PARAMETER
JURNAL MATEMATIKA, STATISTIKA DAN TERAPANNYA

e-ISSN. 2829-6303
Vol. 04 No. 1, April 2025
Page 141-152

FORECASTING RICE PRODUCTION WITH THE HOLT-WINTERS EXPONENTIAL SMOOTHING METHOD

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Abstract

This study aims to forecast rice production in East Java using the Holt-Winters Exponential Smoothing method which can be used to view data with seasonal and trend patterns. The rice production data used in this study comes from the Central Bureau of Statistics (BPS) which includes production data for the last five years. The results of the analysis show that this method provides a sufficient level of accuracy in forecasting and is also effective in providing estimates of rice production as well as assisting in strategic decision-making on the management of the agricultural sector and food security.

Keywords: *Forecasting, Holt-Winters Smoothing, Rice.*

doi: https://doi.org/10.30598/parameterv4i1pp141-152

1. INTRODUCTION

East Java plays a crucial role in supporting Indonesia's national food security. East Java Province not only provides local food supply but also contributes greatly to the national food supply as one of the major food barns. According to data collected by the Central Bureau of Statistics, East Java Province is the largest rice producer in Indonesia. In 2023, rice production reached 9.71 million tons of milled dry grain (MDG), equivalent to 5.61 million tons of rice. Overall, the trend of rice production in East Java shows a decline in rice production from 2020 to 2023, an issue influenced by reduced harvest areas and variations in crop productivity [1].

Although East Java is the largest rice producer in Indonesia, the productivity of the rice crop in East Java has experienced changes in recent years. These fluctuations are also thought to be caused by climatic variables, which can affect plant growth and development, especially temperature, rainfall, and humidity. These unpredictable fluctuations can cause difficulties in food planning.

Accurate forecasting of rice production is necessary to ensure rice availability and anticipate changes in production. The use of appropriate forecasting models not only makes rice production estimation more accurate, but also helps in resource planning, responding to market demand, and making strategic decisions.

According to [2], the Holt-Winters Exponential Smoothing method can be used for data with trend and seasonal patterns so that for forecasting in this study the Holt-Winters Exponential Smoothing method will be used. This method has the advantage that this analysis is tried three times and produces good forecasting results.

The consideration of using the Holt-Winters Exponential Smoothing method in this study is because the method has a high level of accuracy so that it can help plan production and keep rice prices stable, meeting general food needs.

The condition of rice production in East Java still faces problems such as weather changes, land availability, and production efficiency. Therefore, predictions about rice production are needed to enable the government to make appropriate policies to keep rice availability and prices stable and encourage the growth of the agricultural sector in the region. This research aims to predict rice production in East Java using the Holt-Winters Exponential Smoothing method because this method can handle data that has seasonal components and trends, so it can provide a more accurate estimate of rice production fluctuations based on historical data. This research aims to help farmers and policy makers plan production and keep rice prices stable in the region.

2. RESEARCH METHODS

2.1. Research Characteristics

This research uses a quantitative method approach which is a deductive thinking model by collecting and analyzing numerical data to describe, explain, predict, or control phenomena [3]. In this research, secondary data is used in the form of rice production data in East Java Province during the period 2019 to 2023 obtained from the Central Statistics Agency (BPS).

The forecasting method used is Holt-Winters Exponential Smoothing (HWES) with an additive approach, because the seasonal pattern in rice production data shows relatively constant fluctuations from year to year. Additive models are more appropriate for data with seasonal components that tend to remain fixed or stable in magnitude over time.

