An FFT-Based Method for Wave Decomposition from Wave and Tide Monitoring Using A01NYUB Sensor

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***Abstract*—Monitoring Sea level to obtain tide and wave values using acoustic sensors has the potential to be influenced by other factors. This causes the measurement results to have noise that can affect the quality of the resulting monitoring data. This study aims to decompose the monitoring results of the time series sea level data, to show the recorded wave variations. This study is located in Teluk Awur, Jepara, Indonesia. Sea level data was recorded for ten days using the A01NYUB ultrasonic sensor starting on November 4, 2022, to November 13, 2022. The results of the recording data from the A01NYUB sensor were decomposed using Fast Fourier Transform (FFT) and Continuous Wavelet Transform (CWT) based on the classification of the wave period. The results of the decomposition of sea level data from the sensor show that there are several classifications of waves with different periods. There are Ordinary Gravity Waves with a period of 15s-30s and an amplitude of ~1 cm; with Infragravity Waves a period of 30 s – 5 m and an amplitude of ~8.5 cm; are Long Period Waves with a period of 5min – 12h and an amplitude of ~60 cm; Ordinary Tide Waves with a period of 12h – 24h and an amplitude of ~10 cm; and Trans tidal Waves with a period of 12h – more and an amplitude of ~7.9 cm. The monitoring data were also adjusted to the MSL datum. The waters of Jepara have tidal characteristics, namely tidal asymmetry.The tides in Teluk Awur are mixed tides prevailing semi-diurnal. The A01NYUB ultrasonic sensor can record wave data with the lowest period which is Ordinary Gravity Waves and the highest period which is Trans Tidal Waves.**

***Keywords*—FFT, Tide Waves, Sea Level Monitoring**

I. Introduction

Sea level and wave monitoring data is needed in many marine sectors. The urgency to increase disaster mitigation efforts, coastal and coastal safety, as well as analyzes related to the potential for renewable resources from the sea really need monitoring data on sea parameters such as waves and tides[1]. The process of acquiring and monitoring sea level and wave data has been carried out using several methods. One method of monitoring sea level is by using an ultrasonic sensor. The use of ultrasonic sensors for sea water level measurements is a reliable and more affordable method compared to other instrumentation methods[2]. Adrianto et al.'s research[3] measures ocean waves using an ultrasonic sensor called the Modified Ultra Sonic Device (MUSD). The improvement made to the measurement process is to increase the sampling frequency up to 6.0z, so that the tool can retrieve sea level elevation data every 1 second interval. The results of this study show high accuracy and show that ultrasonic sensors can accurately measure sea level. The use of ultrasonic sensor for water level measurements is also used by Andang et al.,[4]using the JSN-SRT04 sensor. The research shows that the process of measuring the water level is more accurate than using manual measurements. This is indicated by the results of the measurement error of the ultrasonic sensor which is 0.74%. Ginanjar et al.,[5] monitored the sea level process using an A01NYUB type ultrasonic sensor. The sensor has a maximum detection distance of 750 cm and a resolution of 1 mm. This research shows that the use of the A01NYUB sensor is accurate and has results that are in accordance with the standardized tidal measurements of the Indonesian Geospatial Information Agency (BIG). The process of monitoring sea level data with ultrasonic sensors facilitates and improves the quality of the process of acquiring tidal and wave data. Thus, this data can be put to good use for coastal, offshore and disaster mitigation activities.

Research on monitoring sea level data for tidal and wave data using ultrasonic sensors has been widely carried out and shows accurate results and low error values. However, research regarding the results of further analysis related to the categorization of wave types and sea-state conditions from the time series data recording of the data obtained has not been widely carried out. Information regarding the categorization or types of waves found at the study site is very important to know. The process of monitoring sea level with an ultrasonic sensor can record ocean surface waves, which show local weather conditions when they form and also conditions at previous times at other locations[6]. Sea state condition information obtained from monitoring results is very useful for offshore activity processes and also activities that depend on and are affected by sea conditions. In order to know the wave type categorization from the observed time series data, it is necessary to decompose the wave data.

