Open Access
Volume 5 Issue 2
Research Article

Journal of Water Engineering and Management
ISSN: 2582-6298

Probability Analysis of Annual Maximum Daily Rainfall for Karnataka, India

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Article Info

Article History:
Received on: January 15, 2024
Revised on: July 11,2024
Accepted on: September 12, 2024
Published on: September 30, 2024

Published by Academic Hope

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DOI: XXX

How to Cite:
Prakas, A., Raj, P., Kumari, J. and Singh, V., 2024. Probability analysis of annual maximum daily rainfall for Karnataka, India, Journal of Water Engineering and Management 5(2):9-12. DOI: https://doi.org/10.47884/jweam.v5i2pp09-12

Abstract

Daily rainfall data for 22 years (2000–2022) were obtained from the Global Weather Data for SWAT and analyzed to assess annual and monthly rainfall variability. The annual series was examined to determine maximum and minimum rainfall values, while the monthly series was processed to evaluate monthly patterns. Statistical parameters such as standard deviation and coefficient of variation (CV) were also calculated for the study period. Results showed that the annual maximum daily rainfall varied widely between 1 mm and 10.55 mm, indicating substantial temporal variability. Monthly analysis revealed that October consistently received the lowest rainfall across all study years, whereas July and August recorded the highest rainfall, highlighting the dominance of the monsoon season. Among the months, August exhibited the lowest CV (58.35%), followed by September (61.82%), suggesting comparatively stable rainfall patterns during these months. In contrast, June recorded the highest CV (75.04%), indicating greater inter-annual variability. Further, frequency analysis showed that the maximum daily rainfall values estimated using both Normal and Log-Pearson Type III distributions at a 20% probability of exceedance were highest during the months of July to October.

Keywords Frequency analysis: Rainfall variation: Probability distribution: Average method: Weibull's formula.

Introduction

Rainfall is a vital component of the hydrological cycle, linking weather and climate systems. In India, agriculture and the economy largely depend on timely and adequate rainfall. Nearly 70% of the country's agricultural area is rainfed, with about 80% of annual rainfall (≈1200 mm) occurring during the southwest monsoon from June to September. However, rainfall distribution is highly uneven across regions and seasons, leading to both floods and droughts. Efficient use and analysis of rainfall data are essential for improving agricultural productivity and designing water management structures such as dams, canals, and drainage systems. Probability and frequency analyses help predict rainfall magnitudes for different return periods, supporting safer and more economical infrastructure planning. Karnataka, situated around 610 m above sea level, experiences a humid subtropical to tropical climate. The state faces recurrent floods, waterlogging, and occasional landslides during monsoon seasons, intensified by urbanization. Understanding rainfall trends is crucial for managing irrigation, reservoir operations, and regional water resources. Global climate change has altered rainfall patterns worldwide, increasing the frequency and intensity of extreme events. As nearly 80% of India's agricultural income depends on rainfall, variations in intensity or distribution directly impact soil moisture, groundwater recharge, and crop yields. Climate change studies commonly use variables such as precipitation, solar radiation, humidity, wind speed, temperature, and snow cover (Agarwal et al., 1988; Bara and Lal, 2008). In regions dominated by rainfed agriculture, irregular rainfall poses a major threat to food and environmental security (Bhakar et al., 2006, 2008).

Considering these factors, the present study analyzes rainfall trends in Karnataka over the past 22 years (2000–2022) to understand variability and its implications for agriculture and water resource management.

Materials and Methods

Study Area

The study area is Karnataka, India which lies between 15^{o}19.04′ N and 75^{o}42.83′ E. Karnataka is furnished with on average 1248 mm of rainfall per year. The driest weather is in December when an average of 1.35 mm (0.05 in) of rainfall (precipitation) occurs whereas maximum temperature goes up to 45.6°C. The state is bordered by Maharashtra, Goa, Kerala, Tamil Nadu, Andhra Pradesh, and the Arabian Sea, covering 191,791 km^2—around 5.83% of India's area. Karnataka is an agriculturally significant state, leading in the production of coffee, silk, sandalwood, ragi, and sunflower, and ranking second in maize, grapes, pomegranate, and onion output. Major crops include rice, maize, pulses, oilseeds, sugarcane, cashews, and chillies, making it one of India's most diverse and productive agricultural region. Karnataka has a subtropical monsoon climate with four seasons—winter, summer, southwest monsoon, and post-monsoon—experiencing significant rainfall variation across months.

