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Design rainfall estimation using probabilistic approach for Adilabad district of Telangana

A. M. Waghaye*, V. Siddenki and Nidhi Kumari

* Corresponding Author, Tel.: +91 9552205271

E-mail address: waghayeabhishek@gmail.com

Department of Civil Engineering,
Rajiv Gandhi University of Knowledge Technologies
RGUKT Basar Campus,
Mudhole Mandal,
Adilabad district,
Telangana -504107

Note:

A. M. Waghaye
Lecturer
Dept. of Civil Engg.
RGUKT Basar

Nidhi Kumari
Lecturer
Dept. of Civil Engg.
RGUKT Basar

V. Siddenki

Student
Dept. of Civil Engg.
RGUKT Basar

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ABSTRACT: This paper presents the estimation of design rainfall of Adilabad district at different probability levels. The 30 years (1972-2001) monthly rainfall data of Adilabad district were analyzed by EasyFit software to identify the best fit probability distribution. Chi–square test is used as a goodness of fit criteria. It was found that General extreme value, Gamma distribution and Gumbel max were best fitted to monsoon (June-Sept), post-monsoon (March-May) and pre-monsoon (Oct-Feb) season respectively. The data was then processed to identify the design rainfall received in a monsoon (June-Sept)), pre-monsoon (March-May) and post-monsoon (Oct-Feb) season. Analysis of 30 years (1972-2001) rainfall data in the study area showed an average annual rainfall of Adilabad district is 1024.8 mm. According to India Meteorological Department (IMD), the meteorological drought year is defined as a year in which less than 75% of the average annual rainfall is received. Based upon these criteria, the years 1972, 1974, 1984 can be characterized as drought years. After fitting the probability distribution, the frequency factor method was used to estimate the design rainfall at different probability level which can be use to design catchment to cultivated area ratio of microcatchment water harvesting system.

Key words: Chi-Square test; Design rainfall; EasyFit; Gamma; General extreme value; Gumbel; Probability distribution

INTRODUCTION

Of all the planet's renewable sources, water has unique module. Water is essential for the survival and livelihood of every human. It also regulates ecosystems, grows our food and powers our industry. Water is the key resource for the human/animal health, socio-economic development, and the survival of earth's ecosystems. All these Properties are making the water utilizing rate in exponential. At present, about 10% of the world's freshwater supplies are used for maintaining health and sanitation, whereas agriculture accounts for about 70% and industries about 20% of the world's freshwater supplies (Machiwal and Jha, 2012).

Analysis of rainfall would enhance the management of water resources applications as well as the effective utilization of water resources. Most of the hydrological events occurring as natural phenomena are observed only once. One of the important problem in hydrology deals with interpreting past records of hydrologic events in terms of future probabilities of occurrence. The procedure for estimating frequency of occurrence of a hydrological event is known as frequency analysis (Bhakar *et al.*, 2006). Analysis of rainfall data strongly depends on its probability distribution pattern. It has long been a topic of interest in the fields of meteorology in establishing a probability distribution that provides a good fit to rainfall data. Several studies have been conducted in India and abroad on rainfall analysis and best fit probability distribution function such as normal, log-normal, Gumbel, Weibull and Pearson type distribution were identified.

Probability and frequency analysis of rainfall data enables us to determine the expected rainfall at various chances. Rainfall at 80 percent probability can be safely taken as assured rainfall, while 50 per cent chance can be considered as the maximum limit for taking any risk (Bhakar *et al.,* 2008). Distribution fitting is the procedure of selecting a statistical distribution that best fits to a data set. The distribution functions are mainly used to determine the risk and uncertainty. The best fit of distribution allows you to develop valid models of random processes you deal with, protecting you from potential time and money loss.

Analysis of maximum rainfall of different return periods is a basic tool for safe and economic planning and designing of small dams, bridges, culverts, irrigation and drainage work etc. Through the nature of rainfall is erratic and varies with time and space, yet it is possible to predict design rainfall fairly accurately for certain return periods using various probability distributions ((Bhakar *et al.,* 2006).

Lee (2005) studied the rainfall distribution characteristics of Chia-Nan plain area and showed that log– pearson type III distribution performed the best in probability distribution. To investigate the effect of each factor on rainfall within the area longitude, latitude, average annual rainfall and elevation are taken as variable.

Sharma and Singh (2010) analyzed the daily rainfall data of 37 years to identify the best fit probability distribution for study area. The lognormal and gamma distribution were found as the best fit probability distribution for the annual and monsoon season period of study, respectively. Generalized extreme value distribution was observed in most of the weekly period as best fit probability distribution.

