AJES
ASIAN JOURNAL OF ENVIRONMENTAL SCIENCE ■ VOLUME 9 | ISSUE 2 | DECEMBER, 2014 | 80-86
e ISSN-0976-8947
DOI: 10.15740/HAS/AJES/9.2/80-86 ■ Visit us : *www.researchjournal.co.in*

A CASE STUDY

Probability distribution of rainfall for Kolhapur region

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Article Chronicle :
***Received* :**
10.11.2014;
***Accepted* :**
20.11.2014

SUMMARY : Rainfall is one of the most important natural input resources to crop production and its occurrence and distribution is erratic, temporal and spatial variations in nature. Most of the hydrological events occurring as natural phenomena are observed only once. One of the important problem in hydrology deals with the interpreting past records of hydrological event in terms of future probabilities of occurrence. Rainfall analysis is a prerequisite for proper designing of any soil and water conservation structure. Daily rainfall data will be collected from Department of Agronomy, College of Agriculture, Kolhapur for the year 2012-13. For this study Normal, Log-normal and Gumbel distributions of probability are used. From the analysis it was concluded that, Log- pearson type III distribution was found to be good for probability distribution of rainfall in the Kolhapur region.

HOW TO CITE THIS ARTICLE : Mehendale, Gauri, Sawant, Rupesh, Mohite, Digamber, Deshmukh, Vidya and Shinde, Sangita (2014). Probability distribution of rainfall for Kolhapur region. *Asian J. Environ. Sci.*, **9**(2): 80-86.

Key Words :
Distribution of rainfall, Hydrology, Log pearson type IV distribution, Log normal distribution, Log pearson type III distribution

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Rainfall is one of the most important natural input resources to crop production and its occurrence and distribution is erratic, temporal and spatial variations in nature. Most of the hydrological events occurring as natural phenomena are observed only once. One of the important problem in hydrology deals with the interpreting past records of hydrological event in terms of future probabilities of occurrence. Analysis of rainfall and determination of annual maximum daily rainfall would enhance the management of water resources applications as well as the effective utilization of water resources.

Analysis of rainfall data is strongly depends on its distribution. Several studies have been conducted in India and abroad on rainfall analysis and best fit probability distribution function such as normal, Log - normal Gumbel and Pearson type III distribution were identified. Probability and frequency analysis of rainfall data enables us to determine the expected rainfall at various chances (Bhakar *et al.*, 2008). Such information can also be used to prevent floods and droughts, and applied to planning and designing of water resources related to engineering such as reservoir design, flood control work and soil and water conservation planning. Though the rainfall is erratic and varies with time and space, it is commonly possible to predict return periods using variousprobability distributions (Upadhaya and Singh, 1998). Probability and frequency analysis of rainfall data enables us to determinethe expected rainfall at various chances. Therefore, probability analysis of rainfall is necessary for solving various water management problems and toaccess the crop failure due to deficit or excess rainfall. Scientific prediction of rains and crop planning doneanalytically may prove a significant tool in the hands of farmers for better economic returns (Bhakar *et al.*, 2008).

Rainfall analysis is a prerequisite for proper designing of any soil and water conservation structure. For this study Normal, Log-normal and Gumbel distributions of probability are used. Detailed procedures of estimation of probability by these methods are explained in methodology.

EXPERIMENTAL METHODOLOGY

Study area :

The research work was carried out at the Pad. Dr. D.Y. Patil College of Agricultural

Engineering and Technology, Talsande, Affiliated to Mahatma Phule Krishi Vidyapeeth, Rahuri. The location map of study area is shown in Fig. A Kolhapur is confined at 16^0 42' 17.24" N latitude and 74^0 14' 10.74" E longitudes with an altitude of 605 m above MSL. The climate in this region is dry and temperate. The region receives about 1019.5 mm average annual rainfall. Thus rainfall analysis plays an important role to obtain the probability of arrival of monsoon for crop and irrigation management.

Data collection :

Daily rainfall data will be collected from Department Regional Agricultural Research Centre, Shenda Park Kolhapur for the year 1992-2012.