2.2. Research Process

In this research, the Holt-Winters Exponential Smoothing method is applied. The steps taken during this research process are as follows:

1. Collecting data on rice production in East Java from 2019 to 2023 obtained from the Central Bureau of Statistics (BPS).
2. Identifying the patterns of the data obtained, including trends and seasonality, to determine whether an additive approach is appropriate.
3. Determining smoothing parameters, namely alpha (α) for level, beta (β) for trend, and gamma (γ) for seasonality, either manually or through an optimization process.
4. Initialize the initial values for the components:
   - The initial level (L_0) is calculated as the average of the values in the first one seasonal cycle.
   - The initial trend (T_0) is obtained as the average of the inter-period differences in the first seasonal cycle.
   - The initial seasonal index (S_0) is determined by calculating the difference between each actual value and the seasonal average in the first cycle.
5. Calculating level, trend, and seasonal smoothing based on the additive Holt-Winters Exponential Smoothing formula updated every period.
6. Calculating forecasting values for future periods using the smoothing results.
7. Evaluate the forecasting results using the Mean Absolute Percentage Error (MAPE) error evaluation metric to assess the accuracy of the model

3. RESULTS AND DISCUSSION

3.1. Data Pattern Identification

The analysis of data taken from various points in time in the past to the present to make predictions or forecasting based on patterns that might be learned from what is happening now and in the past is called time series analysis [4].

Four important things that may be biased and will greatly affect the results related to time series analysis, namely the identification of components that shape data over time, such as trends, seasonal factors, cyclical fluctuations, and random influences [4]. Furthermore, to forecast time series data, we use various modeling methods that can capture the relationship between data in a certain period of time.

To measure the quality of a prediction model, we must validate the model by measuring the error in forecasting using various types of assessments such as RMSE (Root Mean Squared Error), MAE (Mean Absolute Error), MAPE (Mean Absolute Percentage Error), MASE (Mean Absolite Scaled Eror), and ME (Mean Eror) [4]. These values give an idea of how well the model captures the patterns in the data and how accurate its predictions are.

The analysis begins by examining patterns and changes in the data by plotting the time series. This allows us to see the general trend, whether it is rising, falling, or no change, as well as whether seasonal patterns may appear every certain period.

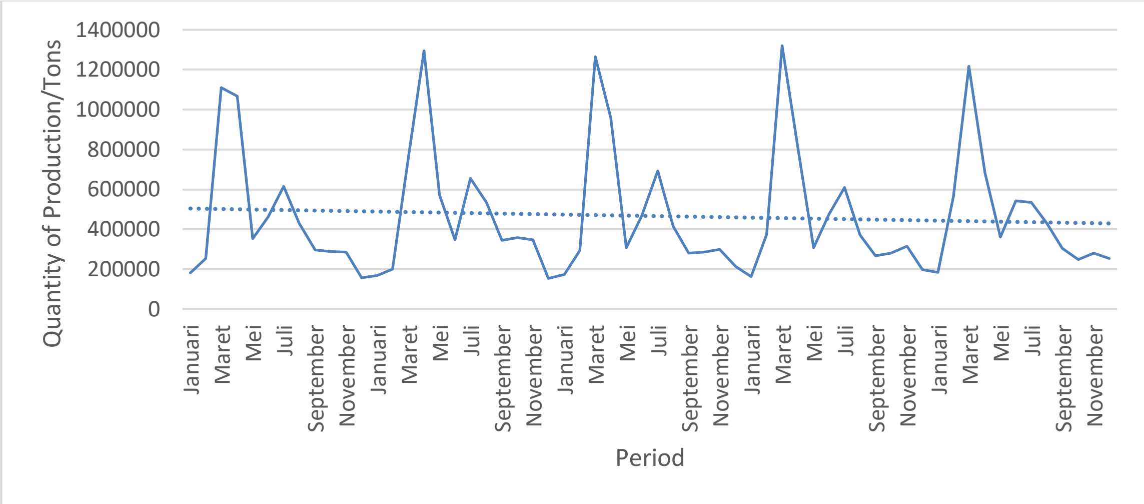

Figure 1. Chart of Rice Production Data in East Java 2019-2023

In forecasting activities, identifying data patterns is very important to produce the right forecasting data. Data that have trend and seasonal patterns are suitable for the Holt-Winters Exponential Smoothing method. As seen in **Figure 1**, the time series plot of rice production in East Java from January 2019 to December 2023. The graph shows a consistent seasonal pattern, with rice production peaking in March every year, coinciding with the main harvest period. After that, there is a decline in production in the following months, especially in January, which is the beginning of the new planting season. This pattern repeats itself on an annual basis and indicates the presence of a seasonal component. In addition, the dashed trend line and the distribution of seasonal points also show an increasing trend in production from year to year, indicating an uptrend pattern.

