Climatic Analysis of Manipal (2011–2026)

1 Introduction and Data Overview

This report presents a climatic analysis of daily atmospheric data for Manipal, India (latitude 13.321617°, longitude 74.79452°, elevation 97 m, timezone Asia/Kolkata). The dataset spans from **January 4, 2011 to January 4, 2026** and consists of daily meteorological observations.

The primary objective of this analysis is to study long-term trends in temperature and precipitation and to quantify potential signals of climate change using simple and interpretable methods.

The key variables considered in this report are:

- **Temperature at 2 m (daily mean, °C)**
- **Daily precipitation sum (mm)**

Additional atmospheric variables such as radiation, humidity, wind, pressure, dew point, and soil moisture were available in the dataset but were not directly used for trend quantification.

2 Exploratory Data Analysis

2.1 Temperature Time Series

The daily temperature time series exhibits strong short-term variability along with a clear annual cycle. This periodic structure reflects seasonal heating and cooling patterns characteristic of coastal Karnataka. Despite daily fluctuations, the temperature signal appears stable and continuous across the full time range.

2.2 Precipitation Time Series

In contrast, the daily precipitation series is highly intermittent. Long periods of zero or low rainfall are interrupted by sharp spikes corresponding to rainfall events. This episodic behavior highlights the fundamentally different nature of precipitation compared to temperature and suggests higher inherent variability.

2.3 Monthly Aggregates

Monthly mean temperature and monthly total precipitation were computed to smooth high-frequency noise and highlight seasonal patterns. Temperature follows a repeatable annual cycle, while precipitation shows strong seasonal concentration, consistent with monsoon-dominated rainfall.

2.4 Distributional Characteristics

The temperature distribution is relatively narrow and approximately unimodal, indicating a stable climatic range with moderate seasonal spread. The precipitation distribution is strongly right-skewed, with many low-precipitation days and occasional extreme rainfall events. This skewness explains why precipitation trends are more difficult to quantify.

3 Trend Quantification Methodology

To satisfy the requirement of quantifying long-term climate trends, a simple linear regression model was applied to yearly aggregated data:

- **Temperature:** yearly mean of daily temperature values
- **Precipitation:** yearly sum of daily precipitation values

Linear regression was chosen for its simplicity and interpretability, allowing direct estimation of average rates of change over time.

4 Results

4.1 Temperature Trend

The linear regression applied to yearly mean temperature produced the following results:

- **Slope:** 0.0480 °C/year (0.480 °C per decade)
- R^2**:** 0.303

The positive slope indicates a gradual warming trend over the 2011–2026 period. An R^2 value of approximately 0.30 implies that the linear trend explains about 30% of the inter-annual temperature variability, which is substantial for climatic data.

4.2 Precipitation Trend

The regression applied to yearly total precipitation yielded:

- **Slope:** 12.51 mm/year (125.1 mm per decade)

- **R^2:** 0.003

While the fitted slope is positive, the near-zero R^2 value indicates that the linear model explains almost none of the observed variability. Year-to-year fluctuations dominate the precipitation signal.

5 Interpretation

5.1 Temperature

The observed warming rate of approximately 0.48 °C per decade suggests a consistent upward trend in temperature during the study period. Although daily and yearly variability exists, the linear trend captures a meaningful portion of the overall signal. This result aligns with broader regional and global observations of gradual warming.

5.2 Precipitation

Precipitation does not exhibit a clear linear trend. The extremely low R^2 value indicates that annual rainfall totals are dominated by inter-annual variability rather than a steady increase or decrease. This suggests that precipitation changes may be driven more by shifts in timing, intensity, or frequency of rainfall events rather than total yearly accumulation.

6 Discussion

The contrasting behavior between temperature and precipitation highlights important climatic differences. Temperature evolves smoothly and is well-suited to linear trend analysis. Precipitation, on the other hand, is episodic and highly variable, making simple linear models less informative.

Rainfall patterns in the region may be influenced by monsoon dynamics, extreme events, and large-scale climate oscillations, which are not adequately captured by yearly linear regression.

7 Limitations

Several limitations should be noted:

- Linear regression does not capture non-linear or seasonal-specific changes.
- Yearly aggregation smooths extreme rainfall events.
- The dataset spans approximately 15 years, which is relatively short for definitive climate trend analysis.

8 Conclusions

The analysis reveals a **clear warming trend** in Manipal, with an estimated increase of approximately 0.48 °C per decade between 2011 and 2026. In contrast, precipitation shows **no robust linear trend**, with variability dominating the signal.

Overall, the results suggest that temperature changes are more consistent and detectable than rainfall changes over the analyzed period. Detecting meaningful precipitation trends likely requires non-linear, seasonal, or event-based approaches.