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Prediction of Dengue Outbreak: A Comparison Between ARIMA and Holt-Winters Methods

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ABSTRACT

Dengue is a globally known infection in which the virus is transmitted by mosquitoes and can lead to death. Selangor has been reported to have the highest incidence of dengue infections among the communities in Malaysia. There is currently a new pandemic, COVID-19, which occurred worldwide, including Selangor, which led to this study on the pattern of dengue cases during COVID-19. The aim of this study is to develop the best model to predict the future value of dengue cases in Selangor. In order to meet the objectives, the ARIMA method and the Holt-Winters method were used to evaluate dengue case data collected in Selangor. The best model was chosen by evaluating the Mean Square Error (MSE), Root Mean Square Error (RMSE) and Mean Absolute Percent Error (MAPE) measurement errors. Then, the forecasted number of dengue cases was calculated using the best model generated. The best model to forecast dengue cases in Selangor is the Additive Holt-Winters model since it showed the lowest values of all measurement errors compared to the Multiplicative Holt-Winters and ARIMA (1,1,0) models.

Keywords: *Prediction, Dengue; Selangor; ARIMA model; Holt-Winters Model*

1. INTRODUCTION

Dengue virus is transmitted by female mosquitoes mainly of the *Aedes aegypti* species and, to a lesser extent, *Aedes albopictus*. These mosquitoes can grow vigorously in the place containing water such as water tanks, containers, and in the stagnant water area. According to [1], four dengue serotypes cause dengue outbreaks designated as DEN-1, DEN-2, DEN-3, and DEN-4. The World Health Organization (2020),[2] has stated that dengue is the most severe mosquito-borne disease globally

In Malaysia history, dengue infection began in Malaysia from Singapore to Penang in 1901. In 1973, the first outbreak of the epidemic was 969 cases and recorded 54 deaths. The disease continued to worsen as the infection spreaded among urban residents throughout the nation [3]. The incidence of dengue has increased dramatically every year, but there has recently been a new outbreak of the virus worldwide known as COVID-19. According to [4] in The Star Newspaper, Dr. Rozita told Bernama that they were all busy fighting COVID-19 and began to forget about the dangers of dengue infection. Although COVID-19 causes the highest death this year, dengue issues should not be taken lightly. In The Star, [5] reported that, from the history of dengue fever cases in Malaysia, the data collected from January to December 29, 2019 showed the highest dengue cases, which is 130,101 cases while the previous highest dengue

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cases that occurred in 2015 were recorded at 120, 836. However, data on the dengue outbreak in Malaysia has shown that the maximum rate of dengue cases occurred in Selangor. From New Straits Time, [6] reported that with the current population of 6.52 million people, Selangor recorded almost 58,000 cases, more than half of the dengue cases in Malaysia as of October 12, 2019, and 49 deaths due to dengue

Several studies were conducted to predict dengue outbreaks in Selangor, as the highest dengue cases have occurred in Malaysia. Therefore, effective prevention procedures can be put in place to prevent dengue infection. Consequently, all research implementations in other countries are also valid to be used in Selangor as they can give some advantages in reducing dengue cases. According to [7], to monitor trends and fluctuations in dengue cases in India, epidemiologic parameters are valuable in identifying related epidemiological factors and the effectiveness of control measures. Detailed information on previous outbreaks of DF/DHF can be used to predict future trends and outbreaks using epidemiological modelling. This enables the health system to prepare the plan better and allocate all resources for effective control of future outbreaks. In epidemiological research to predict infectious diseases such as dengue, malaria and influenza, the modelling of Autoregressive Integrated Moving Averages (ARIMA) is increasingly used in time series.

The ARIMA method can be employed in any data relating to time series forecasting. Various applications of ARIMA methods are available, such as predicting and managing disease outbreaks, predicting wind speed, predicting livestock product consumption, predicting population, and other time series forecasting data. The ARIMA method can increase the forecast accuracy while keeping the number of parameters to a minimum. It is also a suitable and proper method particularly in short-term time series forecasting [8]. According to [7], the result of the study showed that the best-fit model generated by the data was the seasonal ARIMA (1, 0, 0) $(0, 1, 1)_{12}$ model. The ability to adjust the average number of predicted incidences for each year was tested by comparing all actual data on dengue fever cases from 2007 to 2018 with the paired t-test.