3.2. Analysis Using the Holt-Winters Smoothing Method

The Holt-Winters Exponential Smoothing (HWES) method is a forecasting technique used to analyze time series data that has trend and seasonal patterns. This method was developed by Charles Holt (1957) and Peter Winters (1960), and is divided into two main models, namely additive models and multiplicative models [5]. The model selection is adjusted according to the seasonal characteristics in the data: additive models are used when the seasonal fluctuations are constant, while multiplicative models are used when the fluctuations increase or decrease with the level of the data.

In this method, there are three smoothing parameters to be determined, namely α (alpha) for level, β (beta) for trend, and γ (gamma) for seasonality, with the value of each being in the range of 0 to 1 [2]. The challenge in applying HWES lies in determining the most optimal combination of parameter values to minimize the forecasting error. This optimization process aims to produce predicted values with the best level of accuracy, which is usually measured using Mean Absolute Percentage Error (MAPE).

This study specifically uses only the Holt-Winters method because the characteristics of the analyzed data show a clear trend and seasonal pattern, as seen in the time series graph. Therefore, this method is considered the most suitable for this case. Although other models such as ARIMA or single/double exponential smoothing can be used, the selection of HWES in this study was based on the suitability of the data structure and the main focus on regular seasonal patterns.

However, interpretation of the Mean Absolute Percentage Error (MAPE) value as a measure of accuracy still needs to consider the context of the data. Although MAPE has limitations, especially when the actual value is close to zero or the fluctuations are extreme, this is not a problem in this study as the rice production data has relatively stable values that are not close to zero. Therefore, MAPE can be effectively used as a key indicator to evaluate model performance. In this study, MAPE is used as the only measure of accuracy to assess how much average error the Holt-Winters model produces in percentage terms against the actual data.

Furthermore, value calculations are performed to obtain the smoothing level, trend, seasonality and estimated forecasting value of the Holt-Winters Exponential Smoothing method using the following equation:

$$L_0 = \frac{1}{l}(y_1 + y_2 + \cdots + y_l) \tag{1}$$

$$T_0 = \frac{1}{l}\sum_{i=1}^{l}(y_{i+1} - y_1) \tag{2}$$

$$S_0 = \frac{y_t}{L_0} \tag{3}$$

$$L_t = \alpha\left(\frac{y_t}{S_{t-s}}\right) + (1-\alpha)(L_{t-1} + T_{t-1}) \tag{4}$$

$$T_t = \beta(L_t - L_{t-1}) + (1-\beta)T_{t-1} \tag{5}$$

$$S_t = \gamma\left(\frac{y_t}{L_t}\right) + (1-\gamma)S_{t-s} \tag{6}$$

$$F_{t+n} = (L_t + kT_t)S_{t+k+s} \tag{7}$$

with,
y = Observed data,
L_0 = Initial value of level smoothing,
T_0 = Initial value of trend smoothing,
S_0 = Initial value of seasonal smoothing with seasonal length,
L_t = level smoothing,
T_t = trend smoothing,
S_t = seasonal smoothing,
t = time scale of observations,
n = much observed data,
s = seasonal length,
F = forecasting value,
m = forecasting period[2].

In this study, the initial smoothing parameters used were determined manually, namely $\alpha = 0.5$, $\beta = 0.1$ and $\gamma = 0.2$. With this combination of parameter values, a Mean Absolute Percentage Error (MAPE) value of 26% was obtained.

