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Utilization of Measurement Technology in Analyzing Tidal Flooding Run Up Along Semidang Alas Maras Coast

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A B S T R A C T

Tidal floods in the Semidang Alas Maras coast often occur and disrupt community activities. The height and area affected by tidal flood run-up is not the same every time. This research are to identify the factors that influence tidal floods and determine the effect of seasonal changes on tidal flooding run-up along Semidang Alas Maras coast by utilising measurement technology using drones. The method in this research is direct measurements of tides, visual photos topographic using drones, and also secondary data including tidal data from TMD model, rainfall, and wind data during tidal flooding. Based on the results of the study, it was found that tidal flooding run-up along Semidang Alas Maras coast was influenced by tides, high rainfall and wind. The mixed tide type of Semidang Alas Maras is Mixed Tide Prevailing Semidiurnal with a Formzhal number of 0.76. The area affected by the tidal flood run-up for the criteria of no danger and less danger every season is the same. Meanwhile, the criteria for moderately dangerous, dangerous and very dangerous vary every season. The highest area value occurring in the western season, the criteria for moderately dangerous 20% with an area of 83.06 Ha, 21% hazard with an area of 85.78 Ha, and very dangerous 23% with area of 93.95 Ha

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INTRODUCTION

One of the effects of global warming, specifically the rise in sea level as a result of the melting of the polar ice caps, also affects Indonesia, which is a country with a tropical climate (Barnard et al., 2019; Iskandar et al., 2020; Taherkhani et al., 2020). This is one of the repercussions of global warming that affects Indonesia. The rise in sea level is one of the factors that might contribute to tidal flooding, also known as flooding caused by tides . The severity of the tidal flooding that occurs will increase if other factors, such as heavy rainfall or flood inputs from upstream, are present (Putra et al., 2023; Aldardasawi & Eren, 2021; Mohantry et al, 2020).

Because Bengkulu Province is located on the coast and faces the Indian Ocean directly, there is the possibility of tidal flooding occurring there. A tidal flood is an overabundance of water on coastal land that takes place when the tide is at its highest point. This calamity has an effect not only on the damage to infrastructure and regional facilities but also on the social and economic communities (Abdrabo et al., 2023; Imam et al., 2022; Aksa & Afrian, 2022; Mind'je et al., 2019; Zhao et al., 2019). It has an effect on the lives of individuals who reside in coastal areas. The coastal region of Semidang Alas Maras Beach, which is located within the Seluma Regency of Bengkulu Province, is known for being prone to tidal flooding on a regular basis. A tidal flood that took place on October 29, 2019, caused several local homeowners' homes to sustain damage from sea water and also carried items ashore from the ocean.

According to data provided by the Regional Disaster Management Agency (Regency, 2019), this incident seriously damaged a total of 19 homes in the Muara Maras Village and 11 homes in the Padang Bakung Village. Tidal flooding occurred again on November 7, 2021, causing severe damage to dozens of homes in Semidang Alas Maras (South, 2023). Tidal flooding also occurred on October 1, 2021, which caused homes and oil palm plantations owned by residents to be flooded. Tidal floods can inundate areas of the coastline or places that are lower than the high water mark (Egaputra et al., 2022; Sauda et al., 2019).

However, wind and rainfall can also affect tidal flood events, increasing the height of the tidal flood event. This is especially true when high tides happen during the spring tide, when wind or heavy rain are not always present. Water masses generated by the difference in depth will make their way to the coastline, and this in turn will be affected by the topography of the coast. Waves traveling from deep to shallow water (beach) are subject to wave transformation as a result of the beach's shape, characteristics, and tides (Supiyati et al., 2021, 2022; Supiyati & Ekawita, 2019; Triatmodjo, 2016). According to the information presented above as well as the findings of past studies, a scientific investigation into the factors that contribute to tidal flooding along the coast of Semidang Alas Maras in Seluma Regency has not been carried out. On the shore of Semidang Alas Maras, there has been no research conducted on the factors that influence tidal flooding, noro has there been any mapping of the area that is subject to tidal flooding run-up. Because the tides are regarded as one of the elements that cause tidal flooding on the coast of Semidang Alas Maras, the only tidal studies that have been carried out in this region so far are based solely on forecast data and not on direct measurements taken in the field. As a result, the types of tides that occur are unknown, which is unfortunate given that tides are one of the factors that cause tidal flooding.

