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Correlation-based analysis of weighted and unweighted weather indices for rice yield in Kashmir

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Abstract
Rice is a vital staple crop in the Kashmir division, where climatic variability poses significant challenges to agricultural productivity. This study investigates the relationship between rice yield and weekly weather variables: maximum and minimum temperature, rainfall, sunshine hours, and relative humidity over a 39 year period (1985-2023). Using meteorological data from the Indian Meteorological Department (IMD) and yield records from the Directorate of Economics and Statistics, a comprehensive correlation analysis using Pearson's correlation method was conducted based on both unweighted and weighted weather indices.

The findings reveal that weighted weather indices exhibit significantly stronger correlations with rice yield compared to their unweighted counterparts, underscoring their superior predictive value. Among individual variables, rainfall (Z31) and relative humidity (Z51) emerged as the most influential, while interaction-based weighted indices such as Z131 demonstrated exceptionally high correlations ($r > 0.70$). Visual tools like correlation heatmaps and bar plots further validated the strength and direction of these associations.

Keywords: Rice, weighted weather indices, unweighted weather indices, correlation analysis

1. Introduction
Rice plays a central role in the agricultural economy of the Kashmir division, serving as both a staple food and a key livelihood source for rural communities. The crop's significance goes beyond sustenance it is tightly woven into the region's socio-cultural identity and economic resilience. However, like many temperate agricultural systems, rice cultivation in Kashmir is increasingly vulnerable to the effects of climate variability and change. The growing unpredictability of monsoons, rising temperatures, shifting precipitation patterns, and increased frequency of extreme weather events now pose serious challenges to maintaining stable rice production (Zaz *et al*., 2019; Mehmood *et al*., 2024) [10, 8].

Climatic conditions during the crop's growth cycle, particularly during sensitive phases such as transplanting, flowering, and grain filling, have a profound influence on final yield. Research has shown that even minor deviations in temperature, rainfall, or sunshine during these stages can significantly affect productivity (Aggarwal & Sivakumar, 2011) [1]. In Kashmir, long-term meteorological records indicate a warming trend of about 0.8°C since the 1980s, along with decreasing spring precipitation conditions known to adversely impact rice phenology and yield potential.

Understanding how specific weather variables correlate with rice yield is essential for climate-resilient agricultural planning. Correlation analysis serves as a fundamental tool in this context, allowing researchers to quantify the strength and direction of relationships between yield and climatic factors (Lomas *et al*., 1985) [7]. However, traditional correlation approaches often use coarse seasonal or monthly averages, which can mask the critical week-by-week weather fluctuations that exert strong influence on crop outcomes (Davis *et al*., 2019; Auffhammer *et al*., 2012) [6, 4].

To better capture this temporal sensitivity, researchers have developed weather indices aggregated representations of weather variables computed over shorter time frames, such as weeks. These indices allow a more precise assessment of how rice yield responds to varying weather conditions across different growth stages. Unweighted indices typically involve the simple summation of weather data across weeks or variables, whereas weighted weather indices incorporate statistical weights based on the strength of correlation between each weekly observation and the final yield (Singh *et al*., 2019) [9]. The advantage of the weighted approach lies in its ability to highlight the most influential climatic periods, offering a more data-driven understanding of crop climate interactions. This method not only improves correlation strength but also helps identify critical time windows that are agronomically significant information that is often lost when using averaged or static weather data. Against this backdrop, the present study aims to investigate the correlation between rice yield and both unweighted and weighted weather indices over a 39-year period (1985-2023) in the Kashmir division.

2. Methodology

The data for this study were obtained from two primary sources: annual rice yield data spanning 39 years (1985-2023), collected from the Directorate of Economics and Statistics, Government of Jammu & Kashmir, and daily meteorological data acquired from the Indian Meteorological Department (IMD). The rice yield was recorded in tons per hectare (Q/Ha). The weather data included maximum temperature (°C), minimum temperature (°C), rainfall (mm), sunshine hours (hours), and relative humidity (%), all of which are critical factors influencing crop growth, development, and yield. The study was conducted in the Kashmir division, a temperate region with fertile soils and distinct seasonal variations. Its dependence on rice cultivation and growing climate variability makes it a critical area for assessing the impact of weather on crop yield.