The wave data decomposition process can show the variability and characteristics of the waves formed at the research location, so that an understanding of the information and conditions of the waters can be better known[7]. Wave data decomposition can be done using the Fast Fourier Transform method, namely by converting the time domain into a frequency domain which is an orthogonal transformation. In addition to the decomposition in the frequency domain, the decomposition is also carried out in the time and frequency domain using the wavelet method, which is represented by the Continuous Wavelet Transform (CWT) type.[8]. Ginanjar et al.,[5] perform analysis and decomposition of wave data as a result of monitoring tidal and wave data from its ultrasonic sensor-based instrumentation. However, the division and visualization of the decomposition for each wave type based on the period have not been carried out. This study will analyze and demonstrate the visualization of wave decomposition data based on the period using the Fast Fourier Transform (FFT) and Continuous Wavelet Transform (CWT) methods which are shown in the Data Acquisition and Data Processing Flowchart "Fig. 5". The results of the decomposition will be shown in each wave type visualization result. Assuming that the monitoring data are stationary and non-stationary data, the two decomposition methods are the right methods to show the character and type of waves contained in the obtained time series datasets.

II. Materials and Methods

A. Research Location

The installation location of the A01NYUB ultrasonic sensor is located in Marine Science Techno Park, Diponegoro University, which is located on the coast of Teluk Awur, Jepara, Central Java, Indonesia. The data acquisition process using the A01NYUB ultrasonic sensor was taken for 10 days starting from November 4th 2022 to November 13th 2022 with a recording interval of 15 seconds.

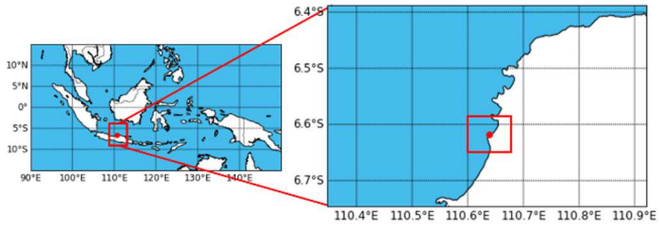


Fig. 1. Research location

The type of tide in the waters of Awur Bay, Jepara is a mixed tide prevailing semidiurnal so that in one day there is a double daily dominant tide[9], [10].Teluk Awur is in the micro-tidal region because the tidal range is below 2 meters. Teluk Awur is also an area that has tidal asymmetry[11]. Tidal asymmetry is caused by the influence of coastal morphology as well as estuary and bay conditions. In addition, the waters of Awur Bay are an area with a high level of diversity of seagrass species, so information about tides is needed to support efforts to conserve marine life in the vicinity.[10].

B. Experimental Setup

A01NYUB ultrasonic sensor is installed using a sensor box at an altitude of 3 meters above the seabed. This height is not the High Highest Water Level value at the installation location, so the sensor can measure sea level elevation correctly, as shown in "Fig. 2".The observation period is carried out every 15 seconds, whereas 15 seconds of the average data recording is carried out every 150 milliseconds. The recorded data is then sent using the internet to the database. The data sent is raw data that does not pass through any filter, so in the raw data, all types of waves are recorded within the shortest period of 15 seconds.

Fig. 2. A01NYUB sensor installation

C. Fast Fourier Transform (FFT)

Fast Fourier Transform (FFT) is an algorithm that takes a sample signal in the time domain and divides it according to its frequency component[12]. The main purpose of the spectral analysis method is to analyze the energy spectrum of a signal after it has been transformed from the time domain to the frequency domain[13]. With Fourier Analysis, it is possible to find all the wave frequencies recorded in the tidal raw data. The Fourier transform can be expressed through the following equation:

$$F(t) = \frac{A_0}{2} + \sum_{n=1}^{\infty} A_n \cos\left(n\omega_0 t\right) + B_n \sin(n\omega_0 t) \qquad (1)$$

D. Continuous Wavelet Transform (CWT)

In general, the wavelet transform is a Fourier transform where the window on the wavelet transform can be adjusted by following the following equation[8]:

$$W(a, b, x, \Psi) = \int_{\infty}^{\infty} x(t)\Psi^{*}\left(\frac{tb}{a}\right) dt \qquad (2)$$

Where x(t) is the time series input, Ψ* is the basic wavelet function, a is the frequency scale, and b is the original translation. The CWT of time series data is generally a representation of the difference in data in the vector database set. In this study, the Morlet type of wavelet function is used because it is optimal for tidal wave analysis[11].

