International Journal of Applied Mathematics, Sciences, and Technology for National Defense
Volume 2, Issue 1, 1-8.
e_ISSN: 2985-9352, p_ISSN: 2986-0776
https://www.journal.foundae.com/index.php/JAS-ND
DOI : https://doi.org/10.58524/app.sci.def.v2i1.325

Times series data analysis: The Holt-Winters model for rainfall prediction In West Java

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Article Info

Article history:

Received: December 15, 2023
Revised: February 21, 2024
Accepted: April 07, 2024
Published: April 30, 2024

Keywords:

Holt-Winters
Rainfall
Seasonal
Time Series

Abstract

Time series data analysis is used to analyze data that considers time and data characteristics to predict future events. One of the time series data is rainfall data. Rainfall data has a seasonal pattern because there is a pattern that repeats itself over a certain period. Data analysis that considers the characteristics of seasonal patterns is the Holt-Winters method. The Holt-Winters model is divided into two, namely additive and multiplicative models. This research aims to compare the Holt-Winters additive and multiplicative methods to see the accuracy in predicting rainfall data in West Java. The additive model has level parameter $\alpha =$ 0,435, trend parameter $\beta = 0$, seasonal parameter $\gamma = 1$, and RMSE value 140,174. The multiplicative model has level parameter $\alpha = 0{,}936$, trend parameter $\beta = 0$, seasonal parameter $\gamma = 0{,}247$, and RMSE value 150,020. The additive model has a smaller RMSE value so it can predict future rainfall with greater accuracy.

To cite this article: Hendri, E.P., & Fadhlia, S. (2024). Times series data analysis: holt-winters model for rainfall prediction in West Java. *International Journal of Applied Mathematics, Sciences, and Technology for National Defense,* 2(1), 1-8

INTRODUCTION

Time series analysis is used to analyze data that considers the influence of time. Time series analysis aims to predict a value based on data characteristics. Predicting time series data requires knowing the pattern of the data so that it produces predictions that are close to the actual value. Data patterns are divided into seasonal patterns, cyclic patterns, trends, and irregularities (Hanke, 2005). Seasonal patterns are fluctuations in data that occur periodically within a certain period (Firdaus, 2006).

The data has seasonal pattern characteristics indicated by a strong correlation over time intervals, namely the time that lasts for the number of observations per seasonal period (Hyndman & Athanasopoulos, 2018). Seasonal data analysis using the moving average, single, and multiple exponential methods will produce forecasts that have low accuracy. To improve forecasting accuracy, appropriate methods are needed (Hamidah et al, 2020). One is The Holt-Winters method, which can analyze time series data with seasonal patterns. Holt-Winters starts with analyzing data patterns and then tests the forecasting model, and the forecasting (Zhu et al, 2021).

Holt (2004) extended the exponentially weighted moving averages to allow trend and seasonal variation. Winters (1960) concluded that this exponential forecasting model not only provides better forecasting compared to some other forecasting methods, but it also reacts more efficiently when there is a sudden shift in the time series. The Holt-Winters method is an exponential smoothing method combining the Holt and Winters methods (Kalekar, 2004). The Holt-Winters method is a development of a simple exponential smoothing method that uses three smoothing parameters: level,

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trend, and seasonal (Rosalina, 2015). Holt-Winters is divided into the additive Holt-Winters model and the multiplicative Holt-Winters model. The Holt-Winters additive model is used when seasonal data has a variance that tends to be constant. Meanwhile, the Multiplicative Holt-Winters model is used when seasonal data has variations that tend to fluctuate (Yang et al, 2017).

Rainfall intensity is the amount of rainfall expressed in the height of rain or volume of rain per unit of time, which occurred in one period of time (Wesli, 2008). High or low rainfall can disrupt the country's resilience. Based on Ardian (2011), increased rainfall intensity causes a change in resistance to various typical tropical agricultural commodities and damage to infrastructure. Meanwhile, decreased rainfall can result in reduced water supplies. Therefore, rainfall prediction is significant to maintain the country's resilience.

Rainfall data is seasonal data that has the potential to have data fluctuations because it tends to have repeated patterns over some time. So it can be considered to apply the Holt-Winters model to predict (Liu & Wu, 2022). Holt-Winters technique was applied to forecast non-stationarity seasonal rainfall (Kamruzzaman et al, 2011).

