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Rainfall forecasting using triple exponential smoothing for rice cultivation in lamongan, jawa timur

Shafrila Widyantri[1], Dimara Kusuma Hakim[2], Elindra Ambar Pambudi[3], Maulida Ayu Fitriani[4]
[1,2,3,4]Department of Informatics Engineering, Universitas Muhammadiyah Purwokerto, Indonesia

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ABSTRACT

Rice cultivation is a major agricultural activity that is heavily influenced by weather conditions. Extreme weather events, such as heavy rainfall, can cause farmers' productivity to decline. Rainfall forecasts are important for farmers to help them make the right decisions in managing their farming businesses. This research aims to predict rainfall in Lamongan Regency, East Java province, and provide valuable information to rice farmers to plan the optimal planting season. The method used in this study is Triple Exponential Smoothing (TES), an effective forecasting technique for processing time series data with seasonal patterns. Monthly rainfall data for the last five years formed the basis of the forecast, with data sourced from NASA's Power Data Access Viewer. The analysis results include a Mean Absolute Percentage Error (MAPE) value of 97.559% for rainfall. This rainfall forecast can assist farmers in increasing rice productivity and minimizing the risk of crop failure due to unpredictable weather conditions. With the rainfall weather forecast, farmers are expected to know the suitable months for rice cultivation so that productivity increases

Corresponding Author:

Shafrila Widyantri, Dimara Kusuma Hakim,
Department of Informatics Engineering,
Muhammadiyah Purwokerto University,
Dukuh Waluh Road, Banyumas 53182, Central Java, Indonesia.
Email: shafrilawidyantri3112@gmail.com, dimarakusumahakim@gmail.com
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1. INTRODUCTION

Indonesia is an agrarian country where most of its population lives from farming or agriculture, so agriculture plays an important role in the welfare of the Indonesian people. Agriculture plays an important role as it is the third largest contributor to Indonesia's economic structure. East Java, which contributes 17% to the national food supply, has been experiencing a decline in its production each year[1]. Paddy plants (Oryza sativa L.) are one of the most important cultivated plants in human history. Paddy products worldwide rank third among all cereals, after corn and wheat, but for the majority of people around the world, paddy is their primary source of carbohydrates[2]. The nature of Indonesia affects the climate of this country. Factors that influence the climate include average temperature, rainfall, atmospheric pressure, humidity, wind, the number of atmospheric particles, and meteorology in a specific location over a long period. Climate change can disrupt food availability, reduce access to food and affect food quality. The climate change directly impacts the shifting seasons, making it difficult for farmers to determine the best times to plant and harvest their crops [3]. One climatic element that can be used as an indicator of paddy production and productivity is rainfall[4]. Rainfall is the deposition or deposit of water in liquid or solid form that comes from the atmosphere[5]. Unpredictable rainfall can impact rice farming, such as crop failure, decreased production, and land damage. This is caused by changes in erratic rainfall patterns due to climate change. Rainfall prediction is an important aspect of improving weather and climate information [6].

East Java Province is one of the food producers, particularly paddy. The paddy production in East Java Province in 2022 reached 9.53 tons of GKG. Lamongan Regency is the area with the highest paddy production, while Mojokerto City is the area with the lowest paddy production[7]. Triple Exponential Smoothing (TES) is a forecasting method that can be used to predict rainfall. This method can manage trends and seasonal elements present in time series data. The Triple Exponential Smoothing method is based on three smoothing equations, each for the stationary, trend, and seasonal components[8]. This method is also known as Holt-Winters Exponential Smoothing. This method includes an additional gamma constant value to achieve a smaller smoothing value and more accurate forecasting results[9]. Previously, research was conducted by Adindach Syadza Rizkia, et al. [10], titled "Application of the Triple Exponential Smoothing Method for Rainfall Forecasting in Bogor City." The research was conducted using a similar method with the aim of forecasting rainfall for paddy cultivation in Lamongan Regency, East Java, the forecasting results obtained show that the Additive model is better used for forecasting the amount of rainfall because it has a smaller MAPE value than the Multiplicative model. The forecasting value obtained from the Additive model in forecasting the amount of rainfall in Bogor City in 2021 is around 47.3 mm to 434.9 mm.

