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**Research Paper**

# Assessing the trend of weather parameters and their effect on rice and jute yields in southern part of West Bengal

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**ABSTRACT**

Considering the global concern on climate change, understanding the spatiotemporal variability of meteorological variables and their impact on crop yield is crucial for an agricultural nation like India. In this work, we have analyzed the temperature and rainfall data for seven decades (1951-2020) over the southern part of West Bengal represented by four grid points using Mann-Kendall test and Sen's slope estimator. The results showed no significant trend in average annual maximum temperature, whereas, the average annual minimum temperature exhibited increase in trend at 95 % significance level among all the grids. However, the total yearly rainfall showed no trend, apart for the grid region centered in Bardhaman district showing an increasing trend. The correlation between 23 years (1997-2019) of yield data and climatic variables for different phenophases ranges from -0.47 to +0.72 for *Kharif* rice and -0.47 to +0.60 for jute. Climatic variables averaged over crop phenophases exhibit finer characteristics compared to annual averages and bear significant influence on yield variability as shown by multiple linear regression. Regression analysis indicates that temperatures play a more influential factor in determining *Kharif* rice yields than rainfall and yield equations pertaining to rice exhibits better sensitivity to varying climate than those representing jute yields.

***Keywords***: Climate change, Trend analysis, Temperature, Rainfall, Crop yield, Regression analysis.

The earth, being a dynamic planet, has been governed by interacting subsystems, mainly the atmosphere, hydrosphere, biosphere, and geosphere since its formation. Historically, the average atmospheric temperatures have fluctuated between 'icehouse' periods, marked by cooler global temperatures, and 'greenhouse' periods, characterized by warmer conditions (Scotese *et al.,* 2021). Given our understanding of Earth's past climate patterns, our primary focus should be on how to prepare for scenarios that have historically posed existential challenges to dominant species. According to World Meteorological Organization (WMO), there is a 50:50 chance that the annual mean global temperature shall temporarily attain 1.5°C above the pre-industrial scale (the average over the years 1850-1900) for at least one of the coming five years (WMO, 2022).

Agriculture is considered to be one of the vulnerable areas because of its direct connection to climate variability. Climate pattern and its impact on crop yield have been studied over the past few decades worldwide (Chengzhi *et al.,* 2024) including various locations in India (Krishna Kumar *et al.,* 2004, Dakhore *et al.,* 2024, Praveenkumar *et al.,* 2024). Various active research groups have also studied such trends over the state of West Bengal, too (Mukherjee *et al.,* 2009, Bhattacharya *et al.,* 2013, Banerjee *et al.,* 2015, Biswas *et al.,* 2018, Maity *et al.,* 2024).

West Bengal being the largest producer of rice and jute among all the states of India, therefore, the present paper evaluates the trends of temperature and rainfall over the southern region of West Bengal and their impact on yields of these two rainfed crops.

## MATERIALS AND METHODS

The study area is located in the southern part of West

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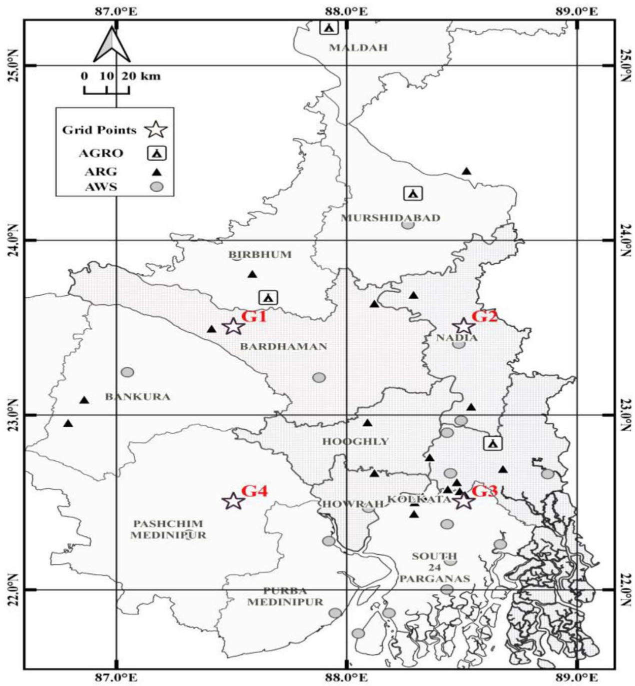