Data Collection and Analysis

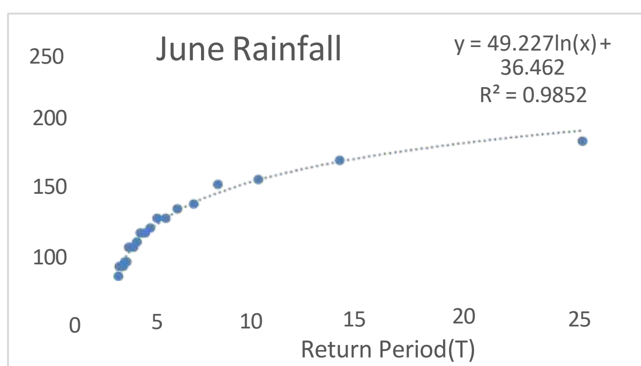
The precipitation data from 2000 to 2022 were obtained from the online portal https://globalweather.tamu.edu/. The data from a single station were analysed to determine maximum, minimum, average rainfall, standard deviation, and variance. For analysis, daily rainfall data were converted into monthly and annual series to identify trends and variability. Statistical parameters such as mean, standard deviation, and coefficient of variation were used to assess rainfall fluctuations. The moving average method was applied to study long-term trends. Further, probability analysis was conducted using Weibull's formula to estimate probabilities of occurrence and return periods. The rainfall trend was also modelled through normal and log-Pearson Type III distributions to estimate expected rainfall values for different return periods. The results helped in understanding rainfall variability, dependability, and design rainfall essential for irrigation planning, flood control, and water resource management in Karnataka.

Results and Discussion

The rainfall trends for Karnataka were analysed using statistical methods, including California Formula, recurrence method, and moving average techniques. Data from 2000–2022 were collected from one station. The minimum mean monthly rainfall was recorded in November (0.09 mm), while the maximum occurred in August (1609.4 mm). The average annual rainfall was 226.73 mm, with a maximum of 636.3 mm and minimum of 9.57 mm (Table 1). The standard deviation and coefficient of variation were also calculated to measure rainfall variability and assess climatic fluctuations across the study period.

The return-period plot for June rainfall shows a strong logarithmic relationship between rainfall intensity and return period, as indicated by the fitted equation $y = 49.227\ln(x) + 36.462y$ and a very high R^2 value of 0.9852 (Fig. 1). This suggests that the model fits the observed data extremely well and explains nearly all of the variability in maximum daily rainfall for June. The curve rises sharply at lower return periods, indicating that rainfall events associated with short recurrence intervals (such as 2–5 years) experience significant variability and rapid increases in rainfall magnitude. However, as the return period increases, the curve gradually flattens, implying that rainfall extremes for longer return periods (beyond 10–20 years) increase at a much slower rate. This behavior reflects the climatic characteristics of June as an early monsoon month, where the onset of rains is often characterized by irregular and highly variable rainfall events, while the probability of very high extreme rainfall remains relatively lower compared to peak monsoon months such as July and August. Overall, the results indicate moderate flood risk and considerable inter-annual variability in June rainfall, making early-season water resource planning and agricultural decision-making particularly important during this period.

Fig 1. Return period of various rainfall amount for



Month June

Table 1 Statistical analysis of rainfall data

Month & Year	June	July	August	September	October
2001	31.64	68.55	68.55	73.83	131.84
2002	47.46	15.82	110.74	31.64	89.65
2003	47.46	10.55	47.46	21.09	116.02
2004	63.28	84.38	73.83	121.29	31.64
2005	131.84	268.95	89.65	110.74	105.47
2006	179.3	89.65	73.83	89.65	68.55
2007	158.2	168.75	94.92	247.85	36.91
2008	42.19	79.1	94.92	84.38	52.73
2009	105.47	110.74	110.74	184.57	73.83
2010	94.92	147.66	174.02	116.02	52.73
2011	42.19	89.65	152.93	31.64	68.55
2012	42.19	58.01	63.28	94.92	52.73
2013	63.28	84.38	36.91	152.93	68.55
2014	42.19	131.84	189.84	63.28	94.92
2015	63.28	21.09	179.3	79.1	47.46
2016	79.1	142.38	68.55	73.83	15.82
2017	84.38	52.73	94.92	179.3	100.2
2018	110.74	21.09	42.19	100.2	26.37
2019	94.92	121.29	195.12	126.56	216.21
2020	79.1	258.4	142.38	221.48	168.75
2021	137.24	163.15	76.4	100.84	119.83
2022	69.23	190.32	174.8	239.45	98.93

