Rainfall probability analysis for crop planning in Sambalpur district of Odisha, India

Abstract

This study was undertaken in the U.G. thesis work in the Dept. Of SWCE, CAET, OUAT, Bhubaneswar during the year 2018-19. Sambalpur district has a geographical area of 6702 sq.km. Sambalpur district has latitude of 21° 28’ 5.4660” N and longitude of 83° 58’ 31.4508” E. The average rainfall at Sambalpur district is around 1377.9 mm, though it receives high amount rainfall but most of the rainfall occurred during kharif. So most of the crops get low yield due to improper crop planning. Thus this study is proposed to be undertaken with the following objective: Probability analysis of annual, seasonal and monthly rainfall data of Sambalpur district. So rainfall data were collected from OUAT, Agril Meteorology Dept. from 2001 to 2017(17 years) monthly, seasonal and annual rainfall were analyzed. Probability analysis has been made and equations were fitted to different distributions and best fitted equations were tested. Monthly, Annual and seasonal probability analysis of rainfall data shows the probability rainfall distribution of Sambalpur district in different months, years and seasons. It is observed that rainfall during June to Sep is slightly less than 1000 mm and cropping pattern like paddy(110 days) may be followed by mustard is suitable to this region. Also if the kharif rain can be harvested and it can be reused for another rabi crop by using sprinkler or drip irrigation, which will give benefit to the farmers. Annual rainfall of Sambalpur district is 1377.9 mm at 50% probability level. 

Keywords: rainfall, probability analysis, crop planning

Sambalpur district has a geographical area of 6702 sq.km. Sambalpur district has latitude of 21° 28’ 5.4660” N and longitude of 83° 58’ 31.4508” E. The average rainfall at Sambalpur district is 1377.9 mm, most of the rainfall occurred during kharif. Thus, this study is proposed to be undertaken with the following objective: Probability analysis of annual, seasonal and monthly rainfall data of Sambalpur district. 

Thom1 employed mixed gamma probability distribution for describing skewed rainfall data and employed approximate solution to non-linear equations obtained by differentiating log likelihood function with respect to the parameters of the distribution. Subsequently, this methodology along with variance ratio test as a goodness-of-fit has been widely employed Kar et al.,2 Jat et al.,3 Senapati et al.,4 and Subudhi et al.,4 applied incomplete gamma probability distribution for rainfall analysis. In additional to gamma probability distribution, other two-parameter probability distributions (normal, log-normal, Weibull, smallest and largest extreme value), and three-parameter probability distributions (log-normal, gamma, log-logistic and Weibull) have been widely used for studying flood frequency, drought analysis and rainfall probability analysis.

Gumbel6 Chow.,7 have applied gamma distribution with two and three parameter, Pearson type-III, extreme value, binomial and Poisson distribution to hydrological data.

Sachan S et al.,8 attempted probability analysis using the rainfall data of 30 years(1976-2005) in various influencing rain gauge stations viz., Damoh, Hatta, Jabera, and Deori falling in Bearnar basin of Bundelkhand region, MadhyaPradesh.

Gumbel,9 Hershfield & Kohlar,9 have applied gamma distribution with two and three parameter, Pearson type-III, extreme value, binomial and Poisson distribution to hydrological data.

Materials and methods

The data were collected from District Collector’s Office, Gajapati district for this study. Rainfall data for 17 years from 2001 to 2017 are collected for the present study to make rainfall forecasting using different methods.

Probability distribution functions

For seasonal rainfall analysis of Gajapati district, three seasons -kharif (June-September), rabi (October to January) and summer (February to May) are considered. The data is fed into the Excel spreadsheet, where it is arranged in a chronological order and the Weibull plotting position formula is then applied. The Weibull plotting position formula is given by

\[ \frac{m}{N+1} \]

where \( m = \) rank number

\( N = \) number of years

The recurrence interval is given by

\[ T = \frac{1}{p} = \frac{N + 1}{m} \]

The values are then subjected to various probability distribution functions namely- normal, log-normal (2-parameter), log-normal (3-parameter), gamma, generalized extreme value, Weibull, generalized Pareto distribution, Pearson, log-Pearson type-III and Gumbel distribution. Some of the probability distribution functions are described as follows:
**Normal distribution**

The probability density is

\[ p(x) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{-\frac{(x-\mu)^2}{2\sigma^2}} \]

where \( x \) is the variate, \( \mu \) is the mean value of variate and \( \sigma \) is the standard deviation. In this distribution, the mean, mode and median are the same. The cumulative probability of a value being equal to or less than \( x \) is

\[ p(x \leq x) = \frac{1}{\sqrt{2\pi}\sigma^2} \int_{-\infty}^{x} e^{-\frac{(x-\mu)^2}{2\sigma^2}} \, dx \]

This represents the area under the curve between \(-\infty\) and \( x \).

