EPH – International Journal of Mathematics and Statistics
ISSN:2208-2212
https://eijms.com/index.php/ms/issue/archive

CORRELATION BETWEEN FOREST FIRE OCCURRENCE AND CLIMATIC VARIABLES IN RANCHI: A STATISTICAL ANALYSIS

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ARTICLE INFO

Received: 02/06/2026
Revised: 05/07/2026
Accepted: 12/07/2026
Published: 20/07/2026

DOI:xyz
Volume:12, Issue:02, April, 2026

Abstract

Forest fire exerts a considerable influence on the ecosystem, biodiversity, carbon cycling and environmental sustainability. Forest fire occurrence has been higher and more pronounced in tropical regions because of climate fluctuations. Events involving forest fires have increased in frequency and severe due to increasing temperature and altered precipitation. The aim of this research is to evaluate the relationship between forest fires, rainfall and temperature during the last 30 years in Ranchi District, Jharkhand, India. The data were statistically analyzed to identify climatic influence on forest fire occurance for annual data between 2004-2025.

Descriptive statistics were used to analyze forest fire records. An analysis of trends showed a notable rise in fire incidents following 2019. Annual rainfall ($r = 0.522$, $p = 0.013$) and mean annual temperature ($r = 0.585$, $p = 0.004$) showed a significant positive association with Pearson correlation. 51.8% of the variation in the yearly occurrence of forest fires was explained by the regression equation (R2 = 0.518). Based on the seasonal analysis, 93.5% of the fire events took place prior to the monsoon season, and The months with the highest number of fire incidents were March and April.

The results revealed that the forest fire activity in Ranchi District is significantly affected by climate variability. They emphasize the importance of fire management based on climate, early warning systems and sustainable forest conservation planning.

Keywords: Forest Fire; Climate Change; Rainfall; Temperature; Multiple Regression

1. Introduction

One of the most destructive natural disasters endangering land ecosystems worldwide is forest fires.They reduce biodiversity, forest output, nutrient cycling, and ecosystem functions. Uncontrolled fires cause economic damage, reduce soil fertility, disrupt water cycles, destroy wildlife habitats, and increase greenhouse gas emissions, thereby contributing to climate change.

The increase in forest fire occurrences linked to global warming has been ascribed to higher temperatures, extended drought periods, reduced fuel moisture, and alterations in precipitation patterns. The way in which climate variables affect forest fire activity has therefore been a major concern in environmental research.

Forest fires occur in thousands in India annually, primarily in tropical dry deciduous forests. Jharkhand is highly fire prone as a result of the abundance of Shorea robusta (Sal) forests, length of dry seasons, heavy leaf litter and the increase in human disturbances. The increase in Ranchi District has been very clear.

Over the past 20 years, forest fires. But, few studies have quantified the effects of rainfall and temperature on the incidence of forest fires at the District level.

Climate variability has been demonstrated to have an impact on forest fires via fuel accumulation and moisture. Precipitation stimulates plant growth which leads to more fuels, and warmer temperatures cause fuels to dry up and increase their potential to ignite. These factors are interrelated and help to explain forest fire occurrence and intensity. This framework informed the choice of variables and the statistical analysis and interpretation of the study results.

2.Study Area

Ranchi District is located in the eastern region of Jharkhand, India, on the Chotanagpur Plateau. With an average height of roughly 620 meters above mean sea level, it spans latitudes 23°00′-23°50′ N and longitudes 84°50′-85°50′ E.

The area has a tropical monsoon climate, with scorching summers and distinct monsoon seasons and chilly winters. It gets approximately 1,495 mm per year of rainfall, and the annual averaged temperature is approximately 12.5 deg. C.

23.2°C. Tropical dry deciduous forests, primarily consisting of Shorea robusta (Sal), occupy a large area of the district, rendering it considerably exposed to seasonal forest fires.

3.Data and Methodology

The data on annual forest fires (2004-2025) were retrieved from official government databases. Information regarding yearly precipitation and average temperature was obtained from meteorological agencies. IBM SPSS Statistics and R software were used for statistical analyses.

3.1 Descriptive Statistics

Temporal variability of the climatic and forest fire data was summarized by descriptive statistical analysis. The following formula was used to determine the arithmetic mean, standard deviation, and coefficient of variation.

The arithmetic mean was calculated as

$$\bar{X} = \frac{1}{n}\sum_{i=1}^{n} X_i$$

where $\bar{X}$ is the mean, X_i represents the i^{th} observation, and n is the total number of observations.