Methodology :

Return period :

Return period or recurrence interval is the average interval of time within which any extreme even of given magnitude will be equally or exceeded at least once. Return period will be calculated by Weibull's plotting position formula (Chow, 1964) by arranging one day maximum daily rainfall in descending order giving their respective rank as:

$$T = \frac{N + 1}{R} \quad .....(1)$$

where,

N = The total number of year

R = The rank of observed rainfall values arranged in descending order.

Probability distribution functions :

Probability distribution functions of rainfall may be calculated by using following three methods.

– Normal distribution
– Log-normal distribution (LND)
– Gumbel distribution
– Log-pearson type III.

Normal distribution :

For normal distribution, the frequency factor '*Kr*' can be expressed by following equation (Chow, 1988) :

$$K_T = \frac{x_t - \mu}{\sigma} \quad ....(2)$$

This is the same as the standard normal variate z. The value of z corresponding to an expedience of p (p=1/T) can be calculated by finding the value of anintermediate variable w :

$$w = \left[\left(\frac{1}{p^2}\right)\right]^{\frac{1}{2}}, \ (0 < p \le 0.50) \quad .....(3)$$

$$z = w - \left[\frac{2.515517 + 0.802853w + 0.010328w^2}{1 + 1.432788w + 0.189269w^2 + 0.001308w^3}\right] \quad .....(4)$$

When, p > 0.5, 1-p is substituted for p in equation (4) and the value of z is computed by equation (5) is given a negative sign (Bhakar *et al.*, 2006). The frequency factor *KT* for the normal distribution is equal to z, as mentioned above.

Log-normal distribution :

For Log-normal distribution, it is assumed that Y= ln X is normally distributed [the value of variate'X' (rainfall) is replaced by its natural logarithm]. The expected value of rainfall '*XT*', at return period T, can be obtained from the relation

$$XT = \exp\ (YT) \quad .....(5)$$

$$Y_T = \bar{Y}(1 + C_{VY}K_T) \quad .....(6)$$

where, 'Y' is the mean and 'Cvy' is the co-efficient of variation of and :

$$K_T = \frac{Y_t - \mu_y}{\sigma_y} \quad .....(7)$$

Table A : Probability distribution function by various distributions

Sr. No.	Distribution	Probability density function	Range	Equation for the parameters in terms of the sample moment
1.	Normal	$f(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{x-\pi}{\sigma}\right)^2}$	$-\infty < x < \infty$	$\mu = \bar{x},\ \sigma = S_x$
2.	Log-normal (y=in x)	$f(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{y-\pi_y}{\sigma y}\right)^2}$	$0 < x < \infty$	$\mu_y = \bar{y},\ \sigma_y = S_x$
3.	Gumbel	$f(x) = \frac{1}{\alpha}\exp \left[-\frac{x-y}{\alpha} - \exp\left(-\frac{x-\mu}{\alpha}\right)\right]$	$-\infty < x < \infty$	$\mu = \bar{x} + 0.5772\alpha,\ \alpha = \frac{S_x\sqrt{6}}{\pi}$
4.	Log pearson type III	$f(x) = \frac{1}{a_y(b)}\left(\frac{y-c}{a}\right) e^{-\frac{1}{2}\left(\frac{y-c}{a}\right)}$	$0 < x < \infty$	$\mu = \bar{x},\ \sigma = S_x$