Table 2 Monthly extreme rainfall statistics and variability indicators (2000–2022)

Time Series	Mean rainfall (mm)	Max. rainfall (mm)	Min. rainfall (mm)	Standard Deviation (mm)	Coef. of Var. (%)
June	82.25	179.3	31.64	40.83	49.64
July	108.11	268.95	10.55	71.84	66.45
August	107.05	195.12	36.91	50.59	47.25
September	115.66	247.85	21.09	64.57	55.82
October	83.53	216.21	15.82	47.99	57.45
Mean rainfall (mm)	82.25455	108.1127	107.0582	115.6632	83.53136
Max. rainfall (mm)	179.3	268.95	195.12	247.85	216.21
Min. rainfall (mm)	31.64	10.55	36.91	21.09	15.82
Standard Deviation (mm)	40.83465	71.83835	50.58443	64.56607	47.99273
Coef.of Var. (%)	49.64425	66.44763	47.24948	55.82249	57.45474

Across 10, 25 and 50-year return periods, July consistently has the highest predicted daily rainfall (225, 304 and 363 mm), followed by September (221, 291 and 344 mm), then August (187, 241 and 282 mm), October (162, 215 and 255 mm), and June (150, 195 and 229 mm). The step-up from a 10- to 25-year event is sizeable for every month about 31% for June, 35% for July, 29% for August, 32% for September and 32% for October while the increase from 25 to 50 years is smaller (18–20% for most months and 18% for June), which is consistent with a logarithmic/weakly concave growth of extremes with T (Table 3). From 10 to 50 years, the cumulative escalation is 53% for June, 61% for July, 50% for August, 56% for September and 57% for October, indicating that design storms strengthen notably with rarer events, most strongly in July and least in August. Relative to June, July's design storm is 1.50× (10-yr), 1.56× (25-yr) and 1.59× (50-yr) higher, underscoring July as the dominant extreme-rain month in the season; September is only slightly lower than July at each T, suggesting comparable hydraulic stress during late monsoon peaks. Practically, for spillways, urban drainage and culvert sizing, July and September should control the design; August provides the next-critical check, while June and October, though lower, still require attention for early/late monsoon bursts, especially where antecedent wetness or operational constraints elevate risk.

Table 3 Rainfall for Return Period of 10, 25 and 50 Year

Year/Months	10-years	25-Years	50-years
	Predicted rainfall (mm)		
June	149.811	194.917	229.039
July	225.350	303.627	362.841
August	187.382	241.014	281.584
September	220.537	290.560	343.530
October	162.426	215.102	254.951

Conclusions

This study analyzed rainfall trends in Karnataka using daily data (2000–2022) to compute monthly and annual rainfall and predict values for 10-, 25-, and 50-year return periods. Statistical parameters such as mean, standard deviation, and coefficient of variation were calculated. Frequency analysis was performed using Normal and Log-Pearson Type III distributions, while long-term trends were determined using the 5-year moving average method. Results indicated that June to September receive the highest rainfall, with July recording the peak. The lowest variability (CV 47.34) occurred in July, while November showed the highest variation (CV 140.63). Maximum rainfall was estimated for a 25-year return period, with the highest predicted rainfall again in July, followed by August, June, and September. Both statistical distributions showed maximum rainfall at 20% probability of exceedance. The trend analysis revealed an increasing trend in both monthly (June–October) and annual rainfall, indicating rising precipitation over time.

Data Availability Statement

The datasets generated during the current study are available from the corresponding author on reasonable request.

Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Funding

This research received no external funding.

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