Moreover, despite the fact that seasonal changes have a substantial impact on coastal conditions, several of the existing studies on Rob flooding in other regions have not evaluated seasonal fluctuations. The bigger the losses, the less we know about the lead-up to tidal floods (Imam et al., 2022; Sauda et al., 2019), (Philip R. Thompson et al., 2019; Thompson, P. R., Widlansky, M. Hamlington et al., n.d.). So, it's important to study the rise of tidal floods on the coast of Semidang Alas Maras by looking at the effect of seasonal changes (Brunner et al., 2021), and mapping the rise of tidal floods based on measurement data using GPS (Global Positioning System) and aerial photo visualization using drones. This will help reduce flood risks and losses. Efficient flood vulnerability mapping can reduce hazard risk and serve as a key approaches in flood risk management (Andaryani et al., 2021).

Tidal Floods

Tidal floods are inundations of water on the coastal land that occur during high tide. Tidal floods are a threat, because they have an impact on the lives of people living in coastal areas, not only affecting damage to infrastructure and regional infrastructure, but also on the social and economic communities (Arrighi et al., 2019; Maharjana et al., 2024). Tidal flooding occurs when high tides occur during spring tide and is not always followed by the influence of wind, or high rainfall. However, on some occasions wind and rainfall also contribute to increase the number of tidal flood events.

One of the areas where tidal flooding often occurs is the coast of Semidang Alas Maras Seluma. Semidang Alas Maras Beach, to the west is directly facing the Indian Ocean, and to the east are residential areas and Jalan Lintas Barat Sumatera (JALINBAR). When tidal flooding occurs, it will disrupt traffic on JALINBAR (Jalan Lintas Barat Sumatera), and will also damage houses and other village infrastructure. Through the utilization of measurement technology and the application of tidal model, as well as secondary data of wind and rainfall, information regarding the seasonal variations' influence on tidal floods, parameters affecting tidal floods, types of tidal patterns, and mapping of tidal flood run-ups along the coast of Semidang Alas Maras Beach is obtained. This can be considered as one of the solutions to address the occurring issues and as a mitigation effort to reduce the risks and minimize the losses caused by tidal flood disasters on the coastal area of Semidang Alas Maras (Imam et al., 2022; Iskandar et al., 2020; Sauda et al., 2019).

LITERATURE REVIEW

Research Area

The place where the research was conducted was on the coast of Semidang Alas Maras, which is in the Seluma Regency of the Bengkulu Province, as can be seen in Fig. 1. This area is physically located at the coordinates 4°20'27 S to 4°20'38 S and 102°4629 E to 102° This area is physically located at the coordinates 4°20'27'' S to 4°20'38'' S and 102°46'29'' E to 102°46'47'' E.

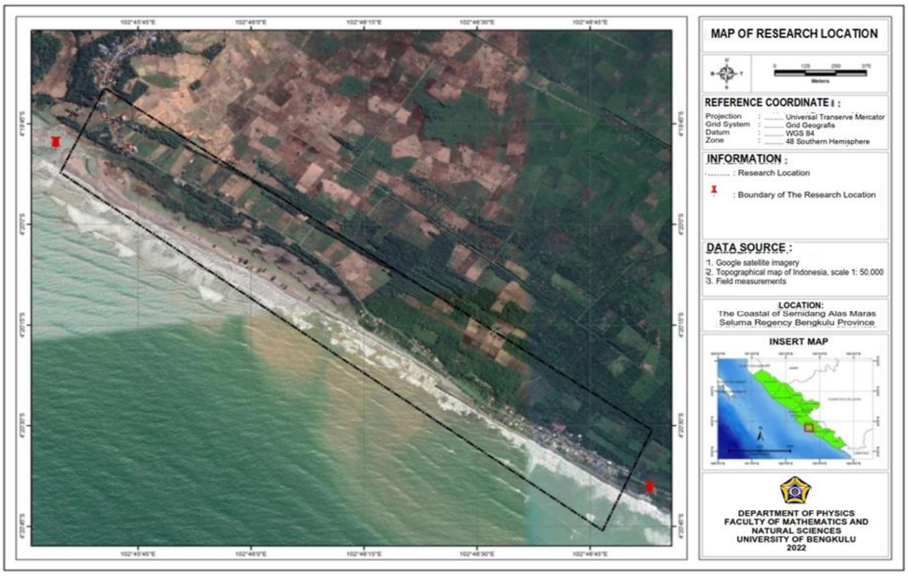

Figure 1. Research Location

Tools and Data

In this study, we be utilizing the instruments and materials: a tide and wave gauge, a drone, GPS, Arcgis 10.3, and WRPLOT. There are two types of data used in this research, namely secondary data and primary data. Secondary data are wind data, rainfall data during October (2019), tides data. Primary data are topography, measurement and observation coordinates, and drone photo visualization.

