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Performance Comparison Between Artificial Neural Network, Recurrent Neural Network and Long Short-Term Memory for Prediction of Extreme Climate Change

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Abstract

Extreme climate change is the most common problem in Indonesia. Extreme climate change for months can cause various natural disasters. Therefore, it is necessary to make predictions about climate change that will occur in order to avoid the risk of future conflicts. This study uses the Artificial Neural Network (ANN), Recurrent Neural Network (RNN) and Long Short Term Memory (LSTM) algorithms by comparing the performance of the three using Mean Squared Error (MSE), Root Mean Squared Error (RMSE) and Mean Absolute Percentage Error (MAPE) evaluations. The results of this study indicate that RNN is better at predicting temperature in Indonesia compared to ANN and LSTM. This is evidenced by the MAPE value generated by the RNN which is smaller than the ANN and LSTM, which is 1.852 %, the RMSE value is 1,870, and the MSE value is 3,497.

Keyword: Artificial Neural Network, Climate, Long Short Term Memory, Predictions, Recurrent Neural Network

1. INTRODUCTION

Climate change is the most common problem experienced by many people. In the current era, people are required to adapt to the consequences of climate change [1]. Climate change that has occurred in the last few months has had an impact on every community activity [2]. Climate change is influenced by rainfall and temperature which show a substantial relationship [3]. Rainfall and changing temperatures will also have an impact on life on earth. Months of extreme climate can cause various natural disasters. For example the forest fires that occurred in California. This occurs due to extreme weather conditions and concomitant drought caused by hot weather and late rainfall [4].

The Head of the Meteorology, Climatology and Geophysics Agency (BMKG), Dwikorita Karnawati revealed that 2016 was the year with the hottest climate for Indonesia with an anomaly of 0,8 °C throughout the observation period from 1981 to 2020. This was disclosed in March 2023. BMKG conducted Observations from 117 stations, obtained the results of the analysis, namely the average air temperature in May 2023 reached 27,4 °C. Climatological air temperatures in May for the 1991-2020 period in Indonesia reached 27,0 °C. Normally it is in the range 20,8 °C – 28,63 °C. Based on these values, the average air temperature anomaly in May 2023 shows a value of 0,4 °C. The air temperature anomaly in Indonesia in May 2023 is the 5th highest during all observations since 1981. A graph of climate change that is occurring in Indonesia can be seen in Figure 1.

In Figure 1 it can be seen that the average air temperature anomaly per station in May 2023 was positive or higher than the climatological average. This intensifying climate change can increase the risk of future conflicts [5]. Therefore, this research will predict climate change that will occur in one of the provinces in Indonesia, namely Riau, which is a city center with active community activities.

Several previous studies have discussed climate. Research conducted by Arora et al., said the prediction results of the air quality index for various cities showed that the RNN produced higher accuracy with the smallest MAPE of 4,70% [6]. Another study was conducted by Lee and friends, that the RNN

algorithm can accurately predict air temperature and relative humidity within 1% error [7]. Besides that. Another study conducted by Kuo et al. said that the RNN with the Gaussian process produced the lowest forecasting error, namely 0,0488 [8]. Related research was conducted by Guo et al., experiments showed that the RNN method achieved an accuracy level of MAE of 6,19 and MAPE of 16,20 and outperformed the comparison model [9].