**Fig. 1**: Location map of the study area with grid points marked with 'star' sign.

Bengal, which also includes lower Gangetic plains (Fig. 1). This area receives rainfall from June to first week of October with annual rainfall ranging from 1400 mm to 1650 mm. The region also experiences a maximum temperature range from about $32^0$C to $41^0$C during summer and 7 $^0$C to 15 $^0$C minimum temperature during winter season. It lies at an altitude of 8 m to 12 m from the mean sea level. West Bengal accounts for about 14% rice production in India and the study zone can be considered as rice bowl of the state. Similarly, major portion of jute in India is also grown in the study area.

Temperature (°C) and precipitation (mm) data spanning 70 years (1951-2020) for specific latitude and longitude were obtained from Rajeevan *et al.,* (2008) and Srivastava *et al.,* (2009). It is assumed that the data corresponding to these specific latitude and longitude represent climatic parameters for an 1° x 1° grid area centered on these grid points. The selected grid points representing the southern part of West Bengal are located at (23.5°N, 87.5°E) in Bardhaman district, (23.5°N, 88.5°E) in Nadia district, (22.5°N, 88.5°E) in South 24 Parganas district, and (22.5°N, 87.5°E) in Paschim Medinipur district as shown in Fig. 1. We obtained district-wise crop yield data for *Kharif* rice (t.ha$^{-1}$) and jute (bales ha$^{-1}$) over a 23-year period (1997-2019) from the Crop production information system (Anonymous, 2024). The phenophases of *Kharif* rice and jute can be divided into several stages of growth as given in Table 1.

For a given grid point, we have chosen three climatic variables, viz., maximum temperature ($T_{max}$), minimum temperature ($T_{min}$) (averaged over whole year and crop phenophases) and total rainfall ($R_{tot}$) (over the year and crop phenophases) to perform the trend analysis by Mann-Kendall (Mann 1945, Kendall 1962) trend test and Sen's slope calculation (Sen 1968) for the available period. In this paper, we have performed both the analysis using the Python based package pyMannKendall (Hussain *et al.,* 2019).

**Table 1**: The phenophases of growth of *Kharif* rice and jute.

| Crops (season) | Phases | Superscript | Duration (days) |
|---|---|---|---|
| *Kharif* rice (July-October) | Vegetative | veg | 55-60 |
| | Reproductive | rep | 30 |
| | Ripening | rip | 25 |
| Jute (April-July) | Pre-fertilizer application | pre | 35 |
| | Post-fertilizer application | post | 65 |

**Table 2**: Mann-Kendall analysis and Sen slope analysis for annual temperature ($T_{max}$, $T_{min}$) and rainfall ($R_{total}$) for the 4 grid points.

| Grid | Parameter | Trend | h | p | Z | slope |
|---|---|---|---|---|---|---|
| 1 | $T_{max}$ | - | False | 0.081 | 1.745 | 0.005 |
| | $T_{min}$ | ↑ | True | 0.028 | 2.202 | 0.005 |
| | $R_{tot}$ | ↑ | True | 0.002 | 3.028 | 5.43 |
| 2 | $T_{max}$ | - | False | 0.139 | 1.478 | 0.003 |
| | $T_{min}$ | ↑ | True | 0.001 | 3.184 | 0.008 |
| | $R_{tot}$ | - | False | 0.336 | 0.963 | 2.223 |
| 3 | $T_{max}$ | - | False | 0.935 | 0.082 | 0 |
| | $T_{min}$ | ↑ | True | 0.005 | 2.83 | 0.007 |
| | $R_{tot}$ | - | False | 0.193 | 1.3 | 2.671 |
| 4 | $T_{max}$ | - | False | 0.915 | 0.107 | 0 |
| | $T_{min}$ | ↑ | True | 0.02 | 2.327 | 0.005 |
| | $R_{tot}$ | - | False | 0.063 | 1.856 | 2.984 |

Symbols '↑'/'↓'/'-' are used as an abbreviation to the term 'increasing/decreasing/no' trend at 95 % CL.

