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WAVE-GENERATED FORECAST IN WEDA BAY, CENTRAL HALMAHERA, BASED ON WIND AND SATELLITE DATA

Jesikha Dwi Aprilia[1], Mohammad Ridwan Lessy[1]*, Nani Nagu[2]

[1]Marine Science Department, Fisheries and Marine Science Faculty, Universitas Khairun
[2]Civil Engineering Department, Engineering Faculty, Universitas Khairun
Jalan Jusuf Abdulrahman, Kelurahan Gambesi, Kota Ternate 97718

*Corresponding author email: mrlessy8375@gmail.com

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ABSTRACT

Ocean waves are an important oceanographic parameter to analyse due to their role in ocean circulation, marine transportation, and coastal management. This research focused on forecasting the height and duration of significant waves in the Weda Bay, utilizing wind data from meteorological stations and altimetry satellite data. The data utilized comprised maximum wind speed and direction records spanning ten years, from 2011 to 2021, collected from two meteorological stations: Baabullah Station in Ternate and Gamar Malamo in Galela. Simultaneously, AVISIO Altimetry satellite data is retrieved from a website that aligns with the temporal measurement range of meteorological station data. The analysis phase initiates with wind speed correction, effective fetch calculation, and high and periodic wave forecasting utilizing Excel software, while satellite data is examined using ArcGIS software. The prediction results for wave height and period indicate that data from the Baabullah station show a significant wave height ranging from 0.00 to 2.33 meters and a significant wave period from 0.09 to 5.07 seconds. In contrast, data from the Gamar Malamo station reveal a significant wave height ranging from 0.02 to 4.28 meters and a significant wave period from 0.20 to 6.85 seconds. The study indicates that BMKG and satellite data produce consistent wave height calculations

Keywords: *Wave Forecasting, Sea Waves, Weda Bay, Altimetry Satellite*

INTRODUCTION

Weda Bay, a semi-open bay in Central Halmahera Regency, features highly promising natural resources, including both renewable resources such as mangroves, coral reefs, seagrass, and fisheries, as well as non-renewable resources like minerals and mining materials (Djamhur *et al.,* 2014). Furthermore, the waters of Weda Bay are crucial as a shipping route for inter-island and inter-regional passenger ships, as well as vessels transporting mining materials. Traditional fishermen also utilize Weda Bay for fishing. Therefore, information on Weda Bay's oceanographic conditions, including wave height, is crucial for transportation safety and coastal management.

Waves are a dynamic oceanographic phenomenon in the ocean. Ocean waves can be categorized into two main types based on their formation process: wind-generated waves and tidal waves. However, wind is the primary factor in ocean wave formation, making them the most dominant form of waves occurring on the ocean surface, both in terms of their frequency and the energy generated by wind (Triatmojo, 2021). Waves themselves represent the mechanism of energy transfer between particles, characterized by the continuous movement of energy from one location to another. The waves will propagate in the direction of the wind's movement, transporting a specific quantity of water mass. Ultimately, it will reach the coastal region as breaking waves.

Wind data has been extensively utilized by researchers for predicting wave heights. This includes studies on the dynamics of Praikalogu beach in West Nusa Tenggara Province, forecasting coastal wave occurrences in Watunohu coastal area through empirical wind data analysis, and analysing sea wave height forecasting using *the Gumbel Fisher Tippet type 1* method, as demonstrated in a case study in Baai Island, Bengkulu (Lubis & Khoirunnisa,

2016; Purwono & Sismiani, 2018; Supiyati, 2008).

Although research on wind-driven wave generation has been extensively conducted, this study offers novelty because it uses a combination of wind data from BMKG stations and satellite altimetry data in a comparative manner. This is to compare manual forecast results with satellite data analysis. According to Richard & Handoko (2020), Satellite altimetry data is currently used to measure sea surface temperature and geostrophic currents; however, it can also be further developed to investigate wave generation.

This study aims to predict wave heights and periods in the Weda Bay using wind data from the nearest meteorological stations and altimetry satellite data. The analysis results will demonstrate the spatial and temporal relationship between wind speed and wave height. The findings will provide significant theoretical and methodological contributions regarding the use of manual and satellite data for wave height forecasting and will contribute to policy advice for local governments and all stakeholders in regulating shipping lanes and coastal development projects in Weda Bay.