III. Results and Discussion

A. Raw Data of Sea Level Monitoring

Raw data results from sea water level monitoring using the A01NYUB sensor are shown in Fig. 3. The measurement results show that the resulting data does not have a significant error value. Based on these results, measurements throughout 10 days, the pattern of the tides can be seen. Raw data results support the research statement[9], [10], that is, the tidal pattern in Awur Bay is a mixed tide prevailing semi-diurnal (in one day there is a double daily dominant tide). The Mean High Water Level (MHWL) value in Jepara waters is 72.48 cm and the Mean Low Water Level (MLWL) is 28.26 cm[14]. Based on monitoring results, these values correspond and indicate that sea water level measurements with the A01NYUB sensor produce data of good quality. To show that the quality of the monitoring data is appropriate and accurate, data comparison was also carried out with comparative data, namely tidal data belonging to the Geospatial Information Agency (BIG) located in Karimun Jawa and Pekalongan. The distance between the Karimun Jawa tidal station and the observation station is 93.4 km, and the distance between the Pekalongan tidal station and the observation station is 108 km. The following is the result of data comparison as shown in Fig. 5:

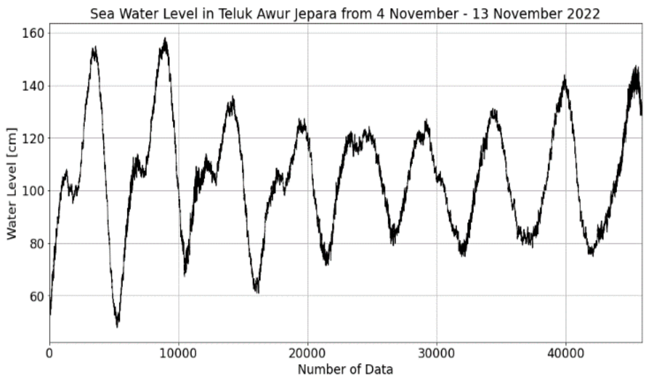


Fig. 3. Raw data of sea water level from A01NYUB sensor

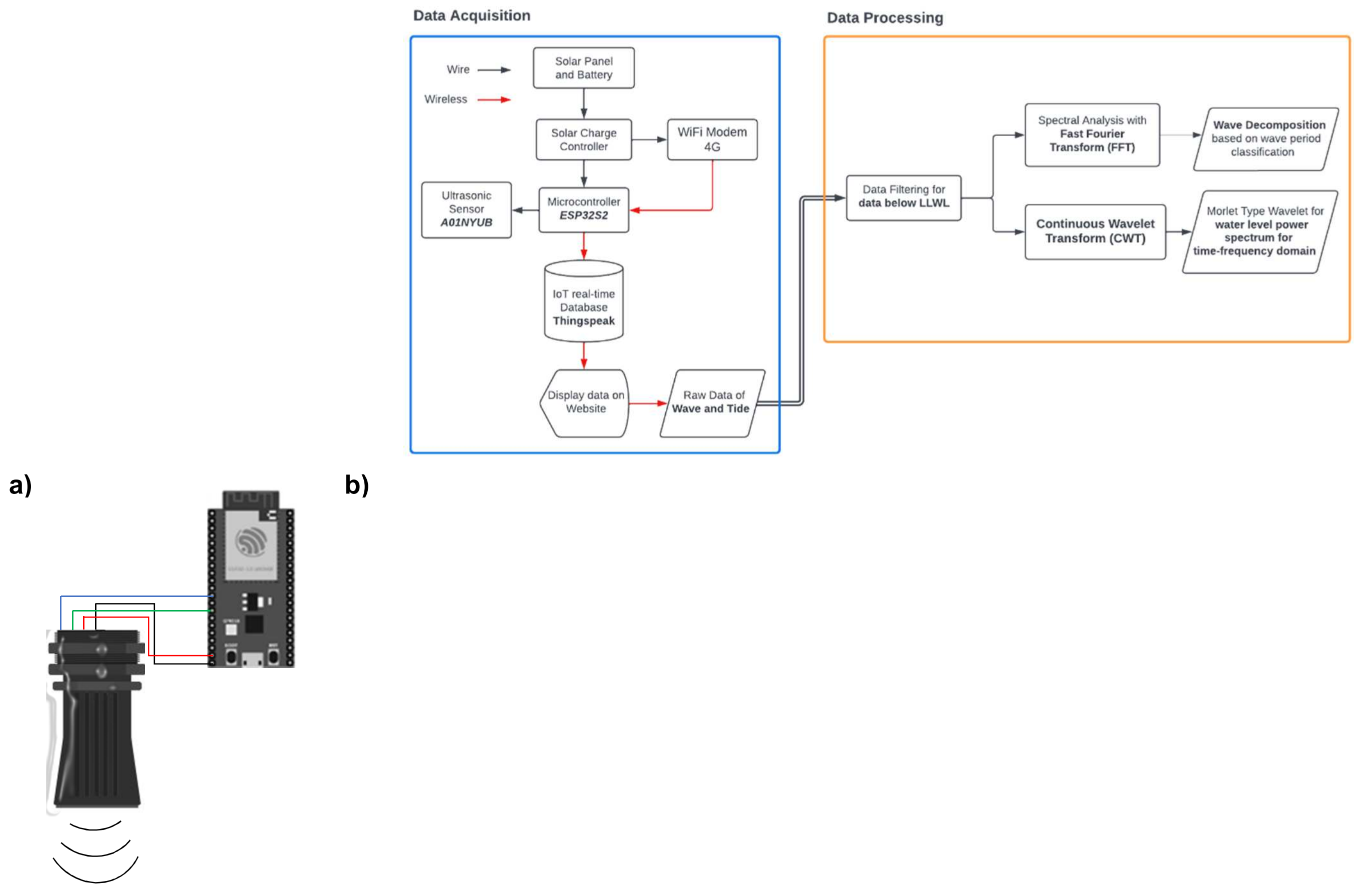


Fig. 4. a) A01NYUB sensor and ESP32S2 b) Data acquisition and data processing flowchart

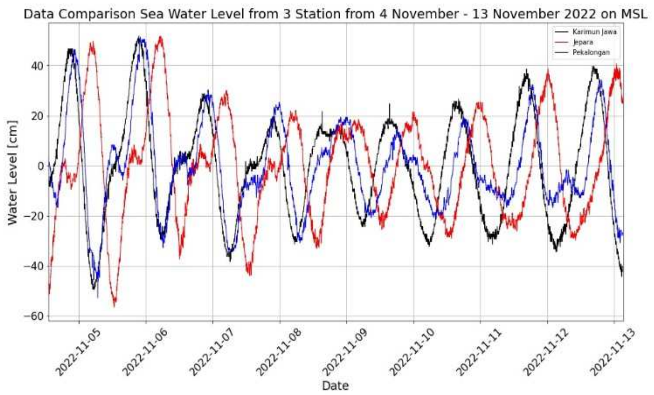


Fig. 5. Data comparison from A01NYUB sensor (red) with Karimun Jawa Station (black) and Pekalongan (blue)