Furthermore, to increase the level of forecasting accuracy, a parameter optimization process is carried out using the Solver feature in Microsoft Excel software. The purpose of this optimization process is to minimize the MAPE value, which is used as an objective function in the search for optimal parameters. The parameter value constraints in this optimization process are set as follows:

- $0 \le \alpha \le 1$
- $0 \le \beta \le 1$
- $0 \le \gamma \le 1$

Through the optimization process, a new combination of smoothing parameter values is obtained that results in a lower forecasting error compared to the initial parameters. The optimized parameter values are $\alpha = 0.601951907, \beta = 0.27680301$, and $\gamma = 0.244049418$. With these parameters, the MAPE value decreased from 0.2622 to 0.2543, or in percentage terms decreased from about 26.22% to 25.43%. This decrease indicates an increase in model accuracy, although it is not very significant.

Table 1. Comparison of MAPE Values Before and After Smoothing Parameter Optimization

Parameters	Before	After
α	0,5	0,601951907
β	0,1	0,27680301
γ	0,2	0,244049418
MAPE	0,262209218	0,254257363

Although the MAPE value of 25.43% is still considered moderate in forecasting accuracy evaluation standards, this result is still acceptable for seasonal and complex data such as rice production. However, interpretation of MAPE needs to be done with caution. MAPE gives an idea of the average error relative to the actual data, but does not describe the error distribution in detail. Therefore, conclusions regarding the accuracy of the model should not be overstated, and still consider that the model has limitations in responding to dynamics that are not reflected in the historical pattern of the data.

As explained in the previous discussion, the additive Holt-Winters Exponential Smoothing method requires determining the initial values of three main components, namely the initial level (L_0), the initial trend (T_0), and the initial seasonal index (S_0). The determination of these three components is very important as it will affect the smoothing results and forecasting accuracy. In this study, these initial values are calculated based on the classical approach, using **Equation (1)**, **Equation (2)**, and **Equation (3)** described earlier.

Taking into account that the data used is monthly, the season length used is set at $l = 12$, representing one annual cycle. Based on calculations using these formulas, the initial value for each component is obtained as presented in **Table 2** below:

Table 2. Holt-Winter Exponential Smoothing Method Initial Value

L_0	T_0	S_0
		0,393568
		0,554299
		2,42206
		2,32603
		0,771701
		1,009888
		1,341815
		0,939713
		0,646991
		0,627867
		0,625066
458643,8	1655,908	0,341002

In **Table 2**, the initial value for trend smoothing is $T_{12} = 1655{,}908$, which means that the rice production data in East Java from 2019 to 2020 has an upward trend.

In applying the Holt-Winters Exponential Smoothing method, the forecasting process is carried out through the smoothing stages of the three main components, namely level, trend, and seasonality. Each component is updated sequentially using **Equation (4)** for level smoothing, **Equation (5)** for trend smoothing, and **Equation (6)** for seasonal smoothing, as explained in the previous section.

Once the three components are completely obtained for each time point in the data series, the forecasting value for the upcoming period is calculated using **Equation (7)**, which is the forecasting formula for m periods ahead.

The results of rice production forecasting using the Holt-Winters Exponential Smoothing method are presented in Table 3 below:

Table 3. Data from Rice Production Forecast in East Java for 2024-2025

Years	Month	Forecasthing
2024	Januari	289607,9
	Februari	577940,4
	Maret	1675424
	April	1411025
	Mei	685131,7
	Juni	881693,6
	Juli	1073878
	Agustus	801593,3
	September	599931,7
	Oktober	588685,5
	November	634275,6
	Desember	444901,3
2025	Januari	528635,8
	Februari	1038841
	Maret	2980846
	April	2512980
	Mei	1228504
	Juni	1576316
	Juli	1916378
	Agustus	1434570
	September	1077731
	Oktober	1057828
	November	1138495
	Desember	803402,3

Table 2 above shows that rice production peaks in March and April, which reflect the main harvest period, with very high figures of 1,674,524 tons in March 2024 and 2,980,846 tons in March 2025. Thereafter, production declines drastically, such as in June with only about 881,693.6 tons in June 2024. In December, the lowest production figures occur, with 449,013.3 tons in 2024 and 803,402.3 tons in 2025, which may signal the onset of a new planting season. In contrast, certain months such as August and September show fairly stable production levels. This pattern indicates a strong planting-harvesting cycle and the importance of good management to anticipate low production periods and capitalize on harvests in peak periods.

