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Correlation analysis of climate conditions on rice prices in semarang 2017-2023

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ABSTRACT

Rice is a vital commodity in Indonesia whose price stability is highly sensitive to climate variability. Semarang City, as a coastal urban center prone to floods and extreme rainfall, plays a strategic role in rice production and distribution in Central Java. This research analyzes the correlation between climate variables and rice prices during the 2017–2023 period using Pearson, Spearman, cross-correlation, and autocorrelation methods. The results show that rice prices have weak to moderate correlations with climate factors, with temperature showing a stronger influence compared to rainfall, humidity, or wind speed. Although Pearson and Spearman tests mostly indicate weak correlations, several results are statistically significant, while cross-correlation analysis demonstrates that climate impacts on rice prices often appear indirectly with time lags. Furthermore, autocorrelation reveals that rice prices are characterized by short-term dependencies without clear seasonality, whereas climate parameters exhibit stronger cyclical patterns. These findings provide valuable insights for developing adaptive strategies and policies to strengthen food security in the face of climate change.

1. Introduction

Rice is a staple commodity that is vital for the lives of the Indonesian people. Economic stability and social welfare can be influenced by fluctuations in rice prices [1], [2]. In this situation, climate conditions play an important role in agricultural production, including rice, as global climate change and local climate

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variability can lead to changes in weather patterns that affect rice crop productivity [3], .

As the capital of Central Java Province, Semarang City plays a crucial role in the agricultural sector, particularly in rice production and distribution. Agricultural programs have even been established by the Semarang City Government as a priority development issue in the RPJMD 2016-2021 [4]. This indicates that the Semarang City Government is committed to enhancing food security and positioning Semarang as a key pillar in rice production and distribution.

Semarang City faces unique local climate issues as a coastal city frequently experiencing floods and tidal flooding, which can damage irrigation infrastructure and farmland [5], while rainfall variability also plays a crucial role in agriculture [6]. According to the BMKG [7], rainfall is considered extreme if it has an intensity of >150 mm per day. High rainfall can cause uncertainty in rice production. Studies on the relationship between climate conditions and rice prices at the local level, like this one, are important for understanding specific dynamics that may not be apparent in national or global analyses.

Nugroho and Hadi (2020) highlighted that temperature anomalies have a significant and consistent impact on rice production in Indonesia [2], making temperature a crucial factor in predicting productivity compared to other climate variables. Similarly, Susanto, Pratama, and Lestari (2019) found that extreme rainfall variability in West Java adversely affected rice yields and led to short-term price volatility, emphasizing the sensitivity of agricultural outcomes to local climate fluctuations [8]. At a broader regional scale, Eka (2024) demonstrated that climate extremes such as floods and droughts in Southeast Asia disrupted not only rice production [9] but also the supply chain, ultimately triggering instability in regional rice markets. Collectively, these studies underline the importance of both climatic factors and supply chain resilience in shaping rice production and price dynamics across different scales.

The purpose of this study on the correlation between climate conditions and rice prices in Semarang City is to identify and measure the extent to which rice price changes are influenced by climate variables. The results of this study are expected to provide valuable insights for stakeholders, including farmers, traders, and policymakers, on how to anticipate and address climate change. Additionally, the findings can help in developing better strategies to reduce risks and adapt to the impacts of climate change on the agricultural sector and food security in Semarang City.

Understanding the relationship between climate conditions and rice prices allows for proactive measures to mitigate the negative effects of climate variability. These measures include the adoption of adaptive agricultural technologies, improved irrigation infrastructure, and the development of rice varieties resistant to extreme climate conditions. Additionally, strengthening early warning systems and providing information to help farmers better plan their planting seasons can enhance local food security. The goal of this research is to gain a better understanding of how rice prices in Semarang City are affected by climate change

and variability. The findings are expected to inform better policies for managing natural resources and food security in the era of climate change.

