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Trend analysis of annual and seasonal temperature and rainfall variability at Lucknow (U.P) (1979-2016) using non-parametric tests

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Abstract
Temperature and rainfall are key climatic drivers of crop productivity in the rice–wheat and sugarcane-based cropping systems of Central Uttar Pradesh. This study examined long-term (1979–2016) annual and seasonal variability and trends in maximum temperature (TMAX), minimum temperature (TMIN), diurnal temperature range (TRAN), mean temperature (Tmean), and rainfall at Lucknow using descriptive statistics and non-parametric tests. Daily weather data from the Agrometeorological Observatory, IISR, Lucknow were analyzed for inter-annual variability (mean, SD, CV, skewness, kurtosis) and trend detection using the Mann–Kendall test, Sen's slope estimator, and Pettitt's change-point test. TMAX showed high stability (CV = 1.86%) with a non-significant decreasing trend (−0.130°C decade^{-1}), while TMIN exhibited a significant increasing trend (+0.188°C decade^{-1}, $p = 0.011$), driven by high-frequency warm-night events after 2005. Consequently, TRAN declined significantly (−0.238°C decade^{-1}, $p < 0.01$), and Tmean showed a non-significant warming trend (+0.140°C decade^{-1}). Rainfall exhibited high inter-annual variability (CV = 25.74%) with positive skewness, indicating elevated risk for rainfed kharif rice establishment. The asymmetric warming pattern — rising night temperatures with narrowing diurnal range rather than hotter days — has direct implications for respiration losses, grain-filling duration, and sucrose accumulation in sugarcane. These findings suggest the need for agronomic adaptation strategies including advancement of wheat sowing windows, adoption of heat-tolerant varieties, and refined nitrogen management under a changing climate in the Indo-Gangetic Plain.

Keywords: Temperature variability, rainfall variability, Mann–Kendall test, diurnal temperature range, climate change adaptation

Introduction

Climate is the most important non-monetary input that governs agricultural productivity and determines the cropping pattern of a region. Among climatic parameters, temperature and rainfall are the two decisive factors that control crop growth, development, and yield through their direct influence on physiological processes such as photosynthesis, respiration, transpiration, and phenological development (Aggarwal, 2008; Hatfield and Prueger, 2015) [1, 3]. Any long-term alteration in their mean, variability, or extremes has direct consequences for food security, especially in densely populated agrarian regions.

India has experienced a significant rise in annual mean temperature by about 0.63°C per 100 years, with winter and post-monsoon seasons warming more rapidly than monsoon season (Kothawale and Rupa Kumar, 2005; IMD, 2022) [7]. The warming is more pronounced in minimum temperature (TMIN) than maximum temperature (TMAX), leading to a decrease in diurnal temperature range (TRAN) in many parts of the country. For crop plants, an increase in TMIN is more detrimental than an increase in TMAX, as it increases maintenance respiration during night, reduces net assimilation, and shortens the grain filling duration in cereals like wheat and rice (Lobell and Ortiz-Monasterio, 2007; Peng *et al.*, 2004) [8, 11].

Uttar Pradesh contributes about 18% to the total food grain production of India and sustains a rice-wheat, sugarcane, and mustard based cropping system. Lucknow, falling under the Central Plain Zone (Agro-climatic Zone-V) of Uttar Pradesh, is characterized by a rice-wheat and sugarcane-mustard rotation. The productivity of these crops is highly sensitive to thermal and moisture regimes. For instance, wheat (Triticum aestivum L.) sown in rabi season requires a cool vegetative period with mean temperature around 15-20°C and a warm grain filling period, while even 1°C rise in mean temperature during reproductive stage can reduce wheat yield by 3-4% in North India (Aggarwal and Kalra, 1994) [2]. Similarly, high TMAX above 35°C during flowering in mustard (Brassica juncea L.) leads to pollen sterility and poor pod setting, while high TRAN affects oil content.

Rainfall variability is equally critical for agronomy in Lucknow region. Although the average annual rainfall of the region is about 860 mm, more than 80% of which is received during the southwest monsoon (June-September), its distribution is highly erratic. The coefficient of variation (CV) of annual rainfall in Indo-Gangetic Plain often exceeds 25%, which directly affects the onset of monsoon, sowing window of kharif rice, and availability of residual soil moisture for rabi crops (Jain and Kumar, 2012) [5]. Delayed monsoon and prolonged dry spells during July-August affect tillering in rice, while excess rainfall during October-November delays wheat sowing and promotes late sown conditions, reducing yield potential by 30-40 kg ha^{-1} day^{-1}. The observed increase in Tmean and decrease in TRAN also alters the growing degree days (GDD) requirement and crop water requirement, necessitating a re-evaluation of crop calendars.

