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Monsoon Induced Sea Waves in Ulee Lheue and Lhoong Waters, Indonesia

Ichsan Setiawan[1,*], Syarifah Meurah Yuni[2], Miftahuddin Miftahuddin[2], Yopi Ilhamsyah[1]

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ABSTRACT

This study aims to predict the characteristics of ocean waves, including wave height, direction and period, in the waters of Ulee Lheue and Lhoong, Aceh Province. This study is motivated by the significant influence of monsoon winds on the formation of ocean waves, which is closely related to global climate change. Wind data were obtained from NCEP (2015-2019) and analyzed using an empirical model from U.S. Army Corps of Engineers, considering wind speed, wind direction, and fetch length in both study areas. The results show that the dominant wind in Ulee Lheue comes from the Northeast with an average speed of 1.8 m/s, producing an average wave of 0.2 meters and a period of 2 seconds. In contrast, in Lhoong, the dominant wind comes from the Southwest with a speed of 3.4 m/s, producing an average wave of 0.7 meters and a period of 5 seconds. These differences in wave characteristics are influenced by geography, sea depth and exposure to dominant winds. These findings are important to support coastal management, mitigation of disasters such as erosion and backwash, and sustainable use of natural resources in Aceh's coastal areas. This research also emphasizes the importance of understanding ocean dynamics in the context of regional climate change.

1. Introduction.

Aceh Province is located between 2º to 6º North latitude and 95º to 98º east longitude with an average height of 125 meters above sea level. To date, Aceh Province has 18 districts and 5 cities. The boundaries of Aceh Province, north and east with Malacca Strait, south with North Sumatra Province and west with the Indian Ocean (Statistics Aceh Province, 2024).

The dominant factor affecting ocean waves is climatological factors, especially monsoons. Under certain conditions, sea waves in Aceh Waters can reach heights between 2 and 3 meters. This phenomenon is thought to be influenced by climate change, one of which is related to monsoon patterns.

In Aceh Waters, there are two main wind seasons: the north east monsoon and the south west monsoon. In December, January and February, which is winter in the northern hemisphere, high pressure centers in Asia and low pressure centers in Australia cause northeast winds to dominate Aceh Waters. Conversely, in June, July and August, which is the northern hemisphere's summer season, low pressure centers in Asia and high pressure centers in Australia cause southwest winds to blow in these waters.

These monsoons play an important role in shaping the characteristics of ocean waves, including their height and period. In addition, the wind also influences shoreline changes through the generated ocean waves. Just as the wind blows sand on the beach, the monsoon plays a role in changing the shape and size of waves coming ashore, and in changing the shoreline. By understanding these wind patterns, we can better understand the dynamics of ocean waves and the changes that occur along the coast (Sorensen, 2006).

This research utilizes a mathematical empirical model from the U.S. Army Corps of Engineers (2006), which incorporates one of the climate change factors, monsoon winds, as an ocean wave generator. Several relevant previous studies also support this research, among others: Setiawan et al. (2008), who studied wave propagation before and after the tsunami in Ulee Lheue waters; Faradila et al. (2017), who analyzed shoreline

[1]Faculty of Marine and Fisheries, Universitas Syiah Kuala, Banda Aceh, 23111, Indonesia.
[2]Faculty of Mathematics and Natural Sciences, Universitas Syiah Kuala, Banda Aceh, 23111, Indonesia.
*Corresponding author: Ichsan Setiawan. E-mail Address: ichsansetiawan@usk.ac.id.

changes in Ladong, Aceh Besar; Irham and Setiawan (2017), who conducted a study of wave-induced currents in the coastal waters of Lhoknga, Aceh Besar; and Setiawan and Irham (2018), who discussed wave trajectories in the waters of Lhoknga, Aceh Besar. This research aims to predict the height, period and direction of ocean waves in the waters of Ulee Lheue and Lhoong, Aceh, to support better coastal management.

Figure 1: Research Location Map.

Source: Authors.

2. Research Methodology.

Waves that occur in the ocean are basically caused by the transfer of energy from the wind to the sea surface. Therefore, in predicting wave parameters such as wave height, period, and direction, wind data is required as the main input. Ocean waves develop within a region called a fetch, the formation of which is strongly influenced by wind speed (U), wind duration (t), and the length of the region subject to continuous wind (fetch length) (Hunt & Sajjadi, 2018; James et al., 2018; Wang et al., 2017; Zakharov, 2018; Berbić et al., 2017; De Girolamo et al., 2017; Kalvig et al., 2013). Ocean waves are predicted using the following empirical formula (U.S. Army Corps of Engineers, 2006):

$$H_{mo} = 4,13 \times 10^{-2} \frac{u_*^2}{g} \left(\frac{gX}{u_*^2} \right)^{1/2} \quad (1)$$

$$T_p = 0,751 \frac{u_*}{g} \left(\frac{gX}{u_*^2} \right)^{1/3} \quad (2)$$

with
H_{m_0}: Sea wave height (m):
T_p : Sea wave period (s);
X : fetch length (m) = F_{eff};

$$u_*^2 = C_D U_{10}^2$$

$$C_D = 0,001\,(1,1 + 0,035 U_{10})$$

C_D: wind friction coefficient;
u_*: friction velocity (m/s);
g: gravitational acceleration (m/s^2)