Several studies have used the Holt-Winters method. Hutapea and Siahaan (2023) researched rainfall forecasting using the Holt-Winters method in North Padang Lawas with model evaluation using mean square error (MSE). Rafian (2022) researched rainfall analysis using Holt-Winters in Jakarta with model evaluation using MSE. Sinay et al (2017) researched rainfall forecasting in Ambon using the Holt-Winter method with model evaluation using MSE. Wiguna et al (2023) researched rainfall forecasting using the Holt-winters method in Bali and model evaluation using mean absolute percentage error (MAPE) and mean absolute error (MAE). Pertiwi (2020) researched rainfall forecasting using the Holt-Winters method in Mataram City and model evaluation using MAPE. Irwan et al (2023) researched rainfall forecasting using the Holt-Winters method in Makasar City and model evaluation using MAPE. Aini et al (2022) researched rainfall forecasting using the Holt-Winters method in Malang City and model evaluation using MAPE. Aini et al (2021) researched rainfall forecasting using the Holt-Winters method in Pasuruan and model evaluation using MAPE.

This research analyzes rainfall data in West Java from January 2019 to December 2022 using the additive Holt-Winters and multiplicative Holt-Winters model methods. This research aims to compare the Holt-Winters additive and multiplicative methods to see the accuracy in predicting rainfall data. Evaluation of the model based on the smallest root mean square error (RMSE). RMSE is used in various related studies with predictions or forecasting (Chai & Draxler, 2024). Because the RMSE value is used to measure the difference between the actual value and the predicted value.

METHOD

This research uses monthly rainfall data in West Java obtained from BPS in West Java, downloaded at https://jabar.bps.go.id/. The data is in the form of monthly rainfall data from January 2019 to December 2022 consisting of 48 observations. The analysis stages are as follows:

1. Data exploration to determine the characteristics of rainfall data in West Java.
2. Create an Adaptive Holt-Winters model (Makridakis et al., 1999) as follows:
   Level : $l_t = \alpha(Y_t - S_{t-s}) + (1-\alpha)(L_{t-1} + b_{t-1})$
   Trend : $b_t = \beta(L_t - L_{t-1}) + (1-\beta)b_{t-1}$
   Seasonal : $S_t = \gamma(Y_t - L_t) + (1-\gamma)S_{t-s}$
   Forecast : $F_{t+m} = L_t + b_t m + S_{t-s+m}$
3. Create a Multiplicative Holt-Winters as follows:
   Level : $l_t = \alpha\left(\frac{Y_t}{S_{t-s}}\right) + (1-\alpha)(L_{t-1} + b_{t-1})$
   Trend : $b_t = \beta(L_t - L_{t-1}) + (1-\beta)b_{t-1}$
   Seasonal : $S_t = \gamma\left(\frac{Y_t}{L_t}\right) + (1-\gamma)S_{t-s}$
   Forecast : $F_{t+m} = (L_t + b_t m)S_{t-s+m}$
   Where:
   α = Level parameter $(0 \le \alpha \le 1)$
   β = Trend parameter $(0 \le \beta \le 1)$
   γ = Seasonal parameter $(0 \le \gamma \le 1)$
   S = Seasonal period

$L_t =$ Level in year t
$L_{t-1} =$ Level in year $t-1$
$b_t =$ Trend pattern in year t
$b_{t-1} =$ Trend pattern in the year $t-1$
$S_t =$ Seasonal pattern
$Y_t =$ Data t
$F_{t+m} =$ Predicted value
$m =$ numbers of predicted values
The advantage of the Holt-winters algorithm is that after observing the period of data change in the time series, the prediction results can be made according to the period of data change (Fan et al, 2020).

4. Comparing Additive and Multiplicative Holt-Winters Model using Root Mean Square Error (RMSE)

$$RMSE = \sqrt{\frac{\sum(y_i - \hat{y}_i)}{n}}$$

Model evaluation based on the Smallest RMSE. The Smallest RMSE has high accuracy for predicting future rainfall.

RESULTS AND DISCUSSION

Data Exploration

Table 1 presents a descriptive statistical analysis of rainfall data in West Java. According to Table 1, October is the month with the highest average rainfall, 442,678 mm, while July has the lowest average rainfall, with only 147.6 mm. The month with the highest monthly rainfall is April, with a value of 671 mm, whereas June has the lowest monthly rainfall of just 30.3 mm. The month with the highest rainfall variance is June, with a value of 36467, 89, while March has the lowest rainfall variance, with a value of 5641.989. This shows that rainfall in June is more variable than other months.

