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ANALYSIS OF TEMPORAL VARIABILITY OF TIDES AT STASIUN PASANG SURUT MAUMERE ON JANUARY 2023

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Abstract :
This study aims to analyze the temporal variability of tides in Maumere from January 12–14, 2023, focusing on frequency components, tidal heights, and the differences between theoretical predictions and observed data. A descriptive quantitative approach was employed, utilizing tidal data processed through the Fast Fourier Transform (FFT) method to identify dominant tidal frequencies and the Root Mean Square Error (RMSE) to evaluate the differences between observed and theoretical tidal heights. The results indicate that the Maumere Sea predominantly exhibits a diurnal tidal cycle, with an average tidal height of 1.57 m. The maximum observed tidal height change reached 0.76 m, whereas theoretical predictions, considering the Earth-Moon distance on January 14, estimated a value of 0.6 m. The RMSE between observed and predicted tidal heights was calculated as 0.34 cm. The novelty of this study lies in the application of FFT to identify tidal frequencies and evaluate the predictive performance of theoretical models on a local scale. This research contributes to improving the accuracy of tidal predictions and understanding tidal dynamics, which are crucial for oceanographic studies and coastal management. The findings demonstrate that FFT is effective in characterizing tidal frequencies and that theoretical models exhibit high accuracy when validated against observational data.

Keywords: Fast Fourier Transform, Maumere, Temporal variability, Tides,

INTRODUCTION

Indonesia, the world's largest archipelagic country, encompasses an area of 8.3 million km², with 6.4 million km² of this being water. This extensive maritime region is subject to tides, which are fluctuations in sea level caused by the gravitational forces of celestial bodies, particularly the sun and the moon (Triatmodjo, 2012). Although the moon is much smaller than the sun, its proximity to Earth makes its gravitational influence on tides significantly stronger—about 2.2 times greater than that of the sun. The Moon can be at closer distance to the average distance to the Earth. This Supermoon configuration is important to be investigated in term of tidal response (Tiatama, et. al, 2024). This phenomenon plays a crucial role in various aspects of oceanography, including coastal dynamics, sediment transport, and marine ecosystems (Nascimento et al., 2021).

Tidal fluctuations at a specific location differ from those at another due to various physical factors, such as topography, water depth, coastline configuration, and the rotation of the Earth, rather than solely its position relative to the equator. The gravitational interactions among the Earth, Moon, and Sun also play a crucial role in this phenomenon (Webb, 2023). In addition to short-term changes such as storms and tides, long-term fluctuations in sea level are influenced by climate change and human activities. In Indonesia, a rise in sea level has been observed from 1993 to 2018, a threat exacerbated by land subsidence and global warming (Febriansyah & Handoko, 2022). However, comprehensive studies on the relationship between tides and climate change in Indonesia remain limited.

The study of tidal variability is essential for understanding sea level change patterns and their impacts on coastal environments (Peng et al., 2023). Tidal patterns vary significantly from one location to another due to local factors such as water depth, seabed topography, the shape and width of straits, bottom friction, and the Earth's rotation, all of which influence the gravitational forces acting on the water. These forces, collectively known as tidal driving forces, cause sea level fluctuations that can be predicted using harmonic constants derived from specific harmonic analysis methods. The process of harmonic analysis involves determining the amplitude and phase of each tidal constituent, which are referred to as the harmonic constants (Rusdin et al., 2024; Mutaqin & Ningsih, 2023). These harmonic constants can be obtained through various methods, such as the least-squares method Rusdin et al. (2024) or the Doodson method (Mutaqin & Ningsih, 2023). Tidal types are categorized based on the frequency of high and low tides observed in a day, reflecting the varied responses of different locations to tidal generating forces. The four main types of tides are: (a) Diurnal tides, with one high tide and one low tide per day and an average tidal period of 24 hours and 50 minutes; (b) Semidiurnal tides, featuring two high tides and two low tides of nearly equal height within 12 hours and 25 minutes; (c) Mixed tides prevailing diurnal, where generally there is one high and one low tide, but occasionally two of each with significantly different heights and periods; and (d) Mixed tides prevailing semidiurnal, which usually have two high and two low tides of different heights, but sometimes one high and one low tide with varied heights and periods (Courtier, 1938, Triatmodjo, 2012).