The dispersion of observations around the mean is measured by the sample standard deviation, which was calculated as

$$S = \sqrt{\frac{\sum_{i=1}^{n} (X_i - \bar{X})^2}{n-1}}$$

where S denotes the sample standard deviation.

To evaluate the relative variability among different climatic elements, the coefficient of variation, expressed as a percentage, was computed as

$$CV = \frac{S}{\bar{X}} \times 100$$

where S is the standard deviation, CV is the coefficient of variation (%), and $\bar{X}$ is the arithmetic mean.

The coefficient of variation is a dimensionless measure of variability and can be used to compare standard deviations of sets of data that have different units or values. A larger CV value indicates that the data is more spread around the mean, while a smaller one means that the data is closer together. The yearly rainfall's long-term patterns, seasonal temperature and forest fire occurrences were characterized by these descriptive statistical measures over the study period in Ranchi District.

3.2 Mann-Kendall Trend Test

To determine whether there were statistically significant monotonic trends in the frequency of forest fires and meteorological factors during the course of the study, the Mann-Kendall trend test was employed. Due to its non-normal distribution dependence and lack of sensitivity to outliers, the Mann-Kendall test is frequently used in hydrological and environmental studies. The Mann-Kendall test statistic (S) was computed using

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \mathrm{sgn}(X_j - X_i)$$

where observations at times i and j are represented by Xi and Xj, respectively. The sign function is defined as

$$\mathrm{sgn}(x) = \begin{cases} 1, & x > 0 \\ 0, & x = 0 \\ -1, & x < 0 \end{cases}$$

The test statistic was adjusted to a normal distribution for sample sizes larger than ten ($n > 10$) using.

$$Z = \begin{cases} \dfrac{S-1}{\sqrt{\mathrm{Var}(S)}}, & S > 0 \\ 0, & S = 0 \\ \dfrac{S+1}{\sqrt{\mathrm{Var}(S)}}, & S < 0 \end{cases}$$

where the variance of the Mann-Kendall statistic is represented by Var(S). Values of Z that are positive show an upward trend, while negative values reflect a downward trend. Statistical significance was assessed at the 95% confidence level ($\alpha = 0.05$).

3.3 Sen's Slope Estimator

The degree of temporal trends found by the Mann-Kendall test was measured using Sen's slope estimator. This non-parametric approach accurately calculates the median rate of change and is insensitive to outliers.
Sen's slope (β) was calculated as

$$\beta = \mathrm{Median}\left(\frac{X_j - X_i}{j - i}\right), i < j$$

where observations at times i and j are represented by Xi and Xj, respectively. A negative β number denotes a downward tendency, while a positive β value indicates an upward trend. The estimated slope is the median change in the variable over a year.

3.4 Correlation Analysis

The relationship of climatic variables (annual rainfall and mean annual temperature) with annual forest fire occurrence was carried out by using correlation analysis. The product-moment correlation coefficient from Pearson and the rank correlation coefficient from Spearman were computed, respectively, for considering the linear and monotonic association.
The Pearson correlation coefficient (r) was calculated as

$$r = \frac{\sum_{i=1}^{n}(X_i - \bar{X})(Y_i - \bar{Y})}{\sqrt{\sum_{i=1}^{n}(X_i - \bar{X})^2 \sum_{i=1}^{n}(Y_i - \bar{Y})^2}}$$

where X_i and Y_i represent paired observations of two variables, and $\bar{X}$ and $\bar{Y}$ denote their respective means.
Pearson's coefficient (r) varies between -1 and +1, where negative values indicate an inverse connection and positive values indicate a direct association. Spearman's rank correlation coefficient (ρ) was additionally computed to evaluate monotonic relationships without assuming normality of the data. Statistical significance of the correlation coefficients was tested at the 95% confidence level ($p < 0.05$).

3.5 Multiple Linear Regression Analysis

Multiple linear regression analysis was used to assess the combined effect of annual rainfall and mean annual temperature on forest fires. The regression model is expressed as

$$FF = \beta_0 + \beta_1 R + \beta_2 T + \varepsilon$$

Where, FF= Annual Forest fire occurrence,
R = Annual rainfall (mm),
T = Mean annual temperature (°C)
β_0 = Regression intercept
β_1 = Regression coefficient for rainfall
β_2 = Regression coefficient for temperature
ε = Random error term

The ordinary least squares approach was used to estimate the regression coefficients. The statistical significance of individual predictors was evaluated using Student's t-test, while the overall model performance was assessed using the coefficient of determination (R2), adjusted R2, the F-test, and associated p-values. Before interpreting the model, the assumptions of linearity, independence of residuals, homoscedasticity, normality of residuals, and multicollinearity were assessed to validate the regression model. These analyses allowed for the measurement of the relative impacts of rainfall and temperature on changes in yearly forest fire incidents in Ranchi District.