**Log-normal (2-parameter) distribution**

The probability density is

\[ p(x) = \frac{1}{\sigma e^{\frac{y^2}{2}} \sqrt{2\pi}} e^{-\frac{(\ln x - \mu)^2}{2\sigma^2}} \]

where \( x = e^y \), where \( y \) is the variate, \( \mu \) is the mean of \( y \) and \( \sigma \) is the standard deviation of \( y \).

**Log-normal (3-parameter) distribution**

A random variable \( X \) is said to have three-parameter log-normal probability distribution if its probability density function (pdf) is given by:

\[ f(x) = \begin{cases} \frac{1}{(x-\lambda)\sigma \sqrt{2\pi}} e^{-\frac{(\ln(x-\lambda)-\mu)^2}{2\sigma^2}}, & \text{if } x > \lambda \\ 0, & \text{otherwise} \end{cases} \]

where \( \mu, \sigma \) and \( \lambda \) are known as location, scale and threshold parameters, respectively.

**Pearson distribution**

The general and basic equation to define the probability density of a Pearson distribution

\[ p(x) = e^{\frac{a + x}{b_0 + b_1 x + b_2 x^2}} dx \]

where \( a, b_0, b_1 \) and \( b_2 \) are constants.

The criteria for determining types of distribution are \( \beta_1, \beta_2 \) and \( k \) where

\[ \begin{align*} 
\beta_1 & = \frac{\mu^2}{\mu_2} \\
\beta_2 & = \frac{\mu_4}{\mu_2} \\
k & = \frac{\beta_1 (\beta_2 + 3)}{4(4\beta_2 - 3\beta_1)(2\beta_2 - 3\beta_1 - 6)}
\end{align*} \]

Where \( \mu_2, \mu_3 \) and \( \mu_4 \) are second, third and fourth moments about the mean.

**Log-Pearson type III distribution**

In this the variate is first transformed into logarithmic form (base 10) and the transformed data is then analyzed. If \( X \) is the variate of a random hydrologic series, then the series of \( Z \) variates where

\[ z = \log x \]

are first obtained. For this \( z \) series, for any recurrence interval \( T \) and the coefficient of skew \( C_z \),

\[ \sigma_z = \text{standard deviation of the } Z \text{ variate sample} \]

\[ = \sqrt{\sum(z - \bar{z})^2 / (N-1)} \]

And \( C_z = \text{coefficient of skew of variate } Z \)

\[ = \frac{N \sum(z - \bar{z})^3}{(N-1)(N-2)\sigma_z^3} \]

\( \bar{z} = \text{mean of } z \) values

\( N = \text{sample size } = \text{number of years of record} \)

**Generalized pareto distribution**

The family of generalized Pareto distributions (GPD) has three parameters \( \mu, \sigma \) and \( \xi \).

The cumulative distribution function is

\[ F_{\xi,\mu,\sigma}(x) = \begin{cases} 1 - \left(1 + \frac{\xi(x-\mu)}{\sigma}\right)^{-\frac{1}{\xi}}, & \text{for } \xi \neq 0 \\ 1 - \exp\left(-\frac{x-\mu}{\sigma}\right), & \text{for } \xi = 0 \end{cases} \]

for \( x \geq \mu \) when \( \xi \geq 0 \) and \( x \leq \mu - \frac{\sigma}{\xi} \) when \( \xi < 0 \), where \( \mu \in \mathbb{R} \) is the location parameter, \( \sigma > 0 \) the scale parameter and \( \xi \in \mathbb{R} \) the shape parameter.

The probability density function is

\[ f_{\xi,\mu,\sigma}(x) = \begin{cases} \frac{1}{\sigma} \left(1 + \frac{\xi(x-\mu)}{\sigma}\right)^{-\frac{1}{\xi}}, & \text{for } \xi \neq 0 \\ \frac{1}{\sigma}, & \text{for } \xi = 0 \end{cases} \]

Or

\[ f_{\xi,\mu,\sigma}(x) = \frac{1}{\sigma + \xi(x-\mu)} \cdot \frac{1}{\frac{1}{\xi}} \]

again, for \( x \geq \mu \), and \( x \leq \mu - \frac{\sigma}{\xi} \) when \( \xi < 0 \)