Unweighted and weighted weather indices were developed to analyze the relationship between climatic variables and rice yield (Agrawal *et al*., 1983) given in Table 1.

Table 1: Un-weighted and weighted weather indices

	Un-weighted weather indices					Weighted weather indices				
	Tmax	**Tmin**	**RF**	**SSH**	**RH**	**Tmax**	**Tmin**	**RF**	**SSH**	**RH**
Tmax	Z10					Z11				
Tmin	Z120	Z20				Z121	Z21			
RF	Z130	Z230	Z30			Z131	Z231	Z31		
SSH	Z140	Z240	Z340	Z40		Z141	Z241	Z341	Z41	
RH	Z150	Z250	Z350	Z450	Z50	Z151	Z251	Z351	Z451	Z51

Correlation analysis was employed to examine the linear relationships between key weather indices temperature, rainfall, sunshine hours, and relative humidity and rice yield (Chairani *et al*., 2022) [5]. Using Pearson's correlation coefficient, the study identified which climatic variables had the strongest influence on yield, providing a basis for selecting predictors in model development and guiding climate-responsive agricultural planning. The Pearson correlation coefficient is calculated using the formula:-

$$r=\frac{\sum(Xi-\bar{X})(Yi-\bar{Y})}{\sqrt{\sum(Xi-\bar{X})^2(Yi-\bar{Y})^2}}$$

Where,

r is the Pearson's correlation coefficient,

Xi and Yi are individual sample points of variables X and Y,

$\bar{X}$ and $\bar{Y}$ are the means of variables X and Y, respectively and

$\sum$ denotes the summation over all data points.

3. Results and Discussion

The correlation analysis summarized in Table 2 demonstrated a marked contrast between unweighted and weighted weather indices in their association with rice yield. In general, weighted indices exhibit stronger and statistically significant correlations, while unweighted indices tend to show weak or non-significant relationships, highlighting the effectiveness of the weighting approach in capturing yield-relevant climatic influences.

For maximum temperature, the weighted index Z11 exhibited a moderate and statistically significant positive correlation with rice yield (r=0.52, P=0.0012), in contrast to the unweighted index Z10, which showed a negligible and non-significant negative correlation (r=-0.049, P=0.777). Similarly, the minimum temperature weighted index Z21 revealed a positive correlation (r=0.354, P=0.034), while the corresponding unweighted index Z20 had an almost zero and insignificant relationship (r=0.004, P=0.983).

Among all climatic parameters, rainfall emerged as the most influential. The weighted index Z31 displayed the strongest positive correlation (r=0.74, p<0.0001), indicating a substantial contribution to rice yield variability. In contrast, the unweighted rainfall index Z30 had a very weak and non-significant negative correlation (r=-0.021, P=0.901). For sunshine hours, the weighted index Z41 showed a significant positive correlation (r=0.536, P=0.0007), whereas Z40 (unweighted) recorded a weak and statistically insignificant negative association (r=-0.187, P=0.275). In the case of relative humidity, the weighted index Z51 demonstrated a strong and significant relationship with yield (r=0.591, P=0.0001), while the unweighted Z50 showed a weak and non-significant correlation (r=0.028, P=0.871).

Further insights are provided in Table 3, which analyzed interaction-based weather indices. Here too, the weighted indices clearly outperformed their unweighted counterparts. Most unweighted interactions (e.g., Z120, Z130, Z150, Z230, Z240, Z250, Z340, Z350 and Z450) demonstrated insignificant correlations, suggesting limited relevance. In contrast, the weighted interaction indices such as Z121, Z131, Z141, Z151, Z231, Z241, Z251, Z341, Z351, and Z451 exhibited strong, statistically significant positive correlations, with p-values consistently below 0.05.

Notably, Z131 (weighted interaction of maximum temperature and rainfall) recorded a very strong correlation (r=0.705, p $\approx$ 0.0000016), reflecting a robust predictive relationship. Other indices like Z141, Z151, Z241, and Z451 also demonstrated high correlation coefficients, ranging between 0.368 and 0.722, underscoring their relevance in yield prediction.