The Mann-Kendall (MK) analysis, a non-parametric test, has been used for trend analysis of the time series data sets for detecting a monotonic trend. Positive values of the normalized test statistic (Z) indicate an increasing trend, while negative value of Z indicates decreasing trend. Here, we consider the trend to be statistically significant when the significance value, $p < 0.05$, representing the threshold beyond which the null hypothesis (no monotonic trend) is accepted. This implies a conclusion drawn at 95 % confidence level (CL) with $|Z|>1.96$. The magnitude of slope of linear best fit line is calculated by using Sen's slope estimator. A positive value of Sen's slope (SS) indicates an upward or increasing trend and a negative value gives a downward or decreasing trend in the time series.

The annual yield data for districts, namely, Birbhum, Murshidabad, Kolkata, Nadia, North 24 Parganas, Purba Medinipur, South 24 Parganas, Bankura, Bardhaman, Hooghly, Howrah, Paschim Medinipur and Purba Medinipur have been employed to calculate area-weighted average annual yield corresponding to all four chosen grids (Fig. 1). Correlation with test of significance (at 95% CL with $p < 0.05$) between the crop yields

**Table 3:** Correlation (r) between the *Kharif* rice/ jute yield and the climatic variables averaged over the development stages for four grid points.

| Parameters | Grid 1 | | Grid 2 | | Grid 3 | | Grid 4 | |
|---|---|---|---|---|---|---|---|---|
| | r | Trend | r | Trend | r | Trend | r | Trend |
| ***Kharif* rice** | | | | | | | | |
| $T_{max}^{veg}$ | 0.27 | ↑ | 0.50* | ↑ | 0.41 | ↑ | 0.34 | ↑ |
| $T_{min}^{veg}$ | -0.06 | ↑ | 0.17 | ↑ | 0.18 | ↑ | 0.08 | ↑ |
| $T_{max}^{rep}$ | 0.53* | ↑ | 0.72* | ↑ | 0.70* | ↑ | 0.66* | ↑ |
| $T_{min}^{rep}$ | 0.41 | ↑ | 0.56* | ↑ | 0.65* | ↑ | 0.44* | ↑ |
| $T_{max}^{rip}$ | -0.02 | – | 0.09 | ↑ | 0.12 | ↑ | 0.40 | ↑ |
| $T_{min}^{rip}$ | -0.14 | – | -0.17 | ↑ | -0.09 | – | -0.23 | – |
| $R_{tot}^{veg}$ | 0.14 | ↑ | -0.42* | – | 0.14 | – | 0.15 | – |
| $R_{tot}^{rep}$ | -0.41 | – | -0.47* | – | -0.02 | – | -0.05 | – |
| $R_{tot}^{rip}$ | 0.05 | – | -0.20 | – | -0.17 | – | 0.09 | – |
| **Jute** | | | | | | | | |
| $T_{max}^{pre}$ | 0.39 | ↓ | 0.60* | ↓ | 0.47* | ↓ | 0.23 | – |
| $T_{min}^{pre}$ | 0.27 | – | 0.38 | – | 0.37 | – | -0.06 | – |
| $T_{max}^{post}$ | -0.03 | – | 0.07 | – | 0.16 | – | 0.29 | – |
| $T_{min}^{post}$ | -0.01 | – | 0.15 | – | 0.21 | – | 0.31 | – |
| $R_{tot}^{pre}$ | -0.47* | ↑ | -0.04 | – | 0.19 | – | 0.04 | – |
| $R_{tot}^{post}$ | -0.09 | ↑ | -0.33 | – | 0.04 | – | -0.19 | ↑ |

Significant 'r' values are marked with '*' and 'Trend' denotes trend of the climatic variable, both at 95 % CL. Symbols '↑'/'↓'/'-' in the 'Trend' column are used for 'increasing/decreasing/no' trend .

and the climatic variables averaged over various growth phases for all the grid points is performed using Python package Pandas' (https://doi.org/10.5281/zenodo.3509134) and 'statsmodels.api' (https://doi.org/10.25080/Majora-92bf1922-011).