Data Processing and Analysis

The secondary data, in the form of wind data, is further processed using WRPLOT to generate a windrose diagram. Rainfall data is processed using Microsoft Excel to produce a Time Series graph. Primary data from in-situ measurements, such as topography and flood distance, as well as visual imagery from drones, are processed using Surfer and ArcGIS software to generate flood risk potential maps. Subsequent data processing involves tidal data processing using the Admiralty method and Formzal number calculation based as in (1):

$$F = \frac{(K_1 + O_1)}{(M_2 + S_2)}$$

In this study, the analysis of the results is carried out quantitatively and descriptive. The analysis quantitatively based on the results obtained from each parameter of the measurement and calculation results. The descriptive analysis is reviewed based on the processing results in the form of images such as windrose diagrams, time series graphs, and the results of mapping the potential danger zone of tidal flood run-up.

METHODOLOGY

In this research, the method used is in situ measurement and observation in the field and also analysis using secondary data. In situ measurements were carried out to obtain data as input for mapping the area of the zone affected by tidal flood run-up, namely measurement coordinates and topography using GPS. While the visualization of tidal flood run up is obtained from the results of processing drone photos using surfer and ArcGIS software. Secondary data in the form of wind data, rainfall during October (2019) were taken from the Meteorology Climatology and Geophysics Agency, while tidal data were obtained from the TMD model results. Data processing and analysis were carried out at the Oceanographic Physics Laboratory, Faculty of Mathematics and Natural Sciences, Bengkulu University.

RESULT AND DISCUSSION

The Parameters Influence Tidal Floods

The results of tidal measurements for 15 days (3rd to 17th August 2022) with a time interval of 1 minute in the form of a graph are shown in Figure 2. Based on the observational data, the average MSL (Mean Sea Level) is 0.42 meters, with a maximum water level elevation of 1 meter and a minimum water level elevation of 0.05 meters. The MSL data were obtained from the observational data.

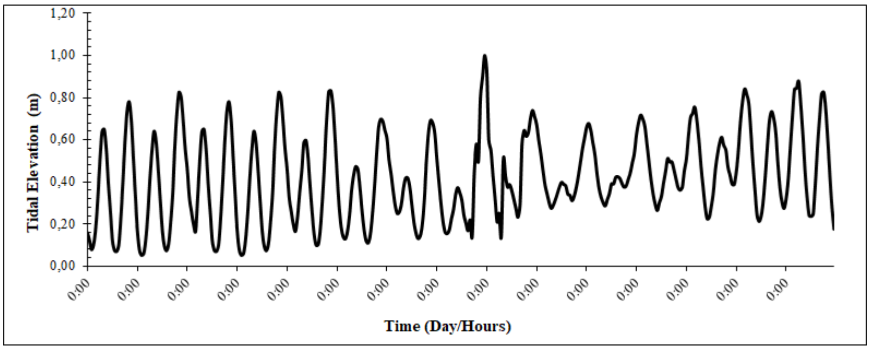

Figure 2. 15-Day Semidang Alas Maras Beach Tide Height Chart (3rd To 17th August 2022)

After being processed using the Admiralty method, the measurement data for 15 days yielded harmonic constant values. These values were composed of the components S0 (the mean water level), M2 (semidiurnal tides influenced by the moon), and S2 (semidiurnal tides influenced by the sun). Components N2 (semidiurnal component), K1 (diurnal tides due to the influence of distance variations due to the elliptical moon trajectory), O1 (diurnal tides influenced by the moon), M4 and MS4 (shallow water) Component O1 (diurnal tides influenced by the moon) Component N2 (semidiurnal component). The value of tidal harmonic constants processed by the Admiralty method at Semidang Alas Maras Beach can be seen in Table 1.

Table 1. Tidal Harmonic Constant Values in the Estuary of Semidang Alas Maras

	S_0	M_2	S_2	N_2	K_1	O_1	M_4	MS_4
A cm	24.5	108.1	71.3	19.2	126.8	8.7	0.9	0.6
g		307.6	215.3	25.1	311.3	61.4	233.3	224.5

The calculation result based on the amplitude values of harmonic components in Table 1 yields a Formzahl number of 0.76. In accordance with the classification of tidal types according to Triatmodjo, Supriadi et al., Ichsari et al., Indrastuti and Chen. Semidang Alas Maras Beach is a mixed tide inclined to double daily (Mixed Tide Prevailing Semi-Diurnal), which means that in one day there is one tide and one low tide, but sometimes for a while there are two tides and two low tides with different heights and periods. Based on tide, rainfall, and wind data, the 26–28 October 2019 tidal flood event was analyzed. Figure 3 displays the 31-day tidal data in a graph, and Fig. 4 displays the October 2019 rainfall data in a graph.

