

Rainfall Forecasting Using the Holt-Winters Exponential Smoothing Method

¹I Komang Arya Ganda Wiguna, ^{2*}Ni Luh Putu Ayu Cintia Utami, ³Wayan Gede Suka Parwita, ⁴I Putu Agus Eka Darma Udayana, ⁵I Gede Iwan Sudipa

^{1,2*,3,4,5}Fakultas Teknologi Dan Informatika, Institut Bisnis Dan Teknologi Indonesia
 Email: kmaryagw@instiki.ac.id¹, ayucintiautami@gmail.com^{2*}, gede.suka@instiki.ac.id³, agus.ekadarma@gmail.com⁴, iwansudipa@instiki.ac.id⁵

<p>Keywords</p> <hr/> <p>Rainfall Forecasting, Holt-Winters Exponential Smoothing Method, MAPE Testing</p>	<p>Abstract. Abiansemal District is dominated by agricultural land, with Subak Blahkiuh being one of the agricultural lands in the district. Agriculture is extremely weather-dependent, particularly during the monsoon season. Therefore, precipitation forecasting is necessary for determining a favorable sowing season. Researchers use the Holt-Winters Exponential Smoothing method with data from 2012 to 2022 for forecasting. Holt-Winters Exponential Smoothing employs two forecasting models. The results of the calculations indicate that the additive model has alpha equal to 0.653467, beta equal to 0.0036348, and gamma equal to 0.1182400. While the multiplicative model has alpha values of 0.8889286, 0.0001 and 0.0246825 for beta and gamma, respectively. For accurate forecasting, it is necessary to examine the error data, specifically the MAE and MAPE. The multiplicative model yielded an MAE of 158.87 and a MAPE of 55.18%, whereas the additive model yielded an MAE of 186.59 and a MAPE of 70.18%. The MAPE values of the additive model and multiplicative model are greater than 50 percent, indicating that the additive and multiplicative models provide inaccurate forecasts. Between the additive model and the multiplicative model, the Holt-Winters Exponential Smoothing method favors the multiplicative model for future precipitation forecasting.</p>
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1. INTRODUCTION

Bali Province is one of Indonesia's 23°N–23°S provinces. Bali has 5,636.66 Km² of land and water. Bali Province has a tropical climate with rainy and dry seasons, like most of Indonesia. Bali's tropical environment boosts agriculture output. Badung Regency is almost entirely agricultural, making it one of Bali's most agricultural places. Agriculture is famous in Badung's northern Abiansemal District. Abiansemal District in Badung Regency includes 18 villages and 6,901 Ha of agricultural land, 57.72% of which is dry. Subak Blahkiuh is an agricultural property between Abiansemal Village and Blahkiuh Village. Subak, owned by Bali's farmers, manages traditional rice fields' irrigation. Subak Blahkiuh has 558 members from Blahkiuh, Abiansemal, Bongkasa, Dauh Yeh Cani, and Pungul.

In Subak Blahkiuh, namely rice, long beans, chilies, corn and vegetable flowers. It consists of three growing seasons, namely the first growing season in January, the second growing season in May and the third growing season in September. For the harvest season for each plant is different, the harvest of rice plants is three months, the harvest of secondary crops such as corn is harvested in 3.5 months and the long bean crop is harvested in two months. Agriculture is very influential on the weather, especially during the rainy season, because during the rainy season there are many pests that attack plants. In addition, heavy rains cause flooded rice fields so that they can soak rice plants, this results in crop failure. Rainfall greatly determines the yields obtained by farmers[1]–[3].

Rainfall is the height of flat-collected rainwater that does not evaporate, leak or flow. Rainfall is measured in millimeters or inches, although Indonesia uses mm. In a flat area of one square meter, one millimeter or one liter of rain can be accommodated[4]. Climate change has prevented the rainy season from occurring in October-April, according to BMKG Region III Denpasar statistics. Local, regional, and global influences affect rain. Temperature, humidity, and wind influence local weather. El-Nino and La-Nina effect Indonesian rain. El-Nino reduces rainfall owing to Pacific Ocean warming, causing drought in Indonesia. El-Nino causes excessive rainfall in Indonesia, while La-Nina cools sea surface temperatures below normal. Regional influences such as MJO (Madden Julian Oscillation) cause rainfall to increase and decrease in pairs from west to east along the Indian Ocean to the Pacific Ocean. Forecasting aids farmers' work.