Tidal-induced seawater mixing and changes in ocean dynamics due to tides also play a crucial role in various tropical marine ecosystems and global climate (Susanto & Ray, 2022; Vulliet et al., 2024). Furthermore, the nonlinear interaction between tides and storm surges during extreme weather events can influence regional ocean dynamics (Yang et al., 2023). Tidal variability also significantly impacts sea level oscillations in various regions, including the Azov Sea (Korzhenovskaia et al., 2022).Tidal fluctuations significantly impact various aspects, including the environment, ecosystems, and human activities. The periodic rise and fall of sea levels can affect ship navigation, access to docks, and port management. During high tide, deeper docks are more accessible, whereas access can become challenging during low tide (Anwar et al., 2023). Sea level changes can influence coral reef formation, sedimentation, and geomorphological processes in coastal regions (Kondrin & Korablina, 2023; Zhou et al., 2023; Jin et al., 2022). Additionally, sea level rise can increase the risk of tsunami hazards in coastal areas (Weiss et al., 2022). In ecosystems, tides influence zooplankton abundance in the Mempawah River estuary and the characteristics of mangrove ecosystems (Rahman & Husen, 2023). Additionally, tidal energy can be harnessed as a renewable energy source and supports activities in ports, water transportation, and flood mitigation (Danial et al., 2021; Triatmodjo, 2010). However, studies linking tidal patterns with tsunami mitigation and their interactions with ecosystems require further research.

Maumere, located on Flores Island, Indonesia, is known as a beach tourism destination, offering natural beauty that makes it ideal for snorkeling and diving. Tidal analysis in this region is relevant due to its influence on fishing activities, maritime transportation, and coastal disaster mitigation, such as erosion and tidal flooding (Liang & Zhou, 2022). However, beach erosion caused by tides raises concerns, as it can reduce tourism areas and damage infrastructure (Candrayana et al., 2023). Tidal stability is crucial for economic activities, particularly in coastal areas and wetlands. Recent studies indicate that a comprehensive understanding of tidal patterns can enhance agricultural productivity, support infrastructure planning, and mitigate disaster risks, all of which contribute to economic sustainability (Zevri, 2023; Agustiani et al., 2022; Sagala et al., 2021; Piani et al., 2022; Handoko et al., 2024). Tidal stability is crucial for economic activities such as fishing and diving, as well as for marine biodiversity. Accurate tidal information is necessary for managing marine resources and ensuring tourism safety (Rosida et al., 2022; Waru, 2022). For instance, Nusa Kutu Beach is only accessible during low tide, yet information on tidal patterns remains limited (Widana et al., 2022).

The urgency of this research is underscored by the vital role of sea level tidal information in various aspects of life, particularly in Indonesia's coastal regions, which encompass more than 13,466 islands and primarily consist of ocean. In Maumere, known as a tourism destination, accurate information regarding tidal patterns is essential to support safe tourism activities and manage environmental impacts such as beach erosion (Candrayana et al., 2023). Understanding local tidal characteristics is also critical for predicting tidal behavior and managing coastal activities, given Indonesia's vast and diverse maritime environment. Nevertheless, studies on tidal patterns related to astronomical factors in Maumere are still very limited, necessitating a more comprehensive analysis of temporal tidal variations across different regions of Indonesia, including the impacts of terrestrial and meteorological factors .