In recent months, an outbreak of disease has occurred, i.e., a new type of coronavirus called COVID-19. As a result, many researchers are conducting studies on the prediction of the COVID-19 epidemic. For this thematic analysis, [9] employed seasonal and non-seasonal variations to stabilize periodicity and term. The study found that the estimation of ARIMA model parameters was based on autocorrelation function (ACF) plot and partial autocorrelation (PACF) plot. The prevalence of COVID-2019 was determined, in which ARIMA (1,0,4) and ARIMA (1,0,3) were the best models chosen.

In addition, ARIMA modelling can also be used for population forecasting. In the previous study,[10]conducted a population forecasting study in China. The results shown that the model has an appropriate fitting effect. For further verification of model effectiveness, non-agricultural population and agricultural population data in the Zhejiang province are processed, reviewed, and tested using the same modelling process. Upon verifying and practising the modelling method, it is concluded that the actual fitting effect of the ARIMA (1, 1, 0) model of all population data is good. Finally, the population of the Zhejiang Province was forecasted for the following years. The results showed that the population estimates of the province of Zhejiang were increasing every year [10].

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The Holt-Winters method is also used in a few time-series data predictions. According to [11], one of the advantages of the Holt-Winters method is that it can give accurate forecasting results compared to more complex techniques. This method is widely used, simple to apply, and generally effective in real-world situations. In addition, [12] stated that, when dealing with trends and seasonal patterns in time series data, this approach is able to adapt. By referring to the previous study by [13] conducted over 13 weeks, Holt Winter's was employed and compared to Double exponential in forecasting future dengue cases. Both methods were adapted to the dengue data. The Holt-Winters method showed a large increase in the forecasted values for Selangor and a slower increase in cases in Wilayah Persekutuan (Federal Territory).

While in the study predicting dengue fever patients in each Malang group, Indonesia, which was conducted by [14], Multiplicative Holt-Winters was found to have the best performance in the low-Malang and medium-Malang groups. However, in the case of High Malang, it is best to use the Multiplicative Decomposition method to predict cases of dengue fever.

There are numerous studies regarding the comparison between ARIMA and Holt-Winters method. [15] compared these two methods to predict the spreading of COVID-19 in India and its states. It was found that ARIMA gives better prediction compared to the Holt-Winters method. Another study conducted by [16], employed both methods to predict the population in West Java. The results revealed that ARIMA method forecasting is better than the Holt-Winters method because the error values were smaller. [17] also applied these two methods in their study to forecast water consumption expenditure in Malaysian universities, specifically at University Tun Hussein Onn Malaysia (UTHM). The results revealed that ARIMA forecasts better than the Holt-Winters method. However, a study done by [18] in predicting the rice price in Tanzania showed that the Holt-Winters method performed better due to its lowest error and closer to the actual data. Both methods have their advantages in making predictions.

In addition to using the time series forecasting model, there are other methods which can predict the dengue outbreaks. There are many dengue prediction methods, such as statistical methods, vector support machines and the Neural Network. [19] used the logistic regression model to estimate the incidence probabilities of dengue outbreak for the villages the next day. The study showed that the sensitivity value was near 80% and the false positive rate was 25%. It shows that this method is good to predict the probability of a dengue outbreak. [20] applied artificial neural networks (ANNs) to predict dengue fever outbreak occurrences in San Juan, Puerto Rico (USA), and in several coastal municipalities of Yucatan, Mexico, based on specific thresholds. The ANNs successfully modelled dengue fever outbreak occurrences because the predictive power was above 70% for all models. In another study conducted by [21], they use the Susceptible, Infected, and Removed (SIR) model to study rebreeding value based on the number of reported cases of dengue fever in South Sulawesi, Indonesia and Selangor, Malaysia. The spread of the dengue virus in both countries reached maximum levels in only a short time.

The present study focuses on predicting dengue events in Selangor using the Autoregressive Integrated Moving Average (ARIMA) model and the Holt-Winters method. Both methods were selected to predict the outbreak of dengue and are deemed more accurate to assess the best fit model. These time series methods are able to accurately predict the forecast data by looking at their minimum error values.

