



Wind Speed Forecast Using the Triple Exponential Smoothing Method in Pangandaran Beach

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Abstract

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Indonesia as a maritime country with a long coastline, holds significant potential in the marine and tourism sectors. However, these sectors are often disrupted by adverse weather conditions, particularly irregular wind speeds. Accurate wind speed forecasting is therefore essential for disaster mitigation. This study aims to forecast wind speed at Pantai Pangandaran using the Triple Exponential Smoothing (TES) method, which is more effective in handling data fluctuations with trend and seasonal patterns. The data used includes daily data from January 2014 to September 2024. The results show that the TES method provides highly accurate forecasts, with a low error rate evaluated through an RMSE of 0.51 and a MAPE of 17.85% for wind speed. These forecasts are expected to support disaster mitigation, enhance safety, and improve the efficiency of activities in coastal areas, particularly at Pantai Pangandaran, in facing adverse weather conditions.

Keywords: Forecast; wind; speed; Pangandaran; Triple Exponential Smoothing

Abstrak

Indonesia sebagai negara maritim dengan garis pantai yang panjang, memiliki potensi besar di sektor kelautan dan pariwisata. Namun, sektor ini sering terganggu oleh kondisi cuaca buruk, terutama akibat kecepatan angin yang tidak teratur. Oleh karena itu, peramalan kecepatan angin yang akurat menjadi sangat penting untuk mendukung mitigasi bencana. Penelitian ini bertujuan untuk meramalkan kecepatan angin di Pantai Pangandaran dengan menggunakan metode Triple Exponential Smoothing (TES), yang lebih efektif dalam menangani fluktuasi data dengan pola tren dan musiman. Data yang digunakan mencakup data harian periode Januari 2014 hingga September 2024. Hasil penelitian menunjukkan bahwa metode TES menghasilkan peramalan yang sangat akurat, dengan tingkat kesalahan yang rendah, yaitu RMSE sebesar 0,51 dan MAPE sebesar 17,85% untuk kecepatan angin. Peramalan ini diharapkan dapat mendukung mitigasi bencana, meningkatkan keselamatan, dan meningkatkan efisiensi aktivitas di kawasan pesisir, khususnya di Pantai Pangandaran, dalam menghadapi cuaca buruk.

Kata-kata kunci: Peramalan; kecepatan; angin; Pangandaran; Triple Exponential Smoothing.



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1. Introduction

Indonesia is both a maritime nation and the largest archipelagic country in the world, with two-thirds of its territory consisting of oceans [1]. Its extensive coastline provides significant advantages for the marine and tourism sectors. However, activities in these sectors are often disrupted by adverse weather conditions that pose risks to safety and efficiency. Such weather conditions are caused by frequently changing and irregular wind speeds, making accurate forecasting challenging [2]. One phenomenon that significantly impacts coastal areas, shoreline structures, and maritime transportation is ocean waves, which are heavily influenced by wind conditions [3]. Wind conditions are monitored in real-time by the National Aeronautics and Space Administration Prediction of Worldwide Energy Resources (NASA POWER); however, future wind conditions cannot be obtained instantly, necessitating the development of wind forecasting models.

Wind speed forecasting has been conducted in several previous studies, one of which is a study by Ryan and Alfiandy (2022) titled "12-Hour Wind Speed Forecasting Using Automatic Weather Observing System (AWOS) Based on Linear Regression" [4]. The results of this study indicate that the Root Mean Square Error (RMSE) values did not show significant differences despite variations in predictor lengths. The RMSE for the 12-hour predictor scheme was 0.63, 1.14, and 3.07 for the lowest, average, and highest wind speeds, respectively. In contrast, the 18-hour predictor scheme demonstrated higher RMSE values of 0.65, 1.18, and 3.10. This suggests that changes in the length of historical data do not significantly affect forecasting accuracy. Additionally, the linear regression method used in the study was not capable of performing time-based forecasting. Therefore, a more suitable method is required to handle data fluctuations with trend and seasonal patterns to improve wind speed forecasting accuracy.

The Triple Exponential Smoothing (TES) method is a suitable forecasting technique for predicting fluctuating variables [5]. This method employs a gamma constant to produce smaller smoothing values, thereby enhancing forecasting accuracy [6]. A study on wind speed forecasting by Hakim et al. (2024), titled "Rainfall, Wind Speed, and Temperature Forecast Using Triple Exponential Smoothing and Gradient Descent," identified optimal parameter values of $\alpha = 0$, $\beta = 0.4$, and $\gamma = 0.6$. Model evaluation yielded results of MAE at 0.99, MSE at 1.64, RMSE at 1.28, and MAPE at 23.51%. These findings indicate the presence of a trend pattern in wind speed data [7].

