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***Research Paper***

# Estimation of minimum assured rainfall using probability of exceedance: A suitable approach for planning rainfed rice

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**ABSTRACT**

Rainfall is one of the most important components of agricultural productivity as it forms the basis of rural livelihoods and food security. In rainfed agricultural regions, where irrigation infrastructure is limited, the rainfall variability directly influences planting schedules, crop growth stages, and yield outcomes. The study presents a systematic approach for estimating minimum assured rainfall using the probability of exceedance (P) by analyzing 50 years (1973-2022) of weekly rainfall data from three Agro-climatic zones of West Bengal: Undulating Red and Laterite Zone, Gangetic Alluvial Zone, and Terai-Teesta Alluvial Zone. Using the CumFreq software, various probability distributions were fitted to historical rainfall data corresponding to the Standard Meteorological Weeks (SMW) 20 to 41. The best-fit models, primarily Generalized Laplace, Generalized Extreme Value (GEV), and Generalized Normal were used to estimate weekly rainfall at 25%, 50%, 75%, and 90% exceedance probabilities. The 75% probability level, representing assured rainfall, was used as a threshold to determine the number of rainy days and guide varietal recommendations for rice cultivation. Results revealed significant variability in rainfall patterns across zones, with notable implications for selecting suitable rice varieties. The findings provide a probabilistic framework to inform agricultural planning and risk mitigation strategies, especially under increasing climate variability in rainfed ecosystems.

***Keywords:*** Rainfall; Exceedance probability; Crop planning; Minimum assured rainfall; West Bengal

Rainfall is a critical factor influencing agricultural productivity, particularly in rainfed regions where crop yields depend heavily on precipitation patterns. In these areas, the timing, intensity, and distribution of rainfall can significantly affect soil moisture levels, planting schedules, and crop growth stages, making effective crop planning a challenge. In addition to average rainfall, understanding rainfall variability and distribution in a given area holds significant, specific and practical importance especially in the field of agriculture and hydrology (Singh and Mulye, 1991). Accurately estimating rainfall probabilities is therefore essential for developing strategies that mitigate the risks associated with erratic weather conditions. Understanding the underlying processes describing the rainfall pattern, distribution and availability in a region is the first step before planning further (Mishra *et al.,* 2013).

Panigrahi and Panda (2021) showed that probability analysis of rainfall offered a better scope for predicting minimum assured rainfall, which is crucial for crop planning in rainfed regions. Exceedance probability is a statistical tool used to determine the chance of rainfall exceeding a specific amount during a timeframe. In relation to agriculture, a method like this can provide farmers with information regarding the frequency at which certain amounts of rainfall are expected or exceeded, and help forecast the conditions required for crop growth. Rainfall distribution typically exhibits a skewed pattern, which can be categorized as advanced, intermediate, delayed or uniform types. To effectively characterize this non-Gaussian rainfall data, probability distributions are commonly utilized (Sharda and Das, 2005). Exceedance probability estimates are particularly valuable in the region with high rainfall variability, as they offer a probabilistic view of precipitation patterns, supporting more informed decision-making around planting dates, crop selection, and water resource management. Utilizing exceedance probabilities in rainfall estimation allows us to make strategic responses for assumed rainfall levels (Sridhara *et al.,* 2016; Manivannan *et al.,* 2016; Sheoran *et al.,* 2008).

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**Table 1:** The probability density functions (PDFs) and parameters of the distributions utilized in the study

