water-energy conservation scheme on a city scale (Chiu et al. 2015). People of Junagadh city face serious problem of scarcity of water and some part of city face even worst, sometimes people brought water tanker outside from the city which put extra burden on their expense. Krishnaveni and Vignesh (2016) revealed that the overall demand of the campus is compensate by harvested rain water for 3 months with 75% dependable rainfall depth by analyzed of rainfall for the past 30 years for the Anna university and calculate the deficit or surplus rainfall of each month. They also suggested that considering 50% dependable rainfall the Anna University attains self-sufficiency round the year in water resource only with the water being harvested.

The people are expenses lots of money to construct luxurious houses, cars and life styles, but lack of aware over roof water harvesting. Water is used since get up in morning to till the sleep at night. We drink water for 7 to 8 times in a day, 3 to 4 times for cooking, bathing and flushing of toilet. The water is among all the natural recourses which used more as compared to others. That's why several slogans are used for water like life is water, if you save water, water will save you. Now, time has came to aware for importance of water and construct roof water harvesting system in houses, apartments, corporate buildings, schools, colleges and offices. Main aim of this research is to optimal design effective size of water harvesting tank for roof water harvesting in Junagadh city, which fill at least 3 out of 4 years. The roof water harvesting is not rocket sciences, but here one scientific approach is carried out. The probability analysis and probability distribution of rainfall were carried out for determine the design rainfall depth. The optimal design of tank was carried out by probability of exceedence of 75% of rainfall (event).

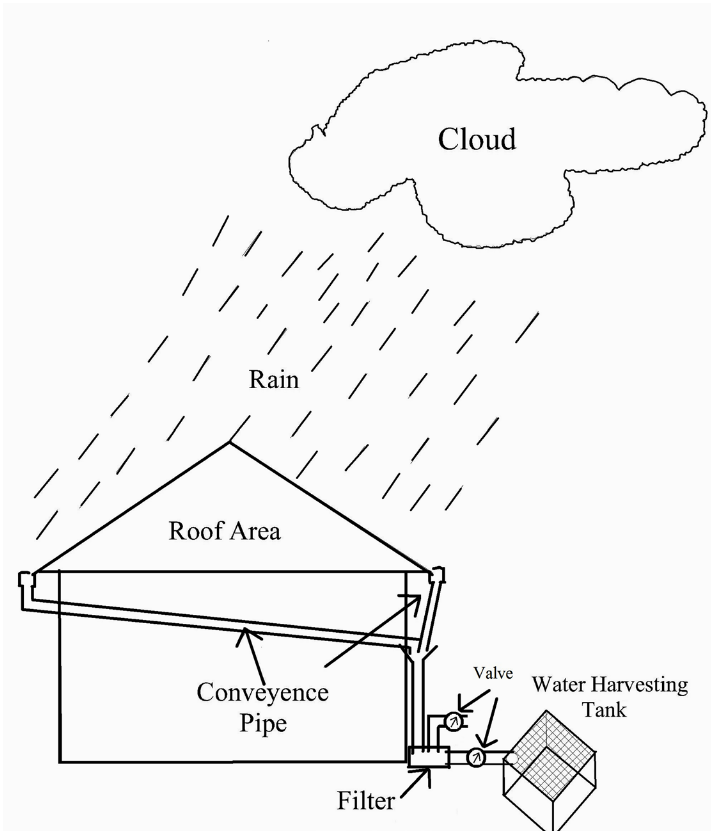


**Fig. 1.** Roof water harvesting system.

**Materials and Methods**

Study area

The Junagadh is old ancient city located in mount hill of the Girnar in Gujarat state (Shaurashtra, Southern part of India) with latitude and longitude 21.5222°N and 70.4579° E respectively. The Junagadh has great culture since long time. Different cultured has ruled this city. The study area is Junagadh urban area (City) where water crisis are found in every summer. The some part of the city are face serious situation, water a being brought outside from the city by water tanker and put extra burden on their expenses.

Data collection

The roof water harvesting tank was designed to with the study of Probability Distribution and Probability Analysis. So, the annual rainfall data of the 30 years (1988-2017) were collected from the Department of Meteorology, College of Agriculture, Junagadh Agricultural University, Junagadh.

Roof water harvesting

This is a simple phenomena as shown Fig. 1. It's an old age practices since so many year ago (Abdullah and Al-Shareef 2009). The rainwater harvesting system can provide environmental and economic advantages over traditional water supply methods. Roof water harvesting is to harvest rainfall which falls in roof of home houses, building, shades.

