The Coastal Hydrodynamics Analysis in The Lampung Bay

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Abstract. The waves play a major role in the hydrodynamics of the sea, which they are very influential on human activities in the ocean. Thus, the knowledge of the waves conditions can provide many advantages, this is a challenge for marine experts in modeling ocean dynamics. The coastal area of Lampung Bay is one of the most densely populated areas in Bandar Lampung. The economic situation in the coastal area of Lampung Bay has been developing for a long time, this can be seen from the many old buildings in the coastal area. The existence of extreme waves in Lampung Bay can be as a concern for determining disaster mitigation planning and zoning around Lampung Bay. Based on the result of tidal analysis using the formzhal number equation, it is known that the type of tides in the research sites is mixed (semi-diurnal dominant) tidal type. According to simulating model of the wave characteristics in Lampung Bay, the sea characteristics can be divided into two, namely slight sea for deep waters of Lampung Bay with a wave height of 0 - 1.25 meters, and moderate sea for waters at the mouth of Lampung Bay with a wave heights of 1.25 - 2.5 meters.

Keywords : hydrodunamics, Lampung Bay, tide, wave

1. Introduction
The waves play a major role in the hydrodynamics of the sea, which they are very influential on human activities in the ocean. An engineer must analyze the waves conditions to design the shipping lanes, offshore structure and coastal structure. Shipping lanes must have low wave-heights in order to ensure the safety of sailing vessels. The wave and current also have an effect on Crude oil exploration in the offshore. Eventhough the accident of drilling activity may take place away from coast, the oil pollution could be transported to onshore by wind drift, wave drift and currents [1]. In addition, the wave conditions also affect to heat transport, waste at the sea, the distribution of nutrients and fishing grounds, the potential for coastal disaster. Thus, knowledge of the waves conditions can provide many advantages, this is a challenge for marine experts in modeling ocean dynamics.

The coastal area of Lampung Bay is one of the most densely populated areas in Bandar Lampung. The coastal area used for industry, fishing port, and settlement [2]. The economic situation in the coastal area of Lampung Bay has been developing for a long time, this can be seen from the many old buildings in the coastal area. Based on field observations, many residential areas are protruding and facing directly into the coastal area without green belt.

Given the strategic use of space on the coast of Lampung, disaster mitigation activities are important (urgent). Mitigation activities are an effort to increase positive factors in disaster management as well as efforts to reduce negative factors [3]. The existence of extreme waves in Lampung Bay can be as a concern for determining disaster mitigation planning and zoning around...
Lampung Bay. On the other hand, the research on the hydro-oceanographic characteristics of Lampung Bay, especially regarding extreme waves, is still rarely done. Therefore, it is necessary to conduct research on the prediction of extreme waves in Lampung Bay.

2. Methodology

2.1 Research Sites
The research was conducted in Lampung Bay, Lampung Province, Indonesia. Detailed location can be seen in Figure 1.

![Figure 1. Lampung Bay, Lampung Province (Source: Google Earth)](image)

2.2 Tools and Material
The tools used in this research are a set of computers and their supporting software. The materials used in this study are timeseries wind data for 10 years (2009-2018), tidal data (1 month) obtained from the Tide Observation Station, Panjang (BIG), bathymetry data and Lampung Bay’s base map.

2.3 Tidal Analysis
Water level data (tidal data) in this study were obtained from the Badan Informasi Geospasial Department (BIG) with a data length of 30 days of observation. From tidal observation data, we can determine the tidal constituents that are useful in predicting the tidal elevation for 20 years prediction to get the water level change especially the highest and lowest water level. Tidal type can be determined by the formzahl number equation with using tidal constants [4]:

\[ F = \frac{K1+O1}{M2+S2} \]  

The type of tide could be one of the following:
- \( F < 0.25 \) = semi-diurnal
- \( 0.25 < F < 1.50 \) = mixed (semi-diurnal dominant)
1.50 < F < 3.00 = mixed (diurnal dominant)
F > 3.00 = diurnal

2.4. Wave Analysis
The daily data of wind speed and magnitude had been converted to the significant wave height and significant wave period using Shore Protection Manual (SPM) 1984 method. The input parameters of SPM hindcast method can be categorized as wind speed, fetch length, and wind duration [5]. Wind speed data of this study was obtained from the website of ECMWF. Fetch is an area or a distance of the formation of the wave resulted by wind blowing, which is assumed relatively constant for each of the directions of wind coming to a focal point. Effective fetch length calculation is done using the help of based maps with the location of a large enough scale, so it can be seen the islands or the mainland that affects the formation of the wave at a given location. Determination of the focal point of fetch should be taken on the position of the deep ocean waters near the reviewed location. This reason because the winds generated wave is formed at deep sea in the waters, and then formed wave will be propagated toward the shore and then it broke along with a certain depth called breaking point near to the shore.

