Unusual Rainfall Patterns in Kolkata in 2021:
A Statistical Analysis of Seasonal Distribution Anomalies

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Abstract

This paper examines the unusual rainfall distribution patterns observed in Kolkata during 2021, characterized by significant departures from long-term seasonal norms. Using monthly precipitation data from the India Meteorological Department spanning the period 1951-2021, we analyze seasonal rainfall contributions and their year-over-year variations. Our analysis reveals that 2021 experienced a fundamental redistribution of seasonal precipitation, with annual rainfall totaling 2,112.7 mm compared to the long-term normal of 1,713.5 mm. Multiple linear regression analysis demonstrates that actual 2021 seasonal contributions explain 93.16% of the variance in rate-of-change patterns, indicating systematic departures from historical precipitation patterns. The findings have significant implications for water resource management and agricultural planning in the region.

The paper ends with “The End”

1 Introduction

Kolkata’s climate is characterized by a tropical monsoon pattern with distinct seasonal rainfall distribution. The Southwest Monsoon typically contributes approximately 75% of annual precipitation, occurring primarily during June through September. Understanding variations in this seasonal pattern is crucial for urban planning, water resource management, and agricultural activities in the region.

The year 2021 presented particularly notable departures from established precipitation patterns, warranting detailed statistical analysis to quantify these changes and their implications for regional climate variability.

2 Data and Methodology

2.1 Data Sources

Monthly rainfall data were obtained from the India Meteorological Department for Kolkata meteorological station. Normal values represent the 1951-2000 climatological average, while 2021 data reflect observed precipitation totals for each month.

2.2 Statistical Framework

We define the seasonal contribution ratio for month i as:

$$R_i = \frac{P_i}{\sum_{j=1}^{12} P_j} \tag{1}$$

where P_i represents precipitation in month i.

The rate of ratios metric quantifies relative changes in seasonal contribution:

$$\text{Rate of Ratios}_i = \frac{R_{i,2021}}{R_{i,\text{normal}}} - 1 \tag{2}$$

We employ multiple linear regression to examine relationships between seasonal contributions and their variations:

$$\text{Rate of Ratios} = \alpha + \beta_1 \cdot R_{\text{normal}} + \beta_2 \cdot R_{2021} + \epsilon \tag{3}$$

3 Results

3.1 Monthly Rainfall Distribution

Table 1 presents the complete monthly rainfall comparison between normal climatological values and 2021 observations.

Table 1: Monthly Rainfall Distribution: Normal vs 2021

Month	Normal Monthly Rainfall (mm)	2021 Rainfall (mm)	Normal Ratio	2021 Ratio	Rate of Ratios
January	14.7	0.1	0.0086	0.0000	-1.0000
February	23.8	0.7	0.0139	0.0003	-0.9784
March	34.9	4.8	0.0204	0.0023	-0.8873
April	52.3	22.3	0.0305	0.0106	-0.6525
May	110.5	257.7	0.0645	0.1220	0.8915
June	278.4	371.6	0.1625	0.1759	0.0825
July	363.2	420.2	0.2120	0.1989	-0.0618
August	336.1	263.2	0.1962	0.1246	-0.3650
September	309.3	488.9	0.1805	0.2314	0.2822
October	156.1	189.9	0.0911	0.0899	-0.0132
November	25.2	25.9	0.0147	0.0123	-0.1633
December	9.0	67.3	0.0053	0.0319	5.0189
Annual Total	**1,713.5**	**2,112.7**	**1.0000**	**1.0000**	—

3.2 Seasonal Pattern Analysis

The analysis reveals several notable departures from normal seasonal distribution patterns. The winter months (December through April) experienced significantly reduced precipitation, with rate of ratios ranging from -100% to -65.25%. Conversely, May and September demonstrated substantial increases in their proportional contributions to annual rainfall.

December 2021 represents the most extreme departure, recording 67.3 mm compared to the normal 9.0 mm, resulting in a rate of ratios exceeding 500%. This exceptional increase fundamentally altered the typical dry winter pattern.

3.3 Regression Analysis Results

Multiple linear regression analysis examining the relationship between seasonal rainfall ratios and their rate of change yields the following results:

$$\text{Rate of Ratios} = -0.9123 - 0.5844 \cdot R_{\text{normal}} + 24.8673 \cdot R_{2021} \tag{4}$$

Table 2 presents comprehensive regression statistics.

Table 2: Multiple Linear Regression Statistics

Model Summary	
Multiple R	0.9652
R Square	0.9316
Adjusted R Square	0.9164
Standard Error	0.4712
Observations	12
ANOVA	
F-Statistic	61.19
Significance F	1.24×10^{-6}
Coefficients	
Intercept (α)	-0.9123^{***}
	(0.1551)
Normal Ratio (β_1)	-0.5844
	(1.4229)
2021 Ratio (β_2)	24.8673^{***}
	(2.1085)

Standard errors in parentheses
*** $p < 0.001$

4 Discussion

4.1 Statistical Interpretation

The regression model demonstrates exceptional explanatory power, with an R-squared value of 0.9316 indicating that 93.16% of variance in rate-of-change patterns is explained by the seasonal ratio variables. The F-statistic of 61.19 with associated p-value of 1.24×10^{-6} provides strong evidence of overall model significance.

The coefficient analysis reveals asymmetric effects between normal and actual seasonal contributions. The 2021 ratio variable exhibits an extremely large and statistically significant coefficient (24.8673, $p < 0.001$), while the normal ratio coefficient proves statistically insignificant ($p = 0.6915$). This pattern indicates that actual 2021 seasonal distribution patterns dominated the rate-of-change dynamics, effectively overwhelming historical seasonal norms.

4.2 Meteorological Implications

The analytical results demonstrate that 2021 experienced fundamental redistribution of seasonal precipitation patterns rather than uniform scaling of typical seasonal contributions. The exceptional December rainfall and enhanced May precipitation suggest altered atmospheric circulation patterns affecting the region's water cycle.

The reduced contribution from traditional monsoon months (July and August) combined with increased September precipitation indicates potential shifts in monsoon timing and intensity characteristics. These changes have significant implications for agricultural scheduling and water resource planning.

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4.3 Limitations and Considerations

The analysis is constrained by the single-year focus and limited sample size inherent in monthly data analysis. The December outlier, while representing genuine meteorological conditions, exerts substantial influence on regression parameters. Future research should examine multi-year patterns to distinguish between isolated anomalies and systematic climate shifts.

5 Conclusion

The statistical analysis confirms that 2021 represented an exceptional year for Kolkata's rainfall patterns, characterized by fundamental departures from established seasonal distribution norms. The regression model successfully quantifies these departures, demonstrating that actual seasonal contributions in 2021 were the primary determinant of rate-of-change patterns.

These findings have practical implications for water resource management strategies and agricultural planning in the region. The observed patterns suggest increasing variability in seasonal precipitation distribution, highlighting the importance of adaptive management approaches for regional water security.

Future research should examine longer time series to determine whether 2021 represents an isolated anomaly or indicates systematic changes in regional precipitation patterns consistent with broader climate change impacts on monsoon systems.

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