Despite its agronomic importance, a location-specific, long-term analysis of annual TMAX, TMIN, TRAN, Tmean, and rainfall for Lucknow is lacking for the recent climate change period (1979-2016). Most previous studies are confined to state or national averages, which often mask local agronomic realities. Descriptive statistics such as mean, standard deviation, CV, skewness, and kurtosis help in understanding the stability and risk associated with climatic parameters for crop planning. For example, high CV and positive skewness in rainfall indicate high risk for rainfed farming, while negative skewness in TMIN with high kurtosis indicates increased frequency of extreme cold or warm night events.

Non-parametric trend analysis tools like Mann-Kendall test and Sen's slope estimator are extensively used in agro-climatology because they are robust and do not assume normality of data (Mann, 1945; Sen, 1968) [10, 13]. Such analysis helps agronomists to quantify the rate of warming or change in rainfall per decade and to adjust agronomic practices such as variety selection, sowing time, and irrigation scheduling accordingly.

Therefore, the present investigation was carried out to (i) characterize the inter-annual variability of temperature and rainfall at Lucknow during 1979-2016 through descriptive statistics relevant to crop production, and (ii) assess the magnitude and direction of climatic trends to provide a scientific basis for agronomic adaptation strategies such as rescheduling of sowing windows, selection of thermo-tolerant varieties, and efficient water management under changing climate in Central Uttar Pradesh.

Materials and Methods

1. Study area

The present investigation was conducted at the Indian Institute of Sugarcane Research (IISR), Lucknow, located in the central plains of Uttar Pradesh (26.48° N latitude, 80.50° E longitude, and 111 m above mean sea level). The site falls under Agroclimatic Zone V, Central Plain Zone of Uttar Pradesh and is characterized by a humid subtropical climate with hot dry summers (March–June), wet monsoon season (July–September) and cool dry winters (October–February). The mean annual rainfall of the region is about 860 mm, of which more than 80% is received during southwest monsoon. Soils of the experimental farm are deep alluvial, sandy loam to silty loam in texture, classified as Inceptisols, with pH ranging from 7.8 to 8.2. The predominant cropping systems of the area are sugarcane-based systems (sugarcane-ratoon-wheat, sugarcane + mustard intercropping) and rice-wheat rotation.

2. Climatic data and compilation

Long-term daily weather data for the period of 38 years (1979–2016) recorded at the Agrometeorological Observatory, IISR, Lucknow were used for the study. The daily observations of maximum temperature (TMAX, °C), minimum temperature (TMIN, °C) and rainfall (mm) were collected from the observatory records. The daily data were subjected to quality check for missing values and outliers as per the World Meteorological Organization (WMO) guidelines. Short gaps of less than 3 days were filled by linear interpolation, while years with more than 10% missing data were excluded. From the daily data, annual values were computed. The diurnal temperature range (TRAN, °C) and mean temperature (Tmean, °C) were derived as:

$$TRAN = TMAX - TMIN$$

$$Tmean = (TMAX + TMIN) / 2$$

Annual rainfall was obtained by summing the daily rainfall of each calendar year (January to December).

3. Statistical analysis

3.1 Descriptive statistics

To characterize the inter-annual variability and distribution pattern of climatic parameters relevant to crop planning, descriptive statistics were computed for annual TMAX, TMIN, TRAN, Tmean and rainfall. The parameters included long-term mean, standard deviation (SD), coefficient of variation (CV), skewness and kurtosis.

CV (%) was calculated as:

$$CV = (SD / Mean) \times 100$$

Positive skewness indicates a longer tail towards higher values and negative skewness towards lower values. Positive kurtosis indicates a peaked distribution with higher frequency of extreme events, which is important for assessing climatic risks in agriculture.

3.2 Trend analysis

The trend in time series of annual TMAX, TMIN, Tmean, TRAN and rainfall was detected using the non-parametric Mann–Kendall (MK) test (Mann, 1945; Kendall, 1975) [6, 10]. The MK test is widely used in agro-climatology as it does not require data to be normally distributed and is insensitive to outliers.

