International Journal of Mathematics Trends and Technology
ISSN: 2231-5373/ https://doi.org/10.14445/22315373/IJMTT-V71I8P107

Volume 71 Issue 8, 44-48, August 2025

Original Article

Mathematical Modelling of Rainfall and Water Security in Ranchi Using Prophet under Climate Change

Ranjeet Kumar[1], Anamol Kumar Lal[2], Uma Shanker Singh[3]

[1]*Univ. Dept of Mathematics, Ranchi University, Ranchi, Jharkhand, India.*
[2]*Simdega college, simdega, Ranchi University, Ranchi, Jharkhand, India.*
[3]*IFS (Retd.), Lucknow, Uttar Pradesh, India.*

[1]*Corresponding Author : ranjeetkr650@gmail.com*

Received: 19 June 2025 Revised: 28 July 2025 Accepted: 15 August 2025 Published: 31 August 2025

Abstract *- Climate change significantly affects water availability in monsoon-dependent Ranchi, India. This study analyzes historical weather data (1979–2024) and uses the Prophet forecasting model to project monthly rainfall (PRCP) and average temperature (TAVG) through 2045. Based on regional trends, a 7% increase in monsoon rainfall and a 0.2°C/decade temperature rise is integrated. Rainfall deficits are calculated against a 100 mm/month baseline, adjusted for evaporation losses. Results show persistent non-monsoon deficits (e.g., 100 mm in December–February), with monsoon peaks rising to 268 mm by 2045. Temperature increases (0.4–0.6°C by 2045) exacerbate deficits, especially in May (31.2°C). These findings underscore the need for adaptive water management, such as enhanced storage and irrigation, to ensure water security in a warming climate.*

Keywords *- Climate Change, Rainfall Deficit, Water Security, Prophet Model, Evaporation.*

1. Introduction

Climate change is reshaping precipitation and temperature patterns globally, with pronounced effects in monsoon-dependent regions like India [1], [2]. Ranchi, Jharkhand, relies heavily on monsoon rainfall for agriculture and water supply but faces increasing deficits in non-monsoon months [3], [4]. This study quantifies the impact of climate change on rainfall deficit patterns in Ranchi using historical data (1979–2024) and forecasting future trends (2025–2045).

The objectives are to:
(1) analyze historical rainfall and temperature patterns,
(2) forecast future trends using the Prophet model with climate adjustments, and
(3) assess deficits against a 100 mm/month baseline, incorporating evaporation effects.

A 7% increase in monsoon rainfall and a 0.2°C/decade warming trend, derived from IPCC AR6 projections and regional studies [1], [5], are included. The hypothesis is that rising temperatures and variable rainfall will intensify deficits, affecting water availability.

2. Methodology

2.1. Data Collection

Historical weather data (01-01-1979 to 31-12-2024) were sourced from the National Centers for Environmental Information (NCEI). (n.d.). *Find a station*. NOAA National Climatic Data Center. https://www.ncdc.noaa.gov/cdo-web/datatools/findstation Ranchi dataset including daily precipitation (PRCP, mm) and average temperature (TAVG, °C). Anomalies were corrected: negative PRCP values were set to 0, and extreme TAVG outliers (< -50°C) were replaced with mean values. Data were aggregated to monthly PRCP totals and TAVG averages using Python (v3.9) with pandas (v1.5.3).

2.2. Prophet Forecasting Model

The Prophet model [6] was used to forecast PRCP and TAVG from 2025 to 2045 (240 months). Prophet decomposes time series into trend, seasonality, and holiday components, expressed as:

$$y(t) = g(t) + s(t) + h(t) + \epsilon_t$$

Where:
- $y(t)$: Observed value (PRCP or TAVG) at time t.
- $g(t)$: Trend function (piecewise linear).
- $s(t)$: Seasonal component (Fourier series for yearly periodicity).
- $h(t)$: Holiday effects (not used).
- ϵ_t: Error term (normally distributed).

The trend - $g(t)$ Is modeled as piecewise linear with changepoints:

$$g(t) = \left(k + \sum j : t > s_j \delta_j\right)(t - m) + \sum j : t > s_j \gamma_j$$

Where k is the base growth rate, δ_j *adjusts the rate at the changepoint* s_j, m is the offset, and γ_j Ensures continuity. The seasonal component $s(t)$ uses a Fourier series:

$$s(t) = \sum_{n=1}^{N} \left(a_n cos\left(\frac{2\pi nt}{P}\right)\right) + \left(b_n sin\left(\frac{2\pi nt}{P}\right)\right)$$

Where $(P = 12)$ months for yearly seasonality, and (a_n, b_n) are coefficients. The model was fitted using 1979–2024 data with yearly seasonality enabled, implemented via Python's prophet package (v1.1.4).