These findings collectively affirm that weighted weather indices capture the relationship between climatic variables

and rice yield more effectively than unweighted indices. By incorporating the strength of correlation into index construction, the weighted approach enhances predictive precision and offers a more nuanced understanding of climate yield dynamics. Visual representations further support these results. The triangular correlation heatmap (Figure 1) illustrates both positive and negative relationships between key weather indices and rice yield, while the bar plot (Figure 2) highlights the magnitude of correlation coefficients for the most influential variables. These graphical insights reinforce the statistical findings and aid in identifying critical weather parameters that should be prioritized in predictive modeling and adaptive agricultural planning.

Table 2: Correlation coefficients and p-values for main un-weighted and weighted weather indices (Rice)

Un-Weighted Weather Indices	Correlation Coefficient	Weighted Weather Indices	Correlation Coefficient
Z10	-0.048 (0.7768)	Z11	0.516 (0.0012) **
Z20	0.003 (0.983)	Z21	0.354 (0.034) *
Z30	-0.021 (0.901)	Z31	0.740 (0.0001) ***
Z40	-0.187 (0.275)	Z41	0.536 (0.0007) ***
Z50	0.028 (0.871)	Z51	0.590 (0.0001) ***

Significance Levels:
***: $p \leq 0.001$
**: $p \leq 0.01$
*: $p \leq 0.05$

Table 3: Correlation coefficients and significance for interaction weather Indices (Rice)

Un-Weighted	Correlation Coefficient	P-Value	Significance	Weighted	Correlation Coefficient	P-Value	Significance
Z120	-0.030	0.859	NS	Z121	0.399	0.015	*
Z130	0.006	0.970	NS	Z131	0.705	0.000	***
Z140	-0.188	0.270	NS	Z141	0.528	0.000	***
Z150	0.030	0.859	NS	Z151	0.368	0.026	*
Z230	0.014	0.934	NS	Z231	0.721	0.000	***
Z240	-0.191	0.262	NS	Z241	0.491	0.002	**
Z250	0.052	0.762	NS	Z251	0.442	0.006	**
Z340	-0.088	0.607	NS	Z341	0.722	0.000	***
Z350	-0.041	0.811	NS	Z351	0.718	0.000	***
Z450	-0.148	0.387	NS	Z451	0.535	0.001	***

Significance Levels:
***: $p \leq 0.001$
**: $p \leq 0.01$
*: $p \leq 0.05$
NS: Not Significant ($p > 0.05$)

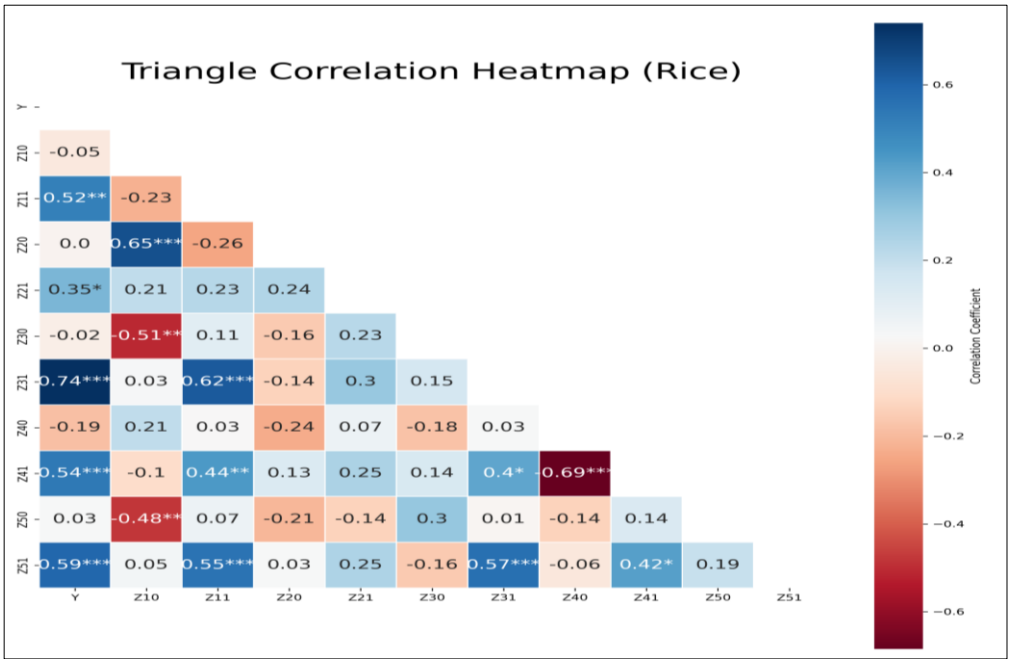

Fig 1: Correlation heat map for rice (main unweighted and weighted indices)

