Coastal storm waves detection system design using Beaufort scale standardization and Sugianto wave forecasting method in Timbulsloko, Demak, Central Java, Indonesia

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Abstract. Storm is defined as a disturbance of the atmosphere marked by winds and usually by rain. Coastal storms must comprise a maritime component, such as waves, currents and/or water levels. Coastal storm detection is necessary so the number of casualties and losses caused by these events can be reduced. The method used in this system is the Sugianto wave forecasting method with standardization of coastal storms using the Beaufort scale. The purpose of this study is to build up an internet of things based system to observe coastal storm information and wave forecasting data from wind speed data that obtained in Timbulsloko, Demak, Central Java, Indonesia. The tidal data is processed using the Admiralty method. This system was built using Arduino Uno equipped with anemometer JL-FS2 to measure wind and waves parameters. The power source from 100 wp solar panels stored in a 40 Ah accumulator. Data from field instrument is stored to the IoT MAPID database using NodeMCU ESP8266. This system is placed in Timbulsloko, Demak. The results of field observation then validated using BMKG. This method could be applied in other location along the north coast of Java. The results of field observation showed an average wind speed 3.9848 m/s; significant wave height 0.4632 m; significant wave period 3.8641 s; wave energy 493.90 J/m²; wind energy 116.74 W/m².

1. Introduction
Coastal storms are meteorological disturbances to water conditions (waves or water levels) that have the potential to change the morphology of an area and expose the backshore to waves, currents, and inundation. This event is associated with the occurrence of a cyclonic system that can directly attack the shoreline. Coastal storms usually coincide with strong winds [1]. Wind is a motion of air parallel to the earth's surface caused by the earth's rotation, as well as the difference in air pressure around it. The wind moves from an area of high pressure to an area of low pressure. The amount of wind speed has the potential for high waves. The wind blowing over the sea surface is the main generator of waves [2]. Waves are one of the important parameters in water dynamics that have an influence on changes in coastal and marine areas [3]. Generally, waves formed by strong winds are usually of a less steep type than waves formed by weak winds. Where the average wave height produced by the wind is the wind speed, time, direction, and distance the wind blows [4]. While the waveforms caused by storms are the
result of significant changes in weather to water conditions. Wave speed can reach 7 - 10 meters, these waves can destroy the coast with its vegetation and the coastal area as a whole [5]. The waters of the north coast of Java have the potential to experience storm surges that occur during the eastern monsoon which is indicated during the month of May [11]. Tidal events make waves occur periodically. Tidal waves are caused by strong winds, such as storms that occur in coastal areas [6].

Coastal storms can cause changes in the meteorology and morphology of the area, such as extremely high rain intensity, high wind speeds, erosion in coastal areas, damage to residential areas and coastal ecosystems, so that sea levels rise to residential areas which are always accompanied by destructive wave heights. [1]. In addition, it is exacerbated by climate change which can trigger an increase in the frequency of extreme wave events that cause coastal storms to occur [7]. Coastal storms are disasters that cause high wind intensity, so that waves and currents become very extreme and dangerous for coastal residents who have their livelihoods as fishermen. In the Central Java region during the last 5 years there were 128,006 people who were affected by the risk of coastal storms. The coastal storms affect the morphological conditions of the region, the economy and the social life of the people living in the area [8].

Therefore, it is necessary to have an instrument that can monitor the development of storm waves in real time so that it can be accessed by the public. This research also presents opportunities that can be done to mitigate the risk of coastal storms and become a strategic and most cost-effective effort for the northern region of Java. For this reason, an IoT (Internet of Things) based instrument is needed, so that the instrument can perform internet network connectivity, so that the instruments can be connected and exchange data in real time [9]. Coastal storms are closely related to changes in wind speed, so the necessary instruments can detect them based on the Beaufort scale. The Beaufort scale measures wind speed by describing the effect of its speed on sea waves. The greater the Beaufort scale, the stronger the wind will blow, and it can even further damage the coastal area. The Beaufort scale is grouped from 0 m/s to >29 m/s which serves as an indication of calm wind conditions to dangerous winds. The Beaufort scale ranges from number 1 for calm wind gusts to number 12 for wind gusts that can cause destruction [10]. The purpose of this study was to build an Internet of Things based instrument to determine wind and wave conditions in the waters of Timbulsloko, Demak Regency, and from the wind and wave conditions we can detect the possibilities of coastal storm waves there. The benefit of this research is as the source of information on wind and wave data to prevent and minimize disasters in coastal areas.