4.Results and Discussion

4.1 Descriptive Statistics

Forest fire occurrence exhibited considerable interannual variability, ranging from 7 to 766 incidents, indicating substantial climatic and anthropogenic influences.

Table 1. Descriptive statistics of study variables

Variable	Mean	SD	Minimum	Maximum
Forest Fire	105.4	178.8	7	766
Rainfall (mm)	1494.5	403.5	854.7	2553.3
Temperature (°C)	23.17	0.61	22.2	24.5

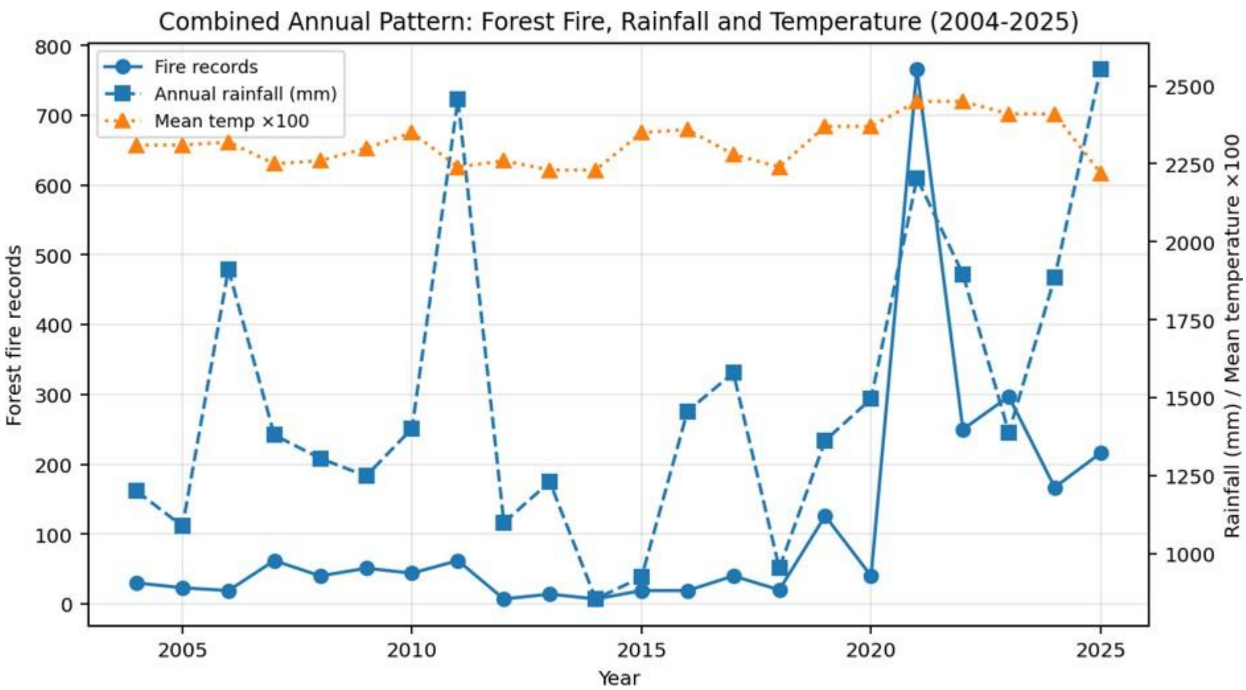

Figure 2. Annual Forest Fire Trend

Over the course of the study, trend analysis showed a rising tendency in forest fires, with a notable acceleration of fire incidents since 2019. The number of fire events was highest in 2021 (766), indicating higher fire susceptibility from climate changes.

4.2 Correlation Analysis

In addition to an association between temperature and the frequency of annual forest fires, a statistically significant positive correlation was found between rainfall and the frequency of annual forest fires. This is a stronger relationship with temperature, suggesting that higher temperatures are likely to lead to increased fire activity through the effects of decreased vegetation moisture and increased fuel flammability.