The Equation of Effective fetch can be written as:

\[ F_{eff} = \frac{\sum_{i=1}^{k} F_i \cos \alpha_i}{\sum_{i=1}^{k} \cos \alpha_i} \] (2)

The SPM Hindcast formulas can be written as:

\[ \frac{g \times T}{U_A} = 68.8 \times \left( \frac{g \times F_{eff}}{U_A^2} \right)^2 \leq 7.15 \times 10^4 \] (3)

\[ H_{mo} = \frac{0.0016 \times U_A^2}{g} \left( \frac{g \times F_{eff}}{U_A^2} \right)^{\frac{1}{2}} \] (4)

\[ T_p = \frac{0.2857 \times U_A}{g} \left( \frac{g \times F_{eff}}{U_A^2} \right)^{\frac{1}{3}} \] (5)

If equation (2) does not satisfy, then the incident wave is the result of the formation of the fully developed wave. Calculation of wave height and period using the following equations:

\[ H_{mo} = \frac{0.2433 \times U_A^2}{g} \] (6)

\[ T_p = \frac{8.134 \times U_A}{g} \] (7)

If the results of a comparative analysis satisfy the above equation, the wave that occurs is the result of not fully developed wave condition. There are 2 (two) types of not fully developed wave condition, namely the fetch limited wave and duration limited wave. To distinguish between both, it needs to be known in advance the critical duration (t_c), as follows:

\[ t_c = \frac{68.8 \times U_A}{g} \left( \frac{g \times F_{eff}}{U_A^2} \right)^{\frac{2}{3}} \] (8)

If t > t_c, then the incident wave is fetch limited condition. But, If t < t_c, then the incident wave is duration limited condition, so we need to replace F_{eff} to become F_{min} as formulated as:
The probability not exceeded ($P$) for each sequence ($m$) is calculated by the following equation:

$$P = 1 - \frac{m - \alpha}{N + \beta}$$  \hspace{1cm} (10)

Where:
- $P$ = The probability not exceeded for a single wave data sequence $m$ in the data set ordered from largest to smallest.
- $m$ = Sequence number of wave data from largest ($m = 1$) to smallest.
- $N$ = Total data.
- $\alpha$ dan $\beta$ = Constants that depend on the distribution function used as shown in the following table.

### Table 1. Constants for Each Distribution Function

| Distribution Function | $k$   | $\alpha$ | $\beta$ |
|-----------------------|-------|----------|---------|
| Gumbel                | 1.00  | 0.44     | 0.12    |
| Weibull 1             | 0.75  | 0.54     | 0.64    |
| Weibull 2             | 0.85  | 0.51     | 0.59    |
| Weibull 3             | 1.00  | 0.48     | 0.53    |
| Weibull 4             | 1.10  | 0.46     | 0.50    |
| Weibull 5             | 1.25  | 0.44     | 0.47    |
| Weibull 6             | 1.50  | 0.42     | 0.42    |
| Weibull 7             | 2.00  | 0.39     | 0.37    |

2. The probability not exceeded ($P_x$) for any data according to the Gumbel and Weibull distribution functions is calculated by the following equations:

$$P_x = \exp \left\{ -\exp \left[ -\left( \frac{x-B}{A} \right) \right] \right\} \hspace{1cm} \text{(Gumbel Distribution)}$$  \hspace{1cm} (11)

$$P_x = 1 - \exp \left[ -\left( \frac{x-B}{A} \right)^k \right] \hspace{1cm} \text{(Weibull Distribution)}$$  \hspace{1cm} (12)
3. To find a match between the data (P) and the distribution function (Px), Px is transformed into a variable \( r_v \) with the following equation:

\[
 r_v = \frac{-\ln(-\ln(Px))}{(Gumbel \, Distribution)} \quad (13)
\]

\[
 r_v = \left[-\ln(1 - Px)\right]^{1/k} \quad (Weibull \, Distribution) \quad (14)
\]

4. Parameters A and B are obtained by the Least Square method in a linear relationship:

\[
x = Ar_v + B \quad (15)
\]

5. After getting the values of A and B, to find the wave height (xRP) in a certain return period (RP = Return Period) can be calculated by the following equation:

\[
 Px = 1 - \frac{K}{N \ast RP} \quad (16)
\]

where:
K = The number of years of the analyzed wave data
N = The number of the analysed wave data (for annual maximum analysis, N = K)