2. Materials

2.1 Location

![Figure 1. Location of the instrument placement for wind and wave data collection](image)
Instrument testing was carried out in the waters of Timbulsloko Village, Sayung District, Demak Regency, Central Java, Indonesia. Geographically, the research area is located on a longitude -6.8912533 and latitude 110.5036096. Based on its location, the Timbulsloko area is directly affected by wind and waves from the Java Sea during the west season, namely in December-February. The basic sediment type found on the Timbulsloko beach is sandy mud with the dominant vegetation is mangrove ecosystem.

2.2 Materials
This coastal storm monitoring system uses two microcontrollers consisting of Arduino UNO R3 and NodeMCU ESP8266 which are connected by Software Serial. The anemometer sensor used in recording wind data is the JL-FS2 type which uses a 12 V voltage input and an analog signal reading. To run the system during data reading, two 50wp solar panels and a 12v 20 Ah accumulator are used, each of which is installed in parallel. Then for sending data from NodeMCU ESP8266 to the IoT MAPID database, this system uses portable Wi-Fi with the Smartfren signal provider type. Testing of this instrument was carried out for 12 days starting from January 12th to January 23rd, 2021 with a measurement interval of 30 seconds.

The recorded wind and wave data is then validated with data from the local meteorological institution, namely from the Tanjung Emas Meteorological BMKG Station, Semarang. The station was chosen because it has a closer distance to the system research area. In addition, there is tide prediction data obtained from the Geospatial Information Agency to determine the types of tides found in the Timbulsloko Village area, Sayung District, Demak.

3. Methodology

3.1 Coastal Storm Wave System

![Diagram of Coastal Storm Wave System]

This system was built with the method of the Internet of Things to facilitate the delivery of coastal storm information to the database. Internet of Things is a computer connection concept that utilizes the internet, thus connecting many objects on a device [12]. This system uses a JL-FS2 anemometer connected analogously to the Arduino UNO R3 to record the analog signal converted into wind speed.
The JL-FS2 anemometer is connected to the solar charge controller to get a voltage input of 12 V so that it can work optimally. Then the data recorded in the Arduino UNO R3 will be converted into wind speed in knots, wind energy, significant wave height, significant wave periods, and wave energy.

The converted data is then sent to the Internet of Things database provided by PT. MAPID with IoT Mapid products via NodeMCU ESP8266 with 30 second intervals. Sending data to the database uses internet access in the form of 4G Wi-Fi Portable which gets power from the solar charge controller. Overall power comes from a 100 wp solar panel and a 12 v 40 Ah accumulator connected to the solar charge controller.

3.2 Data Conversion Method

Based on its speed, the wind can be categorized based on its energy and is usually expressed in the Beaufort scale. The relationship between speed and wind energy is stated in Meteorological Office Publication No. 180, London [13].

\[ V = \frac{0.836B^2}{2} \]  
(1)

where V is the wind speed (m/s) and B is the Beaufort scale.

This wind data can be directly converted into significant wave heights and significant wave periods using empirical wind wave forecasting equations [14].

\[ H_s = 0.0016U^2 + 0.0406U \]  
(2)

\[ T_s = 0.15U + 2.892 \]  
(3)

where \( H_s \) is the significant wave height (m), U is the wind speed (knots), and \( T_s \) is the significant wave period (s).

After obtaining significant wave height data and significant wave periods, it can then be seen the value of the wave energy that occurs at the research location. Wave energy is changes from one point to another point along one wavelength and energy from the average one unit area which stated in this following form [15].
where $E$ is the wave energy ($J/m^2$), $\rho$ (rho) is the density of seawater ($Kg/m^3$), $g$ is the gravitational acceleration of the earth ($m/s^2$), and $H$ is the wave height ($m$).

To see the correlation between the BMKG observation data and the observation data from the storm detection system, the correlation method is used such as the research used by [16].

$$r = \frac{N(\Sigma XY)-(\Sigma X \Sigma Y)}{\sqrt{N(\Sigma X^2-(\Sigma X)^2)}-N(\Sigma Y^2-(\Sigma Y)^2)}}$$

Tide data from the prediction of the Geospatial Information Agency (BIG) was processed using the least square method to find the type of tides that occurred in the waters of Timbulsloko, Demak.