Research by Affandi et al. [11], titled "Development of Weather Forecasting Mobile Application for Food Crop Determination Using Triple Exponential Smoothing Method" with result weather forecasting from month 1 of 2011 to month 5 of 2017 using the Triple Exponential Smoothing method on temperature data gets the smallest MAD value of 0.7050026709838 by using alpha 0.1. Humidity data gets the smallest MAD value of 4,522655267 by using alpha 0.4. Rainfall data gets the smallest MAD value of 129.119557 using alpha 0.1. The length of irradiation data gets the smallest MAD value of 1,186391209 by using alpha 0.5. In the next period, the Triple Exponential Smoothing method can be used for forecasting with alpha 0.1 for temperature, 0.4 for humidity, 0.1 for rainfall and 0.5 for length of irradiation. The research by Relin Nelfi Yolanda et al. [12], titled "Application of the Triple Exponential Smoothing Method in Forecasting Pineapple Production in Riau Province." The forecasting was carried out using one of the types of Triple Exponential Smoothing methods, namely Multiplicative Triple Exponential Smoothing, with the Minitab 16 software, considering the MAPE, MAD, and MSD values. It resulted in MAPE = 3.7%, MAD = 1.93%, and MSD = 7.05%, which can be categorised as very good, thus producing an accurate forecast.

The limitations of previous researchers only look at the sales of a product not the climate that can affect a person's productivity. This research using the Triple Exponential Smoothing method can help forecast rainfall by combining level, trend and seasonal components more accurately. The Triple Exponential Smoothing method takes into account seasonal fluctuations as well as changes in trends over time, which can help farmers in scheduling planting and irrigation planning.

2. METHOD

The data source in this study is secondary data using monthly rainfall statistics for a five-year interval from January 2019 to December 2023, by accessing information through the National Aeronautics and Space Agency website. Data is created by downloading previous data, a non-experimental design is used for data extraction which is then processed and analyzed to produce a forecasting score. In this study, the rainfall variable was used. The Triple Exponential Smoothing (TES) method was chosen for forecasting as it can manage data that has a trend and seasonal elements simultaneously. The additive Triple Exponential Smoothing model is a forecasting method that uses three smoothing equations to forecast the next data value while the Multiplicative Triple Exponential Smoothing model is a forecasting method that uses three smoothing equations to process time series data containing seasonal components. Triple Exponential Smoothing (TES) Multiplicative model is a forecasting method that can be used to predict rainfall. TES Multiplicative model is one of the forecasting methods that use time series data. How the TES Multiplicative model works:

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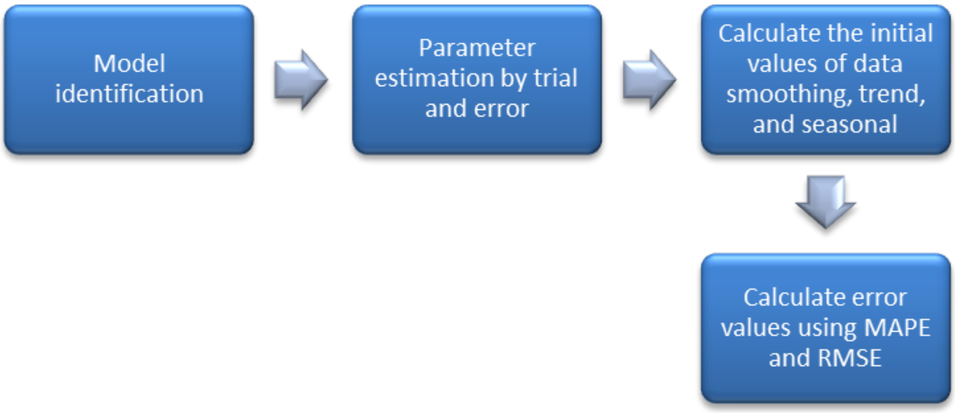

Figure 1. Research flow

Multiplicative TES model can be used to predict rainfall because it can manage seasonal elements and trends that exist in time series data. The advantage of the Exponential Smoothing method is that it reduces data storage problems, there is no need to store all historical data, just the last observation, the last forecast, and a constant value. The use of Microsoft Excel application to process data with the smallest MAPE value is shown as a good forecasting criterion.