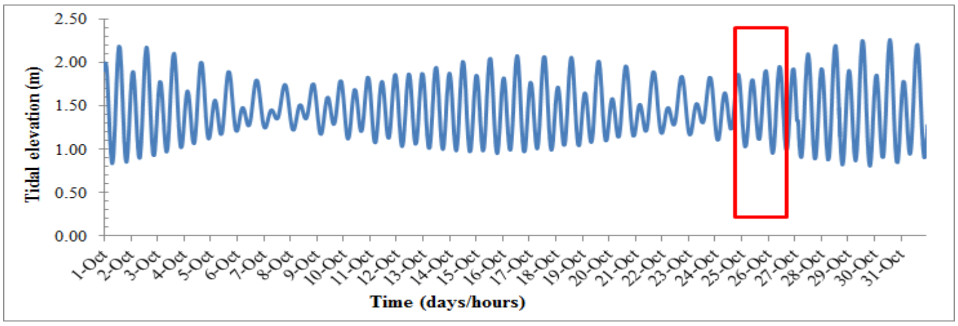

Figure 3. Chart of the Tidal Elevation for October 2019

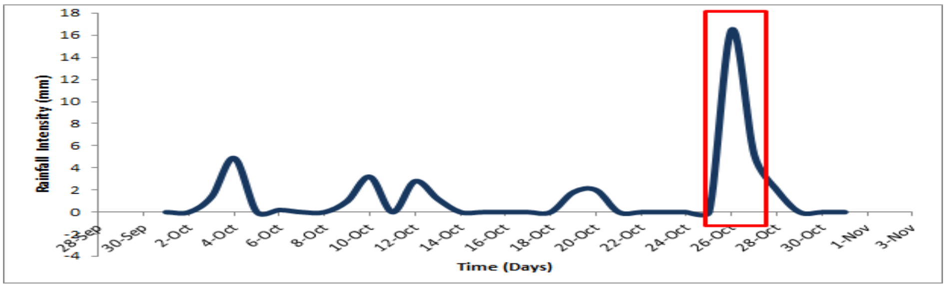

Figure 4. Chart of the Rainfall for October 2019

The maximum elevation value occurs during the full moon tide on October 29, 2019, at 2.3 m and the minimum at 0.7 m, while the highest rainfall intensity in October 2019 occurred on October 26 at 16 mm, marked by a red box. This was preceded by high rainfall of 16.5 mm during the night with a wind speed of 4 knots from the South, as seen in Figure 5. This condition caused a 2 m rise in tide elevation and triggered significant tidal flooding over 3 days, from October 26 to October 28, 2019, along the coast of Semidang Alas Maras Beach.

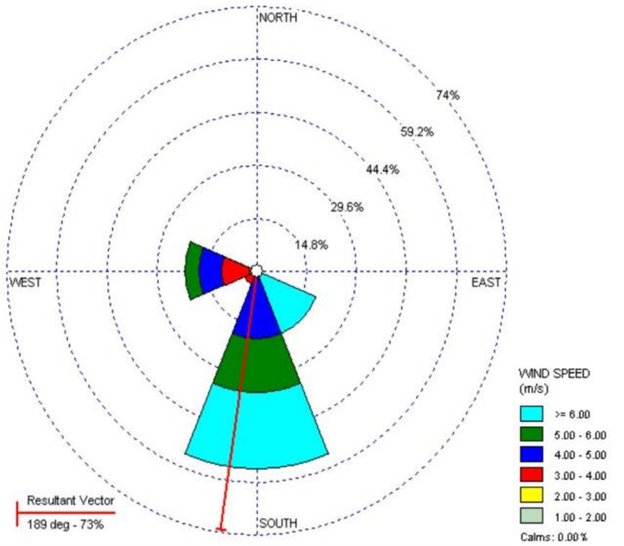

Figure 5. The Windrose Diagram for October 2019

Figure 6 shows a graph of the elevation of the tides, and Fig. 7 shows a graph of the rainfall that resulted from those tides. Together, these two graphs illustrate another tidal flood event that occurred on October 1, 2021. On the basis of Fig. 6, an MSL of 0.47 m was obtained, with the maximum water level occurring on the first of October 2021 at 1.78 m and the lowest water level occurring on the second of that month at 0.22 m.