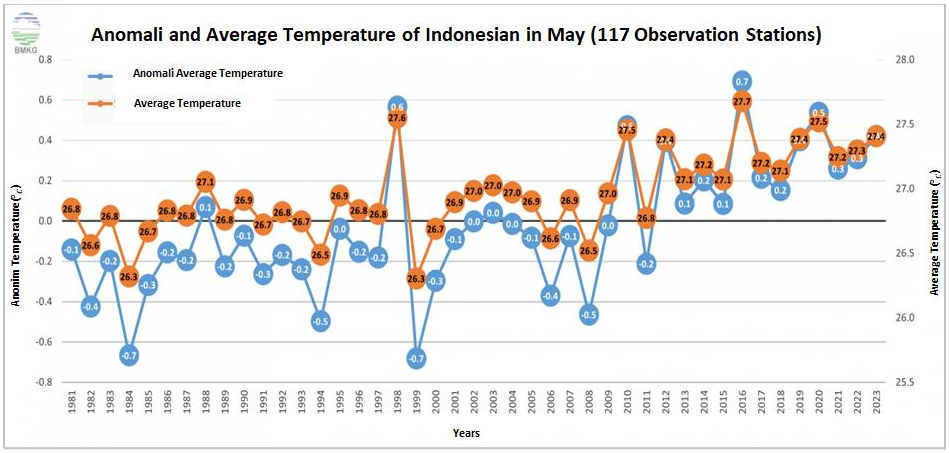

Figure 1. Average air temperature anomaly in Indonesia (https://www.bmkg.go.id/?lang=ID)

Research conducted by Roy in 2021 said that the deep learning model, namely the Long-Short Term Memory (LSTM) and the bi-directional LSTM network (Bi-LSTM) can be used to predict the Evapotranspiration of Subtropical Climate Zones with a Shannon Entropy of 1 [10]. Another related study was conducted by Patil and colleagues, that hyperparameter-based LSTM can predict temperature accurately by having a root mean square error (RMSE) value of 0,250 compared to the traditional LSTM of 0,35 RMSE [11]. Another study conducted by Sekertekin and colleagues, showed that a comparison of hourly and daily prediction results showed that the Long Short-Term Memory (LSTM) neural network provided the highest accuracy in predicting short-term air temperature one hour in the future and one day in the future. And especially showed higher performance than all adaptive neuro-fuzzy inference system (ANFIS) models with an RMSE value of (0,6436-1,3599) [12].

Meanwhile, in his research Buckland revealed that the Artificial Neural Networks (ANN) model is the best model compared to the others, because the test can be estimated accurately and more precisely [13]. Based on research conducted by Amaratunga and friends, it shows that the results of applying the ANN model are very stable [14]. Research conducted by Rani and friends also explains that architecture provides better efficiency in weather prediction compared to conventional methods [15].

Based on previous studies, researchers used the Python programming language by applying the Recurrent Neural Network (RNN), Long Short Term Memory Network (LSTM) and Artificial Neural Network (ANN) algorithms to predict the trend of temperature rise in Pekanbaru City with variations in temperature data that have not too far a range. This study aims to provide predictions regarding the climate conditions and trend of temperature rise in Indonesia based on historical data over a ten-year period, from 2014 to 2023.

2. MATERIAL AND METHOD

Deep learning algorithm approach that aims to provide predictions regarding climate conditions and trend of increasing temperatures in Indonesia based on historical data . The stages in this study can be seen in Figure 2.

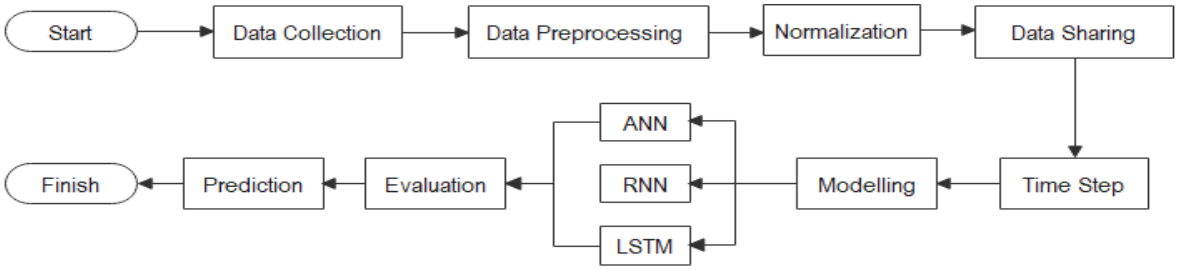

Figure 2. Research Methodology

Based on Figure 2, the first step is data collection. After the dataset is collected, normalization and data division using the Hold Out technique are performed. Time step process and modeling using three Deep Learning algorithms, namely ANN, RNN and LSTM. The final stage is to evaluate using MSE, RMSE, and MAPE so that the prediction results are obtained.

