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RESEARCH PAPER

Design rainfall estimation using probabilistic approach for Adilabad district of Telangana

A.M. WAGHAYE, V. SIDDENKI, NIDHI KUMARI AND V.K. INGLE

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 Indian Meteorological Department (IMD), the meteorological drought year is defined as a year in which less than 75 per cent 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 micro-catchment water harvesting system.

KEY WORDS : Chi-Square test, Design rainfall, EasyFit, Gamma, General extreme value, Gumbel, Probability distribution

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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 per cent of the world's freshwater supplies are used for maintaining health and sanitation, whereas agriculture accounts for about 70 per cent and industries about 20 per cent of the world's freshwater supplies (Machiwal and Jha, 2012 and Chow, 1964).

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 (Dabral *et al.*, 2009 and Singh *et al.*, 2012). 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 per cent 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 and Singh, 2001). 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; Kumar, 2000 and Kumar *et al.*, 2007).

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.

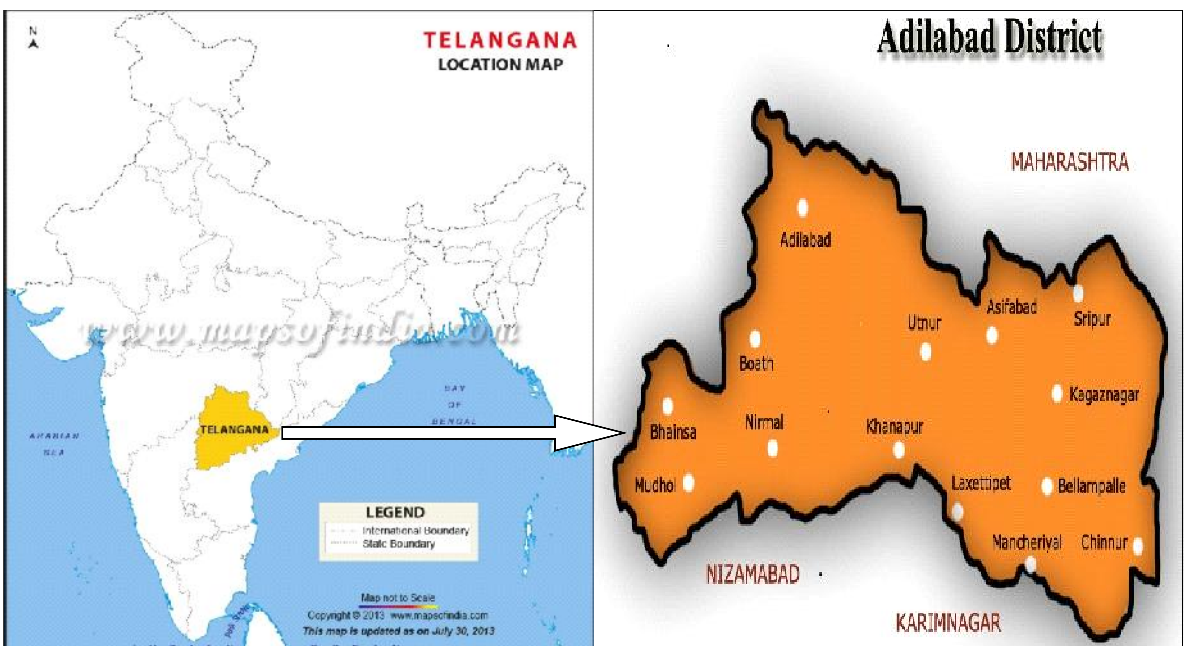

Fig. A : Rotary unit in operation at KVK, Andro

EXPERIMENTAL PROCEDURE

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.

Study area :

Adilabad district is the northern-most district of state Telangana. Adilabad is located between 77 46' and 80 00' longitude and 18 40'and 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. Fig. A 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 :

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

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 a 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 Table A.