As outlined in the background, this research aims to address the following problem statements:

a) What is the linear correlation between climate conditions and rice prices in Semarang City during the 2017-2023 period?
b) What is the monotone correlation between climate conditions and rice prices in Semarang City during the 2017-2023 period?
c) What is the lag correlation between climate variables and rice prices in Semarang City during the 2017-2023 period?
d) What is the overall correlation between climate variables and rice prices in Semarang City during the 2017-2023 period?

The purpose of this research is to find answers to the problems outlined in the problem statement. The objectives are:

a) To determine the linear correlation between climate conditions and rice prices in Semarang City during the 2017-2023 period by identifying and analyzing the linear relationship using Pearson's correlation test;
b) To identify the monotone correlation between climate conditions and rice prices during this period through Spearman's correlation analysis;
c) To determine the lag correlation between climate variables and rice prices by using cross-correlation analysis;
d) And to identify and analyze the correlation between climate variables and rice prices with previous data during the 2017-2023 period using autocorrelation tests.

2. Method

The research steps are described in Figure 1.

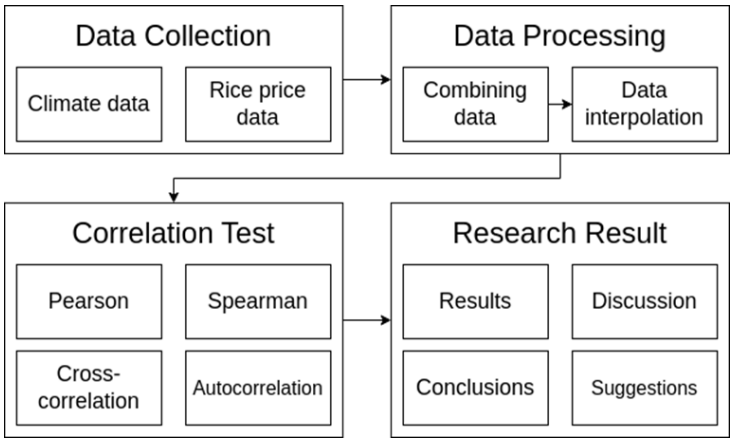


Figure 1. Research methodology

Figure 1 shows the methodology of this research, which follows a four-stage process to investigate the relationship between climate and rice prices. This

research begins with the collection of climate data and rice price data. Next, these datasets are combined and processed using data interpolation techniques to ensure consistency. A comprehensive correlation analysis is then conducted, employing Pearson, Spearman, cross-correlation, and autocorrelation tests to examine the linear, monotonic, time-lagged, and temporal dependencies within the data. Finally, the research presents the results of these analyses, drawing conclusions about the link between climate variables and rice prices. The findings are further discussed in detail, and suggestions are offered for future research or policy implications to mitigate climate-related risks to rice production.

Data Collection

In this research, we use two datasets: climate data and rice price data, sourced from the BMKG data website [10] and the SIHATI Jateng website [11]. The time range for both datasets is the same, from February 1, 2017, to December 31, 2023. For the climate data, we limit it to the climate data of Semarang City obtained from the Central Java Climatology Station. For the commodity data, we use the price data of IR 64 Premium rice.

In this research, we encountered several limitations in data collection, including: 1) Data from the BMKG website can only be obtained on a monthly basis, requiring us to collect and merge the data one by one; 2) The rice price data available is for the entire cities or regencies in Central Java. We filtered it to obtain data specifically for Semarang City and Central Java Province. We successfully obtained the necessary data. The rice price data includes two columns: one showing the rice prices in Semarang City and the other for Central Java Province. The climate data comprises eight columns, which can be seen in Table 1.