The rainfall is collected in water harvesting tank from the roof of houses through the conveyance pipe and simple filter. It is necessary to install filter for filter collection of and put by pass passage for excess water after having tank full. The rainfall water could store for long time because it's pure water i.e.next monsoon season. The rainfall water is considered as pure water. It can be used for drinking, cooking, bathing, washing of cloths, toilet, kitchen gardening, to irrigate small plants which grows at home.

Pobability distribution

Let the arrange the rainfall in ascending order like X1<X2<X3<X4..... <X30 and give the tank lowest rank 30, 29, 28, 27,....3, 2, 1 respectively. Cummulitive frequency analysis was carried out by different methods through CUM freq program. The best fit distribution model was also developed.

Probability analysis

Probability analysis estimate rainfall depths that can be expected for selected probabilities or return periods. The estimates are required for the design of volume of water harvesting tanks (Liuzzo et al .2016). The design depth of rainfall is obtained by a probability analysis 30 years of annual rainfall time series.

Let the value of variable (annual rainfall) X1, X2, X3, X4, X5, X6, X7, X8....Xn are for the respective years. Arrange this variable in descending order and give higher rank for higher variable and lowest rank for lowest value of variable.

Let P (Xm) denotes the probability of occurrence of rainfall with which the value Xm is equaled or exceeded.

$$P(X_m) = P(X \geq X_m) \quad ...(1)$$

Probability P (Xm) thus indicate that the occurrence of the rainfall or event exceedence m times out of n times

The return period of rainfall (event) were also calculated by the following formula

$$T = 1/(1\text{-Cimulative Frequency}) \quad ...(2)$$

The design rainfall is important to economic parameter for optimization use of natural resources with relation to cost of water harvesting tank (Table1). The 5 probability analysis method were used i.e. 1) Kimball (Weibull 1939), 2) California 1923, 3) Hazen 1930, 4) WMo 1983, and 5) Sevruk and Geiger 1981.

**Table 1.** Methods for estimating probabilities of exceedance or non-exceedance. Where m is the rank number and n is the total number of observations.

| Method | Estimate of probability of exceedance or or non-exceedance (%) |
|---|---|
| Wcibull (Weibull 1939) | m/(n+1)*100 |
| California (California State Department 1923) | (m/n)*100 |
| Hazen (Hazen 1930) | ((m-0.5)/n)* 100 |
| Gringorten (WMO 1983) | (m-0.44)/(n + 0.12)*100 |
| Sevruk and Geiger (Sevruk and Geiger 1981) | ((m-3/8)/(30 + 0.25)*100 |

The depth of rainfall was considered at the probability of 75% exceedence of occurrence by probability distribution and probability analysis.

Rainfall collection efficiency

The rainfall collection efficiency has been considered 80%, while 20% rainfall goes to abstraction loss and cleaning of roof area.

Design of water harvesting tank

Volume of rectangular water harvesting tank is :

0.80*Rainfall at 75% probability of occurrence*Roof area.... (3)

We assumed to be tank is rectangular,
Fig. 2 : Schematic diagram of roof water harvesting

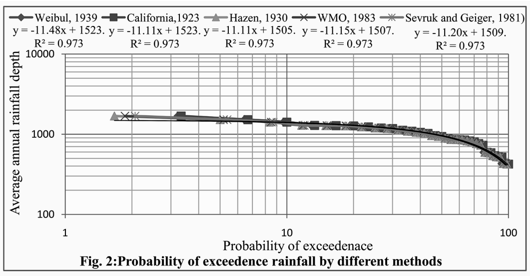


**Fig .2.** Probability of exceedence rainfall by different methods.

tank (put Fig_2 here) Volume of the tank is

$$V = xyz \quad .....(4)$$

Where x is Length, y is Width and z is Height of the tank.

The surface area of the rectangular tank is given by

$$S = xy+2yz + 2zx$$
$$= xy + 2z (x +y)$$

From the eq. (4) z = V/xy, we get

$$S = xy + 2V (1/x + 1/y)$$

Using simple mathematics involving partial derivative, the length, width and height of the tank with minimum surface area (i.e. optimization of cost) is

$$x=y=(2V)^{1/3} \text{ and } z = (V^{1/3}) / 2^{(2/3)}$$

## Results and Discussion

This section carried out for the probability distribution, probability analysis of last 30 years of rainfall data and economic design of water harvesting tank.