6. To determine the suitability of the functions to be used, the Correlation Coefficient (CC) can be calculated by the following equations:

\[
 s_{12} = \sum_{i=0}^{N} r_{vi} x_i = \frac{\sum_{i=0}^{N} r_{vi} \sum_{i=0}^{N} x_i}{N} \quad (17)
\]

\[
 s_{11} = \sum_{i=0}^{N} r_{vi}^2 - \frac{\left(\sum_{i=0}^{N} r_{vi}\right)^2}{N} \quad (18)
\]

\[
 s_{22} = \sum_{i=0}^{N} x_i^2 - \frac{\left(\sum_{i=0}^{N} x_i\right)^2}{N} \quad (19)
\]

\[
 CC = \frac{s_{12}^2}{s_{11}s_{22}} \quad (20)
\]

2.6 Shallow Wave Prediction
Forecasting wave height in shallow waters and the research location are carried out using a wave propagation model from the deep sea to the shallow sea. The wave forecasting method used is the numerical method with the 2D finite difference equation.

3. Results and Discussions

3.1 Tidal Analysis
Based on the results of calculations using the formzhal number equation, the value is 0.42, so it is known that the type of tides in the research sites is mixed (dominantly semi-diurnal). This means that at the research sites there were mostly 2 times of high tide and two times of low tide in one day, but the height and the period of the waves were different. These results are in line with previous research.
on the west coast of Lampung [4], where the tides are predicted to be influenced by tides in the Indian Ocean.

| Table 2. Important Tidal Elevations Of Lampung Bay |
|-----------------------------------------------|
| **Value of Important Elevations (cm)**         |
| Highest Water Spring (HWS) | 78.47 |
| Mean High Water Spring (MHWS) | 66.04 |
| Mean High Water Level (MHWL) | 36.80 |
| Mean Sea Level (MSL) | 0 |
| Mean Low Water Level (MLWL) | -36.25 |
| Mean Low Water Spring (MLWS) | -55.16 |
| Lowest Water Spring (LWS) | -65.43 |

3.2 Wave Analysis
Based on hourly wind velocity data from January 1, 2009 to December 31, 2018, it was found that the dominant winds came from the northwest, west, southwest, and south directions. These data indicate that the wind speed at the research site is dominated by winds coming from the Indian Ocean. This condition is caused by this site is a large open area.

| Table 3. Distribution Of Wind Velocity And Direction. |
|-----------------------------------------------------|
| **Arah** | Kecepatan Angin (m/s) | 0.5 - 2.0 | 2.0 - 4.0 | 4.0 - 6.0 | 6.0 - 8.0 | >= 8.0 | Total |
|---------|-----------------------|----------|----------|----------|----------|--------|-------|
| N       | 3.01                  | 9.26     | 2.16     | 0.08     | 0.00     | 14.51  |
| NE      | 2.12                  | 4.73     | 1.61     | 0.07     | 0.00     | 8.52   |
| E       | 1.27                  | 1.82     | 0.57     | 0.03     | 0.00     | 3.68   |
| SE      | 1.31                  | 2.65     | 1.69     | 0.53     | 0.09     | 6.27   |
| S       | 1.50                  | 3.87     | 4.56     | 3.23     | 0.91     | 14.07  |
| SW      | 2.09                  | 6.07     | 4.78     | 0.98     | 0.07     | 13.99  |
| W       | 2.62                  | 7.63     | 5.53     | 1.03     | 0.02     | 16.83  |
| NW      | 3.33                  | 10.68    | 5.61     | 0.70     | 0.02     | 20.35  |
| Sub-Total | 17.24                | 46.72    | 26.51    | 6.66     | 1.10     | 98.22  |

|                | Calms |Missing Data | Total |
|----------------|-------|-------------|-------|
| **2009-2018** | 0.88  | 0.90        | 100   |

Based on the results of the hindcasting analysis, the percentage of wave events can be seen in the following table:
Based on the percentage of wave occurrence, it can be seen that the deep-sea waters in front of Lampung Bay are relatively calm with the percentage of calm waves being 78.99%. The wave height above 2 meters is 0.01% of the total occurrence. The dominant waves come from the Northwest, South and West which are the waters of the Indian Ocean.

Table 4 and Table 5 show the distribution of incoming wave directions by season. The rainy season starts from October to March, while the dry season starts from April to September. Based on the data obtained, it is known that both in the rainy season and in the dry season, the wave height in Lampung Bay is influenced by the wave height in the Indian Ocean waters (Table 4 – Table 5, and Figure 2 – Figure 3).