The aim of this study is to forecast wind speed using the Triple Exponential Smoothing method. The parameters used in the forecasting process include wind direction, air temperature, and atmospheric pressure [8]. The results of this study are expected to achieve a high level of accuracy in predicting wind speed in the Pantai Pangandaran area, thereby supporting disaster mitigation efforts, reducing disruptions caused by adverse weather, and enhancing safety and efficiency in activities within the region.

2. Method

The research uses a quantitative method through a time series forecasting approach. Time series is a statistical technique that analyzes historical data to identify patterns and trends [9]. Forecasting with this method involves the process of predicting future values based on the analysis of collected data [10]. A time series is a sequence of observations measured consecutively at specific intervals, with data consisting of either discrete or continuous variables. Forecasting is conducted to predict future values based on historical data, with the aim of developing an accurate model for the subsequent period [11].

2.1. Holt-Winters Exponential Smoothing

Triple Exponential Smoothing, or Holt-Winters Exponential Smoothing, is a time series forecasting method commonly used to analyze and forecast data with trend and seasonal patterns [12]. It uses three smoothing parameters, α , β , and γ , each having values between 0 and 1 [13]. This method involves more complex calculations and is capable of generating smoother predictions by accurately accounting for seasonal changes [14]. Equations (1), (2), (3), and (4) represent the forecasting calculations using the Triple Exponential Smoothing method [7]:

a. Level

Level is used to calculate the most recent average of actual data after removing the effects of seasonality and trend, with the aim of obtaining a more accurate baseline value. The formula for the level can be found in Equation (1).

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

b. Trend

Trend is a formula used to model the consistent change in data patterns over time. The formula for the trend can be found in Equation (2).

$$T_t = \beta(L_t - L_{t-1}) + (1 - \beta)T_{t-1} \quad (2)$$

c. Seasonal

The seasonal component is essential for identifying and calculating repetitive patterns or seasonal cycles that occur regularly in the data. It helps capture periodic fluctuations, such as those occurring daily, monthly, or yearly. The formula for the seasonal component can be found in Equation (3).

$$S_t = \gamma(y_t / L_t) + (1 - \gamma) S_{t-s} \quad (3)$$

d. Forecast

Forecast is used to predict future data values ($t+k$) based on a combination of the current level (L_t), trend (T_t), and seasonal pattern (S_{t+k-s}). The forecast formula can be found in Equation (3).

$$\hat{y}_{t+k} = (L_t + k T_t) S_{t+k-s} \quad (4)$$

Where:

α = Single fixed value for smoothing the level.

β = Single fixed value for smoothing the trend pattern.

γ = Single fixed value for smoothing the seasonal pattern.

y_t = Actual value or statistic at period t .

S_t = Value of the seasonal exponential smoothing at period t .

L_t = Value of the level smoothing at period t .

T_t = Value of the trend smoothing at period t .

k = Number of future periods to be forecasted.

\hat{y}_{t+k} = Forecasted value at period $t+k$.

The Triple Exponential Smoothing method involves several systematic steps to produce accurate forecasts. First, smoothing constants α , β , and γ are determined, with values ranging between 0 and 1. The actual wind speed data for a specific time period is utilized as the input. Using this data, the smoothed level component L_t is calculated based on formula (1). The trend smoothing value T_t is derived using formula (2), followed by the computation of the seasonal smoothing value S_t with formula (3). Once these components are determined, the forecast value \hat{y}_{t+k} is computed using formula (4). The accuracy of the forecast is assessed by calculating the error rate using formulas (6) and

(7). These steps provide an effective method for forecasting seasonal time series data. The flowchart of the Triple Exponential Smoothing algorithm can be seen in **Figure 1**.