| Sl. No. | Distribution | Probability density function | Parameters |
|---|---|---|---|
| 1 | Root-normal | $f(x)=\frac{1}{2\sigma\sqrt{2\pi}}\left\|\frac{1}{\sqrt{x}}\right\|e^{-\frac{1}{2\sigma^2}(\sqrt{x}-\mu)^2}$, $\sqrt{x}\in(-\infty,+\infty)$ | $\mu$ ,$\sigma$ |
| 2 | Log- normal | $f(x)=\frac{1}{x\sigma\sqrt{2\pi}}e^{-\frac{(\ln x-\mu)^2}{2\sigma^2}}, x\ \in(0,+\infty)$ | $\mu$ ,$\sigma$ |
| 3 | Generalized normal | $f(x)=\frac{\beta}{2\alpha\Gamma\left(\frac{1}{\beta}\right)}e^{-\left(\frac{\|x-\mu\|}{\alpha}\right)^{\beta}}$ | $\alpha>0$ (scale), β>0 (shape), μ= location |
| 4 | General extreme value (GEV) | $f(x)=\frac{1}{\sigma}t(x)^{k+1}e^{-t(x)}$, $where\ t(x)$ $=\begin{cases}\left[1+k\left(\frac{x-\mu}{\sigma}\right)\right]^{-\frac{1}{k}} & if\ k\neq 0,\\ exp\left(-\frac{x-\mu}{\sigma}\right) & if\ k=0\end{cases}$ | $k$= Shape, $\mu$= location, $\sigma>0$ (scale) |
| 5 | Generalized Gumbel | $f(x)=\frac{k}{\sigma}e^{-(\frac{x-\mu}{\sigma})^k}e^{-e^{-(\frac{x-\mu}{\sigma})^k}}$ | $k$= Shape, $\mu$= location, $\sigma>0$ (scale) |
| 6 | Weibull | $f(x)=\begin{cases}\frac{k}{\lambda}\left(\frac{x}{\lambda}\right)^{k-1}e^{-\left(\frac{x}{\lambda}\right)^k}, & x\geq 0\\ 0, & x<0\end{cases}$ | $k>0$ (shape) $\lambda>0$ (scale) |
| 7 | Generalized logistic | $f(x)=\frac{\beta e^{-z}}{\alpha(1+e^{-z})^{\beta+1}}, z=\frac{x-\mu}{\alpha}$ | $\alpha>0$ (scale), $\beta>0$ (shape), $\mu>0$ (location) |
| 8 | Log-logistic | $f(x;\ \alpha,\beta)=\frac{\left(\frac{\beta}{\alpha}\right)\left(\frac{x}{\alpha}\right)^{\beta-1}}{\left(1+\left(\frac{x}{\alpha}\right)^{\beta}\right)^2}$ | $\alpha>0$ (scale), $\beta>0$ (shape) |
| 9 | Generalized Laplace | $f(x;m,\lambda,k)=\frac{\lambda}{k+\frac{1}{k}}\begin{cases}e^{\left(\frac{\lambda}{k}\right)(x-m)}, & x<m\\ e^{-\lambda k(x-m)}, & x\geq m\end{cases}$ | $\lambda>0$ (scale) $k$ (asymmetry parameter) (Location parameter) |

This study, therefore employs exceedance probabilities to estimate rainfall amounts to aid crop planning. By offering a framework that incorporates the probabilistic nature of rainfall, this research provides a practical tool to help farmers optimize agricultural productivity, even in the face of climate-induced rainfall variability. A strong understanding of rainfall dynamics and the probabilistic estimation of minimum assured rainfall become essential tools for effective crop planning and risk mitigation.

## MATERIALS AND METHODS

### *Study area*

Three Agro-climatic zones of West Bengal were selected for the study using purposive sampling, namely: (i) Undulating Red and Laterite Zone - comprising Bankura and Puruliya districts, (ii) Gangetic Alluvial Zone - comprising Hooghly and Nadia districts and (iii) Terai-Teesta Alluvial Zone - comprising Jalpaiguri, Cooch Behar districts. These zones were chosen based on the distinct geographical and climate characteristics, which play an important role in determining rainfall behaviour and its effects on rice cultivation.

Fifty years of weekly rainfall data (1973-2022) was procured from IMD, Pune and India Water Resources Information System, National Water Informatics Centre ( https://indiawris.gov.in/wris ). The analysis was carried out using CumFreq, a specialized software designed for frequency analysis (Oosterbaan, 2019).