**Figure 4.** The systematics of data conversion from wind speed to wind energy, the standardization using Beaufort scale, and the output as significant wave height, significant wave period data and wave energy

**4. Results and Discuss**

**4.1 Implementation of the Coastal Storm Detection System in Timbulsloko, Demak**

This coastal storm detection system is applied in the area of Timbulsloko Village, Demak Regency, Central Java, Indonesia with a position in the coastal area of the mangrove forest area. This system is in the tidal zone and experiences very good interactions with various types of winds, such as monsoon winds, sea breezes and land winds. This system is placed in the lowest receding zone away from the low lowest water level (LLWL). The position of the anemometer sensor is 3 meters above sea level without obstructions from the direction of the sea, so it can record wind data very well. The system is located behind the beach wall with a surface height of 2 meters, so that it is protected from the impact of breaking waves heading for the beach.
Apart from the application of a coastal storm detection system at a coastal location, there is also a website interface that displays recording data as a form of the internet of things system. This website interface uses a display created by PT. MAPID with various visualization options. Data can be displayed to the public or in privacy. On the website display, this coastal storm detection system displays five graphs consisting of wind speed, wind energy, significant wave height, significant wave period, and wave energy.

4.2 Tide Prediction in Timbulsloko, Demak

Based on the results of tidal data processing obtained from the prediction of the Geospatial Information Agency (BIG) for 30 days in January 2021, it is known that the type of tide in the Timbulsloko area, Demak is a mix tide prevailing diurnal with numbers formzah 2,051. Based on this processing, the mean sea level (MSL) is 0.013 cm, the high highest water lever (HHWL) value is 42 cm, and the low lowest
water level (LLWL) value is -47.6 cm. The previous research of tides in the Timbulsloko area, Demak has also been conducted by [17]. With the results of the formzahl number 1.68 and the type of tidal is mixed tide prevailing diurnal. The function of the tidal data obtained is to determine the ideal position of the system to be implemented.

Figure 7. Tide chart in Timbulsloko, Demak

4.3 Wind Condition in Timbulsloko

In January, Indonesia experiences the rainy season, where the wind blows from the Northwest to the Southeast with high intensity [18]. The position of the direct detection system is facing the Northwest direction, so that the detection system will record the January winds directly from the Java Sea. Based on wind data recorded by the system, there is wind variability that occurs due to the influence of weather and climate parameters in Timbulsloko, Demak on 12-23 January 2021. The minimum recorded wind value is 0 m/s and the maximum recorded wind value is 15.61 m/s on January 19, 2021.

Figure 8. Wind speed in Timbulsloko, Demak 12\textsuperscript{st} – 23\textsuperscript{rd} January 2021
According to [19] the maximum wind speed that occurred in Timbulsloko, Demak in January based on BMKG data from 2010 to 2014 was 10.3 m/s. The wind analysis method used by [19] is a monthly climatology method, according to [20], the monthly climatology method is to make the average of a parameter in the same month from different years for several years. Data from [19] can be a reference that under normal conditions, the wind speed in January in the Timbulsloko area will be 10.3 m/s. Meanwhile, the wind speed recorded by the system on January 19, 2021 is the recorded wind condition anomaly. It is known that this anomaly is the possibility of the influence of multi-parameter meteorology that occurred in the Timbulsloko and Demak areas such as La Nina, West Munson, and Madden Julian Oscillation. According to [21], when La Nina strengthens, the zonal wind is positive or the west monsoon brings large rainfall, such as the zonal winds in December 2016 which became extreme due to the occurrence of La Nina. According to data from the Bureau of Meteorology Australia, the end of 2020 and the beginning of 2021 are strong La Nina periods that occur in the Pacific Ocean.

In addition, according to the meteorological agency in January 2021 in central to western Indonesia, the outgoing longwave radiation (OLR) value was below the normal line ranging from 185-215 W/m². This indicates the accumulation of clouds in the Central to Western regions of Indonesia due to a decrease in pressure in Indonesia, which has caused very strong winds in several areas such as Semarang-Demak. This phenomenon is related to the Madden Julian Oscillation (MJO) that occurred in Indonesia and affects the wind speed reading by the coastal storm detection system.
This is reinforced by the results of wind speed recording conducted by BMKG on January 19, 2021, the maximum wind speed recorded by BMKG is 12.86 m/s. So, it is known that an anomaly occurred on December 19, 2021 which was detected by BMKG and the coastal storm detection system. This shows that the system created can detect anomalies that occur in the atmosphere and affect the oceans.