The MK test statistic S was calculated as:

$$S = \Sigma_{k=1}^{n-1} \Sigma_{j=k+1}^{n} \operatorname{sign}(Xj - Xk)$$

where Xj and Xk are the annual values in years j and k, respectively, and sign is the signum function. The standardized test statistic Z was computed and tested at 5% and 1% levels of significance. A positive Z value indicates an increasing trend and a negative Z value indicates a decreasing trend. The magnitude of trend was estimated by Sen's slope estimator (Sen, 1968) [13], which gives the median of all pairwise slopes in the time series. The slope Q was expressed as °C $year^{-1}$ for temperature and mm $year^{-1}$ for rainfall. Change point in the time series, if any, was detected using Pettitt's test (Pettitt, 1979) [12] to identify the year of abrupt shift in climate, which is useful for rescheduling crop calendars. All statistical analyses were performed using MS-Excel, OPSTAT and XLSTAT 2020 software. The trend was considered significant when $p \leq 0.05$.

Results and Discussion

1. Descriptive statistics and inter-annual variability

The descriptive statistics of annual climatic parameters for Lucknow (1979-2016) [12] revealed distinct variability patterns (Table 1).

Annual TMAX ranged from 30.13°C (1997) to 33.18°C (1987) with a long-term mean of 31.48°C. The low standard deviation (0.58°C) and CV (1.86%) indicates high stability of day temperature over the years, which is favourable for stable phenological development of rabi crops. Skewness was slightly positive (0.35).

Annual TMIN varied from 15.66°C (1985) to 19.33°C (2010) with a mean of 18.21°C. The CV was 3.50% with a highly negative skewness (-1.93) and high kurtosis (6.70), indicating occasional occurrence of extremely low night temperatures during 1984-85. From an agronomic viewpoint, such low TMIN during tillering stage of wheat is beneficial, but its increasing frequency of high night temperature in recent years is a concern.

The diurnal temperature range (TRAN) averaged 13.27°C and varied from 11.99°C (2007) to 16.56°C (1985). CV was 6.44%, higher than TMAX and Tmean, indicating greater year-to-year fluctuation in day-night temperature difference. Tmean averaged 24.89°C with CV of 1.92%, showing a range of 23.93°C to 25.70°C.

For rainfall, as per long-term summary, mean annual rainfall was 860.10 mm with SD of 222.56 mm and CV of 25.74%. The high CV (>25%) and positive skewness (0.70) indicates high inter-annual variability and risk for rainfed kharif rice establishment. This high variability directly affects sowing window of rice and residual moisture for timely wheat sowing in rice-wheat system of Central UP.

Table 1: Descriptive statistics of annual temperature and rainfall at IISR, Lucknow (1979-2016) [12]

Statistic	TMAX (°C)	TMIN (°C)	TRAN (°C)	Tmean (°C)	Rainfall (mm)
Mean	31.48	18.21	13.27	24.89	860.10
Maximum	33.18 (1987)	19.33 (2010)	16.56 (1985)	25.70 (2015)	1300.00
Minimum	30.13 (1997)	15.66 (1985)	11.99 (2007)	23.93 (1997)	490.66
SD (±)	0.58	0.64	0.85	0.48	222.56
CV (%)	1.86	3.50	6.44	1.92	25.74
Skewness	0.35	-1.93	2.07	-0.12	0.70
Kurtosis	0.98	6.70	5.87	-0.89	0.67