The following graph shows the comparison between the prediction results made using the Holt-Winters Exponential Smoothing method and the actual rice production data.

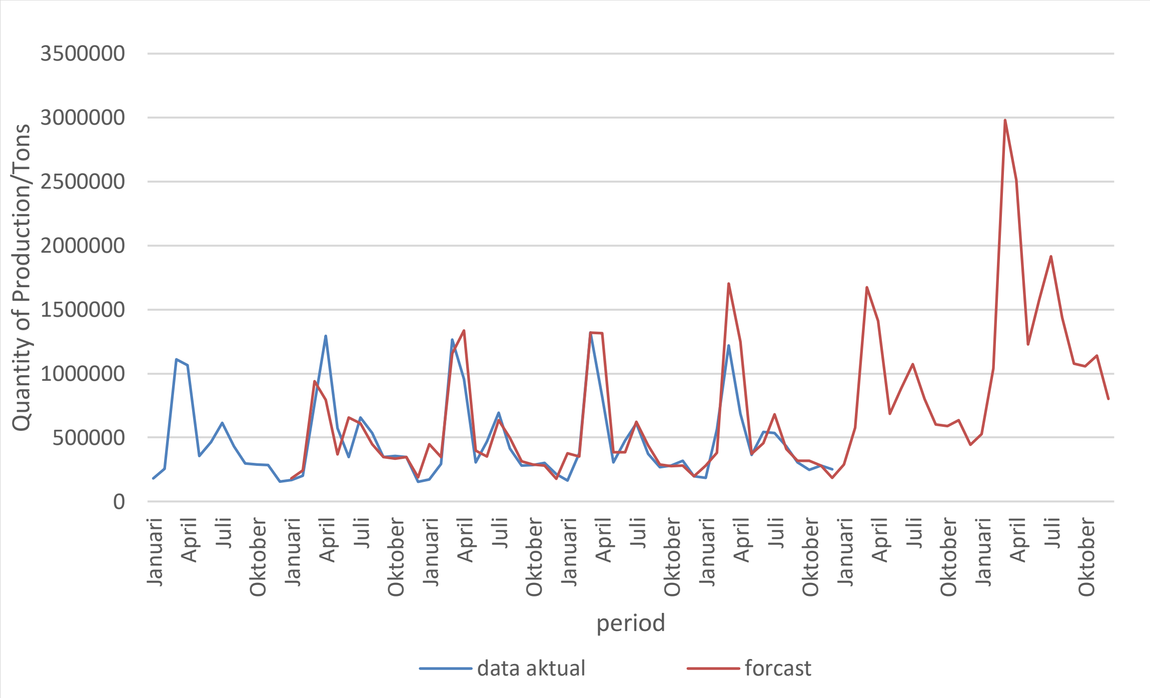

Figure 2. **Comparison Chart of Forecasting Results Data with Actual Data**

Figure 2 presents a comparison between actual data and forecasting results using the Holt-Winters Exponential Smoothing method. The blue line represents the actual data, while the red line shows the forecast results. It should be noted that the forecasting process starts from the second year, as the first year is used as the starting period to calculate the seasonal value in the smoothing process.

Visually, the graph shows that the forecasting line follows the general pattern of the actual data quite well. The seasonal peaks and valleys that occur every year are successfully captured by the model, although there are some deviations between the predicted and actual values at certain points. This is reasonable given that forecasting models such as Holt-Winters focus more on long-term patterns and the stability of trends and seasons, rather than short-term fluctuations or sudden changes that may be influenced by external factors that are not incorporated into the model.