Table 1. West Java rainfall data summary

Month	Average	Maximum	Minimum	Variance
January	226.625	304.3	106.6	8189.416
February	312.675	486.8	150.3	19510.09
March	217.425	292.5	113.2	5641.989
April	441.025	671	271.4	33749.44
May	335.775	510.3	228.5	14807.41
June	235.775	463.7	30.3	36467.86
July	147.6	358.1	53	20440.87
August	249	399.5	41.6	30124.94
September	227.675	353.7	87.7	16411.55
October	442.025	566.5	327.3	11595.48
November	260.475	330	183.6	5744.782
December	329.575	553	224.1	22714.77

Figure 1 displays West Java rainfall data, including observations, trends, seasonal, and random. Based on Figure 1, rainfall data in West Java has a seasonal pattern that shows a recurring pattern so Holt-Winters modeling with an additive model and Holt-Winters modeling with a multiplicative model are used to predict rainfall in West Java.

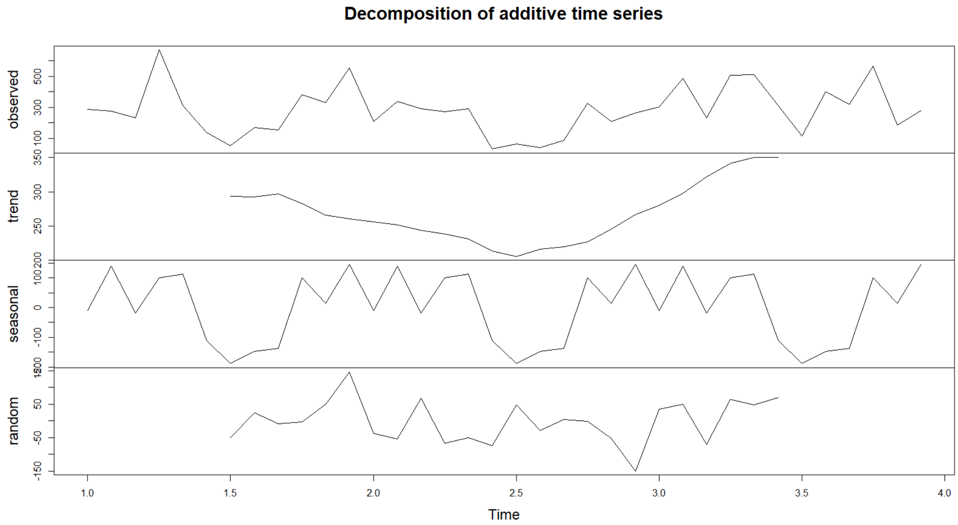

Figure 1. Rainfall composite plot in West Java 2019-2022

Holt-Winters Modelling

The Holt-Winter time series analysis modeling is divided into two, namely the additive model and the multiplicative model which are shown in Table 2. The additive Holt-Winters model has $\alpha = 0.435$, $\beta = 0$, and $\gamma = 1$. The multiplicative Holt-Winters model has $\alpha = 0.936, \beta = 0$, and $\gamma = 0.247$ where parameter α is a smoothing parameter on the data, parameter β is a smoothing parameter on the data to estimate trend elements, and parameter γ is a smoothing parameter on the data to estimate seasonality.

Table 2. Additive and Multiplicative Holt-Winters models coefficients

	Additive	Multiplicative
L_t	214.162	132.473
b_t	-7.269	-7.269
s1	99.529	0.824
s2	196.265	1.352
s3	-8.682	1.198
s4	167.707	1.159
s5	129.538	1.276
s6	-116.051	0.144
s7	-252.083	0.178
s8	-49.168	0.559
s9	-123.836	0.519
s10	124.832	1.359
s11	-128.079	1.214
s12	64.937	2.127

Table 2 is the coefficient value from the Holt-Winters model. Based on Table 2, the Additive Holt-Winters model is obtained

$$F_{t+m} = 214.162 - 7.269m + S_{t-s+m}$$

And the multiplicative Holt-Winters model is obtained

$$F_{t+m} = (132.473 - 7.269m)S_{t-s+m}$$

Holt-Winters Prediction Model

Based on Figure 2 and Figure 3, The actual graph is shown in red and the prediction graph is shown in black from both the Additive and Multiplicative models. Based on Figure 2, the prediction graph has the same trend as the actual graph. Based on Figure 3, the prediction graph has a difference in trend with the actual graph at the tail of the graph. Subjectively, it can be concluded that the additive model is more accurate than the multiplicative model in predicting future rainfall.