Today, the biggest challenge is that how we can effectively balance these water resources such as monsoon excessive rainfall, river and tributaries water and other available resources to fulfill the remaining seasons crop water requirement and to balance the human development and ecosystems welfare in achieving equity, environmental sustainability, and economic efficiency in the face of looming global climate change.

The present study focused on estimation of design rainfall at different probability level which provides indication on management of water resources to satisfy crop water requirement.

MATERIALS AND METHODS

Data collection

The monthly rainfall and evapotranspiration (EVT) data of 30 years (1972-2001) of Adilabad district of Telangana were collected from the meteorological MET DATA Tool of website India Water Portal.

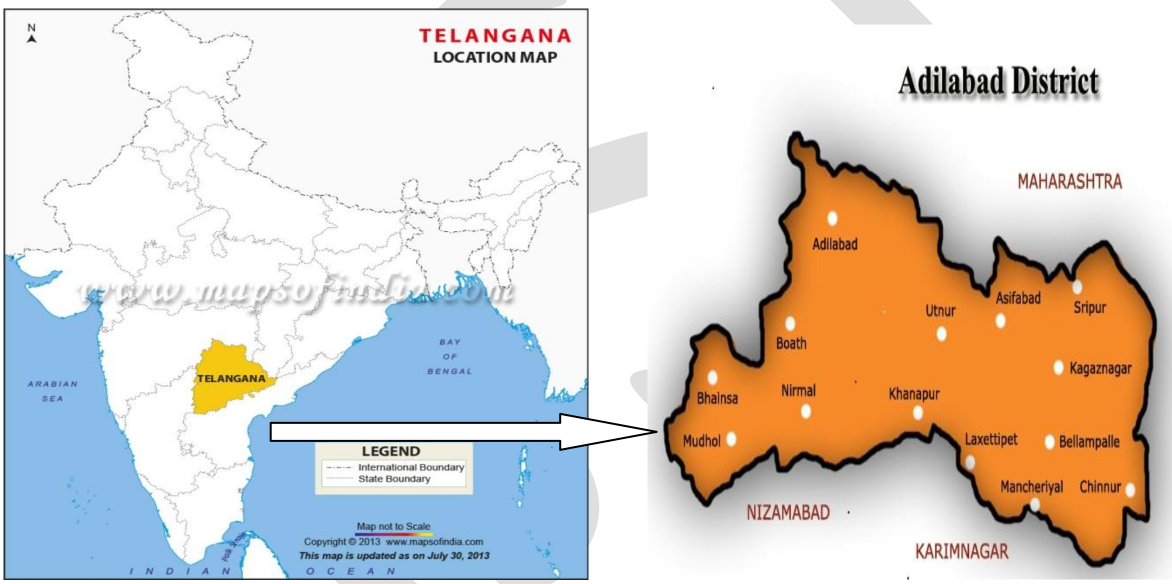

Fig 1. Location of study area in the state of Telangana

Study area

Adilabad District is the northern-most district of state Telangana. Adilabad is located between 77 46’ & 80 00’ longitude and 18 40’& 19 15’ latitude. It is bounded on the North by Yavatmal and Chandrapur districts, East by Chandrapur, West by Nanded district of Maharashtra State and on the South by Nizamabad and Karimnagar districts of Telangana. The most important river that flows through this district is the Godavari. Other important rivers in the district are Penganga, Wardha and Pranahitha. The Kadam and Peddavagu are tributaries of the Godavari. There are rivulets like Santhala, Swarna and Suddavagu which crisscross the district. Figure 1 shows the location of study area in the state Telangana.

The analysis of rainfall data is required to understand the characteristics and to estimate the expected rainfall of a season at different probability levels. The rainfall data of 30-years period (1972-2001) were analyzed by EasyFit software to calculate expected rainfall of a different season at various probability levels.

Probability distribution

One of the important problems in hydrology deals with interpreting a past record of rainfall events, in terms of future probabilities of occurrences. There are many probability distributions that have been found to be useful for hydrologic frequency analysis. The best fit probability distribution was evaluated by using the following systematic steps.

Step I: Fitting the probability distribution

The probability distributions viz. normal, lognormal, gamma, weibull, Pearson, generalized extreme value, gumbel max were identified to evaluate the best fit probability distribution for rainfall. In addition the different forms of these distributions were also tried and thus different probability distributions viz. normal, lognormal (2P, 3P), gamma (2P, 3P), generalized gamma (3P, 4P), log-gamma, weibull (2P, 3P), Pearson 5 (2P, 3P), Pearson 6 (3P, 4P), log-Pearson 3, generalized extreme value were applied to find out the best fit probability distribution

Step II: Testing the goodness of fit

The goodness of fit of a probability distribution can be tested by comparing the theoretical and sample values of the relative frequency or the cumulative frequency function. In the case of relative frequency function, Chi-square test is used.