Triple Exponential Smoothing

Triple Exponential Smoothing is a forecasting method derived from three smoothing equations: stationary, trend, and seasonal, and uses three smoothing parameters: α, β, and γ, each valued between 0 and 1. Triple Exponential Smoothing is very suitable for use when the data pattern is seasonal and trending[13].

The Triple Exponential Smoothing method has two model forms: the additive seasonality model, used when the constant effect differs over time, and the multiplicative seasonality model, used when the magnitude of the seasonal effect changes over time [14]. This research uses the Triple Exponential Smoothing Multiplicative model.

a. Actions in calculations using the Triple Exponential Smoothing technique:

Equations (1), (2), (3) can be used to determine the data smoothing value for the additive model, and for the multiplicative data model, equations (1), (2), and (4) can also be used.

1) Exponential Smoothing Initial Score (SL)

$$S_L = \frac{1}{L}\left(X_1 + X_2 + X_3 + \cdots .. + X_L\right) \quad (1)$$

L = 1,2,3,...,L, L is the seasonal length.

2) Initial value of trend smoothing (TL)

$$T_L = \frac{1}{L}\left(\frac{X_L+1+X_1}{L} + \frac{X_L+2+X_2}{L} + \cdots + \frac{X_L+L+X_L}{L}\right) \quad (2)$$

3) Seasonal smoothing start score (It)
Holt-Winters Additive Design

$$I_t = X_t - S_L \quad (3)$$

Design *Multiplicative Holt-Winters*

$$I_t = \frac{X_t}{S_L} \quad (4)$$

b. Determining the benchmarks α, β, and γ. To determine the values of α, β, and γ, use the solver table to obtain the maximum value. The values are 0≤α, β, and γ≤1.

c. Calculating the initial smoothing value

The Multiplicative Holt-Winters model is used if the time series data has a seasonal pattern with non-constant seasonal variations.

1) Exponential smoothing

$$S_t = a\frac{x_t}{1_{t-L}} + (1-a)(S_{t-1} + T_{t-1}) \quad (5)$$

2) Trend Smoothing

$$T_t = B(S_t - S_{t-1}) + (1-B)\,T_{t-1} \quad (6)$$

3) Seasonal Smoothing

$$l_t = y\frac{x_t}{S_t} + (1-y)l_{t-1} \quad (7)$$

4) Period Prediction

$$F_{t+m} = (S_t - mT_t) + l_{t-L+m} \quad (8)$$

Note :
α =Single fixed value actual statistical smoothing
β =Single fixed value smoothing trend pattern
γ =Single fixed value smoothing seasonal patterns
X_t =Actual scores/statistics in period t
S_t =Statistical exponential smoothing score in period t
l_t =Seasonal score in period t
T_t =Trend score in period t
m =The total future period that will be predicted
F_{t+m} =Prediction score in period t + m

Forecasting

Forecasting is a way to plan and control production to face future uncertainties. Forecasting methods are divided into two categories: qualitative methods and quantitative methods. Qualitative methods are based on opinions and descriptive analysis, while quantitative methods are conducted based on mathematical calculations [15].

Data Mining

Data mining is the process of analyzing data from various perspectives and integrating it into important information. Technically, data mining is the process of finding correlations or patterns among hundreds or thousands of fields in a large relational database [16].

Time Series

A time series is a sequence of events that occur in a specific order over time. Time series forecasting is a prediction used to forecast future events based on past data [17]. The additive Triple Exponential Smoothing model is a forecasting method that uses three smoothing equations to forecast the next data value while the Multiplicative Triple Exponential Smoothing model is a forecasting method that uses three smoothing equations to process time series data containing seasonal components. Triple Exponential Smoothing (TES) Multiplicative model is a forecasting method that can be used to predict rainfall. Multiplicative TES model can be used to predict rainfall because it can manage seasonal elements and trends that exist in time series data. The advantage of the Exponential Smoothing method is that it reduces data storage problems, there is no need to store all historical data, just the last observation, the last forecast, and a constant value.

MAPE (Mean Absolutely Presentage Error)

MAPE is a method that can be used to calculate the accuracy value of prediction methods and relative decisions to determine the deviation of errors from predicted data to actual data. The following is the formula used to calculate MAPE [18].

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

Note :
X_t = Actual score period t
F_t = forecasting score in period t
n = Total number of statistics
Based on the formula above, the smaller the MAPE score, the higher the accuracy of the prediction model. The table below shows the range of values used to evaluate the performance of the forecasting model.