MATERIALS AND METHODS

Data collection

This research was conducted in March 2022 in Weda Bay, Central Halmahera Regency. (**Figure 1**). The online dataset comprises maximum wind speed and direction records spanning ten years (2011 to 2021). Wind data from the past ten years can be employed to analyse wave heights at that time as well as to forecast wave heights for a period of up to 100 years (Azhari *et al.,* 2022; Purwanto *et al.,* 2020). The wind data downloaded from the Meteorology and Geophysical Climatology Agency (BMKG) website www.dataonline.bmkg.go.id and wave height from the AVISO altimetry satellite website https://www.aviso.altimetry.fr/en/home.html. Online BMKG data was collected from Baabullah station in Ternate and Gamar Malamo station in Galela; meanwhile, the satellite data downloaded is aligned with the corresponding data period, date, and month from online BMKG data. The data were categorized by season: West Season (December-February), Transitional Season I (March-May), East Season (June-August), and Transitional Season II (September-November) (Purwanto *et al.,* 2020).

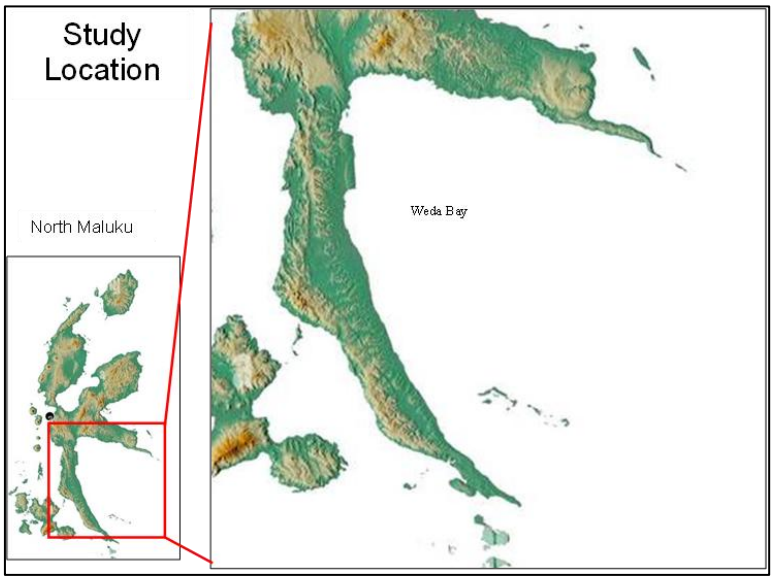


Figure 1. Study Area

Data analysis

This study employed various calculations to determine the height and duration of the waves. The process initiates with the identification of the dominant wind direction through the utilization of WRPLOT 8.0.2 software. Subsequently, wind speed is determined at a designated altitude. The wind data used as input consists of daily maximum wind measurements, which are employed to evaluate wave height and duration. Wind data measurement takes place at altitudes above 10 meters; thus, it is essential to convert this data to accurately represent wind speeds at sea level. The wind conversion calculation uses the following equations: (Supiyati, 2008) ;(Wakkary *et al.,* 2017); (Gusuru *et al.,* 2024).

$$U_{10} = U_z \left(\frac{10}{z}\right)^{\frac{1}{7}} \quad (1)$$

Where, U_{10} is wind speed at an altitude of 10 m; z is wind measurement height.

Subsequently, the result of wind data conversion was employed to determine the stability correction value (*U*) and the wind stress factor (U_A). The stability correction is designed to address the impact of variations in air and sea temperatures. This study did not measure air or sea temperatures; therefore, the R_T value was assumed to be 1.13 (Paruba *et al.,* 2016). Thus, *U* and U_A were calculated using the specified formula: (Parauba *et al.,* 2016); (Satriadi, 2017).

$$U = R_T . R_L . U_{10} \quad (2)$$

$$U_A = 0.71 . U^{1.23} \quad (3)$$

Furthermore, we calculate the effective length of wind retrieval (fetch), which is determined by calculating the effective distance of the wind that generates waves on the sea surface. The Sverdrup, Munk, and Bretschneider (SMB) methods are employed to ascertain effective fetch lengths. The data input consists of the dominant wind direction, which acts as the central axis for a line that stretches roughly 42 degrees to either side, with increments of 6 degrees. Next, the effective fetch was determined by the following equation (Satriadi, 2017); (Gusuru *et al.,* 2024):

$$F_{eff} = \frac{\Sigma Xi \cos \alpha}{\Sigma \cos \alpha} \quad (4)$$

Where, F_{eff} *is Effective Fetch;* Xi is the length of the pickup segment is measured from the observation point of the wave to the end of the pickup; *α* is deviation on both sides of the wind direction, using an increment of 6º to 42º on both sides of the wind direction

The next calculation is the forecasting of wave height significance (*Hs*) and wave period significance (*Ts*) in shallow waters. This calculation is based on Wilson's method (Ukkas, 2009).