Multiple regression analysis was performed to obtain yield equations by employing 22 years of data to assess the impact of variation in climatic parameters on future yields. Regression equations for both the crop varieties are obtained as,

$$\text{Yield} = A + \sum_i \beta i\, X_i + \varepsilon$$

where, summation runs over the climatic parameters, $X_i$, optimized to maximize the adjusted $R^2$ value. Here, $\beta_i$ are the regression coefficients, A is the intercept and ε is the error factor. The crop yield was predicted for the last ($23^{rd}$ ) year for each grid point to validate the respective best fitted model by calculating the percentage relative difference (RD) given by,

$$\text{RD}\ \% = \frac{predicted\ yield - actual\ yield}{actual\ yield} \text{ X } 100.$$

## RESULTS AND DISCUSSIONS

The value of relevant statistical parameters obtained from MK and SS analysis for yearly average of maximum temperature ($T_{max}$), minimum temperature ($T_{min}$) and total rainfall ($R_{tot}$) for the study area over 70 years is presented in Table 2. At 95 % significance level ($p<0.05$ or $|Z|>1.96$), $T_{max}$ showed no significant trend at any of the grid points, whereas, $R_{total}$ showed no trend except the grid region centered in Bardhaman district. However, $T_{min}$ showed a consistent increasing trend for all the four grid points over seven decades time period. This indicates a possibility of warmer winters in south Bengal region, a plausible effect of global warming.

The correlation (r) between crop yields and three climatic variables averaged over the each phenophase for *Kharif* rice and jute for all the grid points are shown in Table 3. The significance test results of correlation and trends of the corresponding climatic variables are also presented at 95 % CL.

For *Kharif* rice, it is observed that $-0.47 \le r \le 0.72$. The temperatures in reproductive phase bear a stronger significant correlation with the yield than the vegetative phase or ripening phases. The reproductive phase is a critical stage for rice growth, where flowering, pollination, and grain formation occur. The temperature conditions during this phase significantly influences the final yield. In the vegetative phase, rice plants are more resilient to suboptimal temperatures because this phase mainly involves leaf and root development. In the ripening phase, suboptimal temperatures have a lesser impact, as grains are already formed and undergoing maturation. It is also observed that, apart from grid 2, rainfall in all phases does not bear any significant correlation with the yields. The influence of weather parameters, mainly temperature on *Kharif* rice production is reported by many scientists (Giri *et al.,* 2017; Dakhore *et al.,* 2024).

For jute, the range is $-0.47 \le r \le 0.60$. Here, only some climatic variables in pre-fertilizer period holds a significant correlation with the yields, whereas, none of them in the post fertilizer phase shows the same. Climatic variables in the pre-fertilizer period strongly correlate with jute yields because they influence the foundational stages of plant establishment and growth. Favorable conditions during this phase ensure robust plant development, enabling the crop to maximize its genetic yield potential. However, in the post-fertilizer phase, the application of fertilizers provides nutrients required for vigorous vegetative growth, reducing the

**Table 4:** Results for multiple regression analysis between the yields and the climatic variables for *Kharif* rice and jute for four grid locations

| Location | Regression model | Adjusted $R^2$ (%) | R.D.(%) |
|---|---|---|---|
| | *Kharif* rice | | |
| Grid 1 | Yield = $-0.181 \times T_{min}^{veg} + 0.211 \times T_{max}^{rep} - 0.079 \times T_{max}^{rip} - 0.001 \times R_{tot}^{rip} + 3.146$ | 33.3 | -12.62 |
| Grid 2 | Yield = $0.305 \times T_{max}^{rep} - 0.001 \times R_{tot}^{veg} - 0.001 \times R_{tot}^{rep} - 6.874$ | 75.0 | -17.71 |
| Grid 3 | Yield = $0.369 \times T_{max}^{veg} - 0.56 \times T_{min}^{veg} + 0.690 \times T_{min}^{rep} - 12.787$ | 55.4 | 5.72 |
| Grid 4 | Yield = $0.229 \times T_{max}^{rep} + 0.101 \times T_{max}^{rip} - 0.134 \times T_{min}^{rip} - 5.006$ | 55.4 | -13.62 |
| | Jute | | |
| Grid 1 | Yield = $-0.026 \times R_{tot}^{pre} + 17.612$ | 31.9 | -27.17 |
| Grid 2 | Yield = $0.624 \times T_{max}^{pre} - 0.365 \times T_{min}^{pre} - 0.002 \times R_{tot}^{post} + 1.769$ | 41.0 | -6.41 |
| Grid 3 | Yield = $0.951 \times T_{max}^{pre} - 16.285$ | 20.2 | -12.16 |
| Grid 4 | Yield = $1.336 \times T_{max}^{pre} - 1.468 \times T_{min}^{pre} + 0.387 \times T_{max}^{post} - 0.005 \times R_{tot}^{post} - 3.52$ | 33.8 | -10.41 |