Table 1. MAPE value term

MAPE Score	Parameter
Less than 10 percent	Very good
10 percent – 20 percent	Good
20 percent – 50 percent	Enough
More than 50 percent	Bad

3. RESULTS AND DISCUSSIONS

Rainfall Data Overview and Trends

The rainfall forecast statistics used as the dataset in this study are the rainfall data of Lamongan Regency. The amount of rainfall data is 60 data points from January 2019 to December 2023.

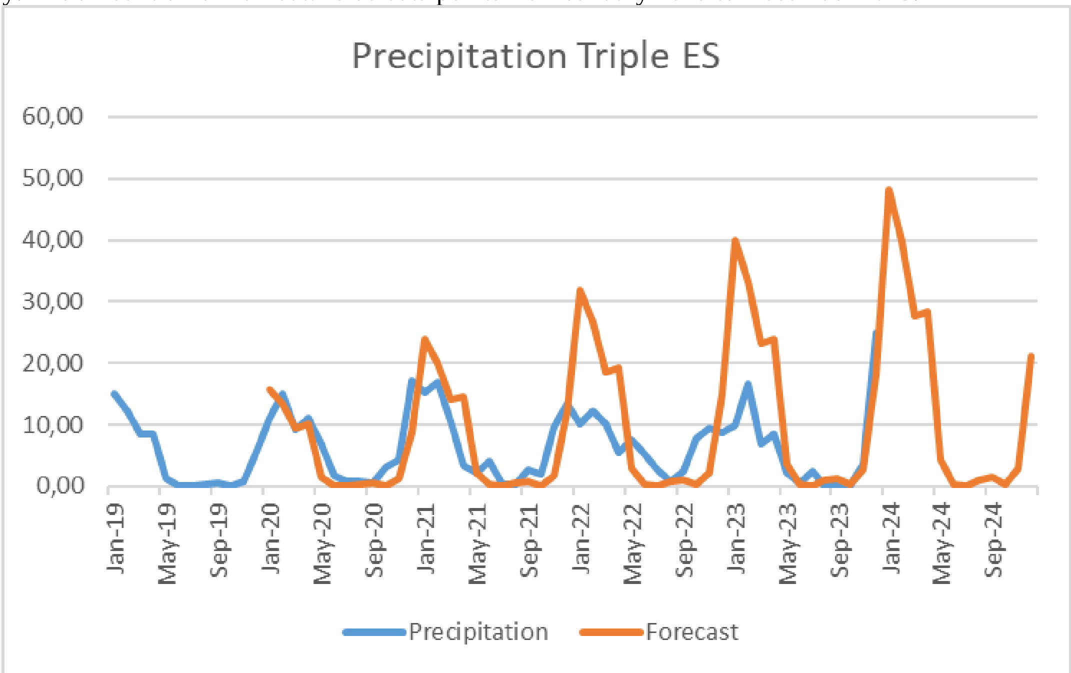

Figure 2. Comparison graph of average rainfall

Based on the graph above, the average rainfall in Lamongan Regency is very varied. The average rainfall statistics were highest in December 2023 and lowest in July 2019. In Figure 1, the data shown fluctuates each year. Figure 1 illustrates the monthly rainfall pattern, with high rainfall typically occurring from November to March each year. Rainfall in the other months is relatively low. This condition occurs repeatedly every year, forming a seasonal pattern in the rainfall statistics of Lamongan Regency. The trend line (red) is higher than the seasonal line (blue) because the trend encompasses the baseline value of the data and long-term changes, which generally have a greater value compared to seasonal deviations. Seasonal only captures periodic fluctuations that occur around the average value determined by the trend.