### *Probability of exceedance and distribution fitting*

Understanding the expected rainfall amounts during specific periods under varying weather conditions is essential for effective crop planning. In this study, weekly rainfall data

**Table 2:** Distributions fitted in weekly rainfall for districts under study

| SMW | Bankura | Puruliya | Hooghly | Nadia | Jalpaiguri | Cooch Behar |
|---|---|---|---|---|---|---|
| 20 | Gen. Laplace | Gen. Laplace | Gen. Normal | Gen. Normal | GEV | Gen. Laplace |
| 21 | Gen. Laplace | Gen. Laplace | Gen. Laplace | Gen. Laplace | Root Normal | Gen. Normal |
| 22 | Root-Normal | Root-Normal | Gen. Laplace | Gen. Laplace | Gen. Laplace | GEV |
| 23 | Log logistic | Root-Normal | Gen. Laplace | Gen. Laplace | GEV | Gen. Laplace |
| 24 | Gen. Laplace | Gen. Laplace | Gen. Normal | Gen. Normal | GEV | Gen. Laplace |
| 25 | Log normal | Gen. Laplace | Gen. Normal | Gen. Laplace | Weibull | Gen. Logistic |
| 26 | Gen. Gumbel | Log Normal | Weibull | Gen. Logistic | Gen. Gumbel | Gen. Normal |
| 27 | Gen. Laplace | Gen. Laplace | Gen. Normal | GEV | Gen. Logistic | Gen. Normal |
| 28 | GEV | Gen. Gumbel | Root Normal | Gen. Gumbel | Gen. Laplace | Gen. Gumbel |
| 29 | Gen. Laplace | Logistic | Gen. Normal | Log Normal | Root Normal | Gen. Normal |
| 30 | Log normal | Gen. Laplace | Log Normal | Log Normal | GEV | Log Normal |
| 31 | Gen. Gumbel | GEV | Gen. Normal | Gen. Laplace | Log Normal | Log Logistic |
| 32 | Gen. Normal | Gen. Normal | Gen. Normal | GEV | GEV | GEV |
| 33 | GEV | GEV | Gen. Normal | Gen. Gumbel | Log Normal | Log Normal |
| 34 | Weibull | Gen. logistic | Weibull | Gen. Laplace | Gen. Gumbel | Weibull |
| 35 | GEV | Gen. Laplace | Gen. Normal | Gen. Laplace | Weibull | Log Logistic |
| 36 | GEV | GEV | GEV | Log Normal | Gen. Normal | Gen. Gumbel |
| 37 | Gen. Gumbel | Gen. Normal | Log Normal | GEV | GEV | Gen. Logistic |
| 38 | Gen. Normal | Gen. Normal | GEV | GEV | Gen. Laplace | GEV |
| 39 | Gen. Normal | Gen. Laplace | Gen. Laplace | Gen. Laplace | Gen. Gumbel | GEV |
| 40 | Gen. logistic | Gen. Gumbel | Gen. Normal | Gen. Laplace | Gen. Laplace | Gen. Gumbel |
| 41 | Gen. Laplace | Gen. Normal | Gen. Laplace | Gen. Laplace | Gen. Laplace | Gen. Logistic |

corresponding to the Standard Meteorological Weeks (SMW) 20 to 41 which typically represent the active monsoon period, were analyzed to estimate the probability of exceedance (P). This analysis was conducted to determine the minimum assured rainfall using suitable probability distribution models, thereby aiding in strategic agricultural decision-making.

The weekly rainfall data was arranged in descending order based on rainfall magnitudes. Each rainfall value was assigned a rank, denoted by *M*, such that the highest rainfall receives rank 1, the second highest receive rank 2, and so on, up to the last record. The total number of records is represented by *N*. The probability of exceedance for each rainfall value was calculated using the Weibull (1939) formula:

$$P = \frac{M}{N+1} \times 100$$

Where, *M* = rank number, *N* = total number of rainfall records

The probability distributions were fitted to the rainfall data using probability analysis to model the relationship between weekly rainfall amounts and their corresponding exceedance probabilities. Various probability distributions used for estimating minimum assured rainfall are summarized in Table 1 (Dingens and Steyaert, 1971; Sharif and Islam, 1980; Varanasi and Aazhang, 1989; Srivastava *et al.,* 2006; Cooray, 2010; Abdelfattah, 2015; Pradhan *et al.,* 2024). The probability distribution fitting and analysis were conducted using a specialized frequency analysis software known as CumFreq, which facilitates accurate estimation of rainfall values at specific probability levels. The weekly rainfall amounts corresponding to specific exceedance probabilities namely, 90% (P90), 75% (P75), 50% (P50), and 25% (P25) were estimated. These values represent the minimum assured rainfall that can be expected or exceeded in a given year.