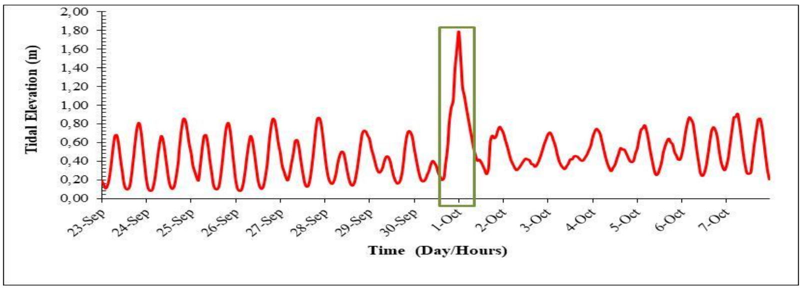

Figure 6. Chart of Tidal Elevation for 15 Days (23 September-7 October 2021) in the Estuary of Semidang Alas Maras

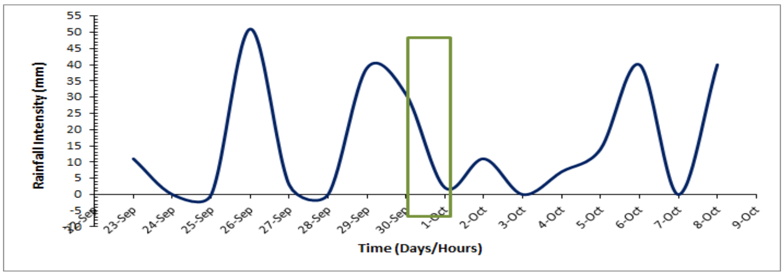

Figure 7. Chart of the Rainfall on September 23 - October 8, 2021

Another tidal flood event took place on October 1, 2021, as shown in the green box in Fig. 6. This time, the maximum tidal elevation was 1.78 m, and it was preceded by heavy rainfall on the night of September 30, totaling 30.9 mm, as well as a wind speed of 5 knots from the northwest. This caused tidal flooding to take place from night to morning. In light of these circumstances, the tidal flooding that took place in the Semidang Alas Maras Coastal Zone was not solely the result of the tides coming in from the ocean; rather, there was also a contribution from significant rainfall both before and during the event that caused the flooding. According to Nurdiawan and Putri, Budiman and Supriadi, the development of tidal floods can be attributed in large part to marine phenomena such as rising sea levels, tides, or external causes such as wind that generate waves. Tidal floods can also be caused by a combination of these and other variables.

Based on the wind direction and wind speed values, as well as the percentage value of wind, plotted in the form of a windrose diagram from September 23 to October 8, 2021, as shown in Figure 8, According to Fig. 8, the predominant wind direction blows from the west, with a minimum wind speed value of 3 knots and a maximum wind speed value of 6 knots. The wind speed ranges from 3 to 6 knots. The lowest wind speed value was recorded on September 26th and October 1st, both of which had a value of three knots. The wind speed value on October 8th was the highest it got, with a value of six knots. The value of wind speed coming from the west is more dominant when compared to the value of wind speed coming from the east. This is because the wind coming from the west blows from the Indian Ocean without any obstructions, whereas the wind coming from the east blows from the Pacific Ocean. Because of this scenario, the shore of Semidang Alas Maras receives a significant amount of precipitation on a regular basis.

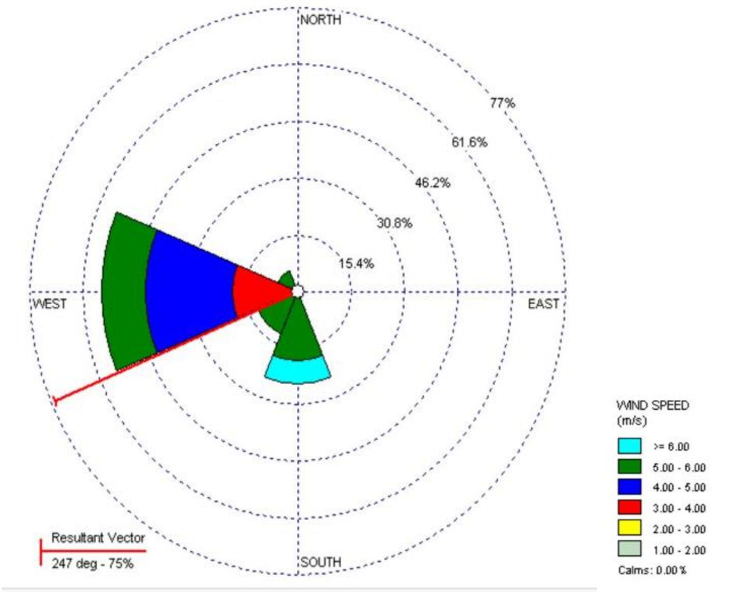

Figure 8. The Windrose Diagram on September 23 - October 8, 2021

Tidal Flooding Run-Up Semidang Alas Maras Coast

The seasonal variations significantly affect coastal conditions; therefore, this investigation of tidal flooding is organized according to the four distinct seasons considered: the Western season, Transition Season I, the Eastern season, and Transition Season II. The western season in 2022 had a maximum tidal elevation of 2 m along the coast of Semidang Alas Maras. The first transitional season had a maximum tidal elevation of 1.5 m, the eastern season had a maximum tidal elevation of 1 m, and the second transitional season had a maximum tidal elevation of 1.78 m. These data on the height of the tide were utilized as an input for the tidal floods. When mapping the tidal flood run-up in Semidang Alas Maras, this data on the tidal elevation is overlaid onto the topographic map of the Semidang Alas Maras Coast. This serves as input for the mapping process, the results of this mapping can be seen in Figure 9.