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2. METHODOLOGY

Figure 1 shows the Process of predicting Dengue Outbreak.

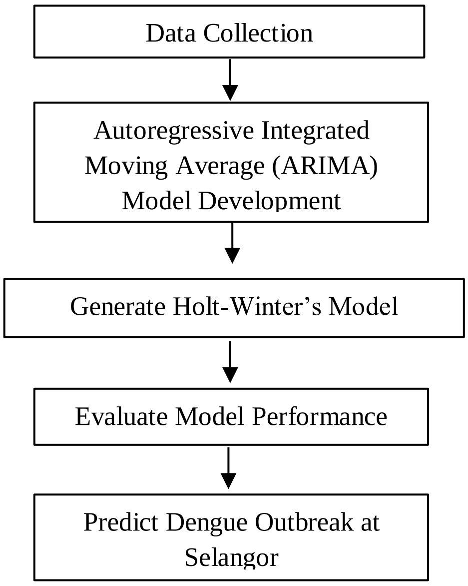

Figure 1: Process of predicting Dengue Outbreak

2.1 Data Collection

The data collected are the total number of dengue cases per week in Selangor from January 2018 to November 2020. Every year in 2018 and 2019, there were 52 weeks. However, data for the year 2020 were collected for 46 weeks. Therefore, the data collected consists of 150 dengue cases to predict the cases for the next six weeks. The data used for this analysis are secondary data provided by the Vector Borne Disease Control Section of the Ministry of Health Selangor. In this study, the data were divided into two parts: training (70%) and test (30%) parts.

2.2 ARIMA Model

The ARIMA model is generated in this study to predict the outbreak of dengue. This model was identified as one of the most effective methods used to predict time-series data. This method is divided into three phases, which are identification, estimation and forecasting phases. The actual data have to be stationary. If the data is not stationary, proceed to the identification stage. Evaluate the stationary data series with three approaches which are ACF, PACF and ADF test. Differencing when the data is still non-stationary. Next, proceed with the estimation phase by checking the parameters estimated for the ARIMA model. The ARIMA model is categorized into three terms, p, d, and q where p is the order of the autoregressive (AR) term, q is the order of the moving average (MA) term, and d is the number of differencing used to obtain the stationary time series data.

These are the mathematical formulas for each term:

Autoregressive (AR), p term,

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$$y_t = c + \phi_1 y_{t-1} + \phi_1 y_{t-2} ..... + \phi_p y_{t-p} + \varepsilon_t \quad (1)$$

Moving Average (MA), q term,

$$y_t = c + \varepsilon_t + \theta_1 \varepsilon_{t-1} + \theta_2 \varepsilon_{t-2} ..... + \theta_q \varepsilon_{t-q} \quad (2)$$

Where ε_t represents white noise.

Number of differencing, d term,

$$\nabla^k y_t = (1-B)^k y^t \quad (3)$$

where B is the lag operator.

Therefore, the general formula for the ARIMA model is as follows,

$$y'_t = c + \phi_1 y'_{t-1} + ... + \phi_p y'_{t-p} + \theta_1 \varepsilon_{t-1} + \theta_2 \varepsilon_{t-2} ..... + \theta_q \varepsilon_{t-q} + \varepsilon_t \quad (4)$$

Where, y'_t is a differenced series.

In this study, ARIMA (1,1,0) was computed for the ARIMA model from the result generated using R-studio software. The general equation can be expressed using equation 4.

2.3 Holt-Winters model

Holt-Winters model method includes three components of mathematical formula, which are the estimation level, the estimation trend and forecast m period in the future. This model consists of two assumptions, the multiplicative effect and the additive effect. In this forecasting method, three parameters are used, namely α, β and γ, as constant values for the smoothing parameters. The value of the α, β and γ parameters is between 0 and 1.

Estimation level for Multiplicative and Additive Holt-Winters:

Multiplicative Effect:

$$L_t = \alpha \left(\frac{y_t}{S_{t-s}} \right) + (1-\alpha)(L_{t-1} + b_{t-1}) \quad (5)$$

Additive Effect:

$$L_t = \alpha (y_t - S_{t-s}) + (1-\alpha)(L_{t-1} + b_{t-1}) \quad (6)$$

Where y'_t is the actual value for period t and S_{t-s} is the prediction seasonality value of $t+1$.