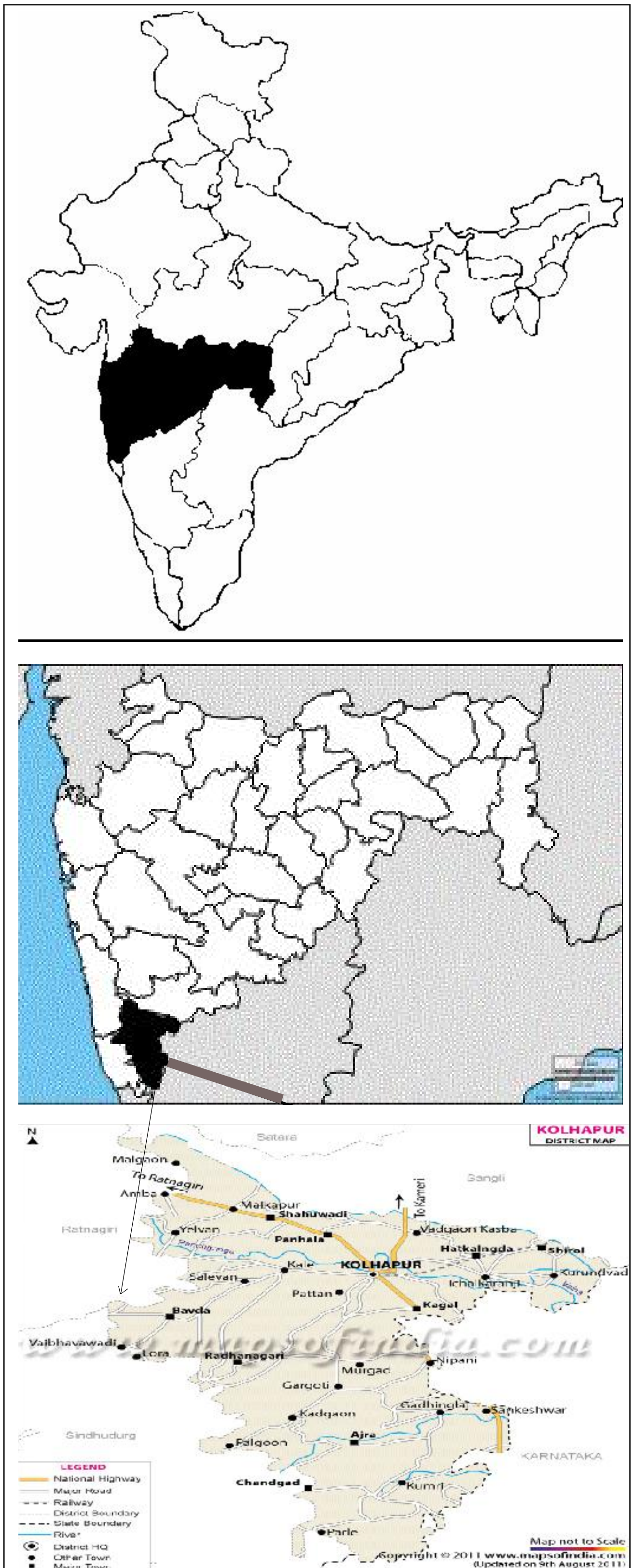

Fig. A : Location map of study area

The value of frequency factor '*KT*' can be computed using equation (6) or found from the standard normal distribution table.

Gumbel distribution :

In Gumbel distribution, the expected rainfall '*XT*' is computed by the following formula:

$$X_T = \bar{X}(1 + C_V K_T) \qquad .....(8)$$

where, X is mean of the observed rainfall, *CV* is the co-efficient of variation; *KT* - frequency factor which is calculated by the formula given by Gumbel (1958) as :

$$K_T = -\frac{\sqrt{6}}{\pi}\left\{0.5772 + \ln\left[\ln\left(\frac{T}{T-1}\right)\right]\right\} \qquad .....(9)$$

Following table shows three probability distributions functions, their range and Equation for the parameters in terms of the sample moment.

Log pearson type-III :

In Log Pearson type-III distribution, the value of variate 'X' (Rainfall) is transformed to logarithm (base 10). The expected value of rainfall 'X_T' can be obtained by the following formulae :

$$X_T = \text{Antilog } X \qquad .....(10)$$

And $\quad \text{Log } X = M + K_T SS \qquad .....(11)$

where, 'M' is the mean of logarithmic values of observed rainfall and 'S' is the standard deviation of these values. Frequency factor *KT* is taken from Benson (1968) corresponding to co-efficient of skewness (*Cs*) of transformed variate as :

$$K_T = \frac{2}{C_S}\left\{\left[\left(Z - \frac{C_S}{6}\right)\frac{C_S}{6} + 1\right]^3 - 1\right\} \qquad .....(12)$$

Testing the goodness of fit of probability distribution :