Table 2. Pearson correlation coefficients

Variable	r	p-value
Rainfall	0.522	0.013
Temperature	0.585	0.004

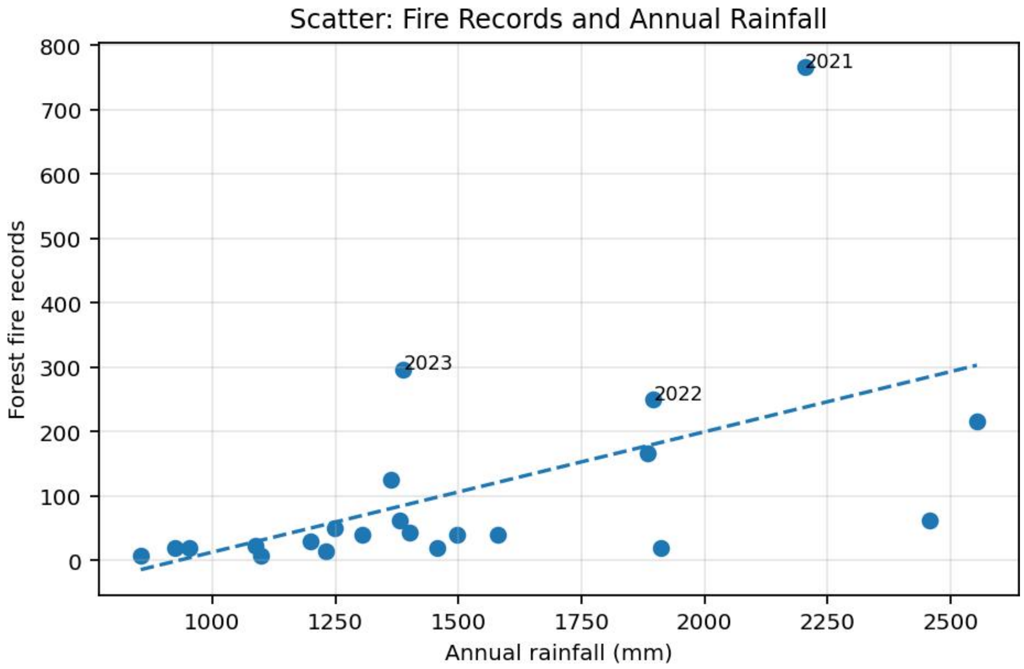

Figure 3. Scatter Plot: Forest Fire vs Rainfall

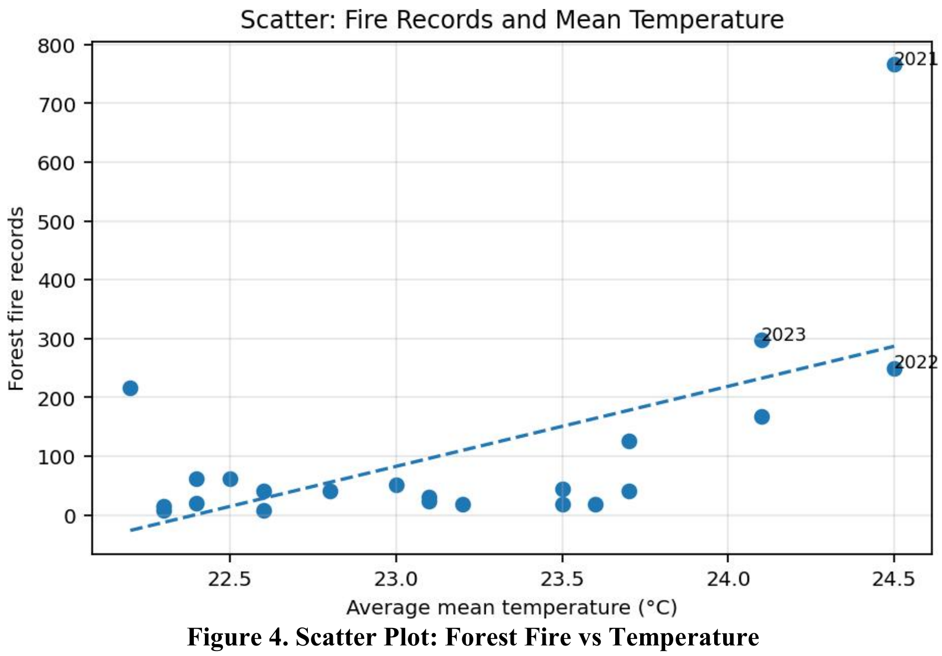

Figure 4. Scatter Plot: Forest Fire vs Temperature

4.3 Multiple Regression Analysis

To evaluate the relationship between the climatic variables and the annual frequency of forest fires, a multiple linear regression model was developed using annual rainfall and mean annual temperature as independent variables and annual forest fire occurrence as the dependent variable [29].