Chi-square test

The Chi-square test statistic (χ^2) is defined as

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

Where

O_i= observed frequency

E_i = expected frequency

i= number of observations (1, 2, …….k)

The null hypothesis for the test is that the proposed probability distribution fits the data adequately. This hypothesis is rejected (i.e., the fit is deemed inadequate) if the value of χ^2 (Eq. 3.4) is larger than limiting value, ${\chi^2}_{v,1-\alpha}$, determined from the χ^2 distribution with v degrees of freedom as the value having cumulative probability 1- α, where α is termed the significance level. This test is for continuous sample data only and is used to determine if a sample comes from a population with a specific distribution.

Step III: Identification of best fit probability distribution

The goodness of fit test mentioned above was fitted to the monthly rainfall data of study area. The test statistic of test was computed and tested at (α=0.01) level of significance. Accordingly the ranking of different probability distributions were marked based on minimum test statistic value. The description of various probability distribution functions regarding probability density function, range and parameters is as shown in table1.

Table 1: Description of various probability distribution functions

Distribution	Probability density function	Range	Parameters
Gamma (3P)	$f(x)=\frac{(x-\gamma)^{\alpha-1}}{\beta^{\alpha}\Gamma(\alpha)}\exp\left(-(x-\gamma)/\beta\right)$	$\gamma \le x < +\infty$	$\sigma = shape\ parameter$ $(\sigma>0)$ $\beta = scale\ parameter$ $(\beta>0)$ $\gamma = location\ parameter$ ($\gamma \equiv 0$ yields the two parameter gamma distribution) $\Gamma = Gamma\ function$
Gamma (2P)	$f(x)=\frac{(x)^{\alpha-1}}{\beta^{\alpha}\Gamma(\alpha)}\exp\left(-(x)/\beta\right)$		
Generalized Extreme Value	$f(x)=\begin{cases}\frac{1}{\sigma}\exp\left(-(1+kz)^{-1/k}\right)(1+kz)^{-1-1/k} & k\neq 0\\ \frac{1}{\sigma}\exp\left(-z-\exp(-z)\right) & k=0\end{cases}$	$1+k\frac{(x-\mu)}{\sigma}>0$ for $k\neq 0$ $-\infty<x<+\infty$ for $k=0$	$\sigma = scale\ parameter$ $(\sigma>0)$ $k = shape\ parameter$ $\mu = location\ parameter$ where $z \equiv \frac{x-\mu}{\sigma}$
Generalized Gamma (4P)	$f(x)=\frac{k(x-\gamma)^{k\alpha-1}}{\beta^{k\alpha}\Gamma(\alpha)}\exp\left(-\left((x-\gamma)/\beta\right)^{k}\right)$	$\gamma \le x < +\infty$	$k = shape\ parameter$ $(k>0)$ $\alpha = shape\ parameter$ $(\alpha>0)$ $\beta = scale\ parameter$ $(\beta>0)$ $\gamma = location\ parameter$ ($\gamma \equiv 0$ yields the three parameter Generalized gamma distribution)
Generalized Gamma (3P)	$f(x)=\frac{kx^{k\alpha-1}}{\beta^{k\alpha}\Gamma(\alpha)}\exp\left(-\left(x/\beta\right)^{k}\right)$		

Distribution	Probability density function	Range	Parameters
Pearson 5 (3P)	$f(x) = \dfrac{\exp\left(-\beta/(x-\gamma)\right)}{\beta\,\Gamma(\alpha)\left((x-\gamma)/\beta\right)^{\alpha+1}}$	$\gamma < x < +\infty$	α = shape parameter $(\alpha > 0)$ β = scale parameter $(\beta > 0)$ γ = location parameter ($\gamma \equiv 0$ yields the two parameter pearson 5 distribution)
Pearson 5 (2P)	$f(x) = \dfrac{\exp\left(-\beta/x\right)}{\beta\,\Gamma(\alpha)\left(x/\beta\right)^{\alpha+1}}$		
Pearson 6 (4P)	$f(x) = \dfrac{\left((x-\gamma)/\beta\right)^{\alpha_1-1}}{\beta B(\alpha_1,\alpha_2)\left(1+(x-\gamma)/\beta\right)^{\alpha_1+\alpha_2}}$	$\gamma \le x < +\infty$	α_1 = shape parameter $(\alpha_1 > 0)$ α_2 = shape parameter $(\alpha_2 > 0)$ β = scale parameter $(\beta > 0)$ γ = location parameter ($\gamma \equiv 0$ yields the three parameter pearson 6 distribution)
Pearson 6 (3P)	$f(x) = \dfrac{\left(x/\beta\right)^{\alpha_1-1}}{\beta B(\alpha_1,\alpha_2)\left(1+x/\beta\right)^{\alpha_1+\alpha_2}}$		
Weibull (3P)	$P(x) = \dfrac{\alpha}{\beta}\left(\dfrac{x-\gamma}{\beta}\right)^{\alpha-1} \exp\left[-\left(\dfrac{x-\gamma}{\beta}\right)^{\alpha}\right]$	$\gamma \le x < +\infty$	α = shape parameter $(\alpha > 0)$ β = scale parameter $(\beta > 0)$ γ = location parameter ($\gamma \equiv 0$ yields the two parameter weibull distribution)
Weibull (2P)	$P(x) = \dfrac{\alpha}{\beta}\left(\dfrac{x}{\beta}\right)^{\alpha-1} \exp\left[-\left(\dfrac{x}{\beta}\right)^{\alpha}\right]$		