At the data collection stage, the dataset used is weather and climate data taken from the noaa.gov website. Table 1 shows the data obtained in the form of temperature in Indonesian territory every day. Data was obtained for the last 10 years from January 2014 to June 2023. Then the data preprocessing stage was carried out using data normalization with the min-max normalization technique as shown in table 1.

Table 1. Data Normalization

Date	TAVG (Degrees Fahrenheit)
2014-01-01	0,6154
2014-01-02	0,4615
2014-01-03	0,5385
2014-01-04	0,3846
2014-01-05	0,2308
2014-01-06	0,3077
2014-01-07	0,3846
2014-01-08	0,3846
2014-01-09	0,3846
2014-01-10	0,4615
…	…
2023-06-16	0,7692

After that the dataset will be divided according to training data and test data using the Hold Out technique. Then the *time step* process is carried out as many as 30 and modeling with ANN, RNN and LSTM algorithms. Then the results will be evaluated to provide predictions regarding climate conditions and the trend of increasing temperature.

2.1 Time Series

Time series analysis is one such procedure statistics applied to forecasting probabilistic structure of circumstances that will occur in the future in the context of decision making decision. Data *time series* is data that consists of one object but includes several time periods such as data daily, weekly, monthly, yearly, and others [16].

2.2 Artificial Neural Networks (ANN)

ANN is included in artificial neural networks programmed by computational models. The technique aims to duplicate the neural structure and function of the human brain. Artificial neural networks are flexible and adaptive. These networks are used in sequential and pattern recognition systems, data processing, robotics and modeling [17]. A pair of patterns consisting of an input pattern and a desired or target pattern is given by the ANN model network[18]. The initial stage of ANN training begins when i is a neuron along with m inputs. The input of neuron i is calculated using the activation function formula 1 and 2 [19].

$$f(x)= \frac{1}{1+e^{-x}} \quad (1)$$

$$y_i = f_i(Net_i) \quad (2)$$

2.3 Recurrent Neural Network (RNN)

RNN is a type of artificial neural network that has the ability to process sequential data or data with a temporal context. RNNs are designed to handle time-dependent data, such as the order of words in a sentence, the time in a time series, and the order in other sequential data. [20]. The RNN equation at each time step is as follows.

$$ht = f(Wxh * xt + Whh * ht\text{-}1 + bh) \quad (3)$$

Where ht is the output at the time step t (timestep), xt is the input at the time step t, ht-1 is the output at the previous time step (t-1), Wxh is the weight matrix that relates input to output, Whh is the weight matrix that connecting previous output to current output and bh is biased.

2.4 Long Short-Term Memory (LSTM)

LSTMs are a type of model in recurrent neural networks (RNNs) specifically designed to deal with long-term dependency problems. The LSTM contains memory cells and gates to adapt network information and recall information over long periods [21]. There are 3 types of gates in the LSTM, namely *forget gates, input gates* , and *output gates* . [22]. In general, the LSTM formula consists to 4, namely [23] :

Forget gates

$$f_t = \sigma(W_{fx} x_t + W_{fh} h_{t-1} + W_{fc} c_{t-1} + b_f) \quad (4)$$

Gate inputs

$$i_t = \sigma(W_{ix} x_t + W_{ih} h_{t-1} + W_{ic} c_{t-1} + b_i) \quad (5)$$

Memory Update

$$c_t = f_t o c_{t-1} + i_t o \emptyset (W_{cx} x_t + W_{ch} h_{t-1} + b_c) \quad (6)$$

Output gates

$$o_t = \sigma(W_{ox} x_t + W_{oh} h_{t-1} + W_{oc} c_t + b_o) \quad (7)$$
$$h_t = ot o \emptyset(c_t)$$

2.5 Mean Square Error (MSE)

MSE is a metric used to measure the extent of the difference between the predicted value and the actual value in a regression model. This metric is generally used to evaluate the predictive quality of a statistical model or machine learning algorithm. The mathematical formula for calculating MSE is as follows [24].

$$\text{MSE} = \frac{1}{m} \sum_{i=1}^{m} (Xi - Yi)^2 \quad (8)$$

With information m indicating a lot of data, X is the actual data value, and Y is the predicted data value.