The expected values of maximum rainfall were calculated by four well known probability distributions, *viz.*, Normal, Log-normal, Log-pearson type III and Gumbel distribution at different selected probabilities *i.e.*, 99, 91, 82, 73, 64, 50, 45, 32, 18 and 5 per cent levels.Among these four distributions, the best fit distributions decided by Chi-square test for goodness of fit to observed values. The Chi-square test statistic is given by the equation :

$$x^2 = \sum_{i=1}^{k} \frac{(O_i - E_i)^2}{E_i} \qquad ....(13)$$

where, Oi is the observed rainfall and Ei is the expected rainfall and will have chi-square distribution with (N –k -1) degree of freedom (d.f.). The best probability distribution function was determined by comparing Chi-square values obtained from each distribution and selecting the function that gives smallest Chi-square value.

EXPERIMENTAL FINDINGS AND DISCUSSION

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

Daily, weekly and monthly rainfall data of Kolhapur region:

Rainfall analysis was carried out from year 1992-2012 in the Kolhapur region. From the analysis, it was observed that, the average annual rainfall from year 1992-2012 was found to be 1149.26 mm. Table 1 gives monthly total rainfall for Kolhapur region from Table 1 it was observed that, July month gives heaviest rainfall *i.e.* 6205 mm followed by October and other months. Minimum rainfall (2743.37 mm) was observed in the month of October.

Table 1 : Total monthly rainfall for Kolhapur region

Sr. No.	Month	Rainfall (mm)
1.	June	4472.74
2.	July	6205.50
3.	August	4742.90
4.	September	3000.50
5.	October	2743.37

Fig. 1 gives the relationship between total weekly rainfall and standard meteorological weeks (SMW) from Fig. 1, it was observed that 30th meteorological week gives maximum rainfall and 43rd meteorological week give minimum rainfall. The average total weekly rainfall was found to be 780.57 mm for the year 1992-2012.

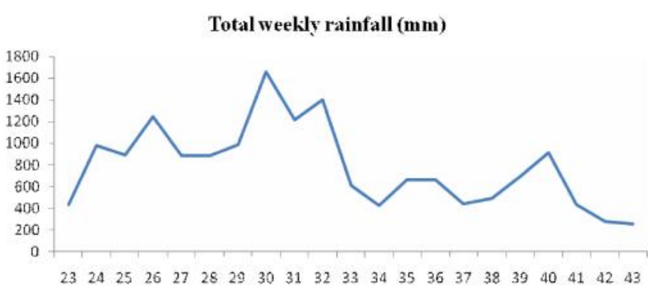

Fig. 1 : Total weekly rainfall for the year 1992-2012

Statistical parameter of the study area :

From Table 2 it was observed that, the average rainfall from 1992-2012 was found to be 84.53 mm and standard deviation of the given data was 48.91. Co-efficient of variation and co-efficient of skewness was found to be 0.58 and 0.254, respectively.

Table 2 : Computation of statistical parameters of annual one day maximum rainfall

Statistical parameter	Formula	Computed value
Average ($\bar{x}$)	$\bar{X} = \frac{1}{N}\sum_{i=1}^{N} X_i$	84.53
Standard deviation (σ)	$f(x) = \frac{1}{\sigma_y\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{y-\mu_y}{\sigma_y}\right)^2}$	48.91
Co-efficient of variation (C_v)	$C_v = \frac{\text{Standard deviation}}{\text{Mean}}$	0.58
Co-efficient of skew ness (Ck)	$f(x) = \frac{1}{\alpha}\exp\left[-\frac{x-\mu}{\alpha} - \exp\left(-\frac{x-\mu}{\alpha}\right)\right]$	0.254

Probability analysis by various methods :

One day maximum daily rainfall corresponding date for the period of 21 years (1992-2012) is presented in Table 3. From Table 3 it was observed that, the maximum (257.7 mm) and minimum (45 mm) annual one day maximum rainfall (ADMR) was recorded during the year 2005 and 2003, respectively. This indicates that the mostly fluctuations were observed during year 2003 and 2005. The average one day maximum rainfall for 21 years was found to be 84.53 mm. It was also observed that 08 years (38.09%) received one day maximum daily rainfall above the average.