To measure the closeness between the forecasting results and the actual data, the Mean Absolute Percentage Error (MAPE) value of 25.43% indicates that the model has moderate accuracy and is acceptable in the context of seasonal forecasting. However, the deviations seen in some periods, such as when production spikes are higher or lower than the general seasonal pattern, indicate the limitations of the model in capturing unexpected changes.

Overall, the graph in **Figure 2** shows that the forecasting results are able to represent the general pattern of rice production quite well. Therefore, the model can be used as a tool in the planning or decision-making process, especially in formulating policies based on seasonal patterns. However, users of the model need to realize that these predictions cannot fully replace an analysis of the external factors that dynamically affect production.

3.3. Model Validation

In this research, model validation is carried out to measure the accuracy of rice production forecasting results using the Holt-Winters Exponential Smoothing method.

The measurement indicator used in this research for validation is MAPE (Mean Absolute Percentage Error).

MAPE or Mean Absolute Percentage Error is a statistical measure used in assessing the accuracy of a forecasting method by calculating the average absolute percentage error between the predicted value and the actual value. MAPE is represented as a percentage, making it easier to understand the results in a broader context. The equation below is used to obtain the MAPE value [6] cited from [7].

$$MAPE = \frac{1}{n}\sum_{t=1}^{n}\left|\frac{X_t - F_t}{X_t}\right| \cdot 100\% \tag{8}$$

where:
n = number of periods
X_t = actual value in period t
[2].

[6] citing [8] stated that a lower MAPE value indicates that the estimation results are more accurate, which indicates that the forecasting method used is quite good. Meanwhile, to understand the level of accuracy of the forecasting results, the interpretation of the MAPE value obtained can be further explained through the following **Table 4**.

Table 4. Interpretation of MAPE Value

MAPE(%)	Interpretation
<10	Very accurate forecastingt
10-20	Good forecasting
20-50	Fair forecasting
>50	Inaccurate forecasting

The MAPE calculation is done by comparing the actual value of rice production from 2019 to 2023 with the predicted value generated by the Holt-Winters Exponential Smoothing method using **Equation (8)**, which obtained a MAPE value of 25%. It can be concluded that the Holt-Winters Exponential Smoothing method has succeeded in forecasting rice production in East Java quite well. The MAPE value indicates a relative error that is still within reasonable limits. The results show that the Holt-Winters method can be used well to forecast future rice production.

3.4. Implications of Forecasting Results

The results of rice production forecasting in East Java have a number of implications that can be utilized by various stakeholders, especially local governments, agricultural agencies, and farmer groups. Information on annually recurring production patterns allows for better planning in the management of rice logistics and distribution.

For example, if forecasting shows that peak production will occur in March, the government can more optimally organize Bulog's harvest absorption strategy so that prices remain stable and farmers do not suffer losses due to surpluses. Conversely, in months that are expected to experience a decline in production, the distribution of food reserves can be prepared earlier to anticipate supply shortages.

For farmers, this information can be used to plan planting and harvesting schedules more efficiently, including arranging the need for production facilities such as fertilizer and water based on predictions of the growing season. In addition, the forecasting model can also support food security programs and become the basis for formulating medium-term strategic policies in the agricultural sector.

4. CONCLUSION

The conclusion of this study shows that the Holt-Winters Exponential Smoothing (HWES) method can be used to forecast rice production in East Java with a fairly good level of accuracy, although there are deviations in some periods. The resulting forecasting results show a consistent seasonal pattern, with peak production in March each year, which is in line with the main harvest season, and declining production in the months afterwards. The Mean Absolute Percentage Error (MAPE) value of 25.43% indicates that the model is feasible to use for rice production forecasting although not perfect.

The implications of these forecasting results are very important for stakeholders such as local governments, agricultural agencies, and farmers. With information on production patterns that repeat every year, planning for rice distribution, crop absorption, and logistics management can be done more effectively. In addition, farmers can plan planting and harvesting schedules more efficiently, support food security programs, and formulate more targeted medium-term agricultural policies.

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