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

$$X_T = \bar{X} + K\sigma_{n-1} \quad (2)$$

Table A Description of various probability distribution functions

Distribution	Probability density function	Range	Parameters
Gamma (3P)	$f(x) = \frac{(x-\gamma)^{\alpha-1}}{\beta^{\alpha}\Gamma(\alpha)}\exp\left(-\frac{(x-\gamma)}{\beta}\right)$	$\gamma \le x < +\infty$	σ=shape parameter (σ>0) β= scale parameter (β>0) γ= location parameter ($\gamma\equiv0$ Yields the two parameter gamma distribution) Γ= gamma function
Gamma (2P)	$f(x) = \frac{(x)^{\alpha-1}}{\beta^{\alpha}\Gamma(\alpha)}\exp\left(-\frac{(x)}{\beta}\right)$		
Generalized extreme value	$f(x) = \begin{cases} \frac{1}{\sigma}\exp\left(-(1+kz)^{-\frac{1}{k}}\right)(1+kz)^{-1-\frac{1}{k}} & k \neq 0 \\ \frac{1}{\sigma}\exp(-z-\exp(-z)) & k = 0 \end{cases}$	$1+k\frac{(x-\mu)}{\sigma} > 0$ for $k \neq 0$ $-\infty < x < +\infty$ for $k = 0$	σ= scale parameter (σ>0) k=shape parameter μ= location parameter where $z \equiv \frac{x-\mu}{\sigma}$
Generalized Gamma (4P)	$f(x) = \frac{k(x-\gamma)^{k\alpha-1}}{\beta^{k\alpha}\Gamma(\alpha)}\exp\left\{-\left(\frac{(x-\gamma)}{\beta}\right)^{k}\right\}$	$\gamma \le x < +\infty$	k= shape parameter (k>0) α= shape parameter (α>0) β= scale parameter (β>0) γ= location parameter ($\gamma\equiv0$) yields the three parameter generalized gamma distribution
Generalized Gamma (3P)	$f(x) = \frac{kx^{k\alpha-1}}{\beta^{k\alpha}\Gamma(\alpha)}\exp\left(-\left(\frac{x}{\beta}\right)^{k}\right)$		
Pearson 5 (3P)	$f(x) = \frac{\exp\left(\frac{-\beta}{(x-\gamma)}\right)}{\beta\Gamma(\alpha)\left(\frac{(x-\gamma)}{\beta}\right)^{\alpha+1}}$	$\gamma < x < +\infty$	α= shape parameter (α>0) β= scale parameter (β>0) γ= location parameter ($\gamma\equiv0$) yields the two parameter pearson 5 distribution)
Pearson 5 (2P)	$f(x) = \frac{\exp\left(\frac{-\beta}{x}\right)}{\beta\Gamma(\alpha)\left(\frac{x}{\beta}\right)^{\alpha+1}}$		
Pearson 6 (4P)	$f(x) = \frac{\left(\frac{(x-\gamma)}{\beta}\right)^{\alpha_1-1}}{\beta B(\alpha_1,\alpha_2)\left(1+\frac{(x-\gamma)}{\beta}\right)^{\alpha_1+\alpha_2}}$	$\gamma \le x < +\infty$	α_1= shape parameter (α_1>0) α_2= shape parameter (α_2>0) β= scale parameter (β>0) γ= location parameter ($\gamma\equiv0$ yields the three parameter pearson 6 distribution)
Pearson 6 (3P)	$f(x) = \frac{\left(\frac{(x)}{\beta}\right)^{\alpha_1-1}}{\beta B(\alpha_1,\alpha_2)\left(1+\frac{x}{\beta}\right)^{\alpha_1+\alpha_2}}$		
Weibull (3P)	$P(x) = \frac{\alpha}{\beta}\left(\frac{x-\gamma}{\beta}\right)^{\alpha-1}\exp\left(-\left(\frac{x-\gamma}{\beta}\right)^{\alpha}\right)$	$\gamma \le x < +\infty$	α= shape parameter (α>0) β= scale parameter (β>0) γ= location parameter (g>0 yields the two parameter weibull distribution)
Weibull (2P)	$P(x) = \frac{\alpha}{\beta}\left(\frac{x}{\beta}\right)^{\alpha-1}\exp\left(-\left(\frac{x}{\beta}\right)^{\alpha}\right)$		

where,
X_T= Value of the variate X of a random hydrological series with a return period T
$\bar{X}$ = Mean
K = Frequency factor
σ = Standard deviation
The standard deviation is calculated by using the following formula :

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

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 co-efficient (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 co-efficient (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.

$$K = \frac{Y_T - \bar{Y}_n}{S_n} \tag{4a}$$

where, Y_T =Reduced variate
$\bar{Y}_n$ = Reduced mean and it's equals to 0.5362
S_n = Reduced standard deviation and it's equals to 1.112.

Table B : Means and standard deviations of reduced extremes (extracted from a more complete table by Gambel)

N	$\bar{Y}_N$	σ_N
10	0.4952	0.9497
15	0.5128	1.021
20	0.5236	1.063
25	0.5309	1.091
30	0.5362	1.112
35	0.5403	1.128
40	0.5436	1.141
45	0.5463	1.152
50	0.5485	1.161
60	0.5521	1.175
70	0.5548	1.185
80	0.5569	1.194
90	0.5586	1.201
100	0.5600	1.206
200	0.5672	1.236
500	0.5724	1.259
1000	0.5745	1.269

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

where, T = Return period

Depending upon the number of samples the $\overline{Y_n}$ and S_n values varies, those values as shown in Table B.