In the past five years, various studies have been conducted to analyze tidal characteristics in Indonesian waters using a range of methods, including the admiralty method, least square method, numerical methods, empirical methods, and others. Wahid et al. (2023) analyzed the types and characteristics of tides in Gesing Beach using the admiralty and least square methods, while Fitriana et al. (2022) employed the least square method with Geomatrix Geotide 3.0.23 software to study tides in Surabaya. Research by Ichsari et al. (2020) utilized three methods—admiralty, least square, and Fast Fourier Transform—to understand tidal characteristics. Additionally, Waru (2022) focused on analyzing the relationship between tidal currents and tides in Labuan Bajo and Maumere. However, to date, tidal pattern analysis has not specifically utilized Excel software. Therefore, this study introduces a novel approach by using Excel to analyze tidal characteristics in Maumere waters through the Fast Fourier Transform method, making it a distinct contribution compared to previous research.

Microsoft Excel can be used to teach physics concepts in an interactive and practical manner. It is emphasized that Excel enables students to perform data simulations and generate graphs, which are highly useful in understanding physical phenomena such as simple harmonic motion (Uddin et al., 2023). One of the methods used in tidal analysis is the Fourier Transform, which allows for the identification of key frequency components in tidal data (Lin et al., 2022). This method has been widely applied in oceanographic research to determine harmonic components contributing to tidal dynamics in various locations (Bowen et al., 2021). The Fast Fourier Transform (FFT) can be integrated with modeling methods to solve geophysical problems, demonstrating the flexibility of this algorithm in various applications (Dai et al., 2022).

Understanding these types is essential for predicting tidal behavior and managing coastal activities in Indonesia's diverse coastal environments. Given Indonesia's vast and varied maritime environment, understanding these local tidal characteristics is crucial. However, there remains a need for more comprehensive analyses of temporal variations in tide patterns across different regions in Indonesia. The predictions and observed of tides can be different due to terrestrial factors and meteorological factors. This study focuses on the temporal variations observed in Maumere from January 12-14, 2023, aiming to provide a clearer understanding of the tidal characteristics specific to this area.

RESEARCH METHOD

Research Design

This study employs harmonic analysis to predict tidal patterns, a method that decomposes tidal signals into their constituent harmonic components to forecast future tides (Stewart, 2008). The research was conducted at the Maumere tidal station over a period from January 12-14, 2023. The primary objective was to analyze the frequency and height of tides and compare these observations with theoretical predictions. The target of the study was to understand the local tidal characteristics and validate the predictive accuracy of harmonic models.

Research Subject

The research subjects included tidal height data collected from the RAD1 sensor at the Maumere tidal station. Instruments used in this study were primarily based on tide gauges installed at the station, which measured the height of the water at regular intervals.

Tidal data were obtained from the Maumere Sea tidal station managed by the Geospatial Information Agency (BIG). The data collection process included monitoring, processing, validation, storage, and archiving. The available data from the Indonesian Geospatial Reference System (SRGI) were downloaded in .txt format and subsequently transferred to Microsoft Excel for further analysis.

Research Procedure

The primary tools used in this study were a computer or other devices capable of retrieving data from the Geospatial Information Agency (BIG) website and data analysis software, namely Microsoft Excel, for data processing. The research procedure was carried out in the following stages:

1. Data download, the data used in this study were obtained from the Indonesian Geospatial Reference System (SRGI) website managed by the Geospatial Information Agency (BIG). The data were downloaded in .txt file format and subsequently transferred to Microsoft Excel worksheets.
2. Initial data Processing, the downloaded data, including information on dates, times, and sea level heights, were inputted into Microsoft Excel worksheets. After the data were entered, tidal visualization graphs were created to facilitate data interpretation.
3. Tidal frequency analysis, tidal frequency analysis was conducted using harmonic analysis with the Fast Fourier Transform (FFT) approach. The analyzed data comprised sea level heights obtained from one of the tidal gauge sensors in Maumere, specifically the RAD1 sensor.
4. Visualization of analysis results, the FFT analysis results were presented in a frequency versus amplitude graph. This graph was used to identify the dominant tidal cycles.

Harmonic analysis is a highly valuable method for predicting future tidal patterns. In addition, numerical modeling approaches are often used to validate observational analysis results and provide more accurate predictions (Robertson, 2023). By utilizing historical data and various analytical techniques, researchers can identify patterns and trends that aid in planning and mitigating risks associated with tidal fluctuations (Gultom et al., 2022; Danial et al., 2021; Handoko et al., 2024; Nirmala, 2024; Kurniawan et al., 2020; Ichsari et al., 2020).