Estimation trend for Multiplicative and Additive Holt-Winters:

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$$b_t = \beta(L_t - L_{t-1}) + (1-\beta)b_{t-1} \quad (7)$$

Where B_{t-1} is the prediction trend value of $t+1$ and b_t is the forecast value for the period t.

Estimation seasonality for Multiplicative and Additive Holt-Winters:

Multiplicative Effect:

$$S_t = \gamma\left(\frac{Y_t}{L_t}\right) + (1-\gamma)S_{t-s} \quad (8)$$

Additive Effect:

$$S_t = \gamma(Y_t - L_t) + (1-\gamma)S_{t-s} \quad (9)$$

Where S_{t-s} is the prediction seasonality value of $t+1$.

Next, generate the prediction for m period in the time ahead for Multiplicative and Additive Holt-Winters:

Multiplicative Effect:

$$F_{t+m} = (L_t + b_t m)S_{t-s+m} \quad (10)$$

Additive Effect:

$$F_{t+m} = L_t + b_t m + S_{t-s+m} \quad (11)$$

For Multiplicative Holts-Winters, the values of α =0.26 , β =1.00 and γ =0.58 and for Additive Holts-Winters, the values of α =0.03 , β =0.08 and γ =0.57. These values are generated by using the solver function in Microsoft Excel.

2.4 Evaluate Model Performance

From the generated models, the goodness of model in which the measurement of errors for accuracy of the forecasted data was obtained from the actual data and the ARIMA model and the Holt-Winters models were compared to the lowest error measurements. There are few measurements of error that can be tested, such as Mean Squared Error (MSE), Root Mean Squared Error (RMSE), and Mean Absolute Percentage Error (MAPE). These error measurements were formulated as follows:

Mean Squared Error (MSE) $= \frac{\sum e_t^2}{n}$ (12)

$$= \frac{e_1^2 + e_2^2 + e_3^2 + ...e_n^2}{n}$$

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$$= \frac{(y_1-F_1)^2+(y_2-F_2)^2+(y_3-F_3)^2+.....(y_n-F_n)^2}{n}$$

$$= \frac{972671.932}{46}$$

Root Mean Squared Error (RMSE)= $\sqrt{\frac{\sum e_t^2}{n}}$ (13)

$$= \sqrt{\frac{e_1^2+e_2^2+e_3^2+.....e_n^2}{n}}$$

$$= \sqrt{\frac{(y_1-F_1)^2+(y_2-F_2)^2+(y_3-F_3)^2+.....(y_n-F_n)^2}{n}}$$

$$= \sqrt{\frac{972671.932}{46}}$$

Mean Absolute Percentage Error (MAPE) = $\left(\frac{1}{n}\sum\left|\frac{e_t}{y_t}\right|\right)(100)$ (14)

$$\text{MAPE} = \left(\frac{\left|\frac{e_1}{y_1}\right|+\left|\frac{e_2}{y_2}\right|+\left|\frac{e_3}{y_3}\right|+......\left|\frac{e_n}{y_n}\right|}{n}\right)\times 100$$

$$= \left(\frac{\left|\frac{(y_1-F_1)}{y_1}\right|+\left|\frac{(y_2-F_2)}{y_2}\right|+\left|\frac{(y_3-F_3)}{y_3}\right|+......\left|\frac{(y_n-F_n)}{y_n}\right|}{n}\right)\times 100$$

$$= \frac{7.44142}{46}\times 100$$

Where the forecast error is e_t, and it is calculated by subtracting the forecast value F_t from the series' actual value; y_t. Here n is the number of effective observations used to match the model. Minimum values of these accuracy measures provide the best fitting models. The lowest measurement of these error values revealed which methods are best suited to the model.