Table 1. Results of performance assessment

Column Name	Description	Unit
Date	shows daily time	day-month-year
Tn	Minimum temperature	°C
Tx	Maximum temperature	°C
Tavg	Average temperature	°C
RH_avg	Average humidity	%
RR	Rainfall	mm
ss	Duration of sunlight	hour
ff_x	Maximum wind speed	m/s
ff_avg	Average wind speed	m/s

Data Processing

The data obtained was still raw and needed to undergo a data processing procedure. Firstly, we combined the climate data into a single dataset as the

downloaded data was in monthly format. Next, we addressed the missing values because both datasets had many empty dates. We used linear interpolation to fill in the missing values. Research on [12] indicates that linear interpolation adapts well to data, making it suitable for filling in missing values. This technique fills in the missing value at a point using the existing data points before and after the missing value.

$$y = y_1 + \frac{(x-x_1)(y_2-y_1)}{(x_2-x_1)} \quad (1)$$

Where y is the missing value point to be filled, x_1, $y_1$are the time and value points before the missing value, and x_2, y_2 are the time and value points after the missing value.

Correlation Test

In this research, we conducted several correlation tests, including Pearson correlation, Spearman correlation, cross-correlation, and autocorrelation tests. For the testing, we utilized the SciPy library for the Pearson test [13], [14] and the Spearman test [15]. These two methods allow users to obtain the correlation coefficient values and their p-values, indicating the significance of the coefficients. Next, we used the NumPy library for the cross-correlation test [16], and finally, we used Pandas for the autocorrelation test[17].

The Pearson correlation

The Pearson correlation test is a statistical test used to measure the linear relationship between two continuous variables [18]. The result of the Pearson correlation test (coefficient) ranges from -1 to 1, indicating a negative to positive relationship between the two variables.

$$r_p = \frac{n(\Sigma xy)-(\Sigma x)(\Sigma y)}{\sqrt{(n\Sigma x^2-(\Sigma x)^2)(n\Sigma y^2-(\Sigma y)^2)}} \quad (2)$$

Where r_p is the Pearson coefficient, n is the number of data pairs, and x and y are the values of the two variables.

The Spearman correlation

The Spearman correlation test is a statistical test used to measure the monotonic relationship between two variables over a specific period [19]. The result of the Spearman correlation test (coefficient) ranges from -1 to 1, indicating a negative to positive relationship between the two variables.

$$r_s = 1 - \frac{6\Sigma d^2}{n(n^2-1)} \quad (3)$$

Where r_s is the Spearman coefficient, d is the difference in ranks between the two variables, and n is the number of data pairs.

The cross-correlation

The cross-correlation test is a statistical technique used to measure the relationship between two variables at specific lags (time shifts) in time series data [20]. The cross-correlation test is useful in time series data analysis for identifying

patterns and relationships between variables that occur at different time intervals [20].

$$r_{xy}(k) = \frac{\sum_{t=k+1}^{n} (x_t - \underline{x})(y_{t-k} - \underline{y})}{\sqrt{\sum_{t=k+1}^{n} (x_t - \underline{x})^2 \cdot \sum_{t=1}^{n-k} (y_t - \underline{y})^2}} \quad (4)$$

Where $r_{xy}(k)$is the cross-correlation coefficient for lag k. Here, x_t and $y_t$represent the values of variables x and y at time t. Additionally, $\underline{x}$ and $\underline{y}$ denote the means of variables x and y, respectively. n indicates the number of observations in the time series data. Lastly, k denotes the lag being tested, which is the time shift between the two variables being analyzed.

The autocorrelation

The autocorrelation test is a statistical technique that examines the correlation between a variable's current value and its previous values in time series data, identifying dependency patterns within the data itself [21]. By using the autocorrelation coefficient, this test helps recognize patterns, trends, and cycles in time series data for further analysis [21].

$$ACF(k) = \frac{\sum_{t=k+1}^{n} (x_t - \underline{x})(x_{t-k} - \underline{x})}{\sum_{t=1}^{n} (x_t - \underline{x})^2} \quad (5)$$

Where $ACF(k)$ is the autocorrelation coefficient for lag k. Here, x_t represents the value of the variable at time t. Additionally, $\underline{x}$ denotes the mean of the variable x. n is the total number of observations in the time series data. Lastly, k is the lag being tested, which is the time shift between the current value and the past value being analyzed.