Data analysis technique

Data analysis was carried out using Fast Fourier Transform (FFT), an algorithm that samples signals in the time domain and translates them into the frequency domain to examine their energy spectrum. Fourier analysis was performed using Microsoft Excel software, allowing for the identification of principal tidal frequencies and discrepancies between observed data and theoretical predictions. This method facilitated a detailed comparison of the observed tidal heights with those predicted by harmonic analysis, enhancing the understanding of local tidal behavior in Maumere.

The use of RMSE as an evaluation metric in tidal height prediction has proven to be highly effective. Various studies have demonstrated that with the application of appropriate models, such as LSTM and wavelet-based models, prediction accuracy can be significantly improved. This underscores the importance of selecting the appropriate model and applying the correct methodology in tidal research (Abubakar et al., 2020; Chen et al., 2020; Yang et al., 2020; Ramadhan et al., 2021). The accuracy of the tidal height predictions was evaluated using the root mean square error (RMSE), a standard statistical measure used to quantify the deviation between observed and predicted values. The RMSE provides insight into the model's performance by highlighting the error distribution in the predictions. The RMSE can be calculated by

$$RMSE = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}\left(h-h_t\right)^2} \qquad \text{……………..(1)}$$

For this study, the maximum observed tidal range, defined as the difference between the highest and lowest water levels, was also analyzed in relation to lunar phases, with particular attention to spring and neap tides. The tidal predictions considered various factors such as the alignment of the Earth, Moon, and Sun during new and full moons, which result in higher tides, and the first and third lunar quarters, which result in lower tides. Maximum waves occur every 2 weeks, should be 1.46 with h= 0.83 m for spring tides.

The maximum height change in tides caused by the moon can be calculated using the work (W) equation on equation 2.

$$\begin{aligned} W &= \int_{r+\delta_1}^{0} F_{Ty}dy + \int_{0}^{r+\delta_2} F_{Tx}dx \\ &= \int_{r+\delta_1}^{0} -\frac{GmM_m y}{D^3}dy + \int_{0}^{r+\delta_2} \frac{2GmM_m x}{D^3}dx \end{aligned} \qquad \text{……………..(2)}$$

with the m, M_m, D are the Earth mass, Moon mass, and distance between Earth and Moon. There are two components of force, x and y. We can calculate equation 1 further to be

$$\begin{aligned} W &= \frac{GmM_m}{D^3}\left[\int_{r}^{0}(-y)dy + \int_{0}^{r}2xdx\right] \\ &= \frac{GmM_m}{D^3}\left[-\frac{1}{2}y^2\right]_r^0 + \left[x^2\right]_0^r \\ &= \frac{GmM_m}{D^3}\left(\frac{r^2}{2}+r^2\right) \\ &= \frac{3GmM_m r^2}{2D^3} \end{aligned} \qquad \text{……………..(3)}$$

We can also take the equality of the work as the work done by the gravitational force. It is

$$\begin{aligned} mgh &= \frac{3GmM_m r^2}{2D^3} \\ h &= \frac{3GM_m r^2}{2gD^3} \end{aligned} \qquad \text{……………..(4)}$$

Hence, we can calcu late the tide height theoretically.

Local factors, such as the influence of narrow estuaries and the natural oscillations of water bodies, were also taken into account to explain variations in tidal height changes (Bacon & Marion, 1965)

RESULTS AND DISCUSSION

The tidal data analyzed in this study spans three days, from January 12 to January 14, 2023, collected from the Maumere tidal station. A time series was constructed from the data to facilitate the initial analysis of tidal patterns as shown in figure 1. The dataset, obtained from the Geospatial Information Agency (BIG) website, includes measurements taken every minute, totaling 2160 data points, starting at 00:01 on January 12, 2023, and ending at 09:55 on January 14, 2023.