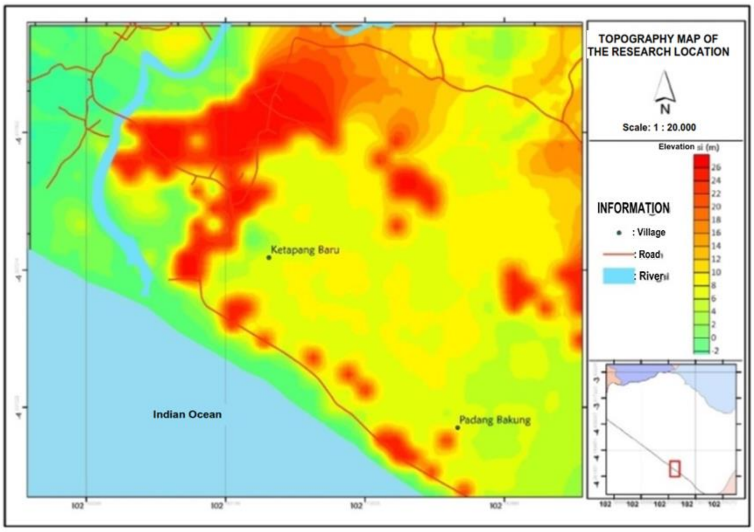

Figure 9. Coastal Topographic Map in the Beach of
Semidang Alas Maras Seluma

Based on the results of measurements taken using GPS and the results of drone photo processing, the topography of Semidang Alas Maras beach was determined, as illustrated in Fig. 9. The map shows the highest elevation, depicted in red at 26 m, and the lowest elevation, depicted in green at -2 m. Additionally, the yellow line indicates the average elevation of 9 m along the coast of Semidang Alas Maras.

The results of overlaying the leveling map and flood level data on the area affected by the tidal flood run-up can be seen from the level of danger seen in each criterion in the Semidang Alas Coastal Area. These levels of danger include no danger, less danger, somewhat danger, danger, and very danger. Table 2. breaks down the ratio of the danger area for each criterion by season. Table 2 demonstrates that the area value of the tidal flood run-up with the criteria of no danger and less danger is the same in each season. The value for no danger is 9%; the area is 38.13 ha; the value for less danger is 26%; the area is 107.57 ha. In the meantime, the thresholds for moderately dangerous, dangerous, and hazardous change significantly during the four distinct seasons.

Table 2. The Dangerous Ratio of the Tidal Flood Run-Up for the Each Criteria Per Season

No.	Season	Criteria	Area (Ha)	Extent (%)
1.	West	No Danger	38.13	9
		Less Danger	107.57	26
		Moderately Dangerous	83.06	20
		Dangerous	85.78	21
		Hazardous	93.95	23
2.	Transitional I	No Danger	38.13	9
		Less Danger	107.57	26
		Moderately Dangerous	89.87	22
		Dangerous	125.27	31
		Hazardous	47.66	12
3.	East	No Danger	38.13	9
		Less Danger	107.57	26
		Moderately Dangerous	110.29	27
		Dangerous	104.85	26
		Hazardous	47.66	12
4.	Transitional II	No Danger	38.13	9
		Less Danger	107.57	26
		Moderately Dangerous	91.23	22
		Dangerous	77.61	19
		Hazardous	93.95	23

The illustration distribution map that illustrates the distribution of tidal flood run-up, may be found in the Fig. 10, which illustrates the west-season tidal flood run-up along the coast of Semidang Alas Maras. The map indicates a zone of 20% moderately dangerous conditions with an area of 83.06 Ha, 21% dangerous with an area of 85.78 Ha, and 23% hazardous with an area of 93.95 Ha. When compared to the other seasons, the western season has the highest risk condition criterion, which can be seen from the fact that it has the highest value of danger and occurs in particularly hazardous locations. This is because during the west season, the greatest elevation height of the tides at Semidang Alas Maras Beach is 2 m, which is 2 m more than it is during any of the other seasons. This is the reason for this phenomenon. This condition is strengthened by Iskandar et al., who argue that higher sea level rises will cause the run-up to be broader and wider. According to the research of Egaputra et al., the most significant contributors to tidal flooding during the west season are large levels of precipitation, followed by strong winds. During the first transitional season, the distribution of tidal flood run-up is seen in the zones of 22% moderately dangerous conditions with an area of 89.89 Ha, 31% dangerous with an area of 125.27 Ha, and 12% hazardous with an area of 47.66 Ha. These conditions are categorized as moderately dangerous, dangerous, and hazardous, respectively.