3. Results and Discussion

Pearson Correlation Test

Table 2. Results of Pearson Correlation Test

	Semarang City		Central Java	
Column	Coefficient	P-value	Coefficient	P-value
Tn	0.047	0.019	0.019	0.346
Tx	0.172	2.588	0.120	1.092
Tavg	0.247	2.036	0.189	9.612
RH_avg	-0.113	1.287	-0.086	1.415
RR	0.0005	0.980	0.014	0.465
ss	0.097	9.159	0.040	0.043
ff_x	-0.154	5.289	-0.130	4.487
ff_avg	-0.085	1.704	-0.073	0.0002

Table 2 shows the results of the Pearson correlation test on climate data and rice price data. Rice prices in Central Java Province exhibit weak to moderate positive correlations with temperature (Tx and Tavg). There is a weak negative correlation with average humidity and wind speed, as well as a very weak correlation with rainfall and sunshine duration, although some are statistically significant. In Semarang City, there are weak to moderate positive correlations with temperature

(Tx and Tavg), weak negative correlations with average humidity and wind speed, and very weak correlations with rainfall and sunshine duration, with some being statistically significant. Overall, climate parameters such as temperature (especially average and maximum) show stronger correlations with rice prices compared to other climate parameters like rainfall or wind speed. These correlations tend to be more significant in Semarang City compared to Central Java Province.

Spearman Correlation Test

Table 3. Results of spearman correlation test

	Semarang City		Central Java	
Column	Coefficient	P-value	Coefficient	P-value
Tn	0.035	0.075	0.021	0.290
Tx	-0.041	0.038	-0.090	6.469
Tavg	0.032	0.109	0.012	0.557
RH_avg	0.098	7.148	0.138	3.455
RR	0.094	2.287	0.125	2.298
ss	0.013	0.526	-0.053	0.008
ff_x	0.052	0.009	0.021	0.283
ff_avg	-0.106	1.042	-0.124	3.849

Table 3 shows that the Spearman correlation between rice prices and various climate component units in Central Java Province and Semarang City is generally very weak, both positive and negative. Although some correlations are statistically significant, such as Tx, RH_avg, RR, ss, and ff_avg, the strength of the correlations remains very weak (below 0.2). This indicates that changes in climate component variables have a very limited relationship with rice prices. Thus, even though there is statistical significance, the practical impact on rice prices is likely insignificant.

Cross-correlation Test

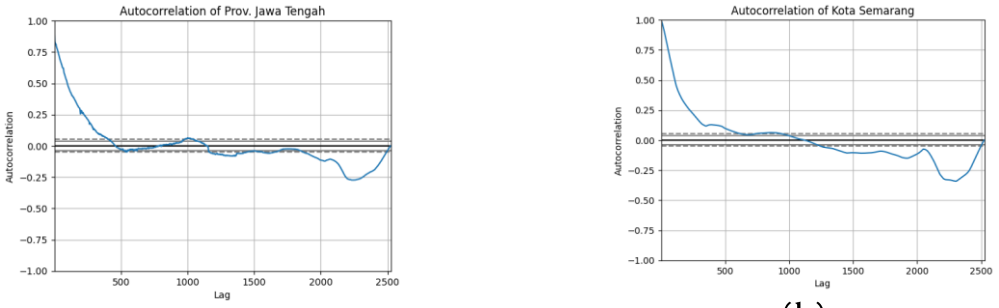
Table 4. Results of Cross-correlation Test

	Semarang City		Central Java	
Column	Max Correlation	Min Correlation	Max Correlation	Min Correlation
Tn	266629.955	-4945222.289	390353.293	-452579.841
Tx	793214.805	-4945222.289	1228286.136	-878287.516
Tavg	609591.434	-4945222.289	622563.113	-878287.516
RH_avg	3918879.340	-4945222.289	5545776.418	-4945222.289
RR	2575660.823	-4945222.289	4465857.804	-4945222.289
ss	1054132.345	-4945222.289	1431280.749	-4945222.289
ff_x	8385781.371	-4945222.289	8771027.403	-4945222.289
ff_avg	376039.644	-4945222.289	463160.695	-4945222.289