**Table 1.** The comparison of data between BMKG observation data and observational data system for wind speed

| Date | Daily Wind Speed BMKG (m/s) | Daily Wind Speed (m/s) |
|------|-----------------------------|------------------------|
|      | Max Wind | Average Wind | Max in Situ | Average in Situ |
| 12   | 6        | 2            | 11.57       | 3,664          |
| 13   | 8        | 3            | 11.28       | 3,258          |
| 14   | 5        | 2            | 8.67        | 2,445          |
| 15   | 4        | 2            | 8.41        | 3,510          |
| 16   | 5        | 1            | 5.22        | 1,340          |
| 17   | 8        | 2            | 12.8        | 3,683          |
| 18   | 6        | 3            | 15.29       | 5,475          |
| 19   | 12       | 3            | 15.61       | 6,250          |
| 20   | 5        | 3            | 11.42       | 4,897          |
Based on the data comparison between BMKG observation data and system observation data, it is known that the maximum value has almost the same pattern, but the value is quite different. Meanwhile, the mean value has a value close to the wind speed value observed by BMKG. This shows that the results obtained from recording wind speed data by the coastal storm detection system have high sensitivity, so that they resemble the actual wind condition patterns. This system is highly recommended to be applied in coastal areas, because it can detect storm waves in coastal areas using simple instruments and has a fairly high accuracy. This system has limitations on the area of use. The calculation of significant wave height and significant wave period can only be used in the northern coast of Java. For other areas, the wind and wave equations must convert using the Derbyshire and SMB methods according to research conducted by [14].

**Figure 12.** Daily wind speed in situ vs BMKG wind in Demak 12-23 January 2021

On January 19, 2021, when the wind with the highest speed during the observation was 15.61 m/s, the system provided information synoptically with the Beaufort Scale standardization. The wind speed is included in the 7 scale with the High Wind category. Referring to the classification of wind storms from research by [22] which is taken from the NOAA SSHWS classification (Saffir-Simpson Hurricane Wind Scale), the highest wind speed as long as the observations were read by the system, it fell into the normal category because it was less than 40 knots (1 knot equals to 0.514 m/s).

**Table 2.** The classification of wind storms

| Wind Storm Category       | Sustained Surface Wind Speed (knots) |
|--------------------------|--------------------------------------|
| Normal                   | <40                                  |
| Major Storm              | 40-57                                |
| Tropical Storm           | 57-65                                |
| Category 1 Hurricane     | 65-83                                |
| Category 2 Hurricane     | 83-96                                |
| Category 3 Hurricane     | > 96                                 |
From the wind speed values obtained, the system will convert the value into wind energy. The maximum wind energy value at the time of recording was January 19, 2021 with a wind energy value of 2472.41 Watt/m². Meanwhile, the average wind energy during the 12 days of recording was 116.74 Watt/m².

Based on the correlation between the wind data recorded by BMKG and the observation of the storm detection system, the correlation value for the average wind speed is 0.775 or 77.5% and for the maximum wind speed is 0.677 or 67.7%. Based on this correlation, it can be seen that the storm observation system design has very good accuracy with quite a striking difference in the maximum wind speed value. Based on the correlation results, it is known that the relationship between the average wind speed has a strong correlation and the relationship between the maximum wind speed has a moderate correlation. Based on the correlation in research conducted by [23]. This correlation indicates normal wind speed and storm surge potential based on the Beaufort scale standardization and the NOAA SSHWS classification (Saffir-Simpson Hurricane Wind Scale) on Table 2. However, the mean value has a pattern that almost resembles the observational data from BMKG, so that for daily wind speed decision making, the resulting data can be used as a reference in research using wind speed parameters as well as for general information.

4.4 Wave Condition in Timbulsloko

Figure 13. Wind energy in Demak 12-23 January 2021

Figure 14. Significant wave height in Timbulsloko, Demak 12-23 January 2021
Based on wind data processing for wave data forecasting with the method found by [14], two main parameters are obtained, namely significant wave height and significant wave period. From the two data, it can also be seen the parameters of the resulting wave energy. The results of forecasting significant wave height from wind speed data have the same pattern as the daily pattern of wind speed, so it is known that the significant wave height and maximum significant wave period are 2.71 m and 7.44 seconds. Meanwhile, the mean value of 12 days of observation for significant wave height and significant wave period is 0.46 m and 3.86 seconds. Then for the maximum wave energy that occurs during the observation is 9197.45 J/m² and for the average value is 493.9 J/m². Based on research conducted by [19], in January 2015 it was found that the maximum wave height in the Timbulsloko, Demak area was 2.73 m with a wave period of 6.13 seconds. When compared with the data from the research results, it can be seen that the results of the recording of the storm detection system made have very good accuracy for forecasting wave height from wind data.