**Table 4. Wave Height And Direction**

| Dir | Wave Heigh (m) | Total |
|-----|----------------|-------|
|     | 0.5 - 0.8      | 0.8 - 1.2 | 1.2 - 1.5 | 1.5 - 2 | >= 2 |
| N   | 0.00           | 0.00      | 0.00      | 0.00 | 0.00 |
| NE  | 0.00           | 0.00      | 0.00      | 0.00 | 0.00 |
| E   | 0.22           | 0.00      | 0.00      | 0.00 | 0.00 |
| SE  | 0.91           | 0.00      | 0.00      | 0.00 | 0.00 |
| S   | 4.05           | 0.01      | 0.00      | 0.00 | 0.00 |
| SW  | 4.09           | 0.69      | 0.08      | 0.01 | 0.01 |
| W   | 4.61           | 0.68      | 0.03      | 0.00 | 0.00 |
| NW  | 4.42           | 0.43      | 0.03      | 0.00 | 0.00 |
| Sub-Total | 18.29 | 1.81 | 0.14 | 0.01 | 0.01 | 20.27 |

**2009-2018**

Calms 78.99

Missing Data 0.74

Total 100

**Table 5. Wave Height And Direction In Rainy Season**

| Dir | Wave Heigh (m) | Total |
|-----|----------------|-------|
|     | 0.5 - 0.8      | 0.8 - 1.2 | 1.2 - 1.5 | 1.5 - 2 | >= 2 |
| N   | 0.00           | 0.00      | 0.00      | 0.00 | 0.00 |
| NE  | 0.00           | 0.00      | 0.00      | 0.00 | 0.00 |
| E   | 0.43           | 0.00      | 0.00      | 0.00 | 0.00 |
| SE  | 1.65           | 0.14      | 0.00      | 0.00 | 0.00 |
| S   | 7.14           | 0.46      | 0.00      | 0.00 | 0.00 |
| SW  | 4.57           | 2.27      | 0.38      | 0.15 | 0.04 |
| W   | 2.72           | 0.97      | 0.04      | 0.01 | 0.00 |
| NW  | 1.43           | 0.19      | 0.02      | 0.00 | 0.00 |
| Sub-Total | 17.94 | 4.04 | 0.44 | 0.16 | 0.04 | 22.62 |

**Rainy Season**

Calms 33486

Missing Data 0.80

Total 33509
Figure 2. Waverose in Rainy Season

Table 6. Wave Height And Direction In Dry Season

| Dir  | Wave Height (m) | Total |
|------|----------------|-------|
|      | 0.5 - 0.8      | 0.8 - 1.2 | 1.2 - 1.5 | 1.5 - 2 | >= 2 |       |
| N    | 0.00           | 0.00      | 0.00      | 0.00    | 0.00  | 0.00  |
| NE   | 0.01           | 0.00      | 0.00      | 0.00    | 0.00  | 0.01  |
| E    | 0.01           | 0.00      | 0.00      | 0.00    | 0.00  | 0.01  |
| SE   | 0.03           | 0.00      | 0.00      | 0.00    | 0.00  | 0.03  |
| S    | 0.51           | 0.01      | 0.00      | 0.00    | 0.00  | 0.51  |
| SW   | 1.71           | 0.62      | 0.03      | 0.00    | 0.00  | 2.35  |
| W    | 4.29           | 2.22      | 0.33      | 0.05    | 0.00  | 6.89  |
| NW   | 5.68           | 2.17      | 0.19      | 0.07    | 0.00  | 8.11  |
| Sub-Total | 12.24    | 5.02      | 0.55      | 0.12    | 0.00  | 17.93 |

Dry Season

|                  | Total   |
|------------------|---------|
| Calms            | 35750   |
| Missing Data     | 0.68    |
| Total            | 35769   |
Figure 3. Waverose in Dry Season
Table 7. Annual Maximum Wave Height