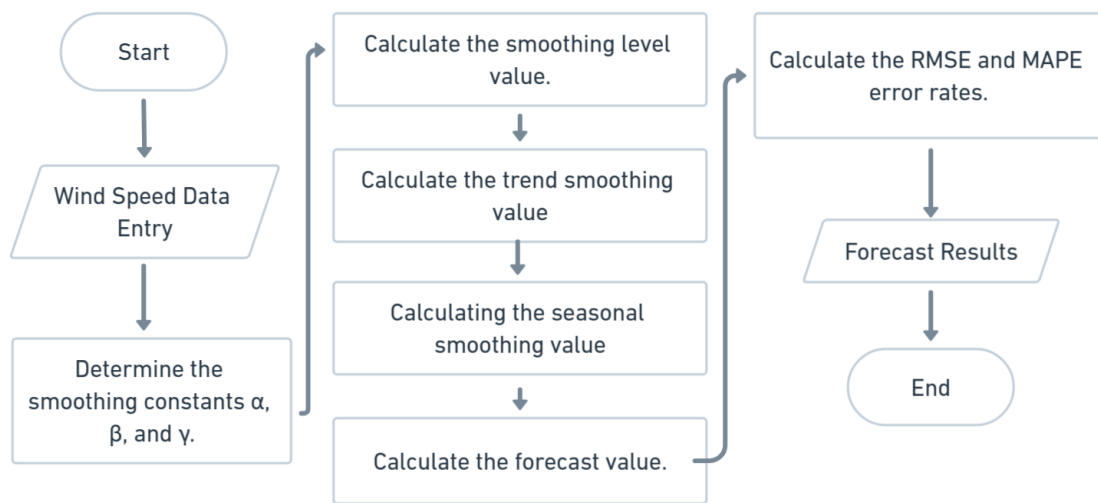


Figure 1. Flowchart of the Triple Exponential Smoothing Method

2.2. Root Mean Square Error (RMSE)

RMSE measures the accuracy of a model's predictions by calculating the square root of the average squared errors. A low RMSE value indicates that the predictions are close to the actual data. Formula (5) is the calculation for the RMSE value.

$$\text{RMSE} = \frac{\sum_{i=1}^n \sqrt{(Y_i - \hat{Y}_i)^2}}{n} \quad (5)$$

Where:

Y_i = initial data

\hat{Y}_i = final data

n = number of data points

2.3. Mean Absolute Percentage Error (MAPE)

MAPE is used to measure the average error produced by a model, or how far the forecast deviates from the actual values [15]. Achieving a perfect accuracy level of 100% in forecasting is difficult. Therefore, it is necessary to calculate the forecasting error rate. Formula (6) is the calculation for the MAPE value.

$$\text{MAPE} = \left(\frac{100\%}{n} \right) \sum_{t=1}^n \left| \frac{X_t - F_t}{X_t} \right| \quad (6)$$

Where:

X_t = actual value at time t

F_t = forecasted value at time t

n = total number of observations

Based on Formula (6), the lower the MAPE value, the higher the accuracy of the forecasting model. A smaller MAPE value reflects a closer match between the predicted and actual values. The range of values for evaluating the forecasting model can be seen in [Table 1](#) [16].

Table 1. MAPE Value Criteria

MAPE Value	Interpretation
<10%	The forecasting results are very accurate
10-20%	Accurate forecasting results
20-50%	The forecasting results are quite accurate
>50%	Inaccurate forecasting results

2.4. Data

The analysis uses wind speed data from Pangandaran Beach, West Java, with a non-experimental design obtained from NASA POWER, covering the period from January 2014 to September 2024. Forecasting was carried out using Python software for data processing.

3. Results and Discussion

The total amount of actual data for each parameter used in this study is 3,923 records, covering the period from January 2014 to September 2024. This dataset excludes 29 February in leap years, as the seasonal code applied is based on 365 days per year. The Seasonal Holt-Winters Exponential Smoothing method utilizes 365 data points for the modeling process, enabling forecasting for the period from January 2016 to September 2025. The comparison charts between actual data and forecasted data are presented in Figures 2, 3, 4, and 5.