Table 4 shows the cross-correlation results between rice prices in Central Java and Semarang City with various climate variables, indicating significant relationships that vary at specific lags. In Central Java, the highest temperature (Tx) has a very strong positive relationship at lag -205 and a strong negative relationship at lag 998, while average humidity (RH_avg) shows a very strong positive relationship at lag 1013 and a negative relationship at lag -219. In Semarang City, the average temperature (Tavg) has a strong positive relationship at lag -7 and a very strong negative relationship at lag -219. Overall, climate factors such as temperature, humidity, rainfall, sunshine duration, and wind speed have a significant impact on

rice prices in both regions, with some variables showing very strong relationships at specific lags. For detailed cross-correlation plots, refer to the Appendix.

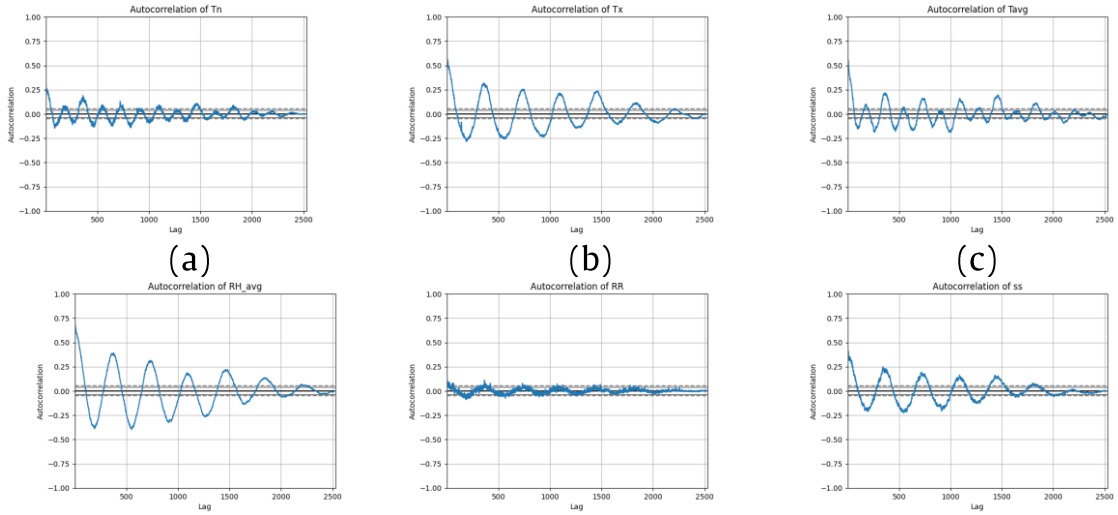
Autocorrelation Test



(a) (b)

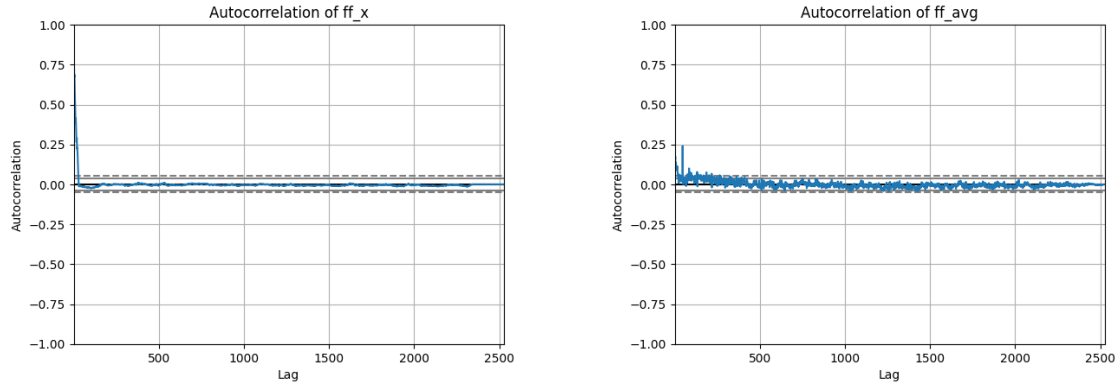
Figure 2. Autocorrelation of rice price data in (a) Central Java and (b) Semarang City.