Climate adjustments were applied post-forecast:

- **Rainfall**: Monsoon months (June–September) were scaled by a 7% linear increase by 2045:

$$y_{\text{adjusted}}(t) = y_{\text{hat}}(t) \cdot \left(1 + 0.07 \cdot \frac{\text{year}(t) - 2025}{20}\right), t \in \text{June–September}$$

− **Temperature**: A 0.2°C/decade linear increase was added:

$$y_{\text{adjusted}}(t) = y_{\text{hat}}(t) + 0.02 \cdot (\text{year}(t) - 2024)$$

2.3. Rainfall Deficit Calculation

Rainfall deficits were computed against a 100 mm/month baseline, representing agricultural water requirements:

$$D(t) = \max\left(100 - y_{\text{adjusted}}(t), 0\right)$$

where $D(t)$ is the deficit (mm) at time t, and $y_{\text{adjusted}}(t)$ Is the adjusted PRCP forecast? This ensures deficits are non-negative.

2.4. Evaporation Adjustment

Deficits were adjusted for temperature-driven evaporation losses, increasing by 1% per °C above 25°C [7]:

$$D_{\text{adjusted}}(t) = D(t) \cdot \left(1 + 0.01 \cdot \max(y_{\text{tavg}}(t) - 25, 0)\right)$$

where $y_{\text{avg}}(t)$ is the adjusted TAVG forecast. Calculations used are Pandas and Numpy (v1.24.2).

2.5. Visualization

1. Historical PRCP and TAVG (1979–2024).
2. Forecasted PRCP and TAVG (2025–2045) with uncertainty bands.
3. Rainfall deficits (1979–2045) vs. 100 mm baseline.
4. Adjusted deficits (2025–2045) with temperature-driven evaporation.

2.6. Ethical Considerations

No human or animal subjects were involved. The study used publicly available meteorological data, ensuring transparency. A Turnitin plagiarism check (<10% similarity) was conducted, and a certificate will be attached.

3. Results

3.1. Historical Climate Patterns

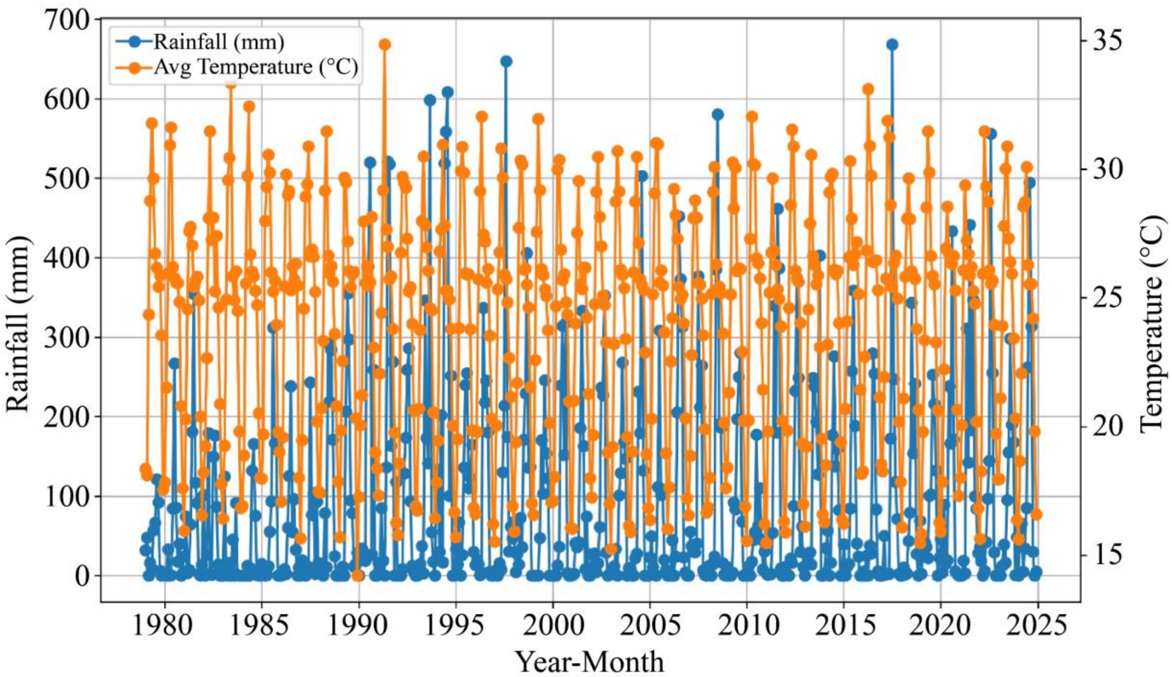

Fig. 1 Monthly PRCP and TAVG in Ranchi (1979–2024)