## RESULTS AND DISCUSSION

Exceedance probabilities were plotted with weekly rainfall and appropriate probability distributions were fitted based on the average absolute differences between observed and calculated values, as presented in Table 2. By fitting weekly rainfall data to various probability distributions across different districts, the study identifies the Generalized Laplace, Generalized Extreme Value (GEV), and Generalized Normal distributions as the most frequently suitable models. These models allow for precise estimation of minimum assured rainfall at various exceedance levels (25%, 50%, 75%, and 90%), aiding in strategic crop planning

The minimum assured rainfall was estimated for each district at different levels of probabilities of exceedance. The rainfall values obtained at 25%, 50%, 75% and 90% probability were plotted against standard meteorological week (SMW) (Fig. 1). The 25% probability of exceedance (P25) indicates that there is a 25 percent chance that actual rainfall will exceed this amount in a given week. This represents higher rainfall levels and is useful for assessing the potential for heavy rainfall or flood risks. Similarly, P50 is often referred to as the median rainfall and reflects the typical or average condition for planning normal cropping practices. P75 is considered as reliable assured rainfall level, especially useful for planning rainfed agriculture while P90 reflects the minimum assured rainfall, occurring in nine out of ten years, and is critical for

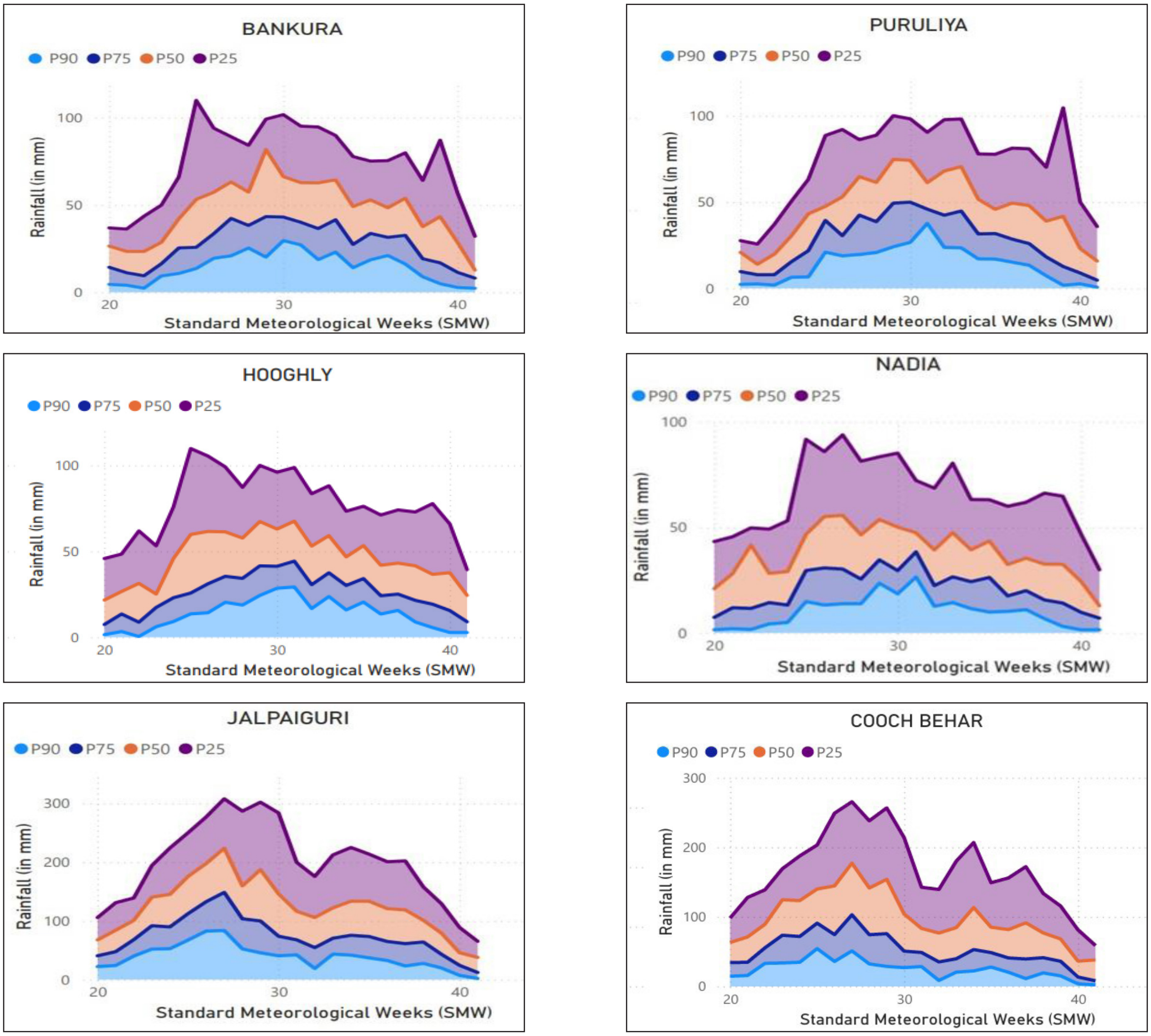


**Fig. 1:** Estimated minimum assured rainfall for different districts at 25% (P25), 50% (P50), 75% (P75) and 90% (P90) probabilities

risk-averse planning, especially in dry years. Bhelawe *et al.,* (2015), Subudhi *et al.,* (2019) and Manna (2023) discussed the significance of these probabilities in agricultural contexts.