$$\frac{gH_s}{U_A^2} = 0.3 \left[1 - \left\{1 + 0.004 \left(\frac{gF_{eff}}{U_A^2}\right)^{1/2}\right\}^{-2}\right] \quad (5)$$

$$\frac{gTs}{2\pi U_A} = 1.37 \left[1 - \left\{1 + 0.008 \left(\frac{gF_{eff}}{U_A^2}\right)^{1/3}\right\}^{-5}\right] \quad (6)$$

Where, *Hs* is significant wavelength (m); *Ts* is significant wave period (seconds); U_A is wind pressure factor (m/sec); F_{eff} is Effective Fetch (m); *g* is earth's gravity (m/sec) = 9.8 m/sec; *π* = 3.14

Further, to examine the relationship between wind speed and wave height, a simple linear regression statistical test was conducted using the equation:

$$Y = \alpha + \beta x \quad (7)$$

Where, *Y* is wave height data; *x* is wind speed; *α* is Intercept; *β* is Slope

Additionally, to validate the manually analysed wave height calculations, a comparison was conducted between wave heights derived from BMKG wind data and those obtained from AVIOS altimetry satellite data. The satellite data collected is wave height forecast data for the period 2011-2021. Then all the data will be visualized based on the season, employing ArcGIS Software 10.8.1 to demonstrate the significant wavelength.

RESULTS AND DISCUSSION

Distribution of Wind Speed and Direction at Baabullah and Gamar Malamo Station.

The analysis of maximum wind speed data from 2011 to 2021 at the Baabullah Ternate station indicates that during the West Season (WS), the predominant maximum wind speed is between 8-11 m/sec, accounting for 46.7% of occurrences, followed by a speed range of 5-8 m/s at 26.7%. The predominant wind direction during this Western Season is from the Northwest. In Transitional Season I (TS1), the frequency of maximum wind speeds is predominantly characterized by speeds of 8-11 m/s (40%) and 5-8 m/sec (33.3%), with speeds exceeding 11 m/s accounting for 23.3%. The wind movement in TS1continues to be predominantly from the Northwest. Additionally, during the East Season (ES), wind speed data from this station indicates that the maximum wind speed closely resembles that of TS1, with wind speeds of 8-11 m/sec occurring at 40%, speeds of 5-8 m/sec at 36.7%, and speeds exceeding 11 m/sec at 20%. Nonetheless, the distinction between these two missions lies in the fact that wind direction during the East Season (ES) is primarily influenced by winds originating from the South and Southwest. The Transitional Season II (TS2) indicates that the percentage of wind speeds ranging from 5 to 8 m/sec is 60%, while speeds exceeding 11 m/sec account for 23.2%. Wind movement is predominantly directed from the North. The analysis results of wind speed distribution and wind direction from the Baabullah Ternate station are illustrated in **Figures 2** and **3**.

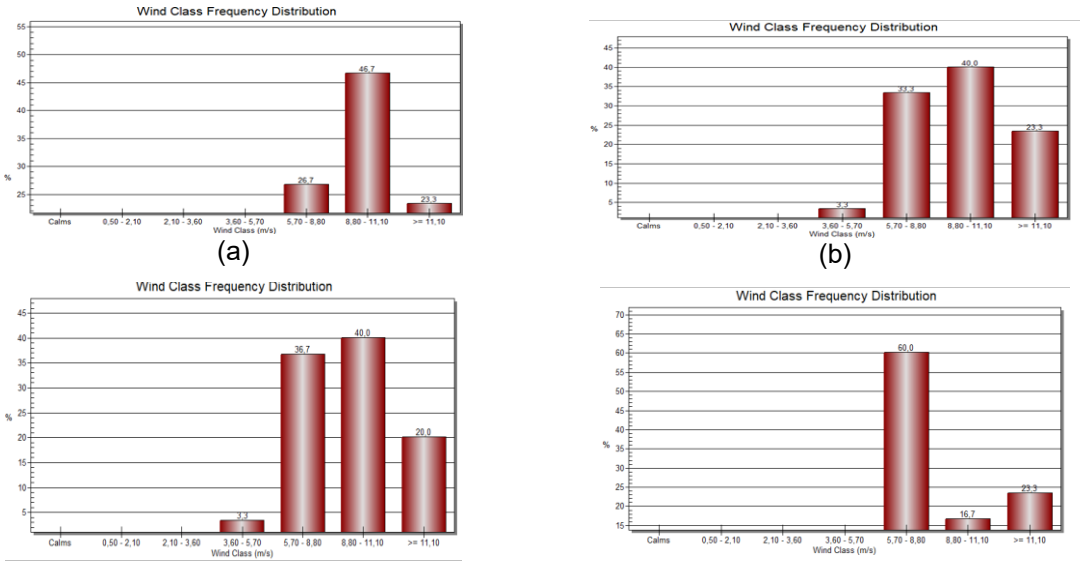


Figure 2. Maximum wind speed distribution in the WS (a), TS1 (b), ES (c), and TS2 (d) from Baabullah Station data