The observed and model-predicted forest fires had a strong positive association (R = 0.720), according to the regression analysis results. 51.8% of the yearly forest fire occurrence variability was explained by the model (Coefficient of determination (R^2) = 0.518 and an adjusted R^2 = 0.468). The modified R2 shows that the combination of temperature and rainfall accounts for roughly 46.8% of the variation in the number of forest fires after adjusting for the number of

predictor variables.
The fitted regression equation is

$$FF = -2847.2 + 0.153R + 117.6T$$

where,
FF= Predicted annual forest fire occurrence,
R= Annual rainfall (mm),
T= Mean annual temperature (°C).
The regression coefficient for Temperature (117.6) indicates a rise of 118 forest fires annually for each 1°C increase in average yearly temperature, assuming rainfall remains unchanged. Likewise, the rainfall coefficient (0.153) is the change in annual fire frequency for every mm of annual rainfall increase (with temperature unchanged). The positive coefficient might indicate indirect effects of rainfall on fire occurrence, due to higher vegetation growth and subsequent fuel buildup, but this has not been confirmed.
The interpretation of relationship should be made with caution since fire dynamic is also influenced by the distribution of rainfall during the season, antecedent wetness and human activities.

Table 3. Regression model summary

Parameter	Value
R	0.720
R^2	0.518
F	10.224
p-value	0.001

The results showed that annual rainfall and mean temperature both are significant factors affecting forest fire occurrence. Rainfall increases vegetation growth and fuel buildup, and higher temperatures increase fuel drying and potential for ignition. The model's reliability may be verified because the Durbin-Watson statistic for the residuals (2.623) indicates that there is no discernible autocorrelation in the residuals [30]. This was a statistically significant regression model ($p < 0.01$) indicating the climatic variables are important predictors of forest fire occurrence in Ranchi District.

4.4 Seasonal Distribution of Forest Fires

During the post-monsoon months (October-November), forest fire occurrence remained very low, with only 1 fire recorded in October and 17 in November. Although rainfall declined, temperature was apparently lower, which helped to mitigate fuel drying and ignition problem. Fire activity remained low during the winter months (December-February) but gradually increased from 23 incidents in January to 71 in February, marking the transition toward the pre-monsoon fire season.

Table 4. Seasonal distribution of forest fire occurrence

Season	Fire Records	Fire Share (%)	Avg. Rainfall (mm)	Avg. Mean Temp. (°C)
Monsoon	5	0.22	309.2	26.77
Post-monsoon	18	0.78	47.35	21.20
Pre-monsoon	2168	93.49	40.61	26.74
Winter	128	5.52	13.70	16.08

Approximately 93.5% of all documented forest fires occurred in the pre-monsoon season, specifically in March and April. The months are marked by elevated temperatures and reduced relative humidity, dry foliage, and increased fuel amounts, creating favorable conditions for fire initiation and proliferation.
The monthly trend indicates a significant inverse relationship between the incidence of forest fires and rainfall. During dry months and high temperatures, fire is most active, and during the rainy months and low temperatures, the fire activity is minimal, and

The monsoons with high rainfall provide very little fire activity. These conclusions suggest that seasonal climatic variables are a more critical factor in determining the occurrence of fire than is the annual mean.

Table 5. Month-wise Fire Records with Climatic Averages

Month	Fire Records	Fire Share (%)	Avg. Rainfall (mm)	Avg. Max. Temp. (°C)	Avg. Mean Temp. (°C)	Season
Jan	23	0.99	11.50	23.08	14.75	Winter
Feb	71	3.06	18.92	26.45	18.39	Winter
Mar	1161	50.06	26.15	30.79	22.72	Pre-monsoon
Apr	841	36.27	23.75	35.85	27.75	Pre-monsoon
May	166	7.16	71.93	36.58	29.75	Pre-monsoon
Jun	4	0.17	229.2	34.20	28.75	Monsoon
Jul	0	0.00	364.4	30.40	26.26	Monsoon
Aug	0	0.00	349.3	30.06	26.18	Monsoon
Sep	1	0.04	294.0	30.15	25.88	Monsoon
Oct	1	0.04	88.46	28.75	23.31	Post-monsoon
Nov	17	0.73	6.23	26.21	19.09	Post-monsoon
Dec	34	1.47	10.69	23.45	15.10	Winter