The 75% exceedance level was identified as the most agriculturally relevant, aligning with the concept of risk-averse decision-making in rainfed agriculture, where farmers prioritized reliability over average outcomes. The rainfall probabilities for each region, calculated at 75% exceedance level, are summarized in Table 3. These values provide an essential benchmark for understanding regional rainfall patterns and their potential impact on crop growth.

The number of days with minimum assured rainfall was computed by analyzing weekly rainfall data. This was done by first identifying the weeks where total rainfall exceeded the threshold value corresponding to the 75% probability of exceedance. The total number of such weeks was converted into an equivalent number of rainy days, assuming a standard meteorological week contains 7 or 8 days. This approach guarantees a thorough and consistent evaluation of the duration of rainfall availability above the assured threshold, which is important for agricultural planning and water resource management. Suitable rice varieties with their characteristics were suggested according to the number of rainy days of each region in Table 4. In districts like Bankura and Puruliya in the Undulating Red and Laterite Zone, short duration varieties such as Aditya (IET-7613) which grow under scarce rainfall conditions were recommended for cultivation. Rainfed varieties with medium duration such as CR Dhan 801 were recommended for the districts in the Gangetic Alluvial Zone. Meanwhile, districts in the Terai-Teesta Alluvial Zone, such as Jalpaiguri and Cooch Behar, were recommended long duration rice varieties like Jalprabha (IET-11896) as a result of the region receiving prolonged rainfall.

## CONCLUSION

This study successfully demonstrated the utility of exceedance probability analysis for estimating minimum assured rainfall across three major Agro-climatic zones of West Bengal. By