The research procedure was conducted as follows:

1. Literature study on ocean waves and monsoon winds
2. Wind data collection from the National Centers for Environmental Prediction (NCEP) 2015-2019. https://psl.noaa.gov/thredds/catalog/Datasets/ncep.reanalysis/Monthlies/surface_gauss/catalog.html.
3. Determination of wind fetch length in Ulee Lheue and Lhoong waters based on Figure 1.
4. Prediction of ocean waves in Aceh waters using equations (1) and (2).
5. Analysis of wave height, direction and period in the waters of Ulee Lheue and Lhoong, Aceh.

3. Results and Discussion.

3.1. Wind.

Wind data from NCEP for the period 2015 to 2019 shows that the wind speed in the waters of Ulee Lheue and Lhoong ranges from 2.3 to 6 m/s. The dominant wind direction in the region is divided between the Northeast and Southwest directions, with the wind contribution from the Southwest direction amounting to 70%, while from the Northeast direction amounting to 30%. This distribution reflects the dominance of westerly monsoon winds that influence atmospheric dynamics in the region.

The highest wind speeds occurred from the Southwest in 2016 and 2018, with speeds ranging from 5 to 6 m/s. Meanwhile, winds coming from the Northeast had lower speeds of around 2.8 to 3.2 m/s in 2015 and 2016. This pattern indicates significant seasonal variability, potentially affecting oceanographic conditions and marine activities in both study areas.

The winds affecting the ocean waves in Ulee Lheue waters are predominantly from the Northeast, while those in Lhoong waters are more influenced by winds from the Southwest. These wind speeds and directions play an important role in shaping wave characteristics in both waters. In Lhoong, stronger Southwest winds can produce larger and more regular waves, while winds from the Northeast in Ulee Lheue tend to produce smaller waves and shorter periods.

According to Chu et al. (2004) and Wang et al. (2014), wind direction and speed have a great influence on wave height, especially in waters that are open to dominant winds. Winds coming at higher speeds from a particular direction tend to increase the wave energy, leading to higher and stronger waves. This phenomenon may explain why the waters of Lhoong, which are more exposed to Southwest winds, have waves with greater height and longer period compared to Ulee Lheue which is more protected from Northeast winds.

In addition, Anusree et al. (2024) also suggested that the interaction between wind and waves is highly dependent on water depth and seabed topography. In shallower waters, the waves formed will have shorter periods and smaller amplitudes, as was the case in Ulee Lheue. In contrast, deeper waters that are exposed to stronger winds tend to produce larger and more regular waves. Therefore, the different wind characteristics in these two locations greatly affect the dynamics of the ocean waves that occur in each water body.

3.2. Sea Wave Height and Period.

The average sea wave height and period for five years in Lhoong waters was 0.7 meters with a period of 5 seconds, moving from the Southwest direction. Meanwhile, in Ulee Lheue waters, the average wave height was only 0.2 meters with a period of 2 seconds, moving in a Northeast direction. This significant difference reflects the different water conditions between the two locations.

Differences in wave height and period can be influenced by various geographical and meteorological factors. Lhoong, which is located more exposed to winds from the Southwest, is likely to be more influenced by stronger wind patterns, resulting in larger and more regular waves. In contrast, Ulee Lheue, which is more sheltered by the surrounding islands, experiences milder wind influences, resulting in smaller waves with shorter periods. This is consistent with the findings of Chu et al. (2004) and Wang et al. (2014) who showed that waters that are more exposed to dominant winds tend to have higher and longer waves.

In addition, the water depth factor also plays a significant role in the characteristics of ocean waves. According to ocean wave theory, shallower water depths usually produce waves with shorter periods and smaller amplitudes (Xiong et al., 2020). The waters of Ulee Lheue, which have a shallower depth compared to Lhoong, allow waves with shorter periods and lower amplitudes. This indicates that seafloor topography and water depth influence wave dynamics, as described by Chen et al. (2020), who found that shallower depths reduce the length of the wave period and result in smaller amplitudes.

Conclusions.

Based on the results obtained, it can be concluded that sea waves in Lhoong waters, which are not obstructed by land or islands, tend to be larger than those in Ulee Lheue waters, which are sheltered by the surrounding islands.

This difference shows the significant influence of geographical and meteorological conditions on the characteristics of ocean waves. Larger waves in Lhoong can impact various marine phenomena, such as coastal erosion and the potential for stronger rip currents. Therefore, an understanding of these wind and wave parameters can be used to develop disaster mitigation measures, such as erosion prevention, rip current control and more effective coastal area management.

In addition, the utilization of beach sand carried by waves can also be an alternative in industry, such as providing sand for paving block installation and cement production. This can be an economic potential that needs to be considered in coastal natural resource management, while supporting environmental sustainability.

Therefore, the results of this analysis not only provide insight into the dynamics of ocean waves, but also open up opportunities for the development of disaster mitigation strategies and environmentally friendly natural resource utilization.

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