Table 3 : One day maximum rainfall for the year 1992-2012

Sr. No.	Year	One day maximum rainfall (mm)
1.	1992	66
2.	1993	107.5
3.	1994	76.5
4.	1995	98.2
5.	1996	121.6
6.	1997	64
7.	1998	46.2
8.	1999	76.8
9.	2000	54.7
10.	2001	85.2
11.	2002	45.4
12.	2003	45
13	2004	65.4
14.	2005	257.7
15.	2006	90.6
16.	2007	160.8
17.	2008	57
18.	2009	85.8
19.	2010	66.5
20.	2011	54
21.	2012	50.2

From Fig. 2 it was observed that, no general trend in rainfall occurrence was observed during the study period from 1992-2012. The average, standard deviation, co-efficient of variation and skewness of ADMR for 21 years is given in Table 3. These practical parameters can be used to find the estimated one day maximum rainfall from different probability distribution functions.

The ADMR for the period of 21 years was plotted against return period in years which is calculated from Weibulls method and presented in Fig. 3. The trend analysis (Fig. 3) for prediction of one day maximum rainfall for different periods was carried out and it is found that the exponential trend line gives better co-efficient of determination $R^2 = 0.8709$ and the equation is $y = 36.627*e^{0.0662x}$ where, Y-ADMR, mm and X-Return period, Year.

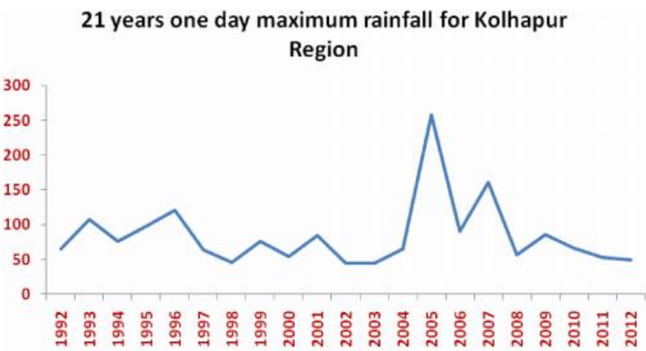

Fig. 2 : Relationship between 21 years one day maximum rainfall

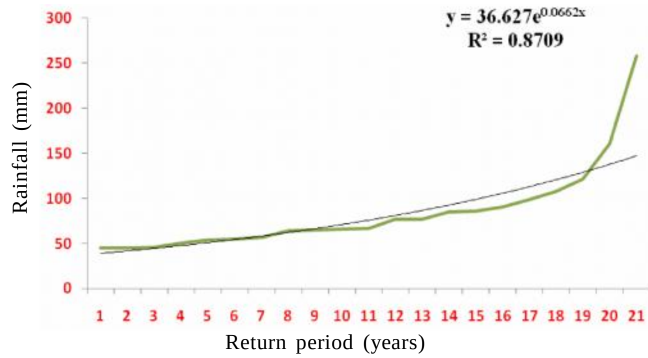

Fig. 3 : One day maximum rainfall with return period

Table 4 gives expected rainfall for various probability distribution functions. Observed rainfall for return periods of 1.05, 1.1, 1.22, 1.38, 1.57, 2, 2.2, 3.14, 5.5 and 22 year were

Table 4 : Observed and expected one day maximum rainfall at different probability

Sr. No.	Probability (%)	Return period (Years)	Observed rainfall (mm)	Expected rainfall for various probability distribution function			
				Normal	Log normal	Log pearson	Gumbel
1.	95	1.05	45	6.41	29.62	43.89	20.08
2.	91	1.1	45.4	21.31	34.52	46.98	29.18
3.	82	1.22	50.2	40.75	44.33	64.56	42.00
4.	73	1.38	54.7	55.18	52.66	67.76	52.83
5.	64	1.57	64	67.53	61.00	65.61	62.02
6.	50	2	66.5	84.53	73.25	69.61	76.50
7.	45	2.2	76.5	90.11	135.03	71.44	81.61
8.	32	3.14	85.8	107.68	131.89	70.79	99.07
9.	18	5.5	107.5	129.06	230.63	108.14	123.76
10.	5	22	257.7	167.43	177.19	174.18	179.49