Forecasting Results Using the Triple Exponential Smoothing

Observations based on rainfall data in Lamongan Regency indicate the formation of a trend pattern. The calculation of the average rainfall using the Holt-Winters exponential smoothing method. In the calculation performed, monthly data for one year was used, resulting in a season length (L) of 48. Then, using equations (1), (2), and (4) to calculate the initial smoothing values, the following results were obtained:

Table 2. Initial score for statistical smoothing

Year	Month	Rainfall	Level (SL)	Trend (TL)	Seasonal
2019	January	15,00 cm			3,40
2019	February	12,26 cm			2,78
2019	March	8,38 cm			1,90
2019	April	8,50 cm			1,93
2019	May	1,26 cm			0,28
2019	June	0,11 cm			0,03
2019	July	0,03 cm			0,01
2019	August	0,31 cm			0,07
2019	September	0,43 cm			0,10
2019	October	0,09 cm			0,02
2019	November	0,82 cm			0,19
2019	December	5,72 cm	4,41	0,20	1,30

Then using the solver table to obtain the optimal benchmark values for the variables α, β, and γ. In this case, the scores of α = 0, β = 0, and γ = 0 are then recapitulated using the Triple Exponential Smoothing method. With the use of the multiplicative pattern according to the stages in the research methodology, the following recap results were obtained.

Table 3. Comparison of actual and predicted data

Year	Month	Actual Data	Prediction	Difference	Absolute Error (AE)	Squared Error (SE)	Absolute Persen Error (APE)
2020	January	11,14 cm	15,67 cm	-4,54	4,54	20,57	40,72
2020	February	15,01 cm	13,37 cm	1,64	1,64	2,69	10,93
2020	March	9,18 cm	9,52 cm	-0,34	0,34	0,11	3,67
2020	April	10,99 cm	10,03 cm	0,96	0,96	0,92	8,75
2020	May	6,86 cm	1,54 cm	5,32	5,32	28,30	77,56
2021	…	…	…	…	…	…	…
2022	…	…	…	…	…	…	…
2023	August	0,08 cm	0,92 cm	-0,84	0,84	0,71	1075,22
2023	September	0,04 cm	1,31 cm	-1,27	1,27	1,61	2860,04
2023	October	0,07 cm	0,29 cm	-0,22	0,22	0,05	303,50
2023	November	3,47 cm	2,55 cm	0,92	0,92	0,86	26,64
2023	December	24,79 cm	18,07 cm	6,72	6,72	45,21	27,12

Table 4. Forecasting rainfall data for 2024

Year	Prediction	Difference	Absolute Error (AE)	Squared Error (AE)
January	48,09 cm	-48,09	48,09	2312,61
February	39,87 cm	-39,87	39,87	1589,38
March	27,63 cm	-27,63	27,63	763,49
April	28,39 cm	-28,39	28,39	805,99
May	4,25 cm	-4,25	4,25	18,09
June	0,39 cm	-0,39	0,39	0,15
July	0,12 cm	-0,12	0,12	0,01
August	1,09 cm	-1,09	1,09	1,18
September	1,55 cm	-1,55	1,55	2,39
October	0,34 cm	-0,34	0,34	0,12
November	2,99 cm	-2,99	2,99	8,93
December	21,16 cm	-21,16	21,16	447,74

Error Analysis and MAPE Calculation

Next, calculate the error value of the estimate that has been made using the MAPE formula based on equation (9):

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

$$MAPE = \left(\frac{100\%}{48}\right) * (4682{,}86)$$

$$= 97{,}559$$

Based on the MAPE value calculations above, the MAPE value for precipitation is 97,559. The MAPE value for temperature is 1.777367889 with a score of α equal to 0.340033249, β equal to 0, and γ equal to 1. The MAPE value for wind speed is 15.44161087 with a score of α equal to 0, β equal to 0, and γ equal to 0.405944683. For suitable rainfall, the average rainfall that is good for paddy growth is around 200 mm for a month. Based on Table 4, the right time for paddy cultivate is January, February, March, April, and December.

4. CONCLUSION

The application of the Triple Exponential Smoothing method for rainfall forecasting on rice cultivation in Lamongan Regency using monthly data from January 2019 to December 2023 produces results with the rainfall variable, where the MAPE value for rainfall is 97.559. The MAPE value for temperature is 1.777367889, with α score equal to 0.340033249, β equal to 0, and γ equal to 1. The MAPE value for wind speed is 15.44161087, with α score equal to 0, β equal to 0, and γ equal to 0.405944683. Based on the 2024 forecast data, the right time to plant rice is January, February, March, April, and December. The results of this study are expected to be used as insight or reference for farmers regarding the months that are good for rice cultivation. With the limitations of this research, namely the high MAPE results for rainfall, it is hoped that future researchers can apply the additive Triple Exponential Smoothing model in the hope that the MAPE value is lower.

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