**Generalized extreme value distribution**

Generalized extreme value distribution has cumulative distribution function

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The extreme value distribution was introduced by Gumbel (1941) and is commonly known as Gumbel’s distribution. It is one of the most widely used probability-distribution functions for extreme values in hydrologic and meteorological studies. According to this theory of extreme events, the probability of occurrence of an event equal to or larger than a value \( x_0 \), in which \( y \) is a dimensionless variable and is given by

\[
 y = \frac{a}{\bar{x}} - 0.45005 \sigma_x
\]

Thus

\[
 y = \frac{1.2825(\bar{x} - x)}{\sigma_x} + 0.577 \quad \ldots \ldots \ldots \ldots \ldots (i)
\]

where \( \bar{x} \) = mean and \( \sigma_x \) = standard deviation of the variate \( X \).

### Result and discussion

The various parameters like mean, standard deviation, RMSE value were obtained and noted for different distributions. The rainfall at 90\%, 75\%, 50\%, 25\% and 10\% probability levels are determined. The distribution “best” fitted to the data is noted down in a tabulated form in Table 1.

| Months    | Best-fit Distribution | RMSE Value | Rainfall at probability levels |
|-----------|-----------------------|------------|-------------------------------|
|           |                       |            | 90%  | 75%  | 50%  | 25%  | 10%  |
| January   | EV type III           | 0.06126    | -    | -    | 2.17 | 17.48| 34.45|
| February  | Log Pearson           | 0.03782    | -    | -    | 3.35 | 14.19| 40.33|
| March     | GEV                   | 0.0752     | -    | -    | -    | 11.46| 26.87|
| April     | Pareto                | 0.05627    | -    | -    | 4.76 | 19.85| 36.06|
| May       | Log Pearson           | 0.03945    | -    | 4.68 | 12.99| 28.42| 55.89|
| June      | Pareto                | 0.04644    | 77.20 | 107.93| 170.47| 261.13| 355.21|
| July      | Log Pearson           | 0.04237    | 289.08| 347.71| 420.13| 499.62| 576.5|
| August    | Weibull               | 0.08646    | 199.83| 298.53| 424.23| 559.63| 685.42|
| September | Weibull               | 0.05028    | 67.40 | 124.84| 214.14| 327.67| 447.36|
| October   | Exponential           | 0.07427    | 3.58  | 18.17 | 50.64 | 106.13| 179.5|
| November  | Gamma                 | -          | -    | -    | 1.93 | 29.18|       |
| December  | Pearson               | 0.08093    | -    | -    | -    | 12.59| 39.38|
In the present study, the parameters of distribution for the different distributions have been estimated by FLOOD frequency analysis software. The rainfall data is the input to the software programme. The best fitted distribution of different month and seasons and annual were presented in Table 1. The annual rainfall in 50% probability was found to be 1377.9 mm for Sambalpur block of Odisha. During Kharif at 50% probability level, the rainfall is 1250.4 mm whereas only 72.7 mm and 54.7 mm was received during rabi and summer respectively.

In the present study, the parameters of distribution for the different distributions have been estimated by FLOOD-flood frequency analysis software. The rainfall data is the input to the software programme. The best fitted distribution of different month and season and annual were presented in Table 6. The annual rainfall in 50% probability was found to be 1377.9 mm for Sambalpur district of Odisha. During Kharif at 50% probability level, the rainfall is 1250.4 mm whereas only 72.7 mm and 54.7 mm was received during rabi and summer respectively.

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Figure 1 Rainfall at different probabilities of monthly, seasonal and annual at Sambalpur block.

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Conclusion

Forecasting of rainfall is essential for proper planning of crop production. About 70% of cultivable land of Odisha depends on rainfall for crop production. Prediction of rainfall in advance helps to accomplish the agricultural operations in time. It can be concluded that, excess runoff should be harvested for irrigating post-monsoon crops. It becomes highly necessary to provide the farmers with high-yielding variety of crops and such varieties which require less water and are early-maturing in Sambalpur district of Mahanadi command area of Odisha. It is also observed that at 75% probability level the June, July, Aug and Sept received more than 100 mm, so farmers of these area can grow crops in upland areas suitably paddy can be grown followed by any rabi crop in rabi season like mustard or kulthi in upland areas. Annual rainfall of Sambalpur district is 1377.9 mm at 50% probability level. It is observed that September month gets highest amount of rainfall compared to other months. Different cropping pattern selected may be may be practiced in this district.

Acknowledgments

None.

Conflicts of interest

None.

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