Figure 2 shows the results of the autocorrelation test on rice price data in two regions: Central Java Province and Semarang City. In Central Java Province, autocorrelation starts at 1.0 and decreases sharply, indicating a decline in similarity between values as the lag increases. This pattern suggests the presence of seasonal or periodic components in the data, but the autocorrelation decreases quickly, implying short-term memory in the time series. Meanwhile, in Semarang City, autocorrelation also starts at 1.0 but drops more drastically with a significant negative peak around lag 5, indicating a strong inverse relationship at certain lags and the potential presence of cyclical patterns in rice prices. Overall, both graphs show short-term dependence and potential seasonal or cyclical behavior in rice prices in both regions, although these patterns vary between Central Java and Semarang, indicating the influence of local factors or different market conditions.



(a) (b) (c)

(d) (e) (f)



(g) (h)

Figure 3. Autocorrelation of climate data in Semarang. (a) Minimum temperature; (b) Maximum temperature; (c) Average temperature; (d) Average humidity; (e) Rainfall; (f) Sunshine duration; (g) Maximum wind speed; (h) Average wind speed.

Figure 3 shows autocorrelation plots for various climate parameters in Semarang, such as minimum temperature, maximum temperature, average temperature, average humidity, rainfall, sunshine duration, maximum wind speed, and average wind speed. The autocorrelation of temperatures (minimum, maximum, and average) and wind speeds (maximum and average) shows strong patterns at small lags, indicating significant day-to-day correlations. Average humidity also shows significant correlations, although potentially weaker. The autocorrelation of rainfall and sunshine duration shows more random or weaker patterns, indicating that the day-to-day correlation for these parameters is not as strong as for others. The autocorrelation of maximum wind speed indicates that the highest wind speeds on a given day have significant correlations with subsequent days, suggesting a stable pattern and high predictability. Similarly, the autocorrelation of average wind speed indicates strong correlations between average wind speeds on consecutive days, reflecting consistency in daily wind patterns. Overall, these autocorrelations illustrate the strength of the day-to-day relationships between climate values, with some parameters showing more significant correlations than others.

Autocorrelation Test

Tabel 5. Table of research result interpretations

Pearson Test (Table 2)				
Column	Central Java		Semarang City	
	Correlation	Significant	Correlation	Significant
Tn	(+) very weak	no	(+) very weak	yes
Tx	(+) weak	yes	(+) weak	yes
Tavg	(+) weak	yes	(+) moderate	yes
RH_avg	(-) weak	yes	(-) weak	yes
RR	(+) very weak	no	(+) very weak	no
ss	(+) very weak	yes	(+) weak	yes
ff_x	(-) weak	yes	(-) weak	yes
ff_avg	(-) very weak	yes	(-) very weak	yes
Spearman Test (Table 3)				
Column	Central Java		Semarang City	

	Correlation	Significant	Correlation	Significant
Tn	(+) very weak	no	(+) very weak	no
Tx	(-) weak	yes	(-) very weak	yes
Tavg	(+) very weak	no	(+) very weak	no
RH_avg	(+) weak	yes	(+) weak	yes
RR	(+) weak	yes	(+) weak	yes
ss	(-) very weak	yes	(+) very weak	no
ff_x	(+) very weak	no	(+) very weak	yes
ff_avg	(-) weak	yes	(-) weak	yes

Cross-correlation Test (Figure 4 dan Figure 5)

Column	Central Java		Semarang City	
	Minimum Point	Maximum Point	Minimum Point	Maximum Point
Tn	1543	1106	-219	914
Tx	998	-205	-219	-210
Tavg	998	-255	-219	-7
RH_avg	-219	1013	-219	1001
RR	-219	-794	-219	2117
ss	-219	-194	-219	1500
ff_x	-219	2282	-219	2284
ff_avg	-219	2044	-219	2086