Several studies explain that forecasting is a technique for estimating a value at a certain time in the future by taking into account past data and current data [5]–[8]. The role of forecasting is very important in various fields such as agriculture, meteorology and geophysics[9]. There are several methods of forecasting, one example is the Holt-Winters Exponential Smoothing method.

The Holt-Winters Exponential Smoothing method is a forecasting method that not only looks at trend factors, but also looks at seasonal factors.[10]. If the data contains trend and seasonality components, the Holt-Winters Exponential Smoothing method can be used, which requires three smoothing parameters, namely α (for the “level” of the process), β (for trend smoothing), and γ (for seasonal component), the values for α , β and γ will minimize MAPE (Mean Absolute Percentage Error)[11]. This method is suitable for forecasting rainfall because it uses data on a time series where the data used is previous rainfall data. The advantages of the Holt-Winters Exponential Smoothing method are that this method is very good at predicting data patterns that have seasonal effects with concurrent trend elements, the method is simple and easy to practice and competitive against more complex forecasting models. So it is very appropriate to use in forecasting rainfall.

Based on the problems above, it is necessary to make the best model for forecasting rainfall using the Holt-Winters Exponential Smoothing method with a case study in Subak Blahkiuh to determine a good planting season for farmers. The data were obtained from observations from the Center for Meteorology, Climatology and Geophysics Region III Denpasar with monthly rainfall data at the Abiansamal Village Station, Badung Regency from January 2012 to December 2022.

2. METHODS

Holt-Winters Exponential Smoothing Method

The Holt-Winter exponential smoothing method is a method that can overcome trend and seasonal factors that appear simultaneously in time series data. This method is based on three elements, namely the original data element, trend and seasonality by giving three consecutive weights in the prediction, namely α , β , and γ . The coefficients α , β , and γ lie between 0 and 1 which are determined subjectively or by minimizing the error value of the forecast[12]–[14]. The Holt-Winter exponential smoothing method is divided into two models, namely the additive and multiplicative models. According to the journal[15]calculations using the additive model are performed if the original data plot shows relatively stable (constant) seasonal fluctuations, while the multiplicative model is used if the original data plot shows varying seasonal fluctuations.

Following are the steps for initializing level, trend and seasonal values.

- Step 1.

Specifies the initial value of the level

$$L_s = (Y_1 + Y_2 + \dots + Y_s) / s$$

Information:

L_s = Initialize Level

Y_s = sth Rainfall Data

s = Seasonal Period ($s=12$)

- Step 2.

Determine the initial value of the trend

$$b_s = \frac{1}{12} \left(\frac{Y_{s+1} - Y_s}{2\alpha} \right)$$

Information:

b_s = Initialize the trend

Y_{s+1} = Rainfall data to-($s+1$)

s = Season Length ($s=12$)

- Step 3.

Determine the initial value of the seasonality index for the multiplicative equation

$$S_p = Y_p / L_s$$

Determine the initial value of the seasonality index for the additive equation

$$S_p = Y_p - L_s$$

Information:

S_p = Seasonal initialization

Y_p = Rainfall Data p

p = Seasonal Period in Year 20

The following are the calculation steps for the Holt-Winters Exponential Smoothing method.