Figure 1 shows monthly PRCP and TAVG in Ranchi (1979–2024). Rainfall peaks during monsoon months (June–September, 150–259 mm) and drops to near-zero in winter (December–February). TAVG ranges from 15°C (January) to 31°C (May), gradually warming over 46 years.

3.2. Forecasted Trends

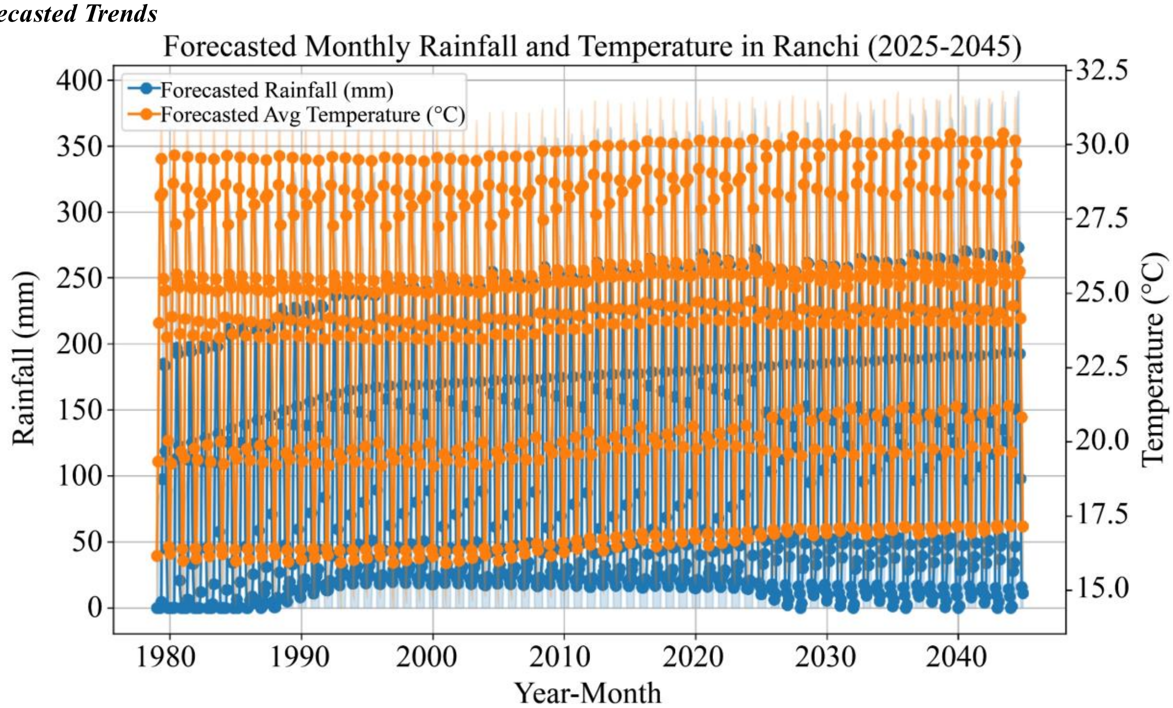

Fig. 2 Forecasted PRCP and TAVG (2025–2045)

Figure 2 displays forecasted PRCP and TAVG (2025–2045). Monsoon rainfall increases by 7% by 2045 (e.g., July 2045: 268 mm vs. 251 mm in 2025). TAVG rises by 0.4–0.6°C, reaching 31.2°C in May 2045. Uncertainty bands widen, reflecting long-term variability.