The hazardous condition covers the same amount of land as the eastern season in the first transitional season, which is a smaller percentage of land than in the western season and the second transitional season, but the hazardous condition zone's area covers more land than the eastern season does. The tidal flood run-up distribution zone in the eastern season has a proportion of 27% with an area of 110.29 hectares, 26% with an area of 104.85 hectares, and 12% with an area of 47.66 hectares. Each of these areas has a different total area. While the transitional season II tidal flood run-up distribution zone reveals that the proportion of the region experiencing moderately dangerous conditions is 22%, with an area of 91.23 Ha, dangerous conditions are 19%, with an area of 77.61 Ha, and hazardous conditions are 23%, with an area of 93.95 Ha.

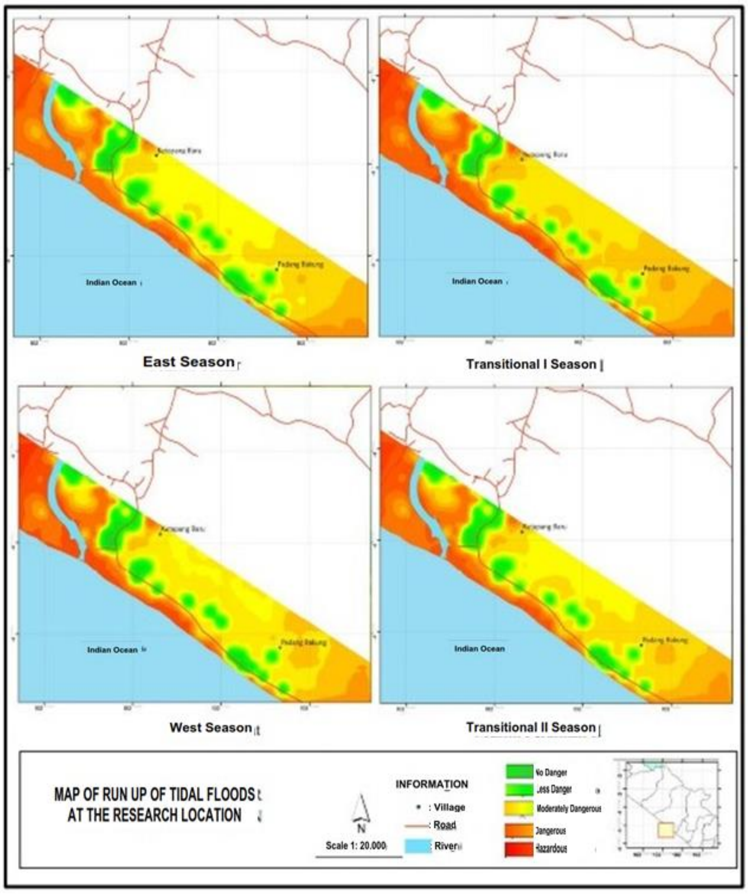

Figure 10. Run Up of Tidal Floods Every Season on the Coastal of Semidang Alas Maras

The distribution zone of the tidal flood run-up along the Semidang Alas Maras coast demonstrates how the area that is subject to tidal floods changes significantly over the course of the year. This is in accordance with Handoyo et al., Widada et al., Iskandar et al., which state that one of the parameters that affect the run-up of tidal floods besides sea level rise is the land topography of an area. The tidal flood hazard criteria follow the topography of the coast of Semidang Alas Maras Beach. The flooding that occurred was not only caused by tides but also by high rainfall, which is why the water discharge entering the Seluma estuary was also high. This is shown by the multiple flood occurrences that took place along the coast of Semidang Alas Maras, which proves that the flooding that took place was not only caused by tides but also by high rainfall [4], [29].

Figure 11 gives a visual representation of the harm resulting from the distribution of tidal floods along Semidang Alas Maras' coast. The image depicts a number of houses that have been damaged as a result of the tidal floods. Despite the fact that many of these homes have had their owners abandon them because of the severe damage they have sustained, some people are still living there. When tidal floods occurred, seawater entered the land, carrying materials from the sea such as rocks, sand, tree trunks, and garbage. These materials directly hit residents' houses, causing them to suffer severe damage. Residents' houses that suffered severe damage were mostly those built right on the beach. This is because when tidal floods occurred, seawater entered the land, carrying materials from the sea.