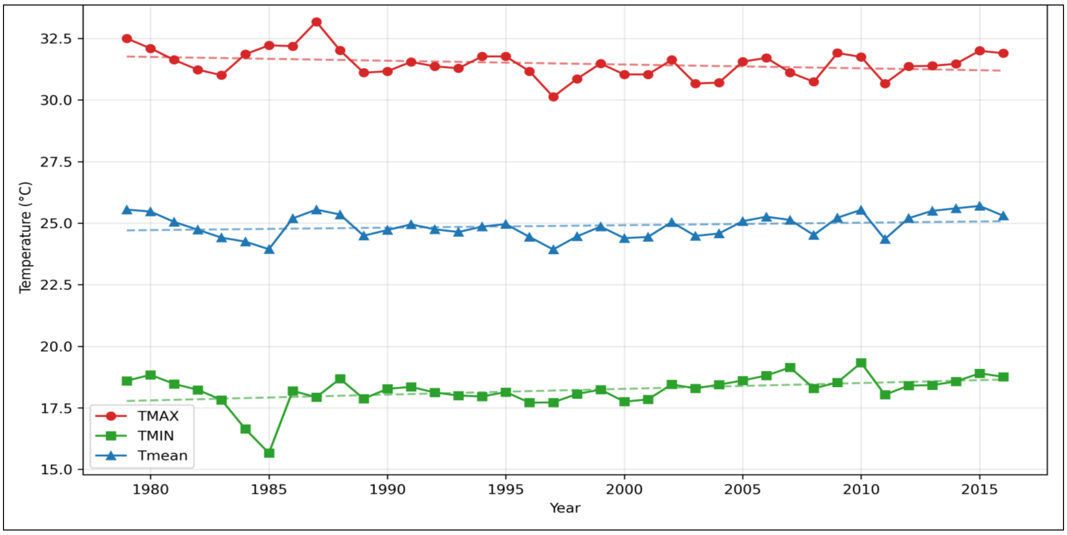

Fig 1: Inter-annual variation of annual TMAX, TMIN and Tmean at IISR, Lucknow (1979-2016) with linear trend

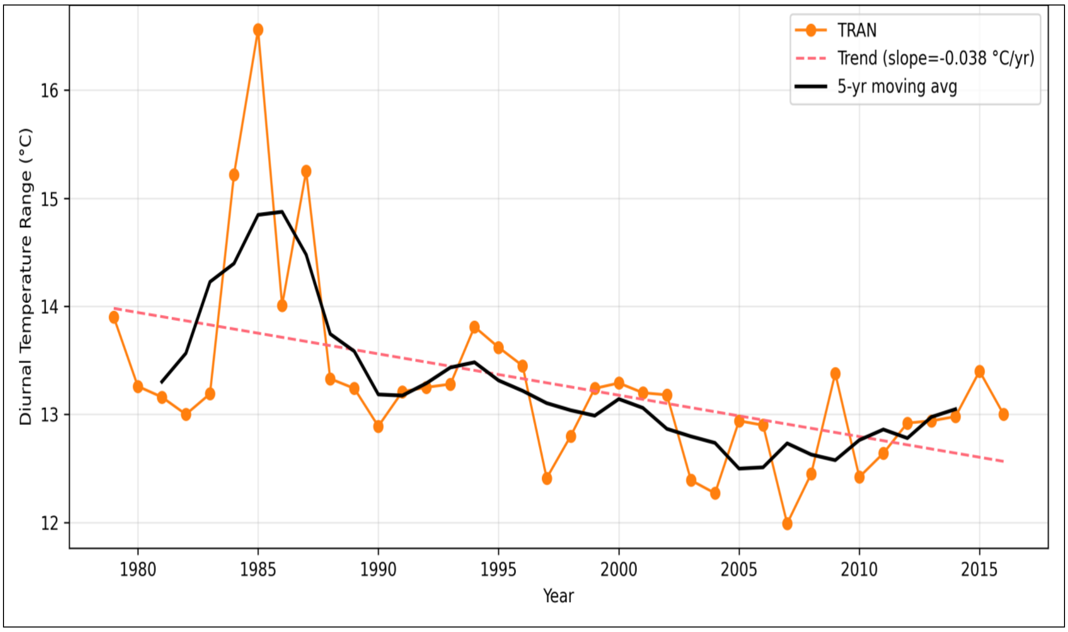

Fig 2: Inter-annual variation of diurnal temperature range (TRAN) with 5-year moving average showing decreasing trend