Table 5 : Chi-square values at different probability levels for different distributions

Sr. No.	Probability	Return period (years)	Normal	Log normal	Log pearson	Gumbel
1.	95	1.05	232.32	7.99	0.03	30.94
2.	91	1.1	27.23	3.43	0.05	9.02
3.	82	1.22	2.19	0.78	3.19	1.60
4.	73	1.38	0.00	0.08	2.52	0.07
5.	64	1.57	0.18	0.15	0.04	0.06
6.	50	2	3.85	0.62	0.14	1.31
7.	45	2.2	2.06	25.37	0.36	0.32
8.	32	3.14	4.45	16.11	3.18	1.78
9.	18	5.5	3.60	65.74	0.00	2.14
10.	5	22	48.67	36.58	40.05	34.08
		324.55		156.83	49.56	81.30

found and presented in Table 4. For different return periods the expected ADMR for different probability distributions such as Normal, Log-normal, Log- pearson type III and Gumbel were calculated and presented in Table 4. From Table 4 it was observed that all distributions give same trend with respect to observed rainfall and for one day maximum rainfall Normal distribution was not fitted well so it was not taken for comparison.

The expected ADMR for different probabilities are graphically represented in Fig. 4. From the Fig. 4 it was observed that the estimated annual ADMR for different probability distributions are following the same trend of observed rainfall. All four probability distribution functions were compared by Chi-square test of goodness of fit and the selecting the function that gave the smallest Chi-Square value determined the best probability distribution functions.

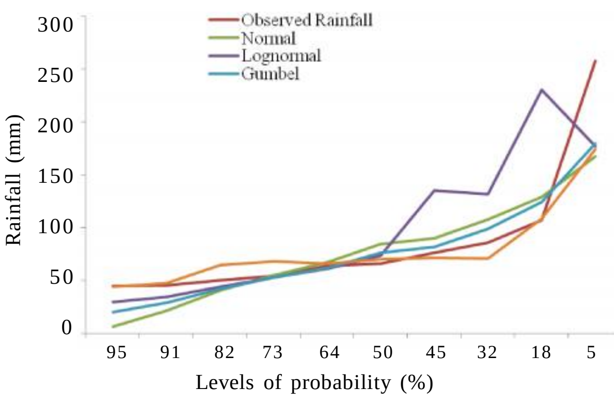

Fig. 4 : Observed and expected rainfall for various probability distribution functions

Table 5 shows the Chi-square values for log-normal, log-pearson type-III and gumbel distributions. From Table 4 it was observed that, the sum of Chi- square were 324.55, 156.83, 49.56 and 81.30 for normal, log-normal, log-pearson type-III and gumbel distributions, respectively. Log-pearson type-III distribution gave the lowest calculated Chi-square among the three probability distribution.

Hence, Log-pearson tripe-III has been found best probability distribution for predicting ADMR for Kolhapur region of Maharashtra. According to this distribution, in a day minimum rainfall of 43.89 mm rainfall can be expected to occur with 99 per cent probability and one year return period and maximum of 174.18 mm rainfall can be received with 1 per cent probability and 100 year return period. A maximum of 71.44 mm rainfall expected to occur at every 2 year which is approaching nearly to the average ADMR. It is generally recommended that 2 to 100 years is sufficient return period for soil and water conservation measures, construction of dams, irrigation and drainage works etc. (Bhakar*et al.*, 2006).

From the above analysis it was concluded that, Log-pearson type III distribution was found to be good for probability distribution of rainfallin the Kolhapur region.Similar work related to the topic was also done by Busari *et al*. (2013); Duan *et al.* (1998); Gamage *et al.* (2013); Kumar *et al.* (2000); Singh *et al*. (2012); Upadhaya and Singh (1998).

Conclusion :

– Average annual rainfall from year 1992-2012 was found to be 1149.26 mm.
– The average total monthly rainfall was found to be 780.57 mm.
– From the above analysis it was concluded that, Log-pearson type III distribution was found to be good for probability distribution of rainfall in the Kolhapur region.

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