2.6 Root Mean Square Error (RMSE)

RMSE is an evaluation metric that is often used to measure the extent of the difference between the predicted value and the actual value in a regression model. RMSE is used to calculate the difference between the actual value and the expected value and divide the total sum obtained by the number of prediction times and draw the roots. RMSE is similar to Mean Square Error (MSE), but RMSE calculates the square root of the MSE to produce a value that is in the same units as the variable being measured. The calculation of the Root Mean Square Error (RMSE) can be seen in the following equation [25].

$$\text{RMSE} = \sqrt{\frac{1}{m} \sum_{i=1}^{m} (Xi - Yi)^2} \quad (9)$$

With information m indicating a lot of data, X is the actual data value, and Y is the predicted data value.

2.5 Mean Absolute Percentage Error (MAPE)

MAPE is a metric commonly used in forecasting and prediction contexts, where it is important to evaluate the percentage difference between the predicted value and the actual value. A measure of relative accuracy used to determine the percentage deviation of the predicted results. MAPE provides an overview of the extent of the prediction error in the form of a percentage of the true value. MAPE is the average absolute error over a given period and then multiplied by 100% to give the result as a percentage. The formula for calculating the MAPE value can be seen as follows [25]:

$$\text{MAPE} = \frac{1}{m} \sum_{i=1}^{m} \frac{Yi - Xi}{Yi} \quad (10)$$

With information m indicating a lot of data, X is the actual data value, and Y is the predicted data value.

3. RESULTS AND DISCUSSION

In this study, a comparison of three algorithms was carried out, namely ANN, RNN, and LSTM with a comparison of accuracy using MSE, RMSE and MAPE. Normalized data is directly applied to the three algorithms.

3.1 ANN

The first prediction process is carried out using the ANN algorithm. The prediction results using the Artificial Neural Network (ANN) algorithm can be seen in Figure 3.

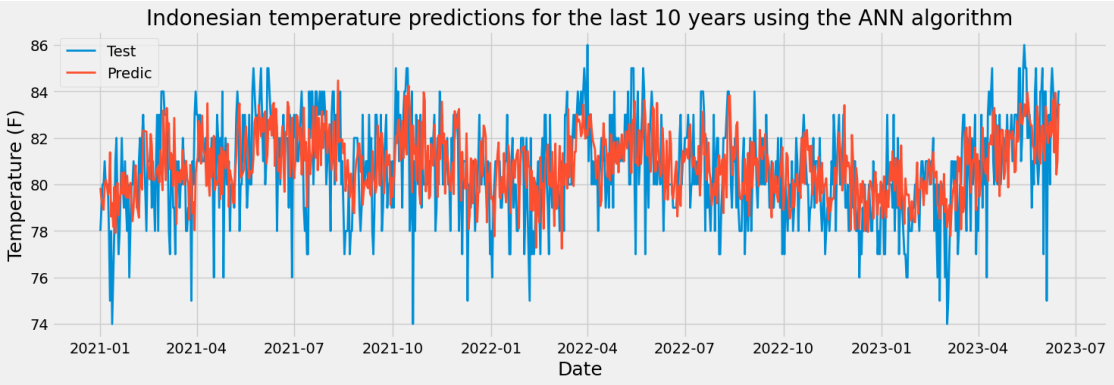

Figure 3 . ANN Visualization Graph

Based on the results of the ANN algorithm modeling in Figure 3, it was found that the temperature data visualization graph has data that is not too different from the original data (testing data). The results of temperature predictions in Indonesia using the ANN algorithm can be seen in Table 2.

Table 2. ANN Prediction Results

Date	TAVG (Degrees Fahrenheit)	Predictions
2021-01-01	78	80,40
2021-01-02	79	78,72
2021-01-03	80	79,83
2021-01-04	80	79,36
2021-01-05	81	79,54
...	...	...
2023-06-12	82	84,10
2023-06-13	83	82,51
2023-06-14	83	81,29
2023-06-15	84	81,76
2023-06-16	84	83,59

Based on Table 2 is obtained prediction temperature use algorithm ANN shows good results you can get seen from prediction every data has no results too different with proven from results evaluation possible performance seen on figure 4.