Probability distribution

There are more than 30 probability distribution methods were tested out of them best fitting probability distribution was found Fisher Type III followed by Poisson distribution, Weibull and normal distribution. The best fit equation for non exceedence event for Fisher Type III probability distribution by Fisher Type III is

$$Freq + \exp [-\{(2310-X) / \exp (30.7317/4.20261)\}\text{^}4.20261]$$

Where, x is rainfall depth. The goodness of fit between observed frequency and calculated frequency is found 0.99. The average absolute difference between observed frequency and calculated frequency were found 2.60.

The probability distribution in which cumulatiive frequency distribution always give non-exceedence of the event. The rainfall depth at 75% exceedence is found 692 mm was calculated by Fisher Type III distribution. The recurrence interval of 75 probability of exceedence of the of rainfall (event) is 4/3 years.

Probability analysis

Probability of exceedence of rainfall by different methods (i. e Weibull 1939, California, 1923, Hazen 1930, WMO 1983 and Servuk and Geiger 1981) were shown in Fig. 2. It shows from the Fig.2 that the good correlation between probability of exceedence versus the average annual depth of rainfall which shown in log-log graph. The goodness of fit of all the methods for probability of exceedence versus average annual rainfall depth is 0.97, which shows the good co-relation between probability of exceedence and average annual rainfall depth.

The probability exceedence by different methods was also shown below in Table 2. It shows from the Table 2 that annual rainfall of last 30 years (1988—2017) is 950 mm, standard deviation is 330.46 and coefficient of variability is 34.80%.

It also revealed from the Table 2 that most of the all the methods shows rainfall depth at 75% of probability exceedence is 731 mm. The Weibull's formula which avoids any complexities and which is most commonly used in Hydrology which revealed rainfall depth at 75% probability of exceedence is 700 mm.

The relationship between probability of exceedence event, average annual rainfall event and recurrence interval were illustrated in Fig. 3. It shows from the Fig. 3 and eq. (2) that the recurrence interval at probability of exceedence of 75% is found 4/3 Tyears, so it can be predict that the water harvesting might be filled in 3 years out of 4 years.

The value of rainfall depth at 75% probability of exceedence by probability distribution method Fisher Type III and prbability analysis by Kimball (Weibull 1938) method were more or less same. So, the rainfall depth was considered 700 mm for optimal design of roof water harvesting tank.

Roof area

The roof area was assumed for calculation purpose

**Table 2.** Probabilities of exceedence by the different methods.

| Year | Rainfall | Rank | Recurrence interval | Weibull 1939 | California 1923 | Probability<br>Hazen 1930 | WMO 1983 | Sevruk and Geiger 1981 |
|---|---|---|---|---|---|---|---|---|
| 2010 | 1689.7 | 1 | 31 | 3 | 3 | 2 | 2 | 2 |
| 2013 | 1520.3 | 2 | 16 | 6 | 7 | 5 | 5 | 5 |
| 2007 | 1416.4 | 3 | 11 | 10 | 10 | 8 | 8 | 9 |
| 1988 | 1290.7 | 4 | 9 | 13 | 13 | 12 | 12 | 12 |
| 2003 | 1280.8 | 5 | 7 | 16 | 17 | 15 | 15 | 15 |
| 2014 | 1271.5 | 6 | 6 | 19 | 20 | 18 | 18 | 19 |
| 2008 | 1236.6 | 7 | 5 | 23 | 23 | 22 | 22 | 22 |
| 2005 | 1197.3 | 8 | 5 | 26 | 27 | 25 | 25 | 25 |
| 1994 | 1176.8 | 9 | 4 | 29 | 30 | 28 | 28 | 29 |
| 2016 | 1125 | 10 | 4 | 32 | 33 | 32 | 32 | 32 |
| 2006 | 1091.5 | 11 | 4 | 35 | 37 | 35 | 35 | 35 |
| 1998 | 1056.8 | 12 | 4 | 39 | 40 | 38 | 38 | 38 |
| 2004 | 1024.9 | 13 | 3 | 42 | 43 | 42 | 42 | 42 |
| 2011 | 962.7 | 14 | 3 | 45 | 47 | 45 | 45 | 45 |
| 1992 | 940.3 | 15 | 3 | 48 | 50 | 48 | 48 | 48 |
| 1997 | 890.1 | 16 | 3 | 52 | 53 | 52 | 52 | 52 |
| 1990 | 860.6 | 17 | 3 | 55 | 57 | 55 | 55 | 55 |
| 1995 | 856.4 | 18 | 3 | 58 | 60 | 58 | 58 | 58 |
| 2001 | 848.6 | 19 | 3 | 61 | 63 | 62 | 62 | 62 |
| 2009 | 825.2 | 20 | 3 | 65 | 67 | 65 | 65 | 65 |
| 2017 | 807 | 21 | 2 | 68 | 70 | 68 | 68 | 68 |
| 2015 | 765.4 | 22 | 2 | 71 | 73 | 72 | 72 | 71 |
| 1996 | 731 | 23 | 2 | 74 | 77 | 75 | 75 | 75 |
| 2000 | 594.8 | 24 | 2 | 77 | 80 | 78 | 78 | 78 |
| 1989 | 588.2 | 25 | 2 | 81 | 83 | 82 | 82 | 81 |
| 2002 | 540.3 | 26 | 2 | 84 | 87 | 85 | 85 | 85 |
| 1993 | 523.8 | 27 | 2 | 87 | 90 | 88 | 88 | 88 |
| 1991 | 519.5 | 28 | 2 | 90 | 93 | 92 | 92 | 91 |
| 1999 | 431 | 29 | 2 | 94 | 97 | 95 | 95 | 95 |
| 2012 | 425 | 30 | 2 | 97 | 100 | 98 | 98 | 98 |
| Mean | | | | 949.6067 | | | | |
| SD | | | | 330.4653 | | | | |
| CV (%) | | | | 34.80023 | | | | |