- Level Smoothing

Additive Model

$$L_t = \alpha(Y_t - S_{t-s}) + (1 - \alpha)(L_{t-1} + b_{t-1})$$

Multiplicative Model

$$L_t = \alpha \frac{Y_t}{S_{t-s}} + (1 - \alpha)(L_{t-1} + b_{t-1})$$

- Trend Smoothing

Additive Model

$$b_t = \beta(L_t - L_{t-1}) + (1 - \beta)b_{t-1}$$

Multiplicative Model

$$b_t = \beta(L_t - L_{t-1}) + (1 - \beta)b_{t-1}$$

- Seasonal Smoothing

Additive Model

$$S_t = \gamma(Y_t - L_t) + (1 - \gamma)S_{t-s}$$

Multiplicative Model

$$S_t = \gamma \frac{Y_t}{L_t} + (1 - \gamma)S_{t-s}$$

- Forecasting Period t

Additive Model

$$F_{t+m} = L_t + b_t m + S_{t-s+m}$$

Multiplicative Model

$$F_{t+m} = (L_t + b_t m) S_{t-s+m}$$

Information:

L_t = Level in the 2nd periodt

L_{t-a} = Level in the 2nd periodt-1

b_t = Trend in the 2nd periodt

b_{t-1} = Trend in the 2nd periodt-1

S_t = Seasonality in the 2nd yeart

S_{t-s} = Smoothing of seasonal factors

Y_t = Data in the 2nd periodt

s = seasonal length

t= Seasonal period

m= Forecasted time period

α = Level weighting parameter ($0 < \alpha < 1$)

β = Trend weighting parameter ($0 < \beta < 1$)

γ = Seasonal smoothing weighting parameter

Model Accuracy Analysis

Based on research[16], the following is the formula used to calculate MAPE (Mean Absolute Percentage Error) and MAE (Mean Absolute Error).

- Mean Absolute Percentage Error (MAPE)

MAPE is a calculation by looking for the absolute error for each period divided by the actual value in that period and an average percentage of absolute errors is made. The calculation:

$$MAPE = \frac{1}{n} \sum_{t=1}^n \left| \frac{A_t - Y_t}{A_t} \right| \times 100\%$$

The MAPE values are as follows:

- <10% means the ability of the forecasting model is very good.
- 10-20% means good forecasting model ability.
- 20-50% means the model's forecasting ability is feasible.
- >50% means bad forecasting model ability.

- Mean Absolute Error(MAE)

MAE is a calculation to determine the level of accuracy that is determined by the resulting error value.

The calculation:

$$MAE = \frac{1}{n} \sum_{t=1}^n |A_t - Y_t|$$

Information:

A_t = Actual data

Y_t = Forecasting data

n = Number of periods

Forecasting Stages

To conduct research on rainfall forecasting, several important steps are needed, namely data collection, initialization or the process of determining the initial value of forecasting and forecasting rainfall. In this study, the Holt-Winters Exponential Smoothing Method was used. This method is one of the time series methods, which in addition to paying attention to trend factors also pay attention to seasonal (seasonal) factors. In general, the stages of this method are as follows:

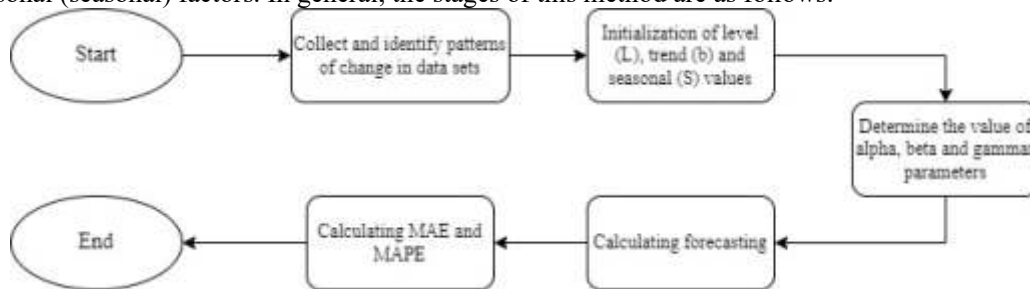


Figure 1. Stages of the Holt-Winters Exponential Smoothing Method

The first step to forecasting using the Holt-Winters Exponential Smoothing method is to collect data, namely rainfall data. After the data is collected, the next step is to determine the initial value of the level, trend and seasonality. Next determine the parameter values α, β and γ , to get the best forecasting value, you can change the parameter values several times. After the initial values of the three variables are obtained, then do the forecasting on the data that has been collected before. Determining the level of accuracy of the method can be calculated using MAE (Mean Absolute Error) and MAPE (Mean Absolute Percent).