After fitting the probability distribution, the frequency factor method was used to estimate the design rainfall.

$$X_T = \overline{X} + K\sigma_{n-1} \tag{2}$$

Where,

X_T = Value of the variate X of a random hydrological series with a return period T

$\overline{X}$= Mean

K = Frequency factor

σ = Standard deviation

The standard deviation is calculated by using the following formula.

$$\sigma = \sqrt{\frac{\sum(X-\bar{X})^2}{N-1}} \qquad (3)$$

Generalized extreme value (GEV) distribution

The generalized extreme value distribution (GEV) is the generalize form of the extreme value type I (Gumbel), extreme value type II (Frechet) and extreme value type III (Weibull) distribution. Frechet distribution is positively skewed and Weibull distribution is negatively skewed distribution. It is a family of three subtypes of distribution, which are classified according to the value of skewness coefficient (g). The skweness coefficient of Frechet distribution has a value of g greater than 1.1396 and Weibull distribution has a value of g less than 1.1396. Frequency factor (K) for Weibull distribution can be determined from frequency factor table for different return period and skweness coefficient. (Heo *et al.,* 2001).

Gumbel or Extreme value type-I Distribution

This extreme value distribution was introduced by Gumbel (1941) and is commonly known as Gumbel's distribution. It is the one of the most widely used probability distribution functions for extreme values in hydrological and meteorological studies.

$$K = \frac{Y_T - \overline{Y}_n}{S_n} \qquad (4a)$$

where Y_T =Reduced variate

$\overline{\mathrm{Y}}_\mathrm{n}$ = Reduced mean and it′s equals to 0.5362

S_n= Reduced standard deviation and it's equals to 1.112

$$Y_T = -\left[0.834 + 2.303\ \log\log\frac{T}{T-1}\right] \qquad (4b)$$

where T = Return period

Depending upon the number of samples the $\overline{\mathrm{Y}}_\mathrm{n}$ and S_n values varies, those values as shown in Table 2.

Table 2: Means and standard deviations of reduced extremes

[Extracted from a more complete table by Gumbel]

N	$\bar{y}_N$	σ_N
10	0.4952	0.9497
15	.5128	1.021
20	.5236	1.063
25	.5309	1.091
30	.5362	1.112
35	.5403	1.128
40	.5436	1.141
45	.5463	1.152
50	.5485	1.161
60	.5521	1.175
70	.5548	1.185
80	.5569	1.194
90	.5586	1.201
100	.5600	1.206
200	.5672	1.236
500	.5724	1.259
1, 000	.5745	1.269

Gamma or Pearson type III distribution (PT III)

It is a frequency analysis method proposed by Foster (1924). This method considers three statistic parameters, mean, standard deviation and skewness, and is a most flexible and reliable method. It is nothing more but an analysis process and is comparatively complicated than others. In this process one has to find out the coefficient of skewness for the data, thereby for that particular coefficient of skewness several frequency factors are available at different return periods. Frequency factor (K) for Pearson type III distribution can be determine for different return period and skewness coefficient from frequency factor table (Harter, 1969) . Coefficient of Skewness (g) can be determined by,

$$g = \frac{n^2 \sum X_i^3 - 3n \sum X_i \sum X_i^2 + 2(\sum X_i)^3}{n(n-1)(n-2)S_Y^3} \qquad (5a)$$

$$or \qquad g = \frac{n \sum (X_i - \bar{X})^3}{n(n-1)(n-2)S_Y^3} \qquad (5b)$$

Where

$\bar{X}$ = Mean of the X values

N = Sample size or number of years recorded.