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 (Phien and Ajirajah, 1984). In this process one has to find out the co-efficient of skewness for the data, thereby for that particular co-efficient 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 co-efficient from frequency factor table (Harter, 1969). Co-efficient of Skewness (g) can be determined by :

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

or $$g = \frac{n\Sigma(Xi - \overline{X})^3}{n(n-1)(n-2)S_Y^3} \tag{5a}$$

where,

$\overline{x}$ = Mean of the X values

N = Sample size or number of years recorded.

EXPERIMENTAL FINDINGS AND ANALYSIS

The results obtained from the present investigation as well as relevant discussion have been summarized under following heads :

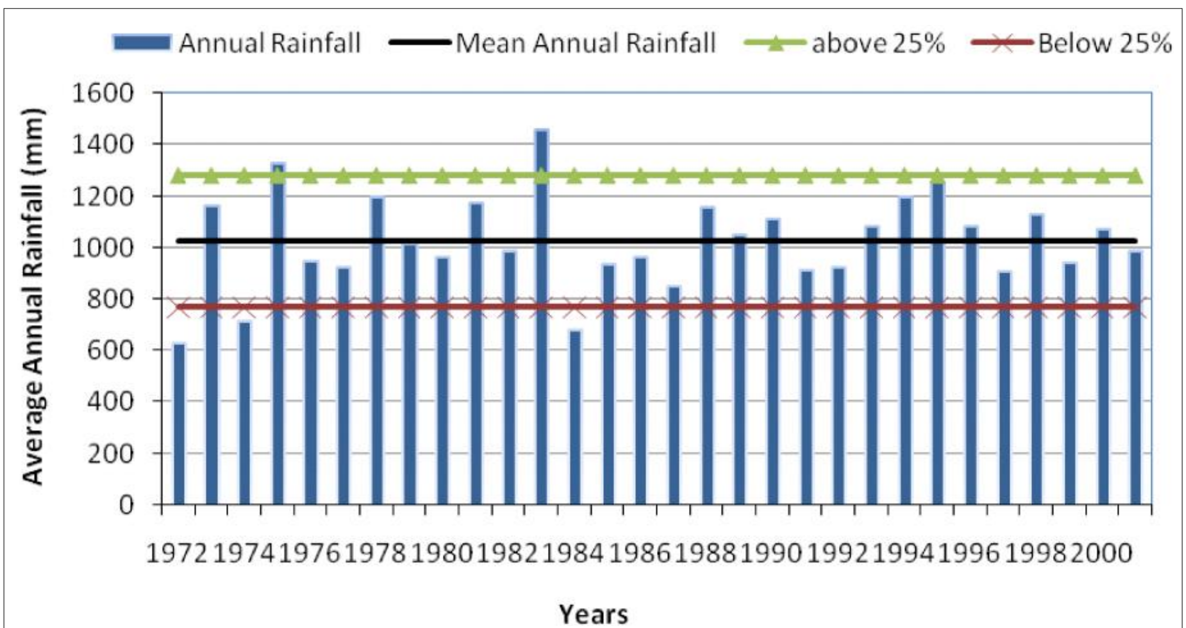

Fig. 1 : Total annual rainfall recorded for the period 1972-2001 in the study area

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. Fig. 1 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. 1). 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 per cent then that year is declared as drought (meteorological drought)

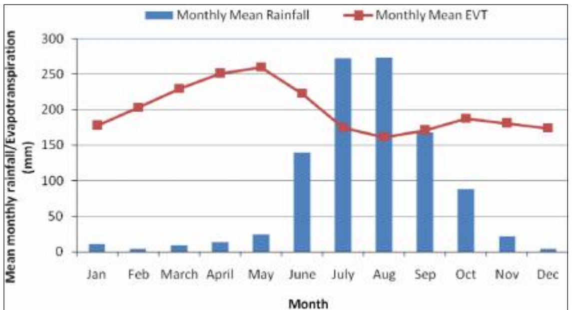

Fig. 2 : Comparison between average monthly rainfall and evapotranspiration

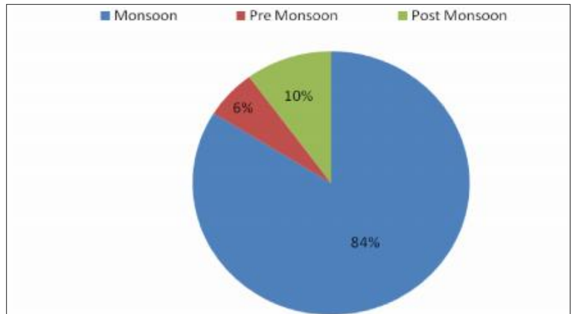

Fig. 3 : Seasonal variation of rainfall in Adilabad district of Telangana

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

Table 2 : Monthly design rainfall for monsoon season at different probability level