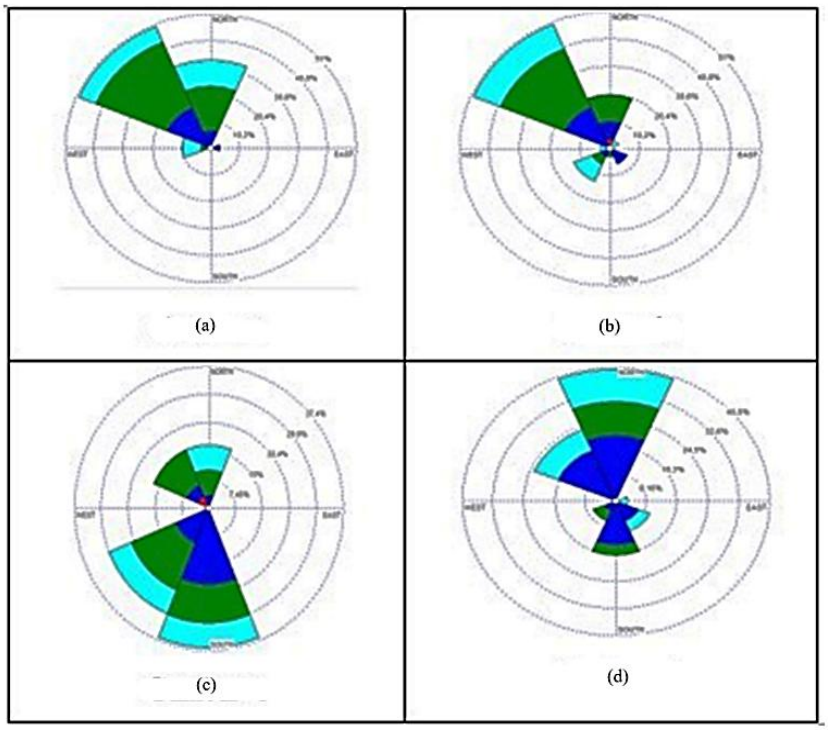


Figure 3. Maximum wind direction distribution in the WS (a), TS1 (b), ES (c), and TS2 (d) from Baabullah Station data

Furthermore, the analysis of maximum wind speed data at Gamar Malamo Station from 2011 to 2021 indicates that during the West Season (WS), wind speeds exceeding 11 m/s account for 90% of occurrences, with the prevailing direction from the North. During Transitional Season I (TS1), maximum wind speeds exhibited variability, with speeds exceeding 11 m/sec accounting for 30% of occurrences, followed by speeds in the ranges of 3-5 m/sec and 5-8 m/sec, each representing 26.7% of the total. In contrast, the prevailing direction of wind gusts on TS1 is more pronounced than that from the West. The predominant wind speed during the East Season ranges from 5 to 8 m/s, accounting for 53.3% of observations, with prevailing directions from the West and Southwest. The Transitional Season II (TS2) indicates a wind speed percentage of 5-8 m/sec at 56.7%, with

the prevailing direction of movement originating from the West and Southwest. **Figures 4** and **5** present the results of the analysis regarding the distribution of wind speed and wind direction from the Gamar Malamo station.