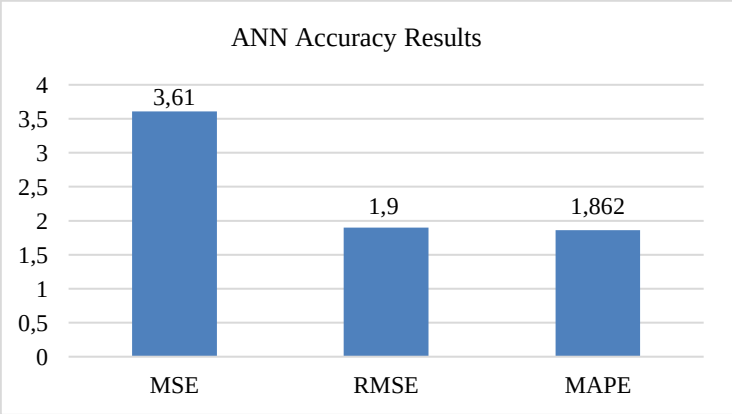

Figure 4. ANN Accuracy Results

Based on figure 4 the evaluations used to measure ANN performance are MSE, RMSE and MAPE with values of 4,099, 2,024 and 2,014. It can be seen that the best evaluation value is found in the MAPE evaluation with a value of 2,014.

3.2 RNN

After the temperature prediction modeling process is carried out using the Artificial Neural Network (ANN) method. Furthermore, temperature prediction will be carried out using the Recurrent Neural Network (RNN) algorithm. The prediction results using the Recurrent Neural Network (RNN) algorithm can be seen in Figure 5.

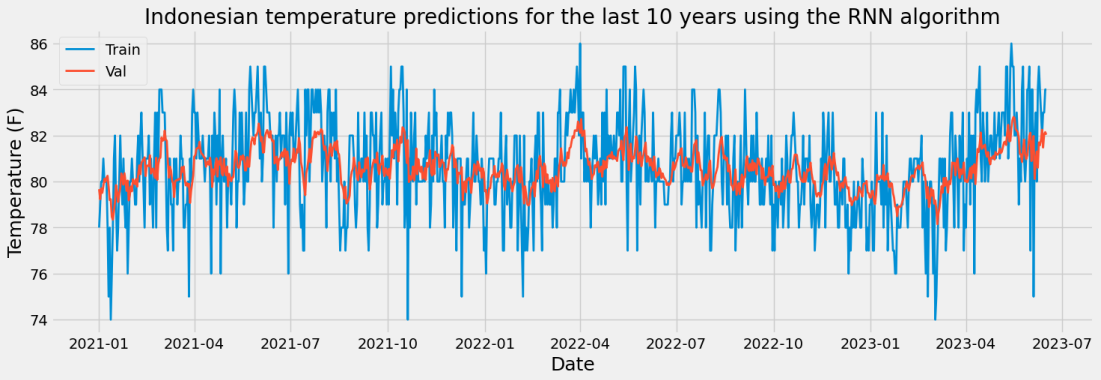

Figure 5 . RNN Visualization Graph

Based on the results of the RNN algorithm modeling in Figure 5, it was found that the temperature data visualization graph has data that is not too different from the original data (testing data). The results of temperature predictions in Indonesia using the RNN algorithm can be seen in Table 3.

Table 3. RNN Prediction Results

Date	TAVG (Degrees Fahrenheit)	Predictions
2021-01-01	78	79,98
2021-01-02	79	79,31
2021-01-04	80	80,24
2021-01-05	80	79,89
2021-01-06	81	80,56
2021-01-07	82	83,17
2021-01-08	83	81,64
2021-01-09	83	82,31
2021-01-10	84	82,27
…	…	…
2023-06-16	84	82,30

Based on Table 3, the temperature prediction using the RNN algorithm shows good results, which can be seen from the predictions that each data has results that are not too different, as evidenced by the results of the performance evaluation, which can be seen in figure 6.