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

year (Subramanya, 2008). On the basis of 25 per cent 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

Table 3 : Monthly design rainfall for post-monsoon season at different probability level

Month	Mean rainfall (mm)	Standard deviation (mm)	Probability (per cent)	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 4 : Monthly design rainfall for pre-monsoon season at different probability level

Month	Mean rainfall (mm)	Standard deviation (mm)	Probability (per cent)	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

meet evapotranspiration demand and vice versa from the October to June as shown in Fig. 2.

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). Fig. 3 shows the seasonal variation of the rainfall. This reveals that area receives about 84 per cent of the total annual rainfall during the monsoon season, 10 per cent during the post monsoon season and 6 per cent during the pre monsoon season. It indicates that more than 80 per cent 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.

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 1 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 (Karim and Chowdhary, 1995). 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 co-efficient (g). For monthly rainfall data of monsoon season, skweness co-efficient 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 (Vogel and Charles, 1989 and Yoo *et al.,* 2005).

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 per cent probability level. Table 1 to 4 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.

From monthly design rainfall, the seasonal design rainfall was calculated at 80, 70, 60, 50 and 20 per cent probability level as shown in Table 5. For pre-monsoon season, the seasonal design rainfall at 80, 70, 60, 50 and 20 per cent 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 per cent probability level found to be 573.9, 659.6, 745.2, 871.2 and 1118.2 mm,

Table 5 : 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

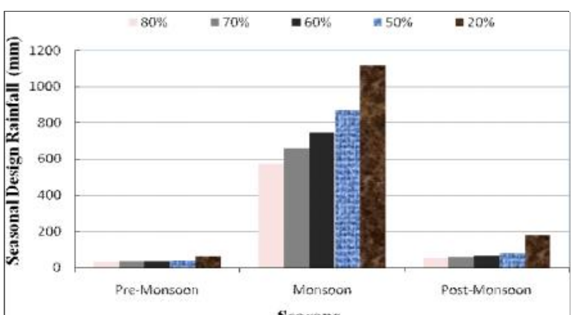

Fig. 4 : Seasonal design rainfall at different probability level

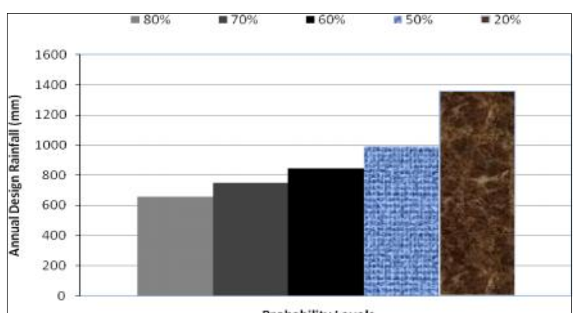

Fig. 5 : Annual design rainfall at different probability level

respectively. For post-monsoon season the seasonal design rainfall at 80, 70, 60, 50 and 20 per cent probability found to be 53.7, 58.6, 66.5, 78.8 and 180.2 mm, respectively. Fig. 4 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 per cent probability level. Fig. 5 shows the annual design rainfall at different probability level. The annual design rainfall 80, 70, 60, 50 and 20 per cent 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.

Conclusion :

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-monsoon, monsoon and post-monsoon season at 80, 70, 60, 50 and 20 per cent probability level. The annual design rainfall at 80, 70, 60, 50 and 20 per cent 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 non-monsoon season.

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MEMBERS OF RESEARCH FORUM

AUTHOR FOR CORRESPONDENCE :

A.M. Waghaye
Department of Civil Engineering, Rajiv Gandhi University of Knowledge Technologies, Basar
ADILABAD (TELANGANA) INDIA
Email: waghayeabhishek@gmail.com

CO-OPTED AUTHORS :

V.K. Ingle, Division of Agricultural Engineering, Indian Agricultural Research Institute, NEW DELHI (INDIA)

Nidhi Kumari and V. Siddenki, Department of Civil Engineering, Rajiv Gandhi University of Knowledge Technologies, Basar
ADILABAD (TELANGANA) INDIA