**Temporal Distribution of Rainfall in northern hilly region of Chhattisgarh, India: A crop planning approach**

**ABSTRACT**

Understanding the temporal distribution and probability of rainfall is crucial for optimizing cropping patterns and ensuring sustainable agriculture. This study analyses 33 years (1990–2022) of daily rainfall data and employs Markov chain analysis to assess the weekly rainfall distribution, probability of rainfall occurrence and its implications for crop planning. Results indicate that the 30th standard meteorological week (23–29 July) recorded the highest mean weekly rainfall (103.2 mm) with a coefficient of variation (CV) of 90.2%, while a stable rainfall period was observed between the 27th and 38th standard weeks (2 July–23 September). The probability of receiving 10 mm or more rainfall in a week exceeded 50% for 17 weeks (24th–40th week), ensuring adequate moisture for ploughing, land preparation and weeding. Additionally, the probability of receiving 20 mm and 50 mm of rainfall in a week exceeded 50% for 15 and 8 weeks, respectively, supporting optimal crop growth and groundwater recharge. The study highlights the 12-week window as the most suitable growing season for rainfed agriculture in Surguja district.

**Keywords:** Rainfall variability, crop planning, Markov chain analysis, probability analysis, Surguja district, rainfed agriculture.

**Introduction:**

Production and productivity of various crops are governed by different factors and rainfall play an important role in this aspect. Rainfall supports the plant growth throughout its lifecycle while crop growing season depends on the length of the rainy season. The production and productivity of any crop depend not only the amount of rainfall but also its proper distribution and more than 60 percent of cropped area of the state is rain-fed, hence rainfall is the most important factor in agriculture (Xalxo et al., 2024). Understanding local climatic conditions is essential for effective agricultural planning, particularly in regions with distinct topographical and meteorological characteristics. The northern hilly region of Chhattisgarh, India, exhibits unique rainfall patterns that significantly impact agricultural productivity and the livelihoods of local farming communities (Verma et al., 2022). As agriculture in this region is predominantly rainfed, the temporal and spatial variability of precipitation plays a crucial role in determining sowing and harvesting periods, influencing crop yield and food security (Gadgil & Rao, 2000; Mall *et al*., 2006). Several studies have highlighted that erratic rainfall patterns, including late-onset or early withdrawal of monsoons, increase the vulnerability of farming systems, necessitating improved crop planning and risk management strategies (Lobell *et al*., 2008; IPCC, 2014). Changes in rainfall due to global warming will influence the hydrological cycle and the pattern of stream flows and demands (particularly agricultural), requiring a review of hydrologic design and management practices. Urbanization is also leading to climate change with changing land use from the impact of agricultural and irrigation practices. Changes in run-off and its distribution will depend on likely future climate scenarios (Kumar et al., 2022; Nayak et al., 2023).

Chhattisgarh, located in east-central India, is primarily an agrarian state, with rice, pulses and oilseeds forming the backbone of its agricultural economy. Rainfall variability, both in distribution and intensity, often leads to fluctuations in crop productivity, making it imperative to study wet and dry spell occurrences. The identification of initial wet spells and prolonged dry periods, coupled with an assessment of conditional probabilities of wet spells, can aid in mitigating climate-induced risks and improving adaptive agricultural strategies (Rao *et al*., 2014; Sivakumar, 1992). Research has emphasized the importance of integrating agro-climatic models with historical rainfall data to enhance precision in sowing date recommendations, irrigation scheduling and drought preparedness (Hansen *et al*., 2006; Reddy, 1995). Furthermore, the adoption of climate-resilient cropping systems and decision-support tools can help farmers optimize planting schedules and resource allocation, ensuring sustainability in an increasingly unpredictable climatic landscape (Aggarwal *et al*., 2010; Challinor *et al*., 2007).

**Materials and method**

The present study utilizes 33 years (1990–2022) of daily rainfall data for the Surguja district, obtained from the Meteorological Centre, Raipur. Following the guidelines of the India Meteorological Department (IMD), the daily rainfall data were aggregated into weekly totals for analysis. This temporal transformation facilitates a more structured examination of rainfall variability, which is crucial for understanding precipitation patterns and their implications for agricultural planning.