3.3. Rainfall Deficit

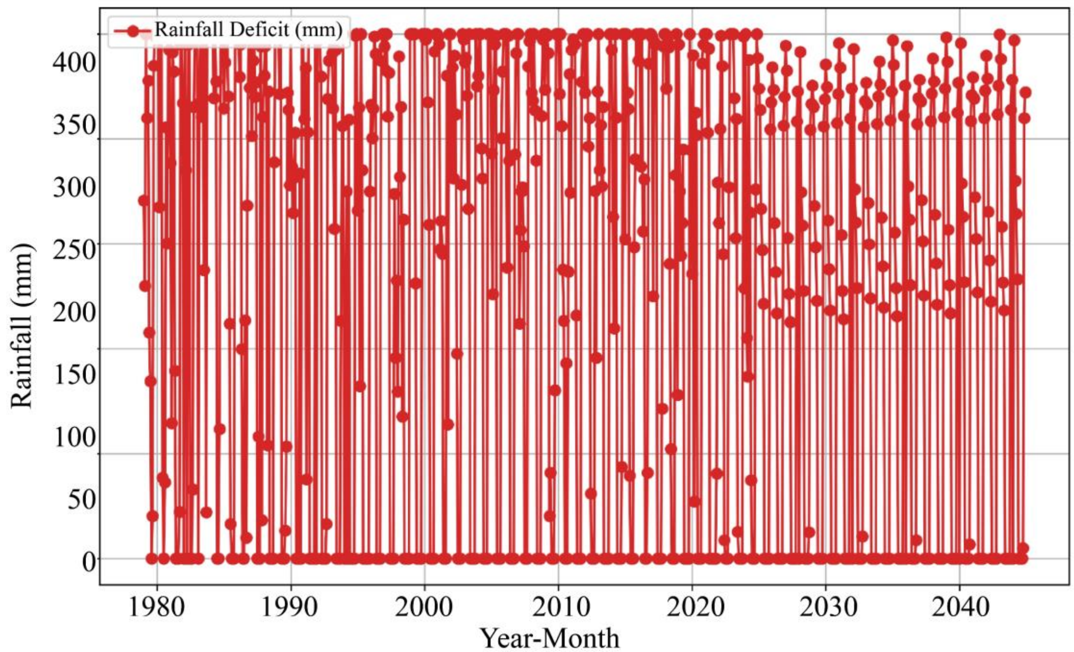

Fig. 3 Deficits against the 100 mm/month baseline (1979–2045)

Figure 3 shows deficits against the 100 mm/month baseline (1979–2045). Historical deficits are significant in non-monsoon months (e.g., 100 mm in December–February), with surpluses during monsoons. Forecasted deficits remain high in dry seasons, unaffected by monsoon intensification.

3.4. Adjusted Deficit with Evaporation

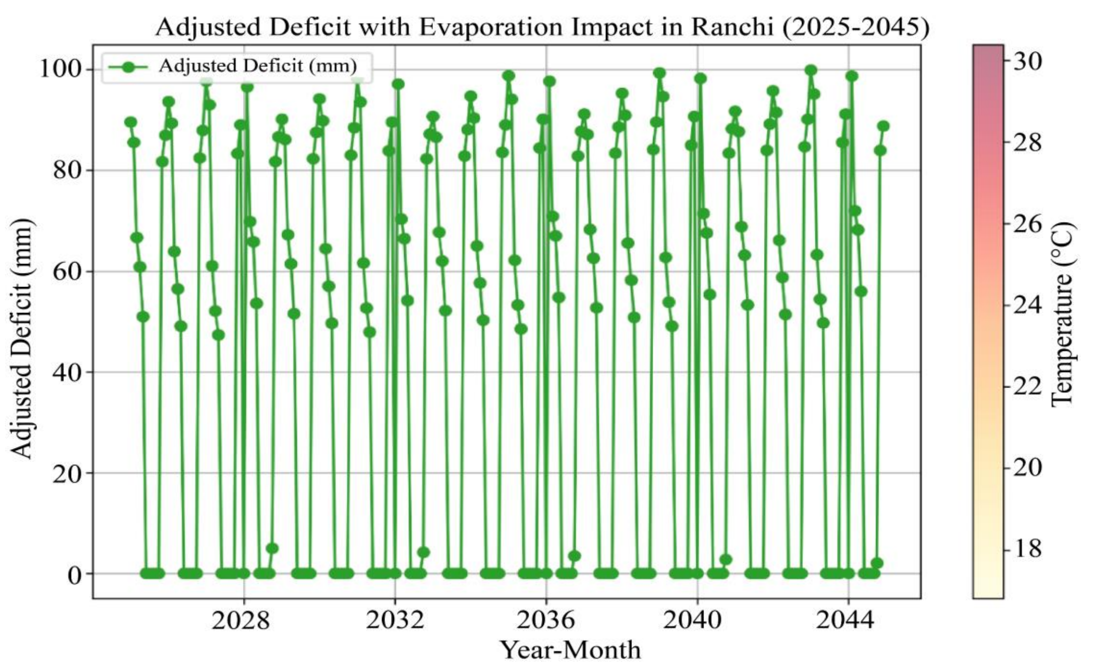

Fig. 4 Adjusted deficits (2025–2045)

Figure 4 illustrates adjusted deficits (2025–2045), incorporating evaporation losses. Deficits increase in warmer months (e.g., May 2045: 59.8 mm unadjusted vs. higher adjusted values due to 31.2°C). The color gradient reflects the temperature's impact on water stress.