RESULTS AND DISCUSSION

Analysis of rainfall data

The analysis of rainfall data is important because it plays a key role in water resources planning and design. The monthly rainfall data of 30 years (1972-2001) were collected for the study area. Figure 2 shows the total annual rainfall recorded for the period 1972-2001 in the study area. The average annual rainfall based on 30 years of data was found to be 1024.8 mm (Fig. 2). During this period, highest amount of rainfall was about 1459.6 mm in 1983 whereas the lowest amount of rainfall was about 627.8 mm during 1972. If the annual rainfall in a year departs from the average annual rainfall by greater than or equal to 25% then that year is declared as drought (meteorological drought) year (Subramanya, 2008). On the basis of 25% departure from the average annual rainfall, years 1972, 1974 and 1984 were the dry years. The highest mean monthly rainfall was observed in the month of August (272.4 mm) whereas lowest in the month of December (3.8 mm). There was sufficient rainfall from the July to September to meet evapotranspiration demand and vice versa from the October to June as shown in fig. 3.

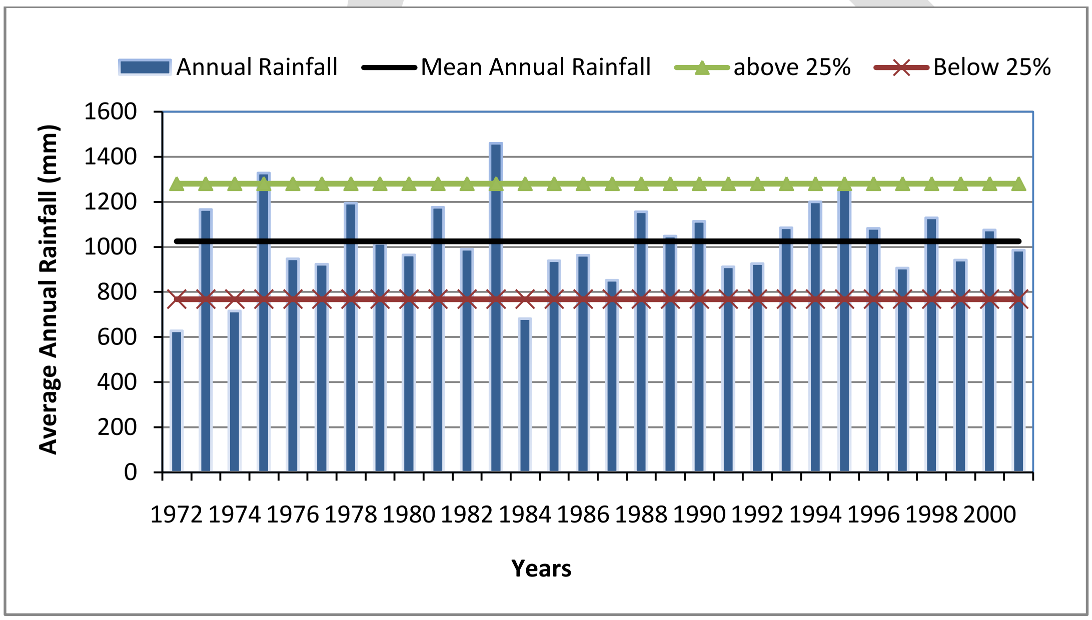

Fig. 2: Total annual rainfall recorded for the period 1972-2001 in the study area