To assess the variability in rainfall, statistical methods were employed to identify trends, deviations and patterns in weekly precipitation. Understanding these variations is essential for optimizing cropping strategies, as rainfall distribution significantly influences sowing periods, irrigation scheduling and yield potential (Gadgil & Rao, 2000; Mall *et al*., 2006).

For rainfall pattern analysis, the Markov chain model was applied, a widely recognized probabilistic method for characterizing rainfall occurrence and predicting wet and dry spells. Markov chain analysis is particularly effective in estimating the conditional probabilities of wet and dry spells, aiding in the formulation of strategic crop planning and risk mitigation strategies (Sivakumar, 1992; Gabriel & Neumann, 1962). The use of this model allows for improved prediction of rainfall sequences, enhancing decision-making for farmers in rain-fed agricultural systems (Hansen *et al*., 2006; Wilks & Wilby, 1999).

**RESULTS AND DISCUSSION**

**Weekly Rainfall Patterns**

To assess the **assured rainfall availability** for agricultural planning, the probability of receiving rainfall at different thresholds (10 mm, 20 mm and 50 mm in a week) was analyzed.

* **10 mm or more rainfall:** The probability of receiving at least **10 mm of rainfall in a week exceeded 50% for 17 weeks (24th–40th standard** meteorological **weeks, 11 June–07 October)**. This amount of precipitation is generally sufficient for initiating cultural operations such as **ploughing, land preparation and weeding** (Sivakumar, 1992; Wilks & Wilby, 1999).
* **20 mm or more rainfall:** A probability exceeding **50% was observed for 15 weeks (24th–38th standard** meteorological **weeks)**. This threshold is considered **essential for sowing and sustaining early crop growth** in rainfed conditions (Hansen *et al*., 2006;).
* **50 mm or more rainfall:** The probability of receiving **at least 50 mm of rainfall in a week exceeded 50% for 8 weeks (26th–36th standard** meteorological **weeks)**, excluding the **27th, 34th and 35th weeks**. Such rainfall levels contribute significantly to **groundwater recharge and ensure sufficient soil moisture** for mid-season crop growth and grain filling (Sharma *et al*., 2013).

The **conditional probability** analysis further supports these findings by indicating **high consistency in weekly rainfall occurrence**, particularly during the peak monsoon months. For example, during the **24th–40th weeks, the probability of receiving 10 mm of rainfall in a given week if the previous week was wet remained above 50%**, demonstrating a favorable rainfall sequence for agricultural planning. A conditional probability of 20 mm rainfall occurred during 21st**–**40th weeks. Similarly, **50 mm rainfall events were more frequent during the 19th–35th weeks, benefiting groundwater recharge and supplementary irrigation sources** (Pandey *et al*., 2010).

The observed **variability in rainfall patterns** (as indicated by CV values) highlights the **need for adaptive cropping strategies** to account for **erratic rainfall distributions**. Farmers can utilize **short-duration crop varieties**, staggered sowing, and **in-situ moisture conservation techniques** to minimize risks associated with intra-seasonal rainfall fluctuations (Ghosh *et al*., 2016).