**Table 3:** Weekly threshold rainfall values (mm) at 75% probability of exceedance for each district

| SMW | Bankura | Puruliya | Hooghly | Nadia | Jalpaiguri | Cooch Behar |
|---|---|---|---|---|---|---|
| 20 | 14.3 | 9.7 | 7.4 | 7.4 | 40.7 | 34.2 |
| 21 | 11.2 | 7.9 | 11.9 | 13.5 | 47.7 | 34.6 |
| 22 | 9.5 | 7.9 | 11.6 | 8.8 | 68.1 | 55.4 |
| 23 | 16.4 | 15.5 | 14.4 | 17.4 | 91.9 | 73.5 |
| 24 | 25.4 | 21.9 | 23.2 | 23.0 | 89.8 | 71.7 |
| 25 | 25.7 | 39.4 | 29.6 | 25.7 | 112.4 | 90.8 |
| 26 | 33.5 | 30.5 | 30.8 | 31.1 | 132.7 | 74.4 |
| 27 | 42.3 | 42.5 | 30.27 | 35.5 | 148.6 | 103.0 |
| 28 | 38.3 | 38.6 | 25.5 | 34.3 | 103.7 | 74.2 |
| 29 | 43.3 | 49.4 | 34.6 | 41.6 | 100.0 | 75.8 |
| 30 | 43.1 | 49.9 | 29.5 | 41.3 | 74.0 | 50.6 |
| 31 | 40.1 | 45.91 | 38.4 | 44.3 | 67.9 | 48.7 |
| 32 | 36.5 | 42.4 | 22.4 | 30.6 | 54.6 | 35.1 |
| 33 | 41.5 | 44.8 | 26.6 | 37.5 | 70.5 | 39.7 |
| 34 | 27.4 | 31.6 | 24.3 | 30.1 | 75.6 | 52.9 |
| 35 | 33.7 | 31.8 | 26.3 | 34.2 | 73.5 | 48.5 |
| 36 | 31.5 | 28.5 | 27.5 | 24.2 | 65.1 | 40.8 |
| 37 | 32.6 | 25.9 | 30.0 | 25.1 | 61.4 | 39.4 |
| 38 | 19.2 | 18.3 | 25.7 | 21.5 | 64.2 | 41.2 |
| 39 | 16.9 | 12.7 | 24.2 | 20.3 | 43.2 | 36.1 |
| 40 | 11.4 | 8.94 | 9.8 | 15.6 | 24.4 | 13.4 |
| 41 | 8.1 | 4.8 | 7.0 | 9.0 | 12.3 | 8.0 |

**Table 4:** Recommended rice varieties, their duration and ecosystem of the concerned Agro- climatic zones

| Agro-climatic zone | District | Number of days with minimum assured rainfall (days) | Rice varieties suggested | Characteristics of the varieties | Ecosystem |
|---|---|---|---|---|---|
| Undulating red & laterite zone | Bankura<br>Puruliya | 80-85 | Aditya (IET-7613) | Crop duration: 90-95 days, semi dwarf (90 cm), grains: long and bold, yield: 33-40 q $ha^{-1}$ | Rainfed (recommended for areas with scarce rainfall) |
| Gangetic alluvial zone | Hooghly<br>Nadia | 100-120 | CR Dhan 801 (IET 25667) | Crop duration: 140 days, semi-dwarf (87 cm), grains: short and bold, white, yield: 44.62-48.55 q $ha^{-1}$ | Rainfed |
| Terai-Teesta alluvial zone | Jalpaiguri<br>Cooch Behar | 140-150 | Jalprabha (IET-11870) | Crop duration: 165-180 days, semi-dwarf (112 cm), grains: short bold, white, yield: 62 q $ha^{-1}$ | Rainfed deep water |

Source: Gene Exploratory Database of Indian Rice Database, ICAR-National Institute for Plant Biotechnology. (*https://rice-garud.icar-web.com/varieties.php*)

analyzing 50 years of weekly rainfall data and fitting appropriate probability distributions, the research identified key rainfall thresholds at 25%, 50%, 75%, and 90% exceedance probabilities. The 75% probability level was chosen as the critical benchmark for assured rainfall, particularly relevant for planning rainfed rice cultivation. The estimation of minimum assured rainfall and corresponding number of rainy days enabled the strategic recommendation of rice varieties tailored to regional rainfall conditions. Short-duration drought-tolerant varieties were suggested for districts with limited assured rainfall, while long-duration, water-intensive varieties were deemed suitable for regions with greater rainfall reliability.


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