Autocorrelation Test (Figure 2 dan Figure 3)

Rice Price Data	Brief Discussion
Central Java	Low and non-significant autocorrelation values indicate that there is no strong dependency pattern between rice prices in previous periods and current rice prices. This suggests that rice prices in Central Java Province are not significantly influenced by rice prices in previous periods.
Semarang City	"Low and non-significant autocorrelation values indicate that there is no strong dependency pattern between rice prices in previous periods and current rice prices. This suggests that rice prices in Semarang City are not significantly influenced by rice prices in previous periods.
Climate Data	Brief Discussion
Tn	Minimum temperature data show significant autocorrelation. This means that the minimum temperature in one period is influenced by the minimum temperature in the previous period. This autocorrelation pattern may indicate the presence of seasonal trends or cycles affecting the minimum temperature in Semarang.
Tx	Maximum temperature data also show significant autocorrelation. This means that the maximum temperature in one period is influenced by the maximum temperature in the previous period. This autocorrelation pattern may indicate the presence of seasonal trends or cycles affecting the maximum temperature in Semarang.
Tavg	Average temperature data show no significant autocorrelation. This means that the average temperature in one period is not influenced by the average temperature in the previous period. This may indicate that the average temperature in Semarang is relatively stable and less affected by seasonal fluctuations or cycles.
RH_avg	Average humidity data show significant autocorrelation. This means that the average humidity in one period is influenced by the average humidity in the previous period. This autocorrelation pattern may indicate the presence of seasonal trends or cycles affecting average humidity in Semarang."
RR	Rainfall data show significant autocorrelation. This means that the rainfall in one period is influenced by the rainfall in the previous period. This autocorrelation pattern may indicate the presence of seasonal trends or cycles affecting rainfall in Semarang.
ss	Data on the duration of sunlight shows significant autocorrelation. This means

	that the duration of sunlight in one period tends to be influenced by the duration of sunlight in the previous period. This indicates that the duration of sunlight in Semarang is relatively unstable and influenced by seasonal fluctuations or cycles.
ff_x	Data on maximum wind speed shows no significant autocorrelation. This means that the maximum wind speed in one period tends not to be influenced by the average wind speed in the previous period. This autocorrelation pattern may indicate the absence of seasonal trends or cycles affecting the maximum wind speed in Semarang.
ff_avg	Data on average wind speed shows no significant autocorrelation. This means that the average wind speed in one period tends not to be influenced by the average wind speed in the previous period. This may indicate that the average wind speed in Semarang is relatively more stable and less affected by seasonal fluctuations or cycles.

Table 5 presents an overall interpretation of the results from the correlation tests conducted. The climate data do not show a strong correlation with rice price data. Both Pearson and Spearman tests indicate weak correlations between climate data and rice prices in Semarang City. The significance in both tests indicates how well the test results can be accepted. However, the cross-correlation test reveals that climate variables have an indirect influence on rice prices. Additionally, the autocorrelation test shows that rice price data do not have a seasonal pattern but do exhibit short-term dependencies on previous rice prices. In contrast, climate data indicate that most climate variables have seasonal patterns, whereas variables like wind speed do not show seasonal patterns

4. Conclusion

This study analyzes the link between climate conditions and rice prices in Semarang using Pearson, Spearman, cross-correlation, and autocorrelation methods. Pearson results show strong correlations between temperature (especially average and maximum) and rice prices, while Spearman indicates generally weak direct relationships with climate variables. However, cross-correlation reveals that factors such as temperature, humidity, rainfall, sunshine, and wind speed significantly influence rice prices at certain time lags. Autocorrelation suggests short-term and seasonal patterns in price movements tied to climate. Overall, understanding local climate–price dynamics is important for improving food security and stabilizing rice prices in Semarang.

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