**Table 3.** The comparison of data between BMKG observation data and observational data system for significant wave period and significant wave height

| Date | Daily Significant Wave Period (s) | Daily Significant Wave Height (m) |
|------|----------------------------------|----------------------------------|
|      | Max In Situ  | Min In Situ  | Average In Situ  | Max In Situ  | Min In Situ  | Average In Situ  |
| 12   | 6.27          | 2.89          | 3.58637227      | 1.72          | 0.01          | 0.41275608      |
| 13   | 6.18          | 2.89          | 3.63225131      | 1.66          | 0.01          | 0.35220202      |
| 14   | 5.42          | 2.89          | 3.42835694      | 1.14          | 0.01          | 0.257329763     |
| 15   | 5.34          | 2.89          | 3.62111926      | 1.09          | 0.01          | 0.371594203     |
| 16   | 4.41          | 2.89          | 3.17829387      | 0.58          | 0.01          | 0.125012723     |
| 17   | 6.62          | 2.89          | 3.80443318      | 2             | 0.01          | 0.461635359     |
Significant wave height data and significant wave period have the same correlation with the height and wave period data from BMKG which is the result of forecasting from wind data using the same method. This means that if compared with BMKG data, the correlation results will not be much different from the correlation results between the wind speed data of this coastal storm detection system and the results of BMKG observations. After correlation for the significant wave period, it is known that the correlation value for the maximum significant wave period is 0.676 or 67.6%, while for the significant wave period the average value is 0.746 or 74.6%. Then for the maximum significant wave height has a correlation value of 0.687 or 68.7% and for the mean significant wave height has a correlation value of 0.743 or 74.3%. Based on the results of this correlation, the coastal storm detection system has very good data quality from the results of forecasting heights and significant wave periods. In addition, forecasting high data and significant wave periods only requires one empirical equation that does not take up much memory on the microcontroller, so that forecasting height data and wave periods through wind data will be faster and more accurate and a short process in the microcontroller.

**Figure 16.** Daily significant wave period in situ vs BMKG significant wave period prediction in Demak 12-23 January 2021
Based on data comparison and correlation between storm detection system recording data and BMKG forecasting data, it is known that the maximum value has a fairly high range of differences, but still has a reasonable correlation because the correlation value is above 50%. Meanwhile, the daily mean value obtained has a low range of differences, a high enough correlation, and shows almost the same pattern, so that the results of the wave height and significant wave period resulting from the forecasting system can be trusted. Similar to the result of wind speed data, this data on height and significant wave periods can be used as a reference for oceanographic meteorological information for mitigating storm surge disasters in coastal areas. In addition, the resulting wave data is significant wave height and period data, meaning that this data can be used in other planning related to coastal engineering to protect coastal areas from destructive waves. If we compare with the previous research conducted by [24], our research has the empirical analysis about the data conversion. We also use Beaufort standardization to classify the wind speed. We can gather the coastal storm information and wave forecast along the coast just by using one sensor, which is an Anemometer.

5. Conclusion
The coast is an area that is very prone to hydrometeorological disasters such as storm surges, so it is very important to create a technology that can detect coastal storms as early as possible and integrate public information that can be accessed freely. This coastal storm detection system can record wind speed data very well and is sensitive to anomalies that occur, this is evidenced by data comparisons in other studies and correlation with local agencies such as BMKG. The compatibility and correlation of this data can be shown based on the pattern of wind speed, significant wave height, and significant wave period for 12 days as well as tropical depression recorded on January 19, 2021 with a maximum speed of 15.61 m/s. Based on these results, this coastal storm detection system is able to solve the problems raised and can become a reference for coastal storm warning information for the public. This coastal storm detection system has the potential to be further developed by adding other storm wave parameters such as air pressure, air temperature, and so on. In addition, other developments such as the interface that is displayed are more accessible and easier to understand.

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