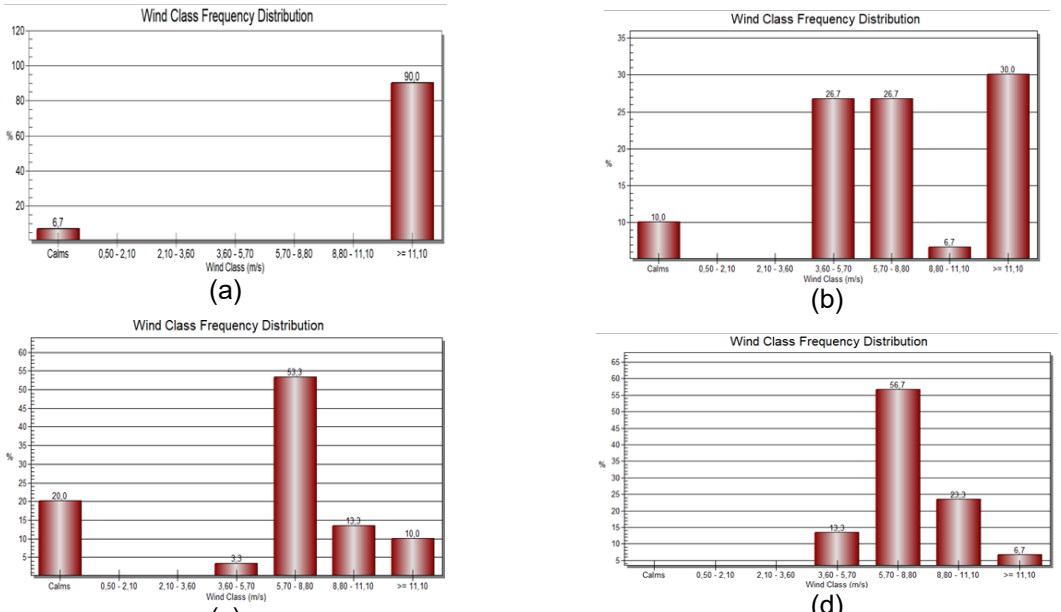


Figure 4. Maximum wind speed distribution in the WS (a), TS1 (b), ES (c), and TS2 (d) from Gamar Malamo Station data

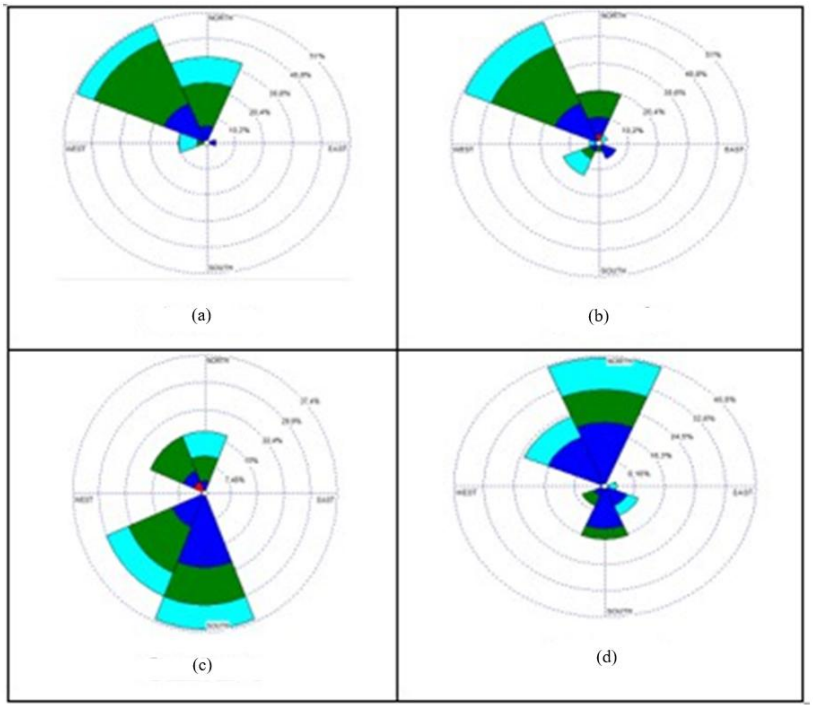


Figure 5. Maximum wind direction distribution in the WS (a), TS1 (b), ES (c), and TS2 (d) from Gamar Malamo Station data

Significant Height (*Hs*) and Wave Period (*Ts*) in the Weda Bay

The calculation results for the correction of wind speed at a height of ten meters indicated that the average maximum wind speed at the surface, based on data from Baabullah station in Ternate, ranged from 8.35 to 9.25 m/sec, with the peak speed occurring during TS2. The calculation results for the effective fetch at Baabullah station indicate 0.46 km for the WS and TS1, and 22.57 km for the ES and TS2 (**Table 1**).

Table 1. Results of wind speed correction calculation at Baabullah Station

Baabullah Station	Effective Fetch (km)	*U10* (m/sec)			*U* (m/sec)			U_A (m/sec)		
		Min	Max	Average	Min	Max	Average	Min	Max	Average
WS	0,46	5,90	22,77	9,11	6,49	25,04	9,65	7,09	37,29	12,31
TS1	0,46	4,22	34,57	9,19	4,64	38,03	10,04	4,69	62,34	12,69
ES	22,57	4,22	22,77	8,35	4,64	25,04	9,18	4,69	37,29	11,12
TS2	22,57	5,06	22,77	9,25	5,57	23,19	9,62	5,86	33,93	11,79