3. RESULTS AND DISCUSSION

3.1 Trend of dengue cases

Figure 2 shows the actual data on the number of dengue cases from Epidemic Week in 2018 to Epidemic Week 46, 2020 with the presence of a trend. According to the graph, the highest number of dengue cases were 2026 cases that occurred in the Epidemic Week 3, 2020. In contrast, the lowest reported dengue cases from the data collected were 392 cases in Epidemic Week 46, 2020. Dengue cases have shown a trend where there was an increase in the number

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of cases in 2019. However, as the new pandemic COVID-19 occurred in early 2020, it shows that the number of dengue cases started to drop dramatically from Epidemic Week 3 to Epidemic Week 16. The number of dengue infections did not increase as much as before the occurrence of COVID-19. After Epidemic Week 16 in 2020, the graph showed that dengue cases dropped under 1000 cases and continue to decline.

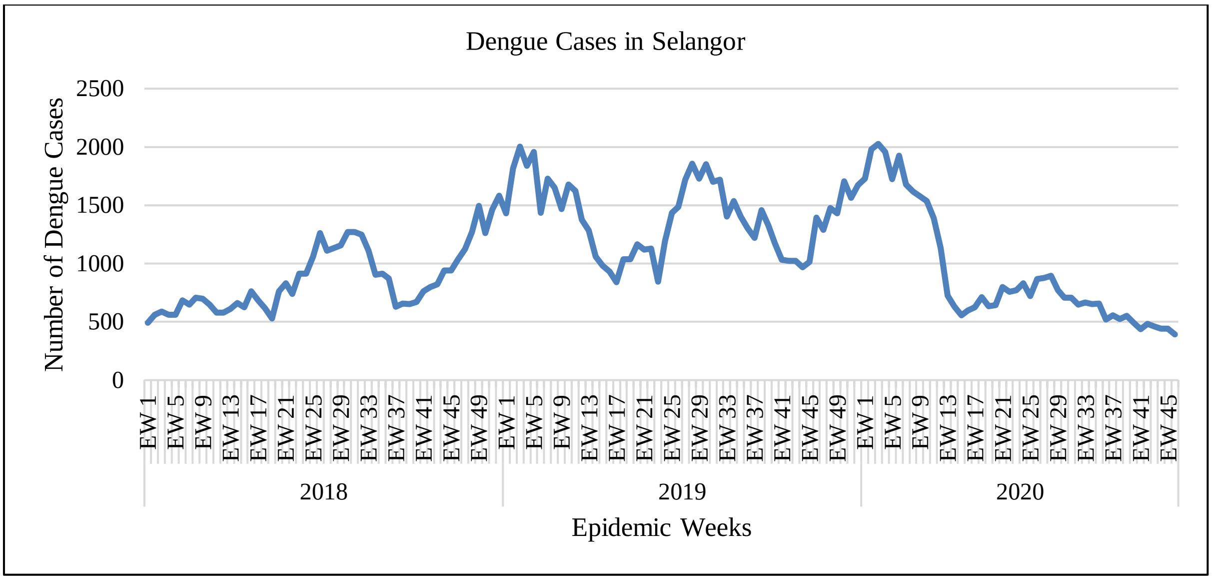

Figure 2: Weekly dengue cases in Selangor from January 2018 to November 2020

3.2 Selection of the Best Model.

The data of the present study were divided into two parts: training (70%) and test (30%) parts. The data selected for the training part were from Epidemic Week 1, January 2018 (n=1) to Epidemic Week 52, December 2019 (n=104). The data for the test part started from Epidemic Week 1, January 2020 (n=105) to Epidemic Week 46, November 2020 (n=150).

From the generated models, the goodness of the model where the measurement of errors for accuracy of the forecasted data was obtained from the actual data. The ARIMA and the Holt-Winters models were compared to the lowest error measurements on the test part of the models. There are three measurements of error that were tested in this study, Mean Squared Error (MSE), Root Mean Squared Error (RMSE), and Mean Absolute Percentage Error (MAPE).

In Table 1, the Additive Holt-Winters model consists of the lowest MSE and RMSE measurement errors with the highest accuracy of the assessment forecast. At the same time, ARIMA (1,1,0) computed the lowest measurement error for MAPE. The MSE of Additive Holt-Winters is 21145.042 where Multiplicative Holt-Winters and ARIMA (1,1,0) are 264552.458, and 22885.064 respectively. The RMSE of Additive Holt-Winters is 145.413, which is lower than Multiplicative Holt-Winters and ARIMA (1,1,0), 514.347 and 151.278. The last measurement error evaluated is MAPE, where ARIMA (1,1,0) has the lowest error measurement with the value of 10.152, Multiplicative Holt-Winters with a value of 26.444 and Additive Holt-Winters with a value of 16.177. Therefore, the Additive Holt-Winters is the best model chosen for predicting the number of dengue cases in Selangor since it has the maximum number of the lowest measurement errors.