is l0 m × 10 m (i.e. 100 square meters).

Roof water harvesting volume

The volume of roof water harvesting was found 56 cubic meters from the eq.3.

Size of the water harvesting tank

The optimal design of roof water harvesting tank was carried out as mention in 2.7. The volume of roof water harvesting tank is 56 cubic meters. The length, width and height of the water harvesting tanks was found 4.82 m and 4.82m, 2.41 m respectively for the assumed roof area 10m × 10m. As per the Bureau of

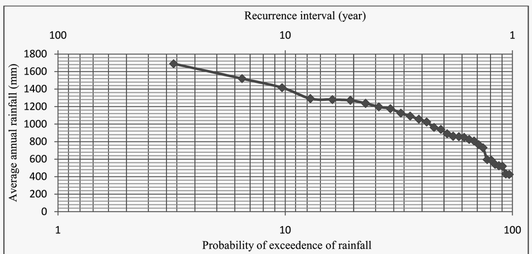


**Fig.3: Relationship between Probability of exceedence, average annual rainfall depth and recurence interval**

**Fig.3.** Relationship between probability of exceedence, average annual rainfall depth and recurrence interval.

Indian Standard IS : 1172-1993, the minimum water requirement for urban population 1,00,000 and above should be provided per capita per day 150 l to 200 l with full flushing system and even reduced up to 135 l for Lower Income Groups (LIG) , Economically Weaker Section of Society (EWS) and depending upon prevailing conditions. So, the roof water harvesting system compensates the demand of water at least minimum 70 to 90 days which is 2 to 3 months for 4 member of family. It gives big relief over the scarcity of water in summer season.

## Conclusion

The roof water harvesting is good concept to harvest water at domestic level. The average annual rainfall, standard deviation and coefficient of variability of rainfall were found 950mm, 330.64 mm and 34.80% respectively. The probability of exceedence of rainfall at 75% rainfall depth was found by 700 mm by Weibull methods which also support of probability distribution method Fisher Type III. Since last 30 years of rainfall data shows the sufficient quantity of rainfall occurs but the coefficient of variability is higher. As per assumed carpet area of 100 square meters, roof water harvesting volume is found 56 cubic meters at 75% probability of exceedence of rainfall depth. The hydrologic design of roof water harvesting tank is caculated, length, width and height of tank is calculated and found 4.82 m, 4.82 m and 2.41 m respectively. This volume of water can compensate the demand of water for 70 to 90 days for 4 number of family member. This volume of water can use to non rainy season or particular summer season. The lots of money are expensed to construct to luxurious houses, bed room, living rooms and swimming pool, purchasing of luxurious cars, but not concerned for roof water harvesting. This simple roof water harvesting system give mental peace in summer where more quantity of water required. Th present example was given foor calculation purpose only. The volume of roof water harvesting tank is depend on the rainfall and roof area. The volume of tank is varied as carpet area and rainfall depth changed. Mostly rainfall depth remained constant, but roof area varied from house to house or building to building. The present approached were carried for study of hydrologic design of water harvesting tank for Junagadh city only. The present approach or concept can also be used for designing of roof water harvesting tank base on their requirement (i.e.drinking, domestic, kitchen gardening and toilet flushing) any urban and rural areas.

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