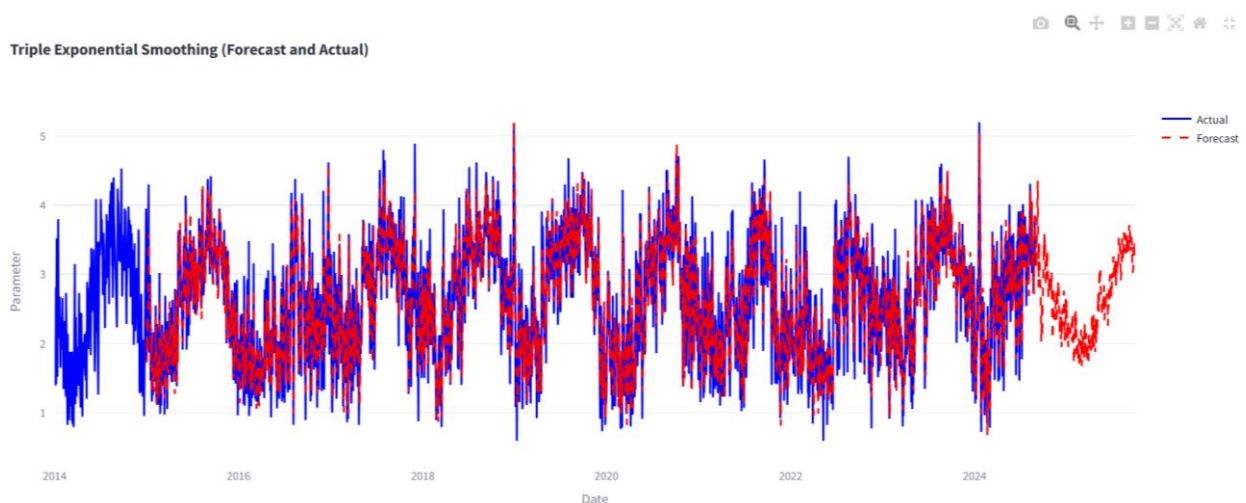


Figure 2. Wind Speed Forecasting Graph

Figure 2 shows the daily data graph and wind speed forecasting results. The highest recorded wind speed was on September 6, 2025, at 3.71 m/s. This value is considered low compared to the threshold for strong winds that can cause damage, according to the Beaufort scale at level 6, with wind speeds ranging from 10.8 to 13.8 m/s [17]. During the period from October 2024 to September 2025, the wind speed remained within a safe category, with no indication of potential disasters in the Pangandaran Beach area. The accuracy of the prediction results, based on RMSE value of 0.51 and MAPE of 17.85%, indicates a good performance of the forecasting method.

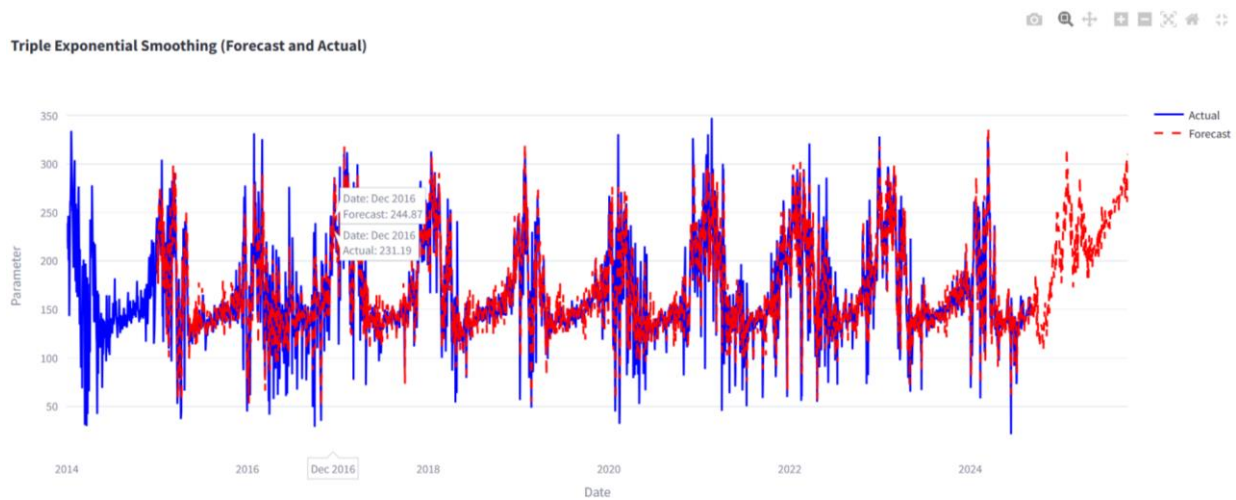


Figure 3. Wind Direction Forecasting Graph

Figure 3 presents the daily data graph and wind direction forecasting results at a height of 10 meters. The largest wind direction was recorded on 25 January 2025, at 316.64°, while the lowest wind direction occurred on 22 October 2024, at 107.76°. These values are within the normal range. For comparison, wind directions that could be potentially hazardous include the Northeast (45°) with wind speeds of 20-30 m/s, which could cause large waves, and the Northwest (315°) with wind speeds greater than 33 m/s, which can trigger storms. During the period from October 2024 to September 2025, the wind directions remained safe. The prediction accuracy, with RMSE value of 30.12 and MAPE of 13.72%, indicates that the forecasting method performed very well.