3. RESULTS AND DISCUSSION

Data Initialization

Before forecasting, the first step is data initialization. Cleaning data is used to find empty data by looking for the average between the previous and following months. The results will be entered into the blank data. After cleaning the data, the data is converted into csv format so that it is readable

on Jupyter Python. The data used in this study is monthly rainfall data from the Abiansemal Station for 10 years, namely data from 2010 to 2022.

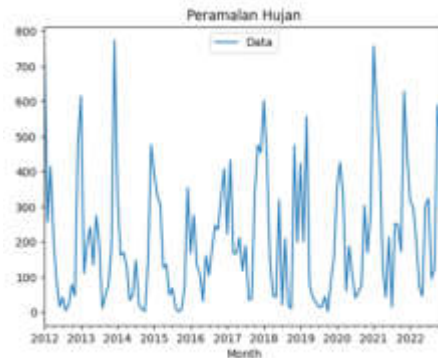


Figure 2. Data plots

It can be seen in Figure 2, that the movement of rainfall increases and decreases every year, this indicates that the data is seasonal data.

Determining Alpha, Beta and Gamma Values

Carrying out tests with a period of six months, use seasonal periods for six months, with the same trend and seasonality as mul, which means that mul is multiplicative and add is additive.

```

=====
Forecast: Multiplicative Model Results
=====
Dep. Variable: Data   No. Observations: 120
Model: Exponential Smoothing   AIC: 4479.046
Date: 2023-02-10   BIC: 4494.928
Optimized: True   AICc: 4472.180
Trend: Multiplicative   BICc: 4498.407
Seasonal: Multiplicative   BIC2: 4498.407
Seasons: Periods: 6   Date: Fri, 10 Feb 2023
Forecast: 180 days   Alpha: 0.8889286
Model Coefficients: Beta: 0.0001
Gamma: 0.0246825

=====
smoothing_level      0.8889286      alpha      True
smoothing_trend      0.0001         beta       True
smoothing_seasonal   0.0246825     gamma     True
initial_level        48.3341111     level     True
initial_trend        1.5984627     trend    True
initial_seasons_1    1.0429404     seasons_1 True
initial_seasons_2    0.1804971     seasons_2 True
initial_seasons_3    0.9749811     seasons_3 True
initial_seasons_4    0.0202970     seasons_4 True
initial_seasons_5    0.9847500     seasons_5 True
initial_seasons_6    1.2412591     seasons_6 True
=====

```

Figure 3. Multiplicative Alpha, Beta and Gamma Output

It can be seen in the output above for the best model for forecasting the multiplicative model, the alpha value or smoothing level is 0.8889286, the beta value or smoothing trend is 0.0001 and the gamma value or seasonal smoothing is 0.0246825.

```

=====
Forecast: Additive Model Results
=====
Dep. Variable: Data   No. Observations: 120
Model: Exponential Smoothing   AIC: 4965.070
Date: 2023-02-10   BIC: 4981.756
Optimized: True   AICc: 4958.499
Trend: Additive   BICc: 4981.497
Seasonal: Additive   BIC2: 4981.497
Seasons: Periods: 6   Date: Fri, 10 Feb 2023
Forecast: 180 days   Alpha: 0.6534669
Model Coefficients: Beta: 0.0036348
Gamma: 0.1182400

=====
smoothing_level      0.6534669      alpha      True
smoothing_trend      0.0036348     beta       True
smoothing_seasonal   0.1182400     gamma     True
initial_level        58.98244       level     True
initial_trend        2.1270202     trend    True
initial_seasons_1    1.1310540     seasons_1 True
initial_seasons_2    0.1262416     seasons_2 True
initial_seasons_3    17.700427     seasons_3 True
initial_seasons_4    0.0202970     seasons_4 True
initial_seasons_5    0.9847500     seasons_5 True
initial_seasons_6    1.2412591     seasons_6 True
=====

```

Figure 4. Additive Alpha Beta Gamma Output

In the value additive model alpha or smoothing level is 0.6534669, beta or smoothing trend is 0.0036348 and gamma or seasonal smoothing is 0.1182400.