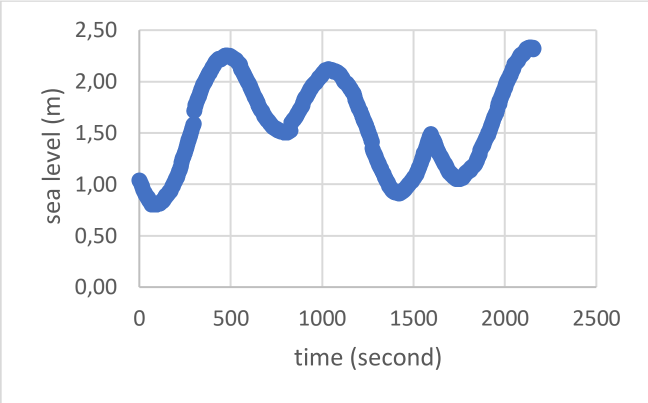

Figure 1. Graph of the sea level at Maumere over period of January 12-14, 2024

For the purpose of Fast Fourier Transformation (FFT) analysis, the dataset was truncated to 2048 data points, ranging from 00:01 on January 12 to 07:53 on January 14, 2023, due to the limitations of FFT analysis in Excel software, which can process only data sizes of 2^n. The FFT analysis was used to identify the dominant tidal frequencies in the dataset as shown in figure 2. The results indicated that the Maumere sea experiences a diurnal tide cycle, characterized by one high tide and one low tide per day. This finding aligns with the known tidal patterns influenced by local geographical features and the alignment of celestial bodies, as discussed in the introduction section. The tidal types is different compared to the Manokwari which has mixed tide prevailing semidiurnal (Suhaemi, 2018).

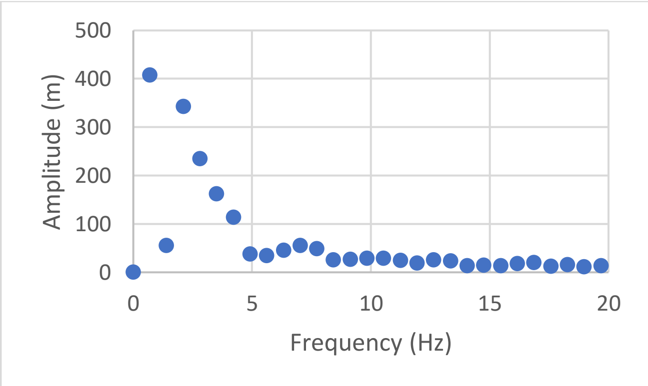

Figure 2. FFT of the sea level at Maumere over period of January 12-14, 2024

The analysis of the maximum tidal height using all data from the Maumere Tidal Station revealed that the highest tide occurred at 09:21 on January 14, 2023, reaching a height of 2.33 meters. The average tidal height over the observation period was calculated to be 1.57 meters, resulting in a maximum change in tidal height of 0.76 meters.

The observed maximum change in tidal height was compared to theoretical predictions based on the distance between the Earth and the Moon, which was approximately 0.37 million kilometers on January 14, 2023, at 09:21. Using the theoretical model, the maximum predicted change in tidal height was 0.6 meters. This prediction was derived from the gravitational forces exerted by the Moon and the Sun, and their alignment during the observation period, specifically during the new moon and full moon phases, as described in the introduction.

The difference between the observed and predicted tidal heights was quantified using the root mean square error (RMSE), which was found to be 0.34 cm. This small error value suggests that the theoretical model provides a reasonably accurate prediction of tidal changes in the Maumere region, although local factors introduce some variability. The discrepancy can be attributed to various local influences, such as seabed topography, the width and shape of straits and bays, water depth, bottom friction, and the Earth's rotation. These factors, discussed in the introduction, are known to affect the tidal characteristics of a region, leading to variations in tidal behavior that differ from theoretical models.