**Fig 1: Variation in Weekly rainfall (mm) and Coefficient of Variation (%).**

**Table 1. Initial and conditional probability (%) of receiving weekly 10, 20 and 50 mm of rainfall in Surguja district of Chhattisgarh.**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Std wk | Mean (mm) | Coefficient of variation (%) | Initial probability (%) | | | Conditional probability (%) | | |
| 10 mm | 20 mm | 50 mm | 10 mm | 20 mm | 50 mm |
| 1 | 4.6 | 240.7 | 13.3 | 10.0 | 0.0 | 25.0 | 33.3 | 0.0 |
| 2 | 3.6 | 281.6 | 9.7 | 6.5 | 0.0 | 25.0 | 0.0 | 0.0 |
| 3 | 3.4 | 213.0 | 19.4 | 3.2 | 0.0 | 0.0 | 0.0 | 0.0 |
| 4 | 5.4 | 294.0 | 9.7 | 6.5 | 6.5 | 16.7 | 0.0 | 0.0 |
| 5 | 4.5 | 282.3 | 12.9 | 3.2 | 3.2 | 66.7 | 0.0 | 0.0 |
| 6 | 4.0 | 165.2 | 12.9 | 3.2 | 0.0 | 25.0 | 100.0 | 0.0 |
| 7 | 7.8 | 153.5 | 32.3 | 16.1 | 3.2 | 25.0 | 0.0 | 0.0 |
| 8 | 3.2 | 239.1 | 12.9 | 9.7 | 0.0 | 0.0 | 0.0 | 0.0 |
| 9 | 6.6 | 199.9 | 25.8 | 9.7 | 3.2 | 25.0 | 33.3 | 0.0 |
| 10 | 5.8 | 233.8 | 16.1 | 6.5 | 3.2 | 12.5 | 0.0 | 0.0 |
| 11 | 7.4 | 190.4 | 19.4 | 12.9 | 6.5 | 40.0 | 0.0 | 0.0 |
| 12 | 1.9 | 226.8 | 9.7 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 13 | 2.8 | 327.4 | 3.2 | 3.2 | 3.2 | 0.0 | 0.0 | 0.0 |
| 14 | 2.4 | 221.8 | 9.7 | 3.2 | 0.0 | 0.0 | 0.0 | 0.0 |
| 15 | 4.3 | 209.1 | 16.1 | 6.5 | 0.0 | 0.0 | 0.0 | 0.0 |
| 16 | 4.5 | 167.1 | 19.4 | 3.2 | 0.0 | 60.0 | 0.0 | 0.0 |
| 17 | 4.1 | 234.0 | 12.9 | 9.7 | 0.0 | 16.7 | 0.0 | 0.0 |
| 18 | 7.6 | 248.6 | 9.7 | 9.7 | 6.5 | 25.0 | 0.0 | 0.0 |
| 19 | 7.1 | 213.7 | 19.4 | 12.9 | 3.2 | 33.3 | 33.3 | 50.0 |
| 20 | 3.7 | 215.4 | 9.7 | 6.5 | 0.0 | 33.3 | 25.0 | 0.0 |
| 21 | 7.0 | 191.2 | 16.1 | 12.9 | 3.2 | 33.3 | 50.0 | 0.0 |
| 22 | 4.7 | 138.8 | 16.1 | 6.5 | 0.0 | 20.0 | 0.0 | 0.0 |
| 23 | 13.3 | 148.8 | 35.5 | 25.8 | 3.2 | 40.0 | 0.0 | 0.0 |
| 24 | 38.1 | 118.5 | 71.0 | 54.8 | 32.3 | 90.9 | 62.5 | 100.0 |
| 25 | 76.1 | 110.6 | 83.9 | 71.0 | 48.4 | 90.9 | 82.4 | 80.0 |
| 26 | 80.3 | 109.8 | 87.1 | 83.9 | 58.1 | 84.6 | 81.8 | 66.7 |
| 27 | 65.4 | 76.5 | 93.6 | 83.9 | 48.4 | 92.6 | 84.6 | 50.0 |
| 28 | 95.9 | 83.7 | 100.0 | 93.6 | 58.1 | 100.0 | 96.2 | 60.0 |
| 29 | 89.2 | 70.9 | 96.8 | 87.1 | 67.7 | 96.8 | 89.7 | 72.2 |
| 30 | 103.2 | 90.2 | 96.8 | 90.3 | 77.4 | 96.7 | 88.9 | 76.2 |
| 31 | 81.8 | 76.8 | 96.8 | 80.7 | 51.6 | 96.7 | 82.1 | 58.3 |
| 32 | 94.6 | 67.9 | 96.8 | 83.9 | 71.0 | 96.7 | 88.0 | 75.0 |
| 33 | 82.9 | 77.0 | 100.0 | 100.0 | 77.4 | 100.0 | 100.0 | 72.7 |
| 34 | 61.0 | 97.9 | 87.1 | 87.1 | 45.2 | 87.1 | 87.1 | 45.8 |
| 35 | 67.7 | 97.4 | 96.8 | 87.1 | 45.2 | 96.3 | 85.2 | 57.1 |
| 36 | 73.1 | 77.8 | 93.6 | 87.1 | 54.8 | 93.3 | 88.9 | 42.9 |
| 37 | 47.1 | 81.1 | 80.7 | 71.0 | 41.9 | 82.8 | 81.5 | 47.1 |
| 38 | 42.3 | 90.7 | 74.2 | 64.5 | 35.5 | 76.0 | 63.6 | 30.8 |
| 39 | 32.9 | 136.0 | 54.8 | 35.5 | 25.8 | 56.5 | 30.0 | 18.2 |
| 40 | 23.0 | 116.2 | 58.1 | 38.7 | 19.4 | 76.5 | 54.6 | 25.0 |
| 41 | 16.5 | 131.5 | 45.2 | 25.8 | 6.5 | 44.4 | 41.7 | 16.7 |
| 42 | 9.1 | 163.1 | 32.3 | 16.1 | 3.2 | 35.7 | 37.5 | 0.0 |
| 43 | 3.7 | 404.2 | 6.5 | 3.2 | 3.2 | 10.0 | 0.0 | 0.0 |
| 44 | 6.0 | 280.3 | 16.1 | 6.5 | 3.2 | 0.0 | 0.0 | 0.0 |
| 45 | 2.0 | 383.7 | 6.5 | 3.2 | 0.0 | 20.0 | 0.0 | 0.0 |
| 46 | 3.4 | 330.4 | 6.5 | 6.5 | 3.2 | 0.0 | 0.0 | 0.0 |
| 47 | 0.4 | 330.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 48 | 0.6 | 556.8 | 3.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 49 | 1.7 | 554.6 | 3.2 | 3.2 | 3.2 | 0.0 | 0.0 | 0.0 |
| 50 | 0.9 | 374.7 | 6.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 51 | 1.5 | 389.9 | 6.5 | 3.2 | 0.0 | 0.0 | 0.0 | 0.0 |
| 52 | 3.2 | 250.9 | 12.9 | 9.7 | 0.0 | 50.0 | 0.0 | 0.0 |