The analysis of the average maximum wind speed at the Gamar Malamo station in Galela indicates that the maximum wind speed varies between 6.61 and 9.06 m/sec, with the highest average occurring during TS1. The calculation results for the effective fetch at Gamar Malamo station indicate 82.90 km for the Western Season, while the fetch distance for the other three seasons is 40.26 km (**Table 2**). The variation in fetch distance at Baabullah station and Gamar Malamo station is significantly influenced by the geographical positioning of these stations, which is affected by the land processing of Halmahera Island and prevailing wind directions. Halmahera Island's position, extending from the east to the south of Ternate Island, obstructs the wind from the West. Accordingly, the geographical conditions of the observation location and the obstacles to wind flow, such as land or surrounding islands, significantly influence the direction and speed of wind movement (Lessy & Abdullah, 2021; Purwanto *et al.,* 2020).

Table 2. Results of wind speed correction calculations at Gamar Malamo Station

Gamar Malamo Station	Effective Fetch (km)	*U10* (m/sec)			*U* (m/sec)			U_A (m/sec)		
		Min	Max	Average	Min	Max	Average	Min	Max	Average
WS	82,90	3,47	14,57	6,61	3,47	16,01	7,13	3,68	21,52	8,39
TS1	40,26	3,47	38,13	9,06	3,47	41,94	9,95	3,68	70,32	12,91
ES	40,26	3,47	13,17	6,98	3,81	14,49	7,55	3,68	19,02	8,75
TS2	40,26	3,47	31,91	6,40	3,81	34,31	7,04	3,68	54,95	8,31

The analysis of wind speed correction and effective fetch shows that the significant wave height in the Weda Bay can range from 0.00 to 2.33 meters, and the significant wave period can range from 0.09 to 5.07 seconds. The average height of the largest wave is 0.83 meters, and the average time of the biggest wave is 3.05 seconds, which occurs in TS2 (**Table 3**). Meanwhile, the findings of the calculation of the height and wave duration from the Gamar Malamo station data suggest that the significant wave height in the Weda Bay can be anywhere from 0.02 to 4.28 meters and the relevant wave period can be anywhere from 0.20 to 6.85 seconds. The average height of the largest wave is 1.09 meters, and the average time of the biggest wave is 3.27 seconds. This occurs in TS1 (**Table 4**).

Table 3. Calculation of the height and wave period in the Weda Bay from Baabullah Station

Baabullah Station	*Hs* (m)			*Ts* (det)		
	Min	Max	Average	Min	Max	Average
WS	0,00	0,63	0,16	0,11	1,57	1,04
TS1	0,00	0,12	0,01	0,09	1,26	0,42
ES	0,00	2,33	0,74	2,12	5,07	2,97
TS2	0,37	2,14	0,83	2,37	4,90	3,05

Table 4. Calculation of height and wave period in Weda Bay from Gamar Malamo Station

Gamar Malamo Station	*Hs* (m)			*Ts* (det)		
	Min	Max	Average	Min	Max	Average
WS	0,02	1,67	0,18	0,20	4,79	2,22
TS1	0,24	3,33	1,09	2,07	5,47	3,27
ES	0,24	1,57	0,68	2,07	4,55	2,88
TS2	0,24	4,28	0,63	2,07	6,85	2,82

Wave Height in the Weda Bay Based on AVISO Altimetry Data

The analysis of altimetry satellite data, processed using interpolation methods in ArcGIS software, revealed significant seasonal variability in wave heights within the Weda Bay (**Figure 6**). During the WS, interpolation results indicate that wave heights in the southern part of Weda Bay, including the East Gane region, range from 1.12 to 1.25 meters. In contrast, the northern part of Weda Bay, encompassing the Weda area to the Patani area, exhibits wave heights ranging from 1.25 to 1.39 meters.

Regarding TS1, the wave height is observed to be lower than that of the WS, measuring between 0.87 and 0.97 meters, which encompasses most of the Weda Bay area. In the ES, satellite data analysis indicates that wave heights across all areas of Weda Bay range from 0.52 to 0.67 meters, reflecting a lower wave height. Conversely, in TS2, the wave rise in the Weda Bay region increased, with wave heights in the southern part of the Eastern Gane region ranging from 0.98 to 1.30 meters. In the Weda area to the Patani area, the wave height ranges from 1.30 to 1.65 meters.