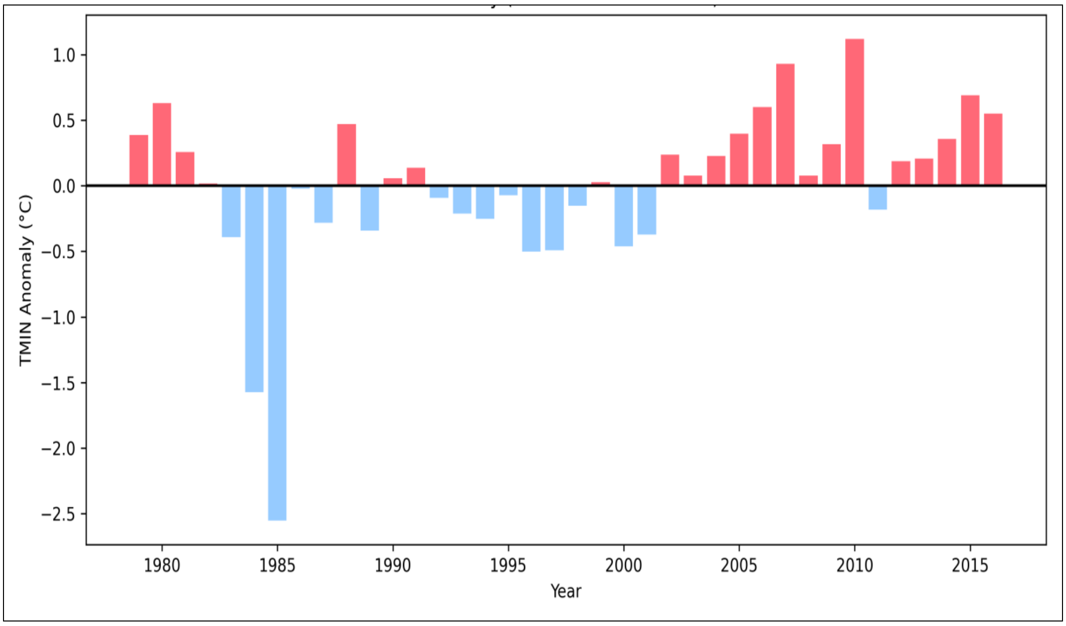

Fig 3: Annual TMIN anomaly (w.r.t. 1979-2016 mean) showing dominance of positive anomalies after 2005

2. Trennalysis using Mann-Kendall and Sen's slope

The non-parametric Mann-Kendall test revealed contrasting trends in temperature parameters (Table 2).

Table 2: Mann-Kendall trend test (Z) and Sen's slope for annual temperature at Lucknow (1979-2016)

Parameter	MK Z value	p-value	Sen's slope (°C $year^{-1}$)	Change per decade	Significance
TMAX	-1.48	0.138	-0.0130	-0.130°C	Non-significant decreasing
TMIN	+2.52	0.011	+0.0188	+0.188°C	Significant increasing ($p<0.05$)
TRAN	-2.93	0.003	-0.0238	-0.238°C	Significant decreasing ($p<0.01$)
Tmean	+1.52	0.128	+0.0140	+0.140°C	Non-significant increasing

Annual TMIN showed a significant increasing trend (Z=+2.52, p =0.011) at the rate of 0.188°C per decade (Fig.3). The anomaly graph clearly shows that after 2005, 9 out of 12 years recorded positive TMIN anomalies, with 2010 (+1.12°C) and 2007 (+0.93°C) being the warmest nights. Agronomically, this is the most critical finding. Night temperature is the main driver of maintenance respiration. Increase in TMIN by 1°C can increase respiration losses in wheat by 10-15% and reduce grain filling duration by 3-5 days, leading to 4-6% yield loss in North India (Lobell *et al.*, 2011). For sugarcane, higher TMIN during ripening phase (Oct-Feb) reduces sucrose accumulation and increases invertase activity, lowering recovery. TMAX showed a non-significant decreasing trend (-0.13°C per decade). This asymmetric warming, where TMIN is rising faster than TMAX, is a typical signature of greenhouse gas induced warming and increased cloudiness / aerosols over Indo-Gangetic Plain, as also reported by Kothawale and Rupa Kumar (2005) [7].

As a consequence, TRAN decreased significantly at -0.238°C per decade ($p<0.01$, Fig.2). The 5-year moving average shows TRAN was >14.5°C during 1984-1987 but dropped to <12.8°C after 2005. Reduction in TRAN is agronomically detrimental. High TRAN (cool nights and warm days) favours higher net photosynthesis and translocation of assimilates to grains. Decreasing TRAN indicates warmer nights, which reduces oil content in mustard and sugar content in sugarcane. Studies in Brassica juncea have shown that every 1°C decrease in TRAN during seed filling reduces oil content by 0.8-1.2%.

Tmean showed a non-significant increasing trend of 0.14°C per decade. Although statistically non-significant, the total increase of about 0.53°C over 38 years has shortened the growing degree days (GDD) accumulation pattern. For wheat, this may lead to forced maturity and for long-duration sugarcane varieties, it may reduce the effective vegetative growth period.

The high CV of rainfall (25.74%) combined with rising TMIN indicates increasing climatic risk for agriculture at Lucknow. The erratic rainfall affects the time of transplanting of rice, which in turn delays wheat sowing beyond the optimum window (15-25 November). Late sown wheat exposed to higher Tmean during grain filling suffers from terminal heat stress.

Conclusion

The climate of Lucknow is shifting towards warmer nights with narrower diurnal range, rather than hotter days. For agronomic adaptation, this necessitates (i) breeding and adoption of varieties with higher heat tolerance during night, (ii) advancement of wheat sowing by 7-10 days to escape terminal heat, and (iii) improved nitrogen management to compensate for higher respiration losses under elevated TMIN.

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