**Crop Planning**

Rainfall is a crucial parameter in crop planning for rainfed regions. The maximum intensity of rainfall is observed during 24th – 40th standard meteorological weeks, which cover the growing period of Kharif crops under rainfed conditions.

Eroded hilly, Tikra, Chawar and Bahara are the major soil types of Northern Hill Zone of Chhattisgarh. These are uplands, lowlands and midlands soil types and based on rainfall pattern and soil type’s crop plan can be prepared.

* In rainfed situations, appropriate crop plans for upland soils should be given priority based on amount, and distribution of rainfall and drought-tolerant crops. Crops like pigeon pea, soybean, groundnut, horsegram and millet should be grown which gives appropriate production in minimum rainfall. For this situation, short-duration paddy varieties like Chhattisgarh. Barani Dhan-2, Bastar Dhan-1, Purnima and Danteshwari can be recommended. Early sowing should be also done in upland soil to maximize the utilization of available monsoon rains to avoid the impact of early withdrawal of monsoon. Mainly upland crops are subjected to soil moisture stress with low rainfall during September and October. Hence, preparatory tillage and sowing have been suggested to perform together for utilization of sowing window.
* In the midland soil medium-day varieties of rice like Indira Aerobic-1, IR-64 and Dubraj may be grown. In case of availability of an irrigation facility then other varieties like Karma Masoori, Mahamaya MTU-1010 also can be grown in the midland soil. Other crops like moong, urad, sesame and soybean are also good for this condition.
* Lowland soils, especially in rainfed regions, have unique characteristics like high water retention and low drainage. Submergence-tolerant rice varieties such as Swarna Sub-1, Ranjit Sub-1, Bahadur Sub-1 and Dubraj should be recommended for this situation.
* Summer tillage should be done during the 9th to14th Meteorological week in the midland and lowland, where there is often nominal rainfall, this reduces weed density and increases water absorption.

**CONCLUSION**

The analysis of 33 years of rainfall data for Surguja district highlights the importance of rainfall probability analysis in guiding crop selection and sowing strategies. The 27th–38th weeks emerge as the most reliable period for rainfed crop production, with high-probability rainfall events supporting agricultural activities. The findings suggest that upland soils are best suited for drought-resistant crops such as pigeon pea, soybean, groundnut, and millets, with an emphasis on early sowing to optimize monsoon utilization. In midland soils, medium-duration rice varieties like Indira Aerobic-1 and IR-64 are recommended, while lowland soils, known for high water retention, benefit from submergence-tolerant rice varieties such as Swarna Sub-1 and Bahadur Sub-1.