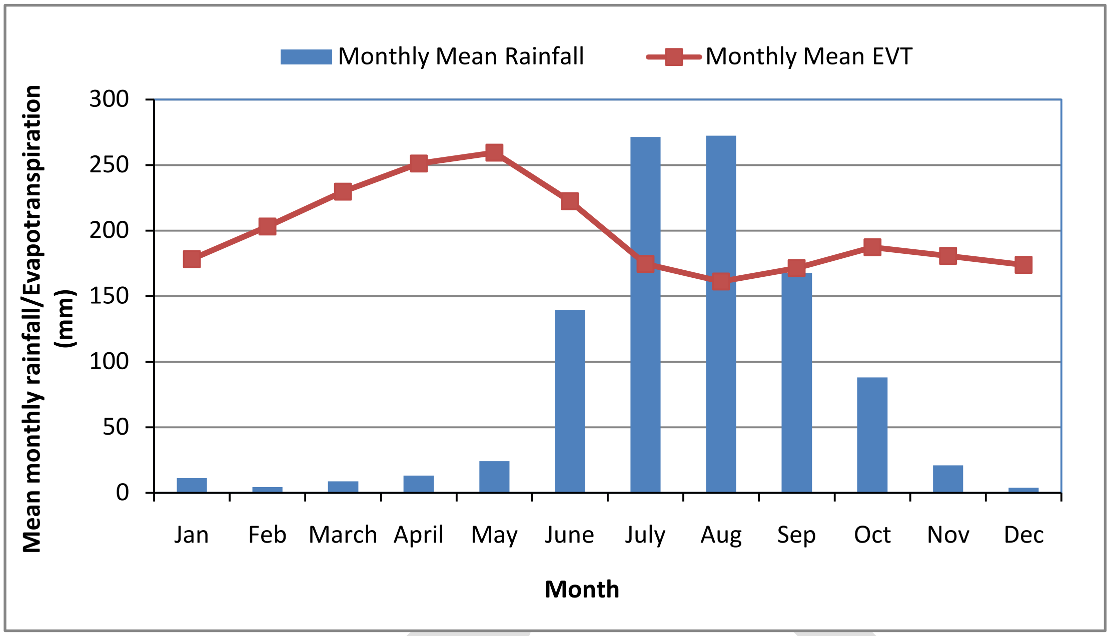

Fig. 3: Comparison between average monthly rainfall and Evapotranspiration

In order to get the seasonal rainfall distribution, the whole year was divided into three seasons namely monsoon (Jun-Sept), post monsoon (Oct-Feb) and pre monsoon (Mar-May). Figure 4 shows the seasonal variation of the rainfall. This reveals that area receives about 84% of the total annual rainfall during the monsoon season, 10% during the post monsoon season and 6% during the pre monsoon season. It indicates that more than 80% of rainfall occurs in monsoon season and remaining 8 month crop suffer from moisture stress. Therefore, it is necessary to predict expected rainfall to design water harvesting system.

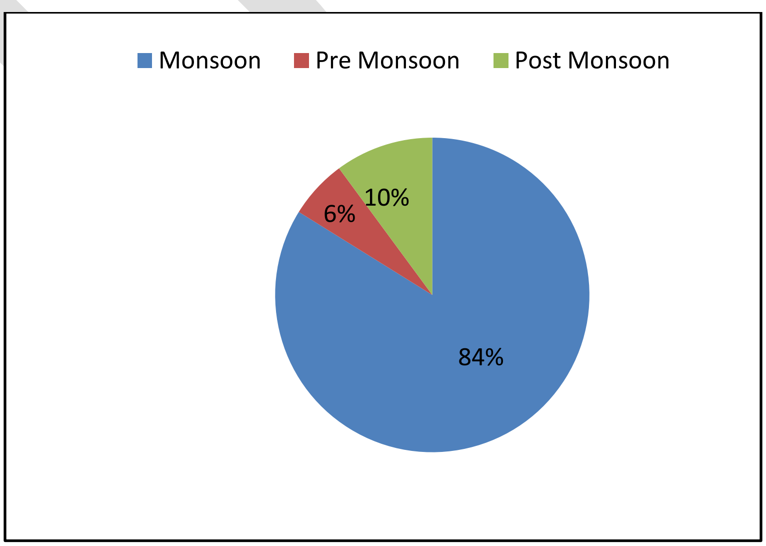

Fig. 4: Seasonal variation of rainfall in Adilabad district of Telangana

Table 3: Best fitted distributions for different seasons

Seasons	Best Fitted Distribution
Pre-Monsoon (March - May)	**Gumbel Max**
Monsoon (June-Sept)	**Gen. Extreme Value**
Post-Monsoon (Oct-Feb)	**Gamma**

Probability analysis

To estimate the design rainfall, the monthly rainfall data of 30 years (1972-2001) was analyzed. The probability analysis of seasonal rainfall data was carried out. To fit the probability distribution to rainfall data, EasyFit software was used with Chi-Square test as a goodness of fit criteria. Table 3 shows the best fitted distribution for different season. According to Chi-Square test, it was found that General extreme value, Gumbel max and Gamma distribution were best fitted to monsoon (June-Sept)), pre-monsoon (March-May) and post-monsoon (Oct-Feb) season respectively. After fitting the probability distribution, the frequency factor method was used to estimate the design rainfall. In case of monsoon season, best fitted distribution is general extreme value distribution. As discussed earlier, general extreme value distribution is a family of three sub type of distribution, which are classified according to the value of skewness coefficient (g). For monthly rainfall data of monsoon season, skweness coefficient is calculated and it was found to be equal to 0.38 which indicate that extreme value type III (Weibull) distribution is best fitted to monsoon season.

After fitting the probability distribution, the frequency factor method was used to estimate the design rainfall. The monthly design rainfall of different season was calculated at 80, 70, 60, 50 and 20% probability level. Table 4 to 6 shows the monthly design rainfall for monsoon, post-monsoon and pre-monsoon season respectively. It was observed that as the probability level increases, the design rainfall decreases and vice-versa. It was also observed that standard deviation value varies from 5.8 mm which is lowest found in month of December to highest value 89.1 mm found in September.