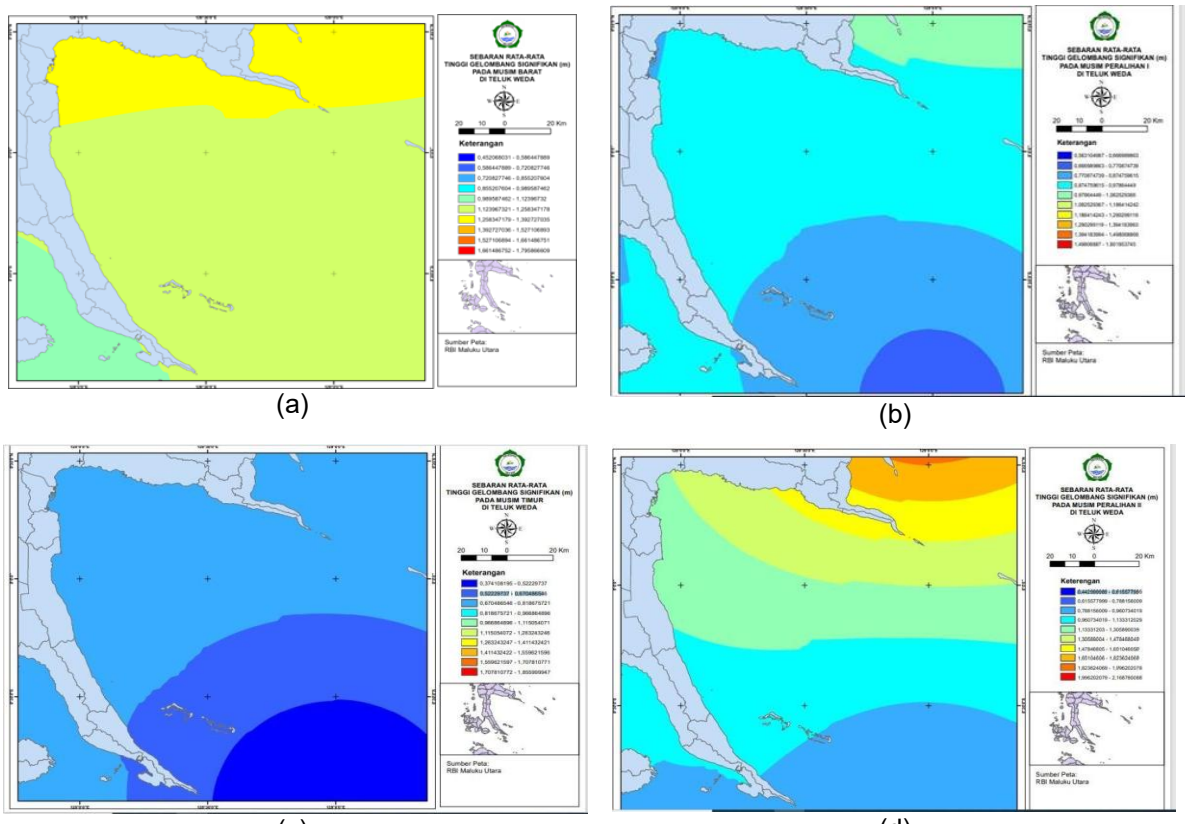


Figure 6. Wave height based on satellite data on the WS (a), TS1 (b), ES (c), and TS2 (d) in Weda Bay

The wavelength analysis results demonstrate that the wave height calculations, utilizing both wind data from the BMKG measurement station and satellite data, yield consistent findings. The highest significant wave height in the Weda Bay is observed during TS2, spanning September to November, and during the WS, from December to February. These results suggest important considerations for navigational safety information, highlighting the need for all vessels to exercise caution during months with high wave activity.

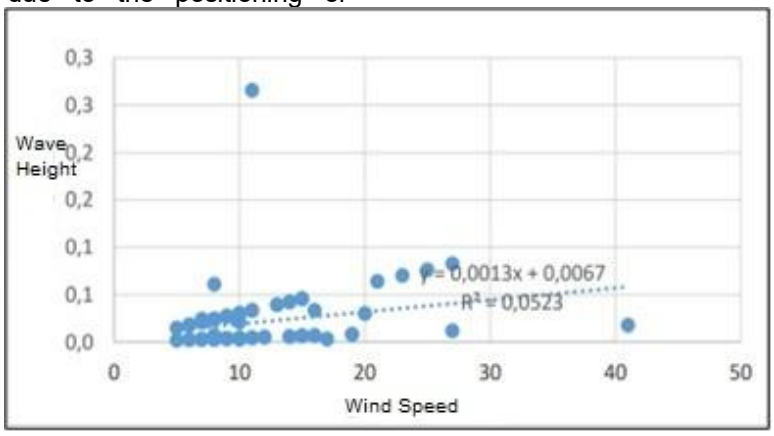
The findings of this study differ somewhat from those of other research conducted in Indonesian waters, where elevated wave activity typically occurs during the WS (**Table 5**). The consistent winds during the WS in Indonesia lead to an increase in sea wave activity in the region. Conversely, in TS1 and TS2, a decrease in wind speed occurs, resulting from the wave height generated. This exception may arise from the semi-closed geographical position of the Weda Bay (Kurniawan *et al.,* 2011).