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Table 1: Measurement Errors for the model developed

MODEL	MSE	RMSE	MAPE
Multiplicative Holt- Winters	264552.458	514.347	26.444
Additive Holt-winters	21145.042	145.413	16.177
ARIMA (1,1,0)	22885.064	151.278	10.152

3.3 Prediction of Dengue Cases

Figure 3 below shows the actual data of dengue cases and estimated dengue cases using the Additive Holt-Winters method from Epidemic Week 1, 2020 to Epidemic Week 46, 2020.The graph shows that the Additive Holt-Winters Method model fit the actual data well.

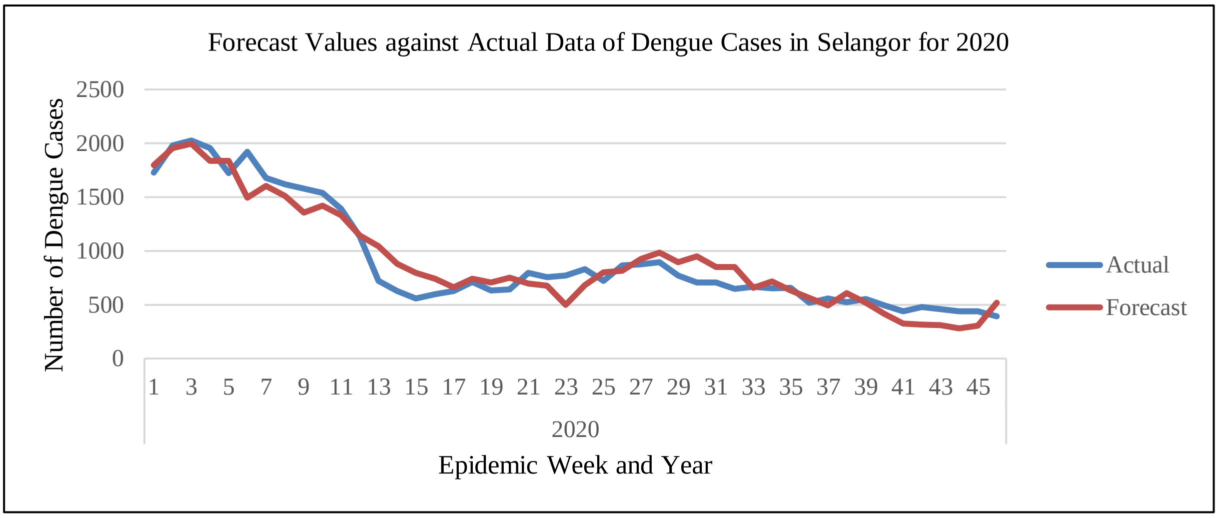

Figure 3: Forecast values against actual dengue cases data in Selangor for the year 2020

The predicted number of dengue cases are computed using the best model selected, which is the Additive Holt-Winters model as shown in Table 2. The number of dengue cases predicted in Selangor on Epidemic Week 47 until Epidemic week 52 increased from 460 cases up to 686 cases.

Table 2: Predicted number of dengue cases in Selangor

Epidemic Week	Predicted Dengue Cases
47	460
48	565
49	544
50	699
51	620
52	686

4. CONCLUSIONS AND RECOMMENDATIONS

This study was conducted to find the best model in predicting dengue case values in Selangor. The best model was evaluated by minimum measurement errors of the model. This study employed two methods to analyse the actual dengue case data in Selangor; ARIMA and Holt-

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Winters methods. Analysis of this study showed that Additive Hot-Winters is the best model since this model generated the highest number of measurement error values compared to ARIMA (1,1,0) and Multiplicative Holt-Winter models. From the predicted values, the study showed a pattern in which dengue cases increased from Epidemic Week 47 to Epidemic Week 52. For future studies, it is recommended to use more time series forecasting models.

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