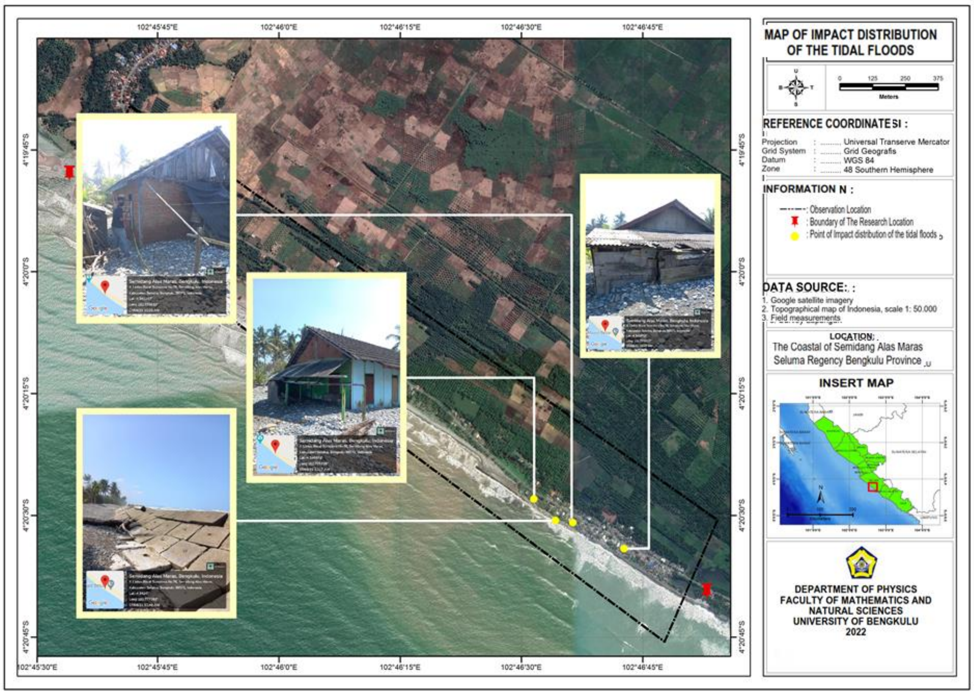

Figure 11. Impact Distribution of the Tidal Floods on the Coastal of Semidang Alas Maras

Since the tide from the ocean and the water moving downstream meet in the estuary, the water is unable to flow normally and instead backs up onto the land, which in turn causes floods on the shore of Semidang Alas Maras. According to (Al-Junaidi et al., 2018) and (Pyanto et al., 2021) tidal flooding is influenced by several factors, including tides, rainfall, altitude, slope, aspects of distance from the river, distance from the sea, drainage density, soil type, and land use. This condition is in accordance with this theory, as it states that tidal flooding is influenced by several factors. In addition, wind is another component that can contribute to tidal flooding along the coast of Semidang Alas Maras. Wind is one of the factors that can cause waves at sea, and waves are one of the factors that can contribute to an increase in sea level elevation. According to

(Egaputra et al., 2021), findings, the wind push that causes waves to form has a significant impact on the development of tidal floods. The height of the sea waves and the force of the energy they carry always vary according to the season, the amount of tidal flood run-up that occurs along the coast of Semidang Alas Maras differs according to the different seasons.

CONCLUSIONS AND RECOMMENDATIONS

The results of the study allow us to draw the conclusion that the seasonal conditions as well as the generating variables, specifically the tides as well as excessive rainfall and wind, have a significant impact on the tidal flooding that occurs along the coast of Semidang Alas Maras. Every season, the area that tidal flood run-up affects is the same in terms of both the absence of risk and the reduction of risk. Although the criteria for moderate danger, danger, and very danger change with each season, the season with the largest area value is the western season. In this season, moderate danger accounts for 20% of the area covered by the criteria, danger accounts for 21% of the area covered by the criteria, and very dangerous accounts for 23% of the area covered by the criteria. Mixed tides with predominant semidiurnal currents characterize the tidal type of the beach at Semidang Alas Maras, which has a Formzhal number of 1.76.

It is recommended not to rebuild houses in zones impacted by tidal floods in order to minimize building damage. Instead, the community should be educated about where to build safe dwellings based on tidal flood area mapping. The findings of the research were collected in order to minimize building damage. Reviewing other factors that create tidal floods, such as the yearly rise in sea level and the yearly subsidence of land, is one way that additional research and development can be carried out.

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