crop's reliance on external climatic factors.

Our analysis indicates that the average annual maximum temperature does not exhibit a discernible trend across the region. In contrast, the average minimum temperature consistently shows an increasing trend across all grid points representing the southern part of West Bengal (Table 2). Interestingly, when both maximum and minimum temperatures are averaged over different phenophases for rice, they demonstrate an increasing trend for the first two phenophases. For jute, no trend is observed for the average minimum temperature at any of the grid points during the two phenophases in contrast to the yearly increasing trend at all locations. Again, the maximum annual average temperature, which didn't show any trend across all the grids, showed a decreasing trend in three of the four grids for pre-fertilizer phase. This suggests that phenophase-specific temperature patterns capture finer characteristics compared to annual averages.

Results for linear regression analysis for all the grid locations is presented in Table 4 for both the crops. For *Kharif* rice, the temperature variables predominantly determine the yields with rainfall having least significant effect for all the grid locations. The range of adjusted $R^2$ implies that 30-75% of variation of rice yields in south Bengal region is explained by variations in the climatic variables chosen so as to maximize the adjusted $R^2$. Rest (100-x) % could be attributed to other issues not captured by the model. RD in each case is below 20 %, which validates all the four models. For eg., considering grid 1, an increase of 1 °C in $T_{min}^{veg}$ (showing an increasing trend, Table 3) implies a decrease of 0.181 t.ha$^{-1}$ in rice yields and an increase of 1 °C in $T_{max}^{rep}$ (showing an increasing trend, Table 3) implies an increase of 0.211 t.ha$^{-1}$ in rice yields. However, $T_{max}^{rip}$ and $R_{tot}^{rip}$, fails to show any significant trend (Table 3) and does not therefore affect the yield variation in future.

For jute, the range of adjusted $R^2$ is 20-41 % which indicates possible other major non climatic factors must be responsible for determining yields in this region as also reflected in RD value reaching as high as 27%. In grid 1, an increase in 1 mm of $R_{tot}^{pre}$ (showing an increasing trend, Table 3) leads to decrease in jute yields by 0.026 bales ha$^{-1}$. The regression analysis for both the crops also highlights the importance of location-specific climatic influence on yield output (Giri *et al.,* 2017).

## CONCLUSION

The present study revealed that in the southern West Bengal region, the average minimum temperature exhibits an increasing trend for all the grids at 95 % significance level and average maximum temperature does not show any significant trend at any of the locations. However, the total annual rainfall shows an increasing trend at only one grid region centered in Bardhaman over the period of seven decades. The *Kharif* rice and jute yield data seem to bear 'moderate negative' to 'strong positive' correlation with the climatic variables. The temperatures in reproductive phase of *Kharif* rice show stronger correlation with the yield than rest of the growth phases. For jute, the observed climatic variables in pre-fertilizer application period only significantly influence the yields. The multiple linear regression analysis for both jute and *Kharif* rice yields show that temperature plays a more significant role in influencing crop yields than rainfall, with substantial spatial variability in the climate-yield relationship, underscoring the importance of location-specific climate conditions. By addressing the future yield variation based on climate trends through agricultural policies, developing nations can assure food security, sustainability and enhanced resilience of local farming communities against growing threat of climate variability.

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