Forecasting With the Holt-Winters Exponential Smoothing Method

The first is to make adjustments and estimates, where there is a plot command which will bring up a graph so it's easy to read. In Figure 5 and Figure 6, it can be seen that the orange color is the test data and the green color is the prediction which shows almost the same graphic shape.



Figure 5. Train Output, Test and Estimation using Holt Winters Multiplicative Model

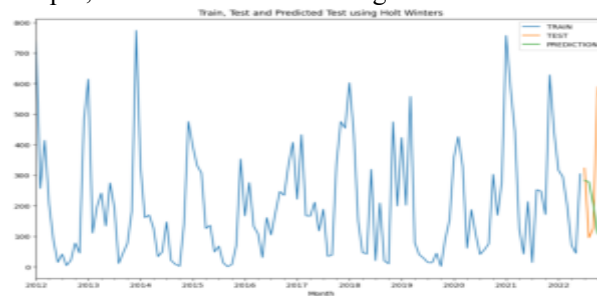


Figure 6. Output Train, Test and Estimates using Additive Holt Winters Model

On the chart train, test and estimates of the multiplicative model form of the test data used and the estimates are almost the same, from July 2022 to December 2022. Meanwhile, the additive model estimates are different from the test data.

Furthermore, to see more clearly the graphs of trains, tests and estimates using the Holt Winters multiplicative and additive models with data test using the last six months, namely July to December 2022.

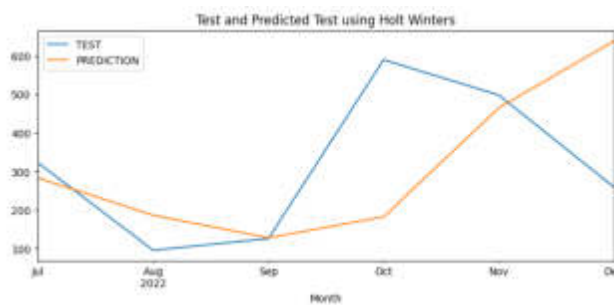


Figure 7. Output Test Data and Multiplicative Model Prediction

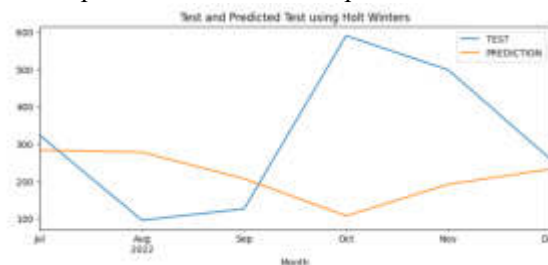


Figure 8. Test Data Output and Additive Model Prediction

In Figure 7 and Figure 8 it shows from July 2022 to December 2022, which can be seen from the blue diagram showing test data and orange indicates predictions. Where from the two Holt Winters Exponential Smoothing models, namely multiplicative and additive models, the test and prediction data have different patterns.

Error Testing

Data testing uses the sklearn module, the command called is Mean Absolute Error and Mean Absolute Percentage Error. Seen in table 3.1 the Mean Absolute Error or (MAE) produces 158.87 and the Mean Absolute Percentage Error produces 55.18%. Where the MAPE value is interpreted if it is more than 50% then it is not good for forecasting.

Table 1. Multiplicative Model Error Value

Test Data	Mark
MAE	158.87
MAPE	55.18%

Table 2. Additive Model Error Value

Test Data	Mark
MAE	186.59
MAPE	70.18%

In Table 2 shows that Mean Absolute Percentage Error (MAE) yields 186.59 and the Mean Absolute Percentage Error (MAPE) yields 70.18%. Where the MAPE value is interpreted if it is more than 50% then it has a bad accuracy value.