Table 5. Average height and wave period each season in some Indonesian waters

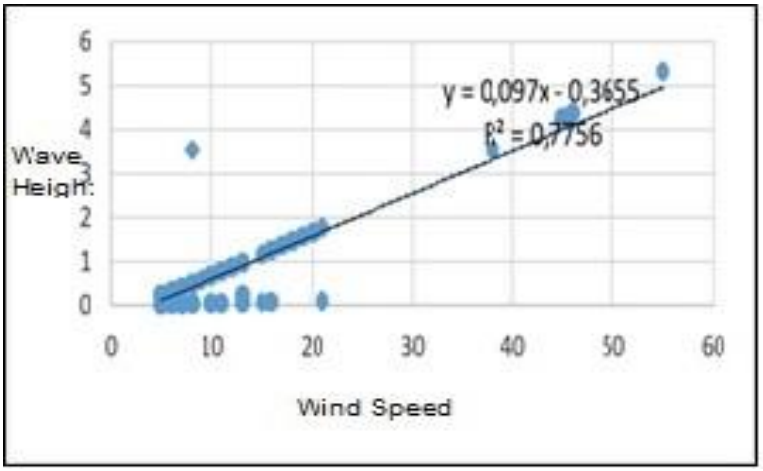
Hs (m)				*Ts (m)*				Research Location	Reference
WS	MP1	ES	MP2	WS	MP1	ES	MP2		
1,61	0,80	1,40	1,33	5,62	3,81	4,63	4,55	Lirang Island, Southwest Maluku Regency	Purwanto et al., (2020)
1,23	1,10	0,63	0,58	5,18	4,85	3,56	3,40	Semarang Waters	Satriadi, (2017)
0,15	0,11	0,11	0,12	1,61	1,37	1,39	1,59	Tanjung Kalian, West Bangka Regency	Azizi, M. I., Hariyadi, Atmodjo (2017)
1,01	0,83	0,55	0,66	5,21	4,90	4,36	4,59	Timbulsloko Waters, Demak Regency	Astuti et al., (2016)
1,80	1,38	1,06	0,99	5,77	5,11	4,08	4,01	Western waters of Ternate Island	Lessy & Abdullah, (2021)
0.16	0.01	0.74	0.83	1.04	0.42	2.97	3.05	The waters of Weda Bay	This research

Correlation of Significant Wind Speed and Wave Height

The simple linear regression analysis conducted on wind speed data and wave generation from Baabullah Station yields the equation Y = 0.0013x + 0.0067, accompanied by a R Square value of 0.0523, indicating 0.5% variance explained. This suggests that while a positive correlation exists between wind speed and wave height at the monitored stations, its impact on wave height formation in the Weda Bay Basin is minimal (**Figure 7a**). The condition arose due to the positioning of Baabullah station in Ternate Island, which was significantly hindered by Halmahera Island, affecting the wind movement patterns in Weda Bay. Meanwhile, the relationship between wind speed and wave height from the Gamar Malamo station yielded the equation Y = 0.097x + 0.3655, with a R Square value of 0.7757, indicating a 77% correlation. The results demonstrate a 77% positive correlation between the wind speed measured at the Gamar Malamo station and the occurrence of significant wave formation in the Weda Bay (**Figure 7b**).



(a)



(b)

Figure 7. The correlation of wind speed (m/s) and wave height (m) from Baabullah station (a) and Gamar Malamo Station (b)

CONCLUSION SUGGESTION

The study concluded that wind data from meteorological stations can predict wave height and periods in water bodies. Data utilized must originate from the nearest meteorological station to the waters under investigation. Furthermore, the application of satellite technology in the study of oceanographic phenomena is advancing, including altimetry satellites that supply data for spatial and temporal analyses of sea surface conditions. Most importantly, the combination of BMKG data and altimetry satellites provides consistent wave analysis results. The analysis of the relationship between wind speed and wave height has yielded data that can be utilized to estimate wave elevation at specific times based on wind speed movement in Weda Bay. This study offers valuable insights that can enhance shipping safety, reduce abrasion, and inform coastal development planning. Further studies are necessary regarding wave transformation and refraction in the coastal zone of Weda Bay.

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