Table 4: Monthly design rainfall for monsoon season at different probability level

Month	Mean rainfall (mm)	Standard deviation (mm)	Probability(%)	Frequency factor	Design rainfall (mm)
June	139.43	58.5	80	-0.8915	87.3
			70	-0.616	103.4
			60	-0.3405	119.6
			50	0.065	143.3
			20	0.86	189.8
July	271.3	82.35	80	-0.8915	197.9
			70	-0.616	220.6
			60	-0.3405	243.3
			50	0.065	276.7
			20	0.86	342.2
August	272.36	80.74	80	-0.8915	200.4
			70	-0.616	222.7
			60	-0.3405	244.9
			50	0.065	277.7
			20	0.86	341.8
September	167.7	89.1	80	-0.8915	88.3
			70	-0.616	112.9
			60	-0.3405	137.4
			50	0.065	173.5
			20	0.86	244.4

Table 5: Monthly design rainfall for post-monsoon season at different probability level

Month	Mean rainfall (mm)	Standard deviation (mm)	Probability (%)	Frequency factor	Design rainfall (mm)
October	88.1	71.14	80	-0.6206	44
			70	-0.57887	47
			60	-0.50863	52
			50	-0.40041	59.7
			20	0.40061	116.6
November	21.02	23.008	80	-0.6206	6.8
			70	-0.57887	7.8
			60	-0.50863	9.4
			50	-0.40041	11.9
			20	0.40061	30.3
December	3.8	5.844	80	-0.6206	0.2
			70	-0.57887	0.5
			60	-0.50863	0.9
			50	-0.40041	1.5
			20	0.40061	6.2
January	11.2	13.79	80	-0.6206	2.7
			70	-0.57887	3.3
			60	-0.50863	4.2
			50	-0.40041	5.7
			20	0.40061	16.8
February	4.3	5.931	80	-0.6206	0
			70	-0.57887	0
			60	-0.50863	0
			50	-0.40041	0
			20	0.40061	10.3

Table 6: Monthly design rainfall for pre-monsoon season at different probability level

Month	Mean rainfall (mm)	Standard deviation (mm)	Probability (%)	Frequency factor	Design rainfall (mm)
March	8.74	11.8	80	-0.37999494	4.3
			70	-0.31705704	5
			60	-0.2427501	5.9
			50	-0.15259629	7
			20	0.33651921	12.8
April	13.2	9.131	80	-0.37999494	9.8
			70	-0.31705704	10.4
			60	-0.2427501	11
			50	-0.15259629	11.9
			20	0.33651921	16.3
May	24.13	22.75	80	-0.37999859	15.5
			70	-0.31705704	17
			60	-0.2427501	18.7
			50	-0.15259629	20.7
			20	0.33651921	31.8

Table 7: Seasonal rainfall at different probability levels

Season	80%	70%	60%	50%	20%
Pre-Monsoon (mm)	29.6	32.4	35.6	39.6	60.9
Monsoon (mm)	573.9	659.6	745.2	871.2	1118.2
Post-Monsoon (mm)	53.7	58.6	66.5	78.8	180.2

From monthly design rainfall, the seasonal design rainfall was calculated at 80, 70, 60, 50 and 20% probability level as shown in Table 7. For pre-monsoon season, the seasonal design rainfall at 80, 70, 60, 50 and 20% probability level found to be 29.6, 32.4, 35.6, 39.6 and 60.9 mm respectively. For monsoon season, the seasonal design rainfall at 80, 70, 60, 50 and 20% probability level found to be 573.9 , 659.6, 745.2, 871.2 and 1118.2 mm respectively. For post-monsoon season the seasonal design rainfall at 80, 70, 60, 50 and 20% probability found to be 53.7, 58.6, 66.5, 78.8 and 180.2 mm respectively. Figure 5 shows the variation of seasonal design rainfall at different probability level. By using seasonal design rainfall, the determination of annual design rainfall was done to know the annual expected rainfall at 80, 70, 60, 50 and 20% probability level. Figure 6 shows the annual design rainfall at different probability level. The annual design rainfall 80, 70, 60, 50 and 20% found to be 657.2, 750.6, 847.3, 989.6 and

1359.6 mm respectively. By knowing design rainfall at different probability level planning of water harvesting system can be done.