Forecasting that is done using both the multiplicative and additive models has a MAPE value above 50%, which means that the forecast is bad. This is because the amount of data used is only 11 years, more data will make the forecast more accurate. For forecasting the future, we compare the MAE and MAPE values between the multiplicative model and the additive model. Because the smaller the error, the better it is to use forecasting in the future. It can be seen in Table 1, namely the error value of the multiplicative model and Table 2, namely the error value of the additive model, where the multiplicative model has a smaller error value than the additive model. So to do forecasting in the future using a multiplicative model.

Future Forecasting

Finals model means the model that we have made before to make forecasts in the future, where researchers make forecasts for the next two years, so the period used is 24 months.

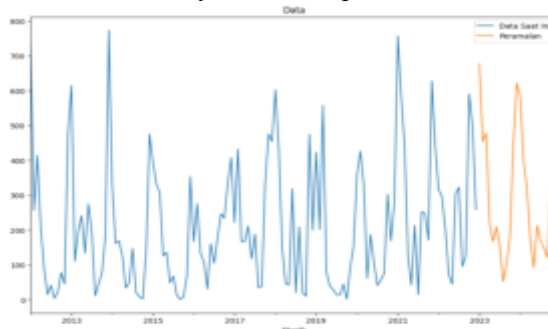


Figure 9. Future Forecasting Graph

Where the orange line shows the forecast for 2023 to 2024. You can see the forecasting pattern follows the previous year's pattern. The data in Table 3 shows forecasting data for 2023 and 2024 more clearly.

Table 3. Forecasting Data for 2023 to 2024

Month	Data
2023-01-01	676.718785
2023-02-01	454.465092
2023-03-01	478.330809
2023-04-01	221.239381
2023-05-01	166.849678
2023-06-01	209.806308
2023-07-01	157.653938
2023-08-01	52.140677
2023-09-01	100.746766
2023-10-01	178.399319
2023-11-01	446.357183
2023-12-01	621.637779
2024-01-01	583.385732
2024-02-01	399.752960
2024-03-01	321.233881
2024-04-01	171.072012
2024-05-01	91.757742
2024-06-01	213.283653
2024-07-01	169.084876
2024-08-01	147.860355
2024-09-01	122.137239
2024-10-01	302.870471
2024-11-01	407.209320
2024-12-01	471.660890

4. CONCLUSION

The forecasting model derived from the discussion is the Holt-Winters Exponential Smoothing additive model, with an alpha value of 0.653466, a beta value of 0.0036348, and a gamma value of 0.1182400. While the multiplicative model has alpha values of 0.8889286, 0.0001, and 0.0246825 for alpha, beta, and gamma, respectively. Before making future forecasts, the two models from the Holt-Winter Exponential Smoothing method are contrasted, focusing on the test data for the additive MAE model of 186.59 and the MAPE model of 70.18 percent. The MAE multiplicative model is 158.87, and the MAPE is 55.18 percent. Where the MAPE value is interpreted, if it is greater than 50%, inadequate forecasting model ability is indicated. Both the additive and multiplicative MAPE model values have a value greater than 50%; for forecasting, use the value with the minimum error. The smaller the error, the more accurate the forecast, and it has been determined that the multiplicative model has a smaller error than the additive model. Then, to make future forecasting results simpler to read, a simple system was designed to display rainfall data in Subak Blahkiuh from 2012 to 2022 for actual data and 2023 and 2024 forecasts. to forecast using the smallest error value. The smaller the error, the more accurate the forecast, and it has been determined that the multiplicative model has a smaller error than the additive model. Then, to make it simpler to read future forecasting results, a simple system was designed to display rainfall data in Subak Blahkiuh from 2012 to 2022 for actual data and 2023 and 2024 for forecasts. to forecast using the least amount of error. The smaller the error, the more accurate the forecast, and it has been determined that the multiplicative model has a smaller error than the additive model. Then, to make it simpler to read future forecasting results, a simple system was designed to display rainfall data in Subak Blahkiuh from 2012 to 2022 for actual data and 2023 and 2024 for forecasts.

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