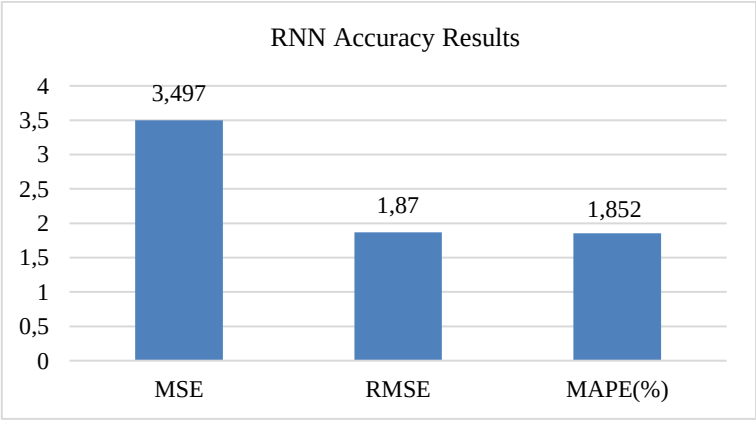

Figure 6. RNN Accuracy Results

Based on figure 6 the evaluations used to measure the performance of the RNN are MSE, RMSE and MAPE with values of 3,497, 1,870 and 1,852. It can be seen that the best evaluation value is found in the MAPE evaluation with a value of 1,852.

3.3 LSTM

The prediction process uses LSTM, data sharing is carried out using the *Hold Out technique*, where training data starts from January 1, 2014 to December 31, 2019, validation data starts from January 1, 2020 to December 31, 2020, and data testing starts from January 1, 2021 to June 16, 2023. The results of data sharing will be predicted using LSTM. From the results of data processing, graphical results are obtained which can be seen in Figure 7.

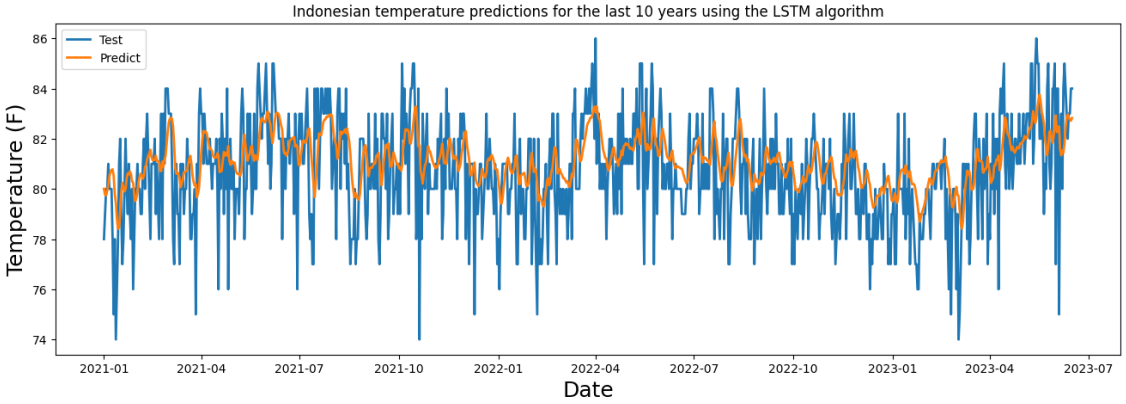

Figure 7. LSTM Visualization Graph

Based on Figure 4, the results show that visually the temperature prediction graph in Indonesia is almost the same as the actual data (testing data). The prediction results using LSTM can also seen in table 4.

Table 4. LSTM Prediction Results

Date	TAVG (Degrees Fahrenheit)	Predictions
2021-01-01	78	79,75
2021-01-02	79	79.56
2021-01-03	80	79,62
2021-01-04	80	79,91
2021-01-05	81	80,17
2021-01-06	80	80,53
2021-01-07	80	80,64
2021-01-08	80	80,65
…	…	…
2023-06-16	84	82,70

The results of temperature prediction in Indonesia using LSTM show almost the same results. This is evidenced by the very good accuracy values obtained as can be seen in figure 8.