The findings of this study provide important insights into the tidal characteristics of the Maumere sea. The identification of a diurnal tide cycle confirms the influence of both celestial mechanics and local geographical conditions on tidal patterns. This research underscores the necessity of considering local environmental factors when modeling tidal behaviors, especially in complex archipelagic regions like Indonesia. Furthermore, the use of FFT analysis proved effective in isolating the primary tidal frequencies, demonstrating the method's utility in oceanographic studies. The observed and predicted tidal heights offer a valuable reference for future research and practical applications, such as coastal management and navigation.

The analysis in this study is limited to a three-day period, which may not fully represent long-term tidal variations. This gap necessitates further studies with longer timeframes to provide a comprehensive understanding of tidal patterns in Maumere. Additionally, although the results demonstrate high accuracy in predicting tidal heights, the influence of seabed topography and local environmental factors still requires further exploration.

These findings have significant implications for coastal management and navigation in Maumere. A better understanding of tidal characteristics can assist in planning coastal infrastructure, such as ports and settlements, and enhance navigation safety for vessels. Furthermore, these findings are relevant to the development of more accurate tidal prediction models that can be applied more broadly across Indonesia's archipelago, emphasizing the importance of considering local environmental factors in tidal modeling.

This research contributes new insights into the tidal characteristics of Maumere, revealing a diurnal cycle influenced by celestial mechanics and local geographical conditions. The use of Fast Fourier Transform (FFT) analysis to isolate primary tidal frequencies provides an innovative approach to tidal studies in Indonesia, particularly within complex coastal contexts. While this method has been previously utilized, its application with minute-by-minute data from Maumere offers greater detail than earlier studies.

A primary limitation of this study is the short time frame, which may not capture seasonal or annual variations in tidal patterns. Technical limitations of the Excel software, which can only process 2048 data points, necessitated data truncation, potentially impacting the results of the FFT analysis. This indicates the need for more advanced analytical tools or larger datasets to achieve more representative results. Furthermore, local environmental factors, such as topography, bottom friction, and sea current interactions, were only discussed theoretically, highlighting the need for further empirical investigation into these influences.

In conclusion, the results of this study highlight the complex interplay between gravitational forces and local environmental factors in determining tidal behavior. The Moon position can be predicted by the calculation and simulation using Stellarium and Python (Wandira & Pramudya, 2023). The Maumere region's diurnal tide cycle and the variations observed in tidal heights reinforce the need for comprehensive, site-specific analyses to accurately predict tidal patterns. These findings contribute to a deeper understanding of tidal dynamics in Indonesia's coastal waters and support the development of more precise tidal prediction models.

CONCLUSION

The analysis using Fast Fourier Transformation (FFT) reveals that the Maumere sea exhibits a diurnal tidal pattern, characterized by a single tidal cycle per day. This finding is significant as it enhances the understanding of tidal behaviors in the region, which are influenced by both celestial mechanics and local geographical conditions. The observed maximum change in tidal height of 0.76 meters, compared to the theoretical prediction of 0.6 meters, demonstrates a close alignment with theoretical models, with a root mean square error (RMSE) of just 0.34 cm. This small error indicates that the predictive models are robust, yet it also highlights the impact of local factors, such as seabed topography and coastal morphology, which can cause deviations from theoretical predictions.

The novelty of this research lies in its application of FFT to accurately characterize the tidal patterns specific to the Maumere sea, providing a more detailed understanding of regional tidal dynamics. These findings contribute valuable insights to the field of oceanography, particularly in predicting tidal behavior in complex coastal environments. Future studies should consider extending the observation period and incorporating additional environmental factors to further refine predictive models and enhance their applicability to other regions.

Based on the research findings, the author recommends that tidal data collection from the Geospatial Information Agency (BIG) website be conducted more meticulously, considering that the data is only available for a maximum of three days and cannot be downloaded directly. Consequently, it is necessary to use copy-paste methods into Notepad or Excel. Furthermore, when analyzing data using the Fast Fourier Transform (FFT) method with datasets exceeding 4069 points, it is advisable to utilize platforms other than Excel, as Excel can only process data up to 4069 (2^n).

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