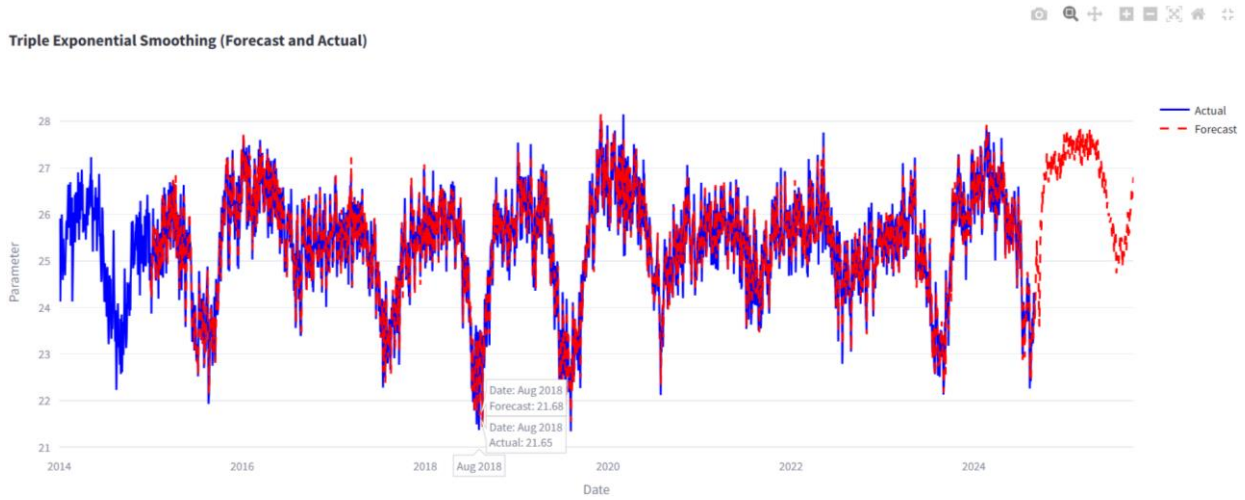


Figure 4. Air Temperature Forecasting Graph

Figure 4 presents the daily data graph and air temperature forecasting results at a height of 2 meters. The highest temperature was recorded on 7 January 2025, at 27.84°C, while the lowest was recorded on 24 July 2025, at 24.73°C. These values are within the normal temperature range of 23–34°C. From October 2024 to September 2025, the air temperature in the Pangandaran Beach area remained within the normal category. The prediction accuracy, with an RMSE value of 0.45 and MAPE of 0.41%, indicates that the forecasting method performed excellently.