| Tahun | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  |
|-------|----|----|----|----|----|----|----|----|
|       | N  | NE | E  | SE | S  | SW | W  | NW |
| 2009  | 0  | 0.31 | 0.52 | 0.89 | 0.83 | 1.13 | 1.74 | 1.81 |
| 2010  | 0  | 0.47 | 0.41 | 0.74 | 0.83 | 1.35 | 1.04 | 1.5  |
| 2011  | 0  | 0.38 | 0.65 | 1.01 | 0.79 | 1.48 | 1.08 | 1.21 |
| 2012  | 0  | 0.36 | 0.56 | 0.8  | 0.91 | 2.04 | 1.27 | 1.19 |
| 2013  | 0  | 0.38 | 0.74 | 0.9  | 0.91 | 1.6  | 1.4  | 1.35 |
| 2014  | 0  | 0.37 | 0.68 | 0.85 | 0.68 | 1.36 | 1.51 | 1.13 |
| 2015  | 0  | 0.42 | 0.74 | 0.68 | 0.78 | 1.11 | 1.52 | 1.2  |
| 2016  | 0  | 0.43 | 0.75 | 0.67 | 0.8  | 2.59 | 0.81 | 0.85 |
| 2017  | 0  | 0.37 | 0.57 | 1.06 | 1.11 | 2.04 | 2.04 | 1.69 |
| 2018  | 0  | 0.41 | 0.44 | 0.81 | 0.81 | 2.14 | 2.14 | 1.65 |
| Max   | 0  | 0.47 | 0.75 | 1.06 | 1.11 | 2.59 | 2.59 | 1.81 |

From the height and wave period (H₅ and T₅) obtained from the calculation of each wind data, an analysis of the frequency of extreme waves that can occur at the study location has been carried out. Based on the analysis of the 50th return period, it is known that the extreme wave height reaches 3m with the incoming wave coming from the Southwest.

Table 8. Extreme wave height

| Return Period | N   | NE  | E   | SE  | S   | SW  | W   | NW  |
|---------------|-----|-----|-----|-----|-----|-----|-----|-----|
| 2             | 0   | 0.385 | 0.592 | 0.826 | 0.807 | 1.580 | 1.337 | 1.322 |
| 5             | 0   | 0.428 | 0.712 | 0.955 | 0.920 | 2.078 | 1.658 | 1.613 |
| 10            | 0   | 0.452 | 0.781 | 1.030 | 1.005 | 2.390 | 1.842 | 1.779 |
| 20            | 0   | 0.473 | 0.840 | 1.093 | 1.090 | 2.672 | 1.999 | 1.922 |
| 25            | 0   | 0.479 | 0.857 | 1.112 | 1.118 | 2.758 | 2.046 | 1.964 |
| 33            | 0   | 0.487 | 0.878 | 1.134 | 1.152 | 2.863 | 2.101 | 2.015 |
| 50            | 0   | 0.497 | 0.908 | 1.167 | 1.203 | 3.014 | 2.181 | 2.087 |
| 100           | 0   | 0.514 | 0.954 | 1.217 | 1.288 | 3.254 | 2.305 | 2.199 |
| 200           | 0   | 0.529 | 0.997 | 1.263 | 1.374 | 3.483 | 2.420 | 2.304 |
| 1000          | 0   | 0.561 | 1.087 | 1.360 | 1.572 | 3.979 | 2.661 | 2.522 |

3.3 Waves in the shallow waters of Lampung Bay

The hindcasting wave heights cannot be directly used as wave data in shallow waters. This is because hindcasting is carried out in deep waters (depth > 30 meters). Analysis of wave distribution in shallow waters was carried out using the 2D finite difference method.

Based on Perka BNPB No. 4 of 2008, it is known that in planning for disaster mitigation areas, data for a return period of 10 years to 100 years are required [5]. In this study, the data used as wave input is extreme wave data with a return period of 50 years (Figure 5) and 100 years (Figure 6).
Figure 4. Wave modelling in Lampung bay

Figure 5. Wave modeling from southwest direction (return period 50 years)

Figure 6. Wave modeling from southwest direction (return period 100 years)
Based on the results of modeling wave characteristics in Lampung Bay, the water type can be divided into two, namely slight sea for deep waters of Lampung Bay with a wave height of 0 - 1.25 meters, and moderate sea for waters at the mouth of Lampung Bay with the wave height of 1.25 - 2.5 meters. The wave heights obtained in this study are the same as the wave height data released by the BMKG through the BMKG-OFS data analyst [8]. The wave height in the waters of Lampung Bay is relatively small. This is due to the large number of small islands in front of the mouth and inside the Lampung Bay. The back-barrier basin is strongly influencing the wave field and current dynamics [9]. These islands are the natural breakwater of Lampung Bay.

4. Conclusion
The conclusion of this study are that the tidal type of Lampung Bay is a mixed (semi-diurnal dominant). And the study shows that the highest tide elevation of Lampung Bay is at an altitude of 78.74 from MSL, the height of the extreme waves in front of the waters of Lampung Bay with a return period of 50 years is 3 meters, and the wave category in waters of Lampung Bay is slight sea, while out waters of Lampung Bay is the moderate sea.

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