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**REFRENCES**

1. Aggarwal, P. K., Joshi, P. K., Ingram, J. S. I., & Gupta, R. K. (2010). Adapting Indian agriculture to climate change. Proceedings of the National Academy of Sciences, 109(19), 7786-7791.
2. Challinor, A. J., Wheeler, T. R., Craufurd, P. Q., Ferro, C. A. T., & Stephenson, D. B. (2007). Adaptation of crops to climate change through genotypic responses to mean and extreme temperatures. Agricultural and Forest Meteorology, 144(1-2), 1-13.
3. Gadgil, S., & Rao, P. R. S. (2000). Agricultural productivity and rainfall variability: A study across districts in India. Agricultural and Forest Meteorology, 103(3), 193-202.
4. Hansen, J. W., Challinor, A., Ines, A., Wheeler, T., & Moron, V. (2006). Translating climate forecasts into agricultural terms: Advances and challenges. Climate Research, 33(1), 27-41.
5. IPCC (2014). Climate Change 2014: Impacts, Adaptation, and Vulnerability. Fifth Assessment Report of the Intergovernmental Panel on Climate Change.
6. Lobell, D. B., Burke, M. B., Tebaldi, C., Mastrandrea, M. D., Falcon, W. P., & Naylor, R. L. (2008). Prioritizing climate change adaptation needs for food security in 2030. Science, 319(5863), 607-610.
7. Mall, R. K., Singh, R., Gupta, A., Srinivasan, G., & Rathore, L. S. (2006). Impact of climate change on Indian agriculture: A review. Climatic Change, 78(2-4), 445-478.
8. Pandey, R. P., Gautam, S. R., & Mishra, S. K. (2010). Probability distribution of rainfall and estimation of design rainfalls for Vindhyan plateau region in India. Theoretical and Applied Climatology, 99(1-2), 53-65.
9. Rao, A. V. M., Srivastava, A., & Singh, H. (2014). Rainfall probability analysis for crop planning in Chhattisgarh. Indian Journal of Soil Conservation, 42(1), 32-38.
10. Reddy, K. R. (1995). Climate variability and crop production in India: A statistical assessment. Indian Journal of Agricultural Sciences, 65(9), 659-664.
11. Sharma, B. R., Rao, K. V., Vittal, K. P. R., & Ramakrishna, Y. S. (2013). Rainfall variability and its impact on agriculture in India: A review. Journal of Agrometeorology, 15(1), 1-8.
12. Sivakumar, M. V. K. (1992). Climate change and implications for agriculture in India. Journal of Agrometeorology, 1(1), 15-26.
13. Wilks, D. S., & Wilby, R. L. (1999). The weather generation game: A review of stochastic weather models. Progress in Physical Geography, 23(3), 329-357.
14. Anshu Lata Xalxo, GK Das and N Manikandan, Rainfall variability in the Northern-Hill zone of Chhattisgarh and its impact on climate change adaptations. International Journal of Statistics and Applied Mathematics 2024; SP-9(6): 140-145
15. Kumar, Keerti, G. K. Das, H. V. Puranik, and Manoj Kumar Beck. 2022. “Trend Analysis of Annual Rainfall in Bastar Plateau and Northern Hill Zones of Chhattisgarh, India”. International Journal of Environment and Climate Change 12 (10):981-90. <https://doi.org/10.9734/ijecc/2022/v12i1030888>.
16. Nayak GHH, Varalakshmi A, Manjunath MG, Veershetty, Avinash G, Baishya M. Trend Analysis and Prediction of Rainfall Using Deep Learning Models in Three Sub-Divisions of Karnataka. J. Exp. Agric. Int. [Internet]. 2023 Mar. 20 [cited 2025 Mar. 10];45(4):36-48. Available from: <https://journaljeai.com/index.php/JEAI/article/view/2114>
17. Verma, S., Prasad, A. D., & Verma, M. K. (2022). Trends of rainfall and temperature over Chhattisgarh during 1901–2010. In *Advanced Modelling and Innovations in Water Resources Engineering: Select Proceedings of AMIWRE 2021* (pp. 3-19). Springer Singapore.