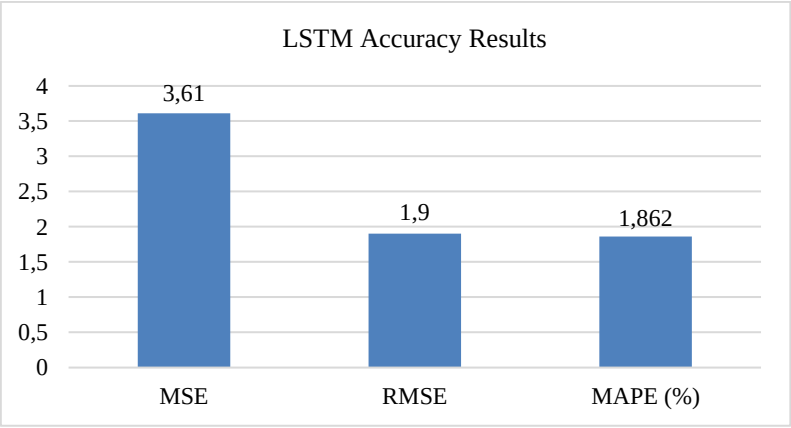

Figure 8. LSTM Accuracy Results

Based on figure 8, the accuracy value using MAPE is better than the other two evaluation methods with a value of 1.862. The accuracy value for LSTM prediction shows that the smaller the accuracy results, the better the process results are.

3.4 Evaluation Comparison

The evaluation value of each algorithm is compared. The three evaluation methods, namely, MSE, RMSE, and MAPE will be compared to see which algorithm is better at predicting temperature changes in Indonesia. MAPE is the best evaluation in making predictions for the three algorithms used. This is because the MAPE value in each algorithm is the smallest evaluation value. The smaller the evaluation value, the better the results. Comparison of the evaluation of the three algorithms can be seen in Figure 9.

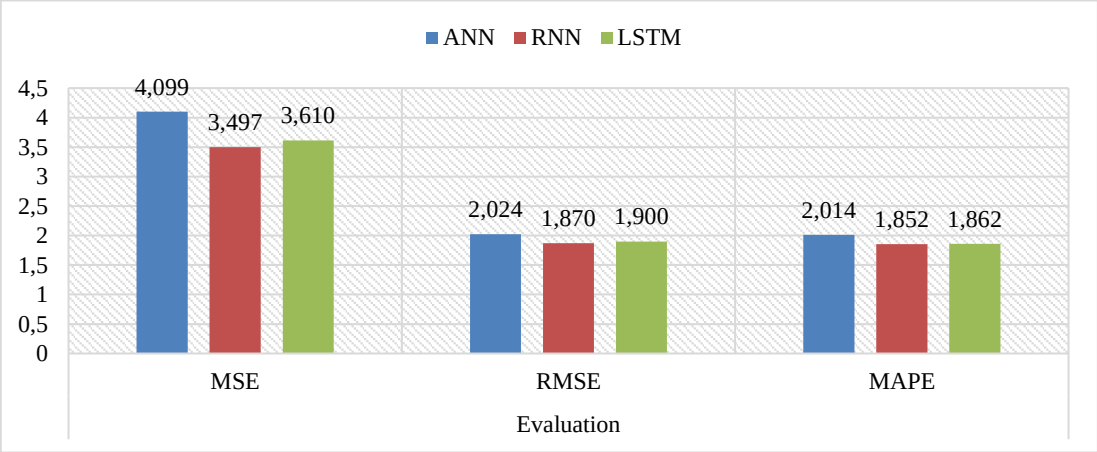

Figure 9. Evaluation Comparison

Figure 9 shows a comparison of the evaluation values between ANN, RNN, and LSTM. As a result, it was found that the RNN algorithm has a smaller MAPE value of 1,852, the RMSE value is 1,870, and the MSE value is 3,497 compared to the other two algorithms. This shows that RNN is the best algorithm in predicting climate change in Indonesia than ANN and LSTM.

4. CONCLUSION

Based on research conducted to predict climate change in a province in Indonesia, the results show that the RNN algorithm is better at predicting temperature in Riau Province compared to ANN and LSTM. This is evidenced by the MAPE value produced by RNN which is smaller than ANN and LSTM, namely 1,852 %. This value is the smallest value among other evaluation values. So that shows that RNN is better than ANN and LSTM in predicting climate change in Indonesia.

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