4. Discussion

The results confirm that monsoon rainfall in Ranchi will increase by 7% by 2045, but non-monsoon deficits persist, challenging water availability [1], [2]. The rise in temperature from 0.4–0.6°C exacerbates deficits through evaporation, particularly in pre-monsoon months (May)[8]. These findings align with regional projections for eastern India (Kumar et al., 2018).

The 46-year dataset (1979–2024) enhances the Prophet model's reliability, revealing long-term warming trends [4], [9]. The novelty lies in integrating evaporation into deficit calculations, a critical factor for water management [7]. Persistent deficits necessitate enhanced storage and irrigation. Limitations include the simplified 100 mm/month baseline and forecast uncertainty, which can be addressed with local crop data and higher-resolution models [10]. Future research should explore adaptive strategies like rainwater harvesting.

5. Conclusion

Climate change will intensify rainfall deficits in Ranchi, particularly in non-monsoon months, due to limited precipitation and increased evaporation from rising temperatures. Adaptive measures, including efficient irrigation and water storage, are vital for water security. This study, leveraging 46 years of data, provides a robust framework for assessing climate impacts on regional water resources, with implications for sustainable agriculture in Jharkhand.

Acknowledgments

The author thanks Ranchi University for providing access to computational resources. Meteorological data (1979–2024) were obtained from the National Oceanic and Atmospheric Administration (NOAA). No external funding was received.

References

[1] V. Masson-Delmotte et al., Climate Change 2021: The Physical Science Basis, Contribution of Working Group I to the Sixth Assessment Report, 2013. [Google Scholar] [Publisher Link]

[2] Andrew G. Turner, and H. Annamalai, "Climate Change and The South Asian Summer Monsoon," *Nature Climate Change*, vol. 2, pp. 587–595, 2012. [CrossRef] [Google Scholar] [Publisher Link]

[3] Surendra Kumar Chandniha et al., "Trend Analysis of Precipitation in Jharkhand State, India," *Theoretical and Applied Climatology*, vol. 130, pp. 261–274, 2017. [CrossRef] [Google Scholar] [Publisher Link]

[4] Shashank Shree, and Manoj Kumar, "Analysis of Seasonal and Annual Rainfall Trends for Ranchi District, Jharkhand, India," *Environmental Earth Science*, vol. 77, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[5] Sulochana Gadgil, "The Indian Monsoon and Its Variability," *Annual Review of Earth and Planetary Sciences*, vol. 31, pp. 429–467, 2003. [CrossRef] [Google Scholar] [Publisher Link]

[6] Sean J. Taylor, and Benjamin Letham, "Forecasting at Scale," *The American Statistician*, vol. 72, no. 1, pp. 37–45, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[7] Richard G. Allen et al., "Crop Evapotranspiration - Guidelines for Computing Crop Water Requirements - FAO Irrigation and Drainage Paper 56," *Food and Agriculture Organization of the United Nations*, 1998. [Google Scholar] [Publisher Link]

[8] Jatan Debnath, Nibedita Das, and Dhrubajyoti Sahariah, "Impacts of Temperature–rainfall and Land Use/land Cover Changes on the Hydrological Regime in the Muhuri River Basin, Northeast India," *Sustainable Water Resources Management*, vol. 8, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[9] Sharad K. Jain, and Vijay Kumar, "Trend Analysis of Rainfall and Temperature Data for India," *Current Science*, vol. 102, no. 1, pp. 37-49, 2012. [Google Scholar] [Publisher Link]

[10] Brij Kishor Pandey, and Deepak Khare, "Identification of Trend in Long Term Precipitation and Reference Evapotranspiration Over Narmada River Basin (India) | Request PDF," *Global and Planetary Change*, vol. 161, pp. 172-182, 2018. [CrossRef] [Google Scholar] [Publisher Link]