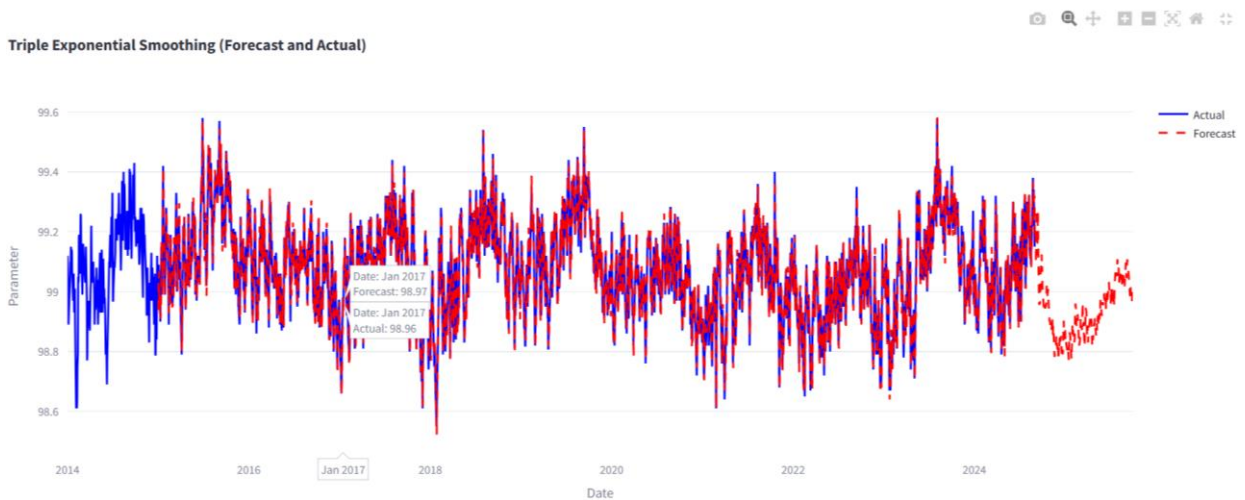


Figure 5. Air Pressure Forecasting Graph

Figure 5 shows the daily data graph and air pressure forecasting results. The highest air pressure was recorded on 30 July 2025, at 99.11 kPa, while the lowest air pressure was recorded on 26 January 2025, at 98.77 kPa. These values remain within the normal range for coastal areas. Extreme air pressure, such as below 95 kPa or above 105 kPa, can indicate unusual or extreme weather conditions. During the period from October 2024 to September 2025, the air pressure in

the Pangandaran Beach area remained within the normal category. The prediction accuracy, with an RMSE value of 0.06 and MAPE of 0.05%, reflects excellent forecasting performance.

Based on the analysis of Figures 2 through 5, no indication of potential disasters is observed in the Pangandaran Beach area during the period from October 2024 to September 2025. The highest wind speeds are well below the threshold for damaging strong winds, while the wind direction and air pressure remain within the normal range without any extreme patterns. The air temperature also remains stable and within the normal range. Overall, the weather parameters analyzed indicate safe conditions, with good prediction accuracy for each variable. The daily forecasting results for wind speed, wind direction, air temperature, and air pressure from 1 October 2024, to 30 September 2025, are presented in [Table 2](#).

Table 2. Wind Speed Forecast Results at Pangandaran Beach

Year	Month	Day	Forecast Results					
			Wind Speed (m/s)	Wind Direction (°)	Temperature (°C)	Surface Pressure (kPa)		
2024	October	1	3.10	126.01	23.75	99.02		
		2	3.44	128.84	23.96	99.01		
		3	3.31	130.17	24.49	98.98		
		4	3.42	127.64	24.58	98.98		
		5	3.62	126.71	25.06	98.97		
		6	3.26	121.47	24.92	98.95		
		7	3.48	123.12	25.10	98.96		
		8	3.00	111.10	24.89	98.95		
		9	3.03	120.77	25.47	98.96		
		10	2.82	123.96	24.90	98.94		
		11	3.25	130.40	24.80	98.95		
		12	3.24	127.45	24.96	98.95		
		13	3.28	129.89	24.78	98.95		
		14	3.14	134.50	24.96	98.95		
		15	3.11	133.38	24.78	98.96		
				16	3.33	132.92	24.36	98.96
			3.06	128.53	27.08	98.96		
		
2025	September	1	3.32	276.22	25.33	99.07		
		2	3.46	277.58	25.23	99.10		
		3	3.34	268.34	25.48	99.07		
		4	3.29	265.37	25.77	99.04		
		5	3.38	269.48	25.96	99.05		
		6	3.71	272.75	25.94	99.08		
		7	3.51	274.69	26.05	99.10		
		8	3.53	278.72	25.90	99.11		
		9	3.58	279.12	25.79	99.09		
		10	3.67	285.47	25.50	99.09		
		11	3.34	285.01	25.62	99.08		
		12	3.33	285.26	25.68	99.08		
		13	3.38	281.58	25.58	99.06		
		14	3.35	282.91	25.93	99.03		
		15	3.53	279.32	26.13	99.04		
		16	3.50	289.33	26.06	99.03		
				18
				26	3.22	274.31	26.34	98.96
		27	3.41	260.55	26.50	98.97		
		28	3.48	285.25	26.62	98.99		
		29	3.24	299.45	26.77	99.01		
		30	3.15	310.20	26.80	99.00		

4. Conclusion

Based on the analysis results, no indications of potential disasters were found in Pangandaran Beach during the period from October 2024 to September 2025. The recorded wind speed was significantly below the damage threshold, with the strong wind threshold capable of causing damage ranging between 10.8 and 13.8 m/s. Furthermore, wind direction and air pressure were recorded within normal limits without any extreme patterns, while air temperature remained stable and within the safe category for coastal areas. Prediction accuracy was demonstrated by RMSE and MAPE values, with wind speed recording an RMSE of 0.51 and MAPE of 17.85%, wind direction an RMSE of 30.12 and MAPE of 13.72%, air temperature an RMSE of 0.45 and MAPE of 0.41%, and air pressure an RMSE of 0.06 and MAPE of 0.05%. These results indicate safe conditions with high predictive accuracy, providing insights for disaster mitigation and supporting safety and efficiency in Pangandaran Beach.

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