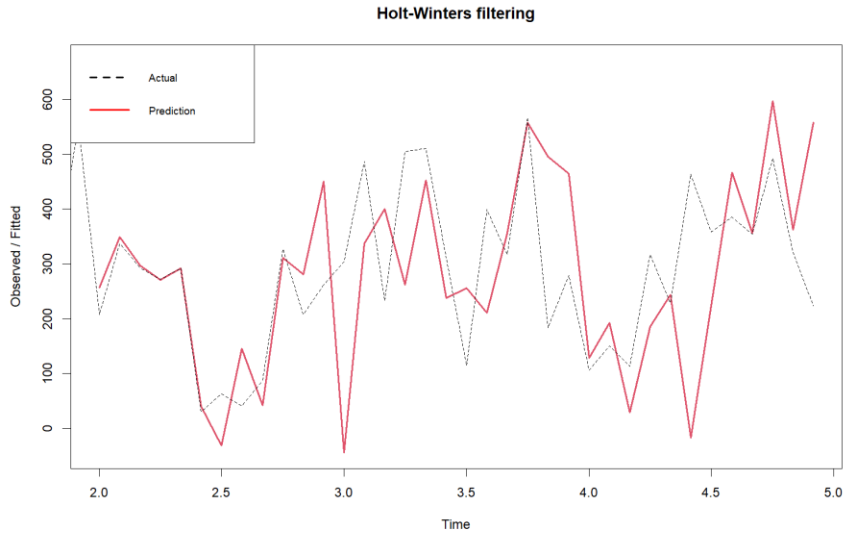

Figure 2. The Additive Holt-Winters model estimation plot

Model evaluation based on RMSE values. If we look at the RMSE value, the additive Holt-Winters model has an RMSE value of 140,174 and the Multiplicative Holt-Winters model has an RMSE value of 150,020. The Additive Holt-Winters model estimates have a smaller RMSE value than the Multiplicative Holt-Winters model so the Additive Holt-Winters model has higher accuracy in predicting future rainfall in West Java.

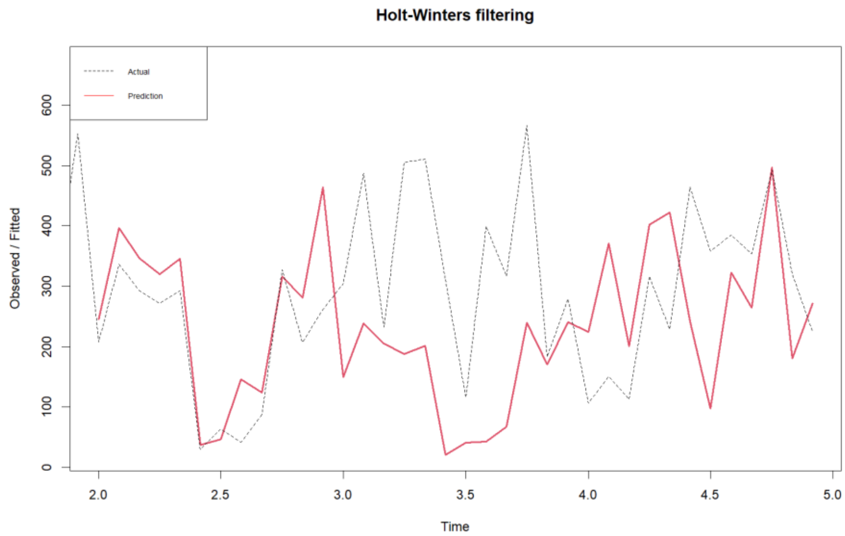

Figure 3. The multiplicative Holt-Winters model estimation plot

CONCLUSION

Based on the previous discussion, it can be concluded that rainfall data in West Java for 2019-2022 has a seasonal pattern so the Holt-Winter method can be used to predict rainfall in West Java. The additive Holt-Winters model has level parameter $\alpha = 0{,}435$, trend parameter $\beta = 0$, and seasonal parameter $\gamma = 1$. The multiplicative Holt-Winters model has level parameter $\alpha = 0{,}936$, trend parameter $\beta = 0$, and seasonal parameter $\gamma = 0{,}247$. The additive Holt-Winters model has an RMSE value of 140,174 and the multiplicative Holt-Winters model has an RMSE value of 150,020. Model evaluation based on the smallest RMSE value. The Additive Holt-Winters model is more accurate in predicting future rainfall because its RMSE value is smaller than the multiplicative Holt-Winters model.

AUTHOR CONTRIBUTIONS

Each author of this article played an important role in the process of method conceptualization, simulation, and article writing.

CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

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