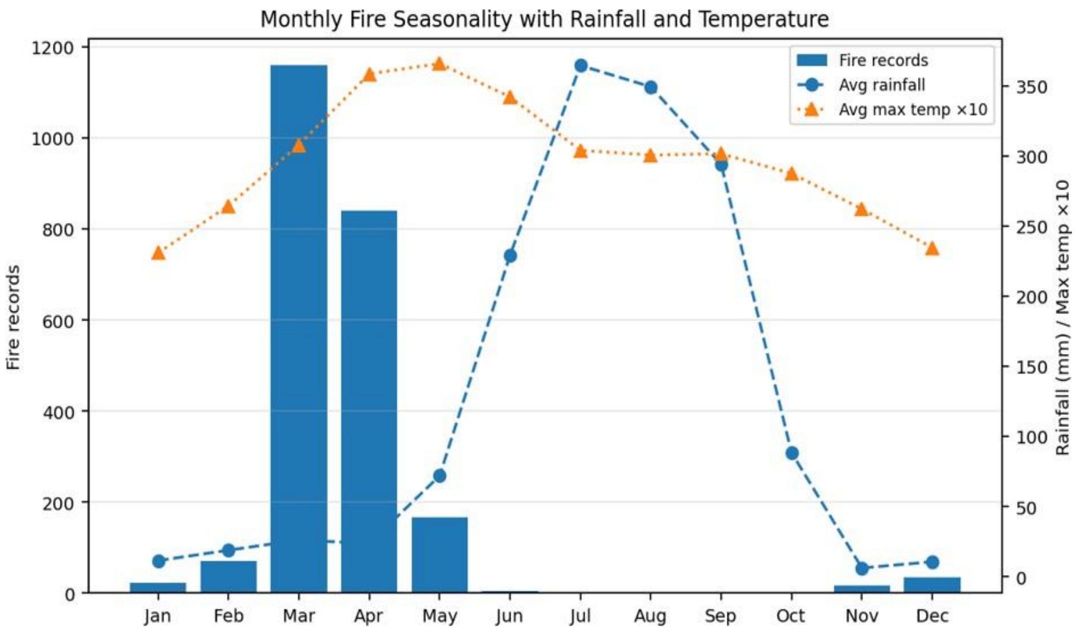

Figure 2: Monthly Fire Seasonality Compared with Average Monthly Rainfall and Maximum Temperature

4.5 Correlation Between Monthly Forest Fire Records and Climatic Variables

Pearson correlation analysis was used to examine the relationship between monthly forest fire data and climatic conditions. The results revealed that average rainfall is negatively correlated with fire occurrence ($r = -0.369$) and the correlation was not statistically significant ($p = 0.238$).

The average minimum temperature showed nearly no association with monthly fire data ($r = 0.006$, $p = 0.985$). There was a positive association between the average temperature ($r = 0.163$, $p = 0.614$) and the normal peak temperature ($r = 0.375$, $p = 0.230$), but not significantly, correlated at the monthly time scale, indicating that warmer temperatures are associated with an increase in fire occurrence, but with low individual impact on the monthly scale.

5.Conclusion

The results show that forest fire activity is seasonal and climate forcing in a complex manner by the rainfall, temperature, moisture availability and fuel availability and condition and not by any one of these climatic factors. Forest fires occurred with significant differences between years, with a sharp rise post 2019. This is despite the fact that over 80% of all recorded fire incidents were actually in the period of 2019 to 2025, reflecting a strong change in the regional fire regime over this time.

The forest fire occurrence was significantly correlated and positively correlated with annual rainfall, monsoon rainfall, average maximum temperature and average mean temperature, respectively, from the correlation and regression analyses. There was the strongest association between average mean temperature and fire occurrence. The positive rainfall-fire relationship indicates that increased rainfall contributes to increased vegetation growth and fuel accumulation, which will further lead to an increase in fire potential during the dry season.

The most convincing evidence for climatic control of fire occurrence was obtained from a seasonal and monthly analysis. The pre-monsoon season accounted for almost 94% of all fires and March-April alone recorded about 86% of fires. These months are known for low precipitation, high temperatures and dry fuel that allows for ignition and spreading of fire. During the monsoon season, there was a near absence of fire in occurrence, in other words, moisture was a key factor in reducing fire activity.

The results indicate that occurrence of forest fires in Ranchi is essentially seasonal, due to pre-monsoon dryness, accumulation of fuels, and climate warming. Climatic variables are, however, not sufficient to fully account for the variability in fire. Additional elements, including human actions, land utilization, fuel categories, forest stewardship, and fire monitoring and reporting systems, contribute to the recognized fire patterns as well.

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