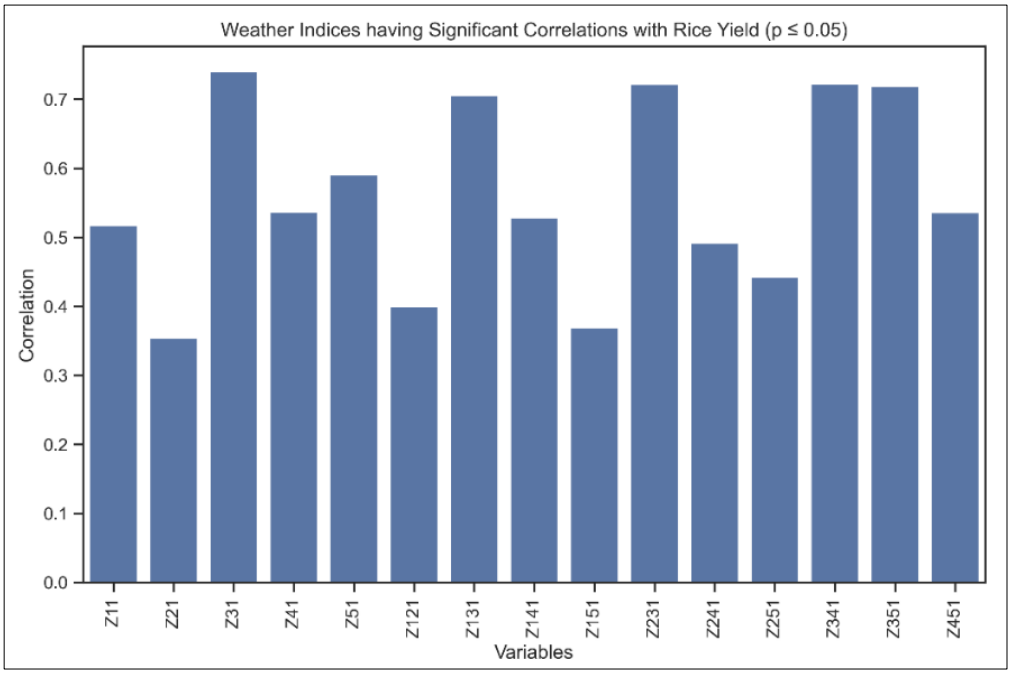

Fig 2: Bar plot of significant correlations between weather indices and rice yield

4. Summary and Conclusion

This study investigated the relationship between rice yield and various weather parameters in the Kashmir division over a 39-year period (1985-2023). By constructing both unweighted and statistically weighted weekly weather indices using data from the Indian Meteorological Department (IMD) and yield records from the Directorate of Economics and Statistics, the analysis aimed to identify the most influential climatic factors affecting rice productivity.

The correlation analysis revealed that weighted weather indices consistently outperformed unweighted indices, showing stronger and statistically significant associations with rice yield. Among all variables, rainfall (Z31) emerged as the most influential factor, followed by relative humidity (Z51), sunshine hours (Z41), and maximum temperature (Z11). Similarly, several weighted interaction indices demonstrated strong correlations, with Z131 (interaction of maximum temperature and rainfall) showing the highest predictive strength.

These results underscore the importance of accounting for the timing and relevance of weekly weather data when assessing crop-climate interactions. The use of weighted indices enables a more refined understanding of how specific climatic conditions during critical crop growth stages influence yield outcomes.

In conclusion, the findings highlight that weighted weather indices are valuable tools for improving yield forecasting and climate risk assessment in agriculture. For a climate-sensitive region like Kashmir, where rice cultivation plays a central role in food security and rural livelihoods, such insights are crucial for informing climate-resilient farming strategies and supporting data-driven decision-making in agricultural planning and policy.

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