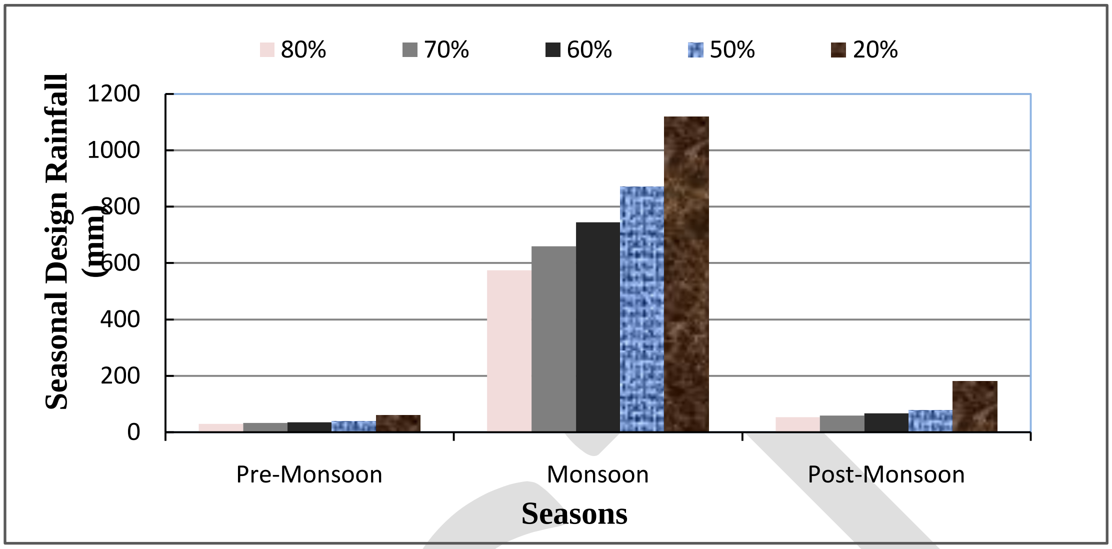

Fig. 5: Seasonal design rainfall at different probability level

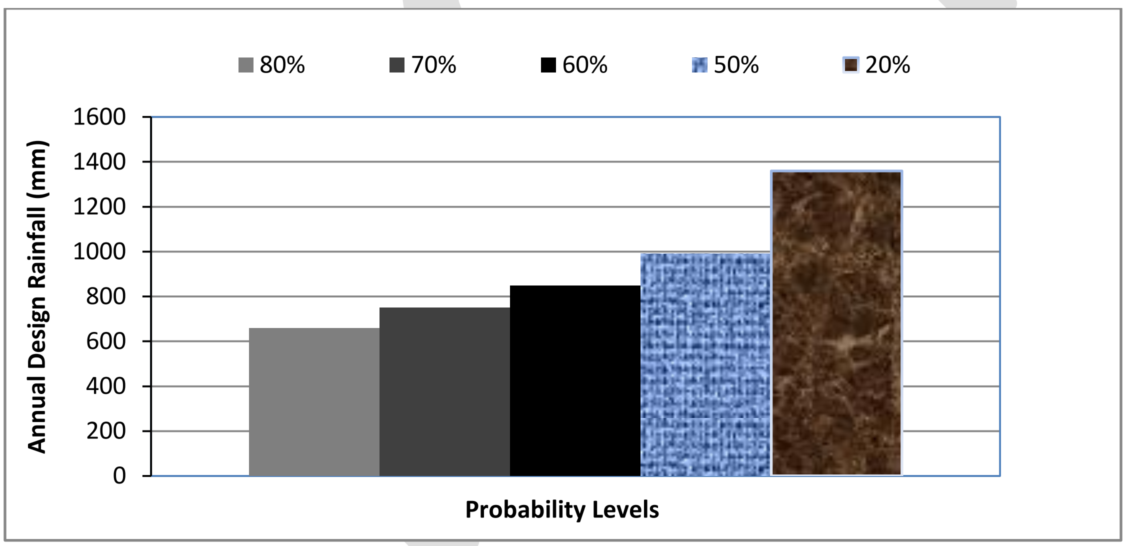

Fig. 6: Annual design rainfall at different probability level

CONCLUSIONS

The analysis of rainfall plays important role in the management of water resources applications as well as the effective utilization of water resources. The hydrologic time series information can be used to prevent floods and droughts, and applied to the planning and designing of water resources related engineering, such as reservoir design, flood control work, drainage design, and soil and water conservation planning, etc. All these works require the rainfall data as a design basis. It was found that General extreme value, Gamma distribution and Gumbel max were best fitted to monsoon (June-Sept)), post-monsoon (March-May) and pre-monsoon (Oct-Feb) season respectively. After fitting the probability distribution, the design rainfall was estimated for pre-monsson, monsoon and post-monsoon season at 80, 70, 60, 50 and 20% probability level. The annual design rainfall at 80, 70, 60, 50 and 20% probability found to be 657.2 mm, 750.6 mm, 847.3 mm, 989.6 mm and 1359.6 mm respectively. The annual design rainfall values play important role in design of catchment to cultivated area ratio of microcatchment water harvesting system to fulfill the crop water requirement during nonmonsoon season.

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