The data comparison results show that the sensor readings have relatively the same amplitude values. In addition, the tidal pattern also shows the same pattern between the tides in Awur Jepara Bay with Karimun Jawa and Pekalongan. However, due to the different tidal locations and causing different tidal propagation, the tidal phases between the three stations are different [15].

B. *Fast Fourier Transform (FFT) Wave Decomposition*

The Fast Fourier Transform (FFT) method for decomposing wave types is carried out using the FFT algorithm programming in Python. The categorization of decomposed wave results is based on the period. The variations in the waves in the ocean are formed due to differences in the origin and nature of surface oscillations which affect the waveform both in terms of height and period [16]. Ocean wave classification which is based on the wave period is used in this research.

Based on the period, ordinary gravity waves are waves with a period of 1s – 20s. ordinary gravity waves are formed due to a condition, namely the wavelength grows longer than 1.5m then the surface pressure is ignored while gravity remains the sole restoring mechanism[16]. The decomposition results of ordinary gravity waves from tidal monitoring data show an amplitude value of ~1cm. Ordinary gravity waves are waves that are influenced by the influence of the wind that blows as the energy generator. Jepara waters researched by [9], the results also show that the waters of Jepara are greatly influenced by the conditions and influence of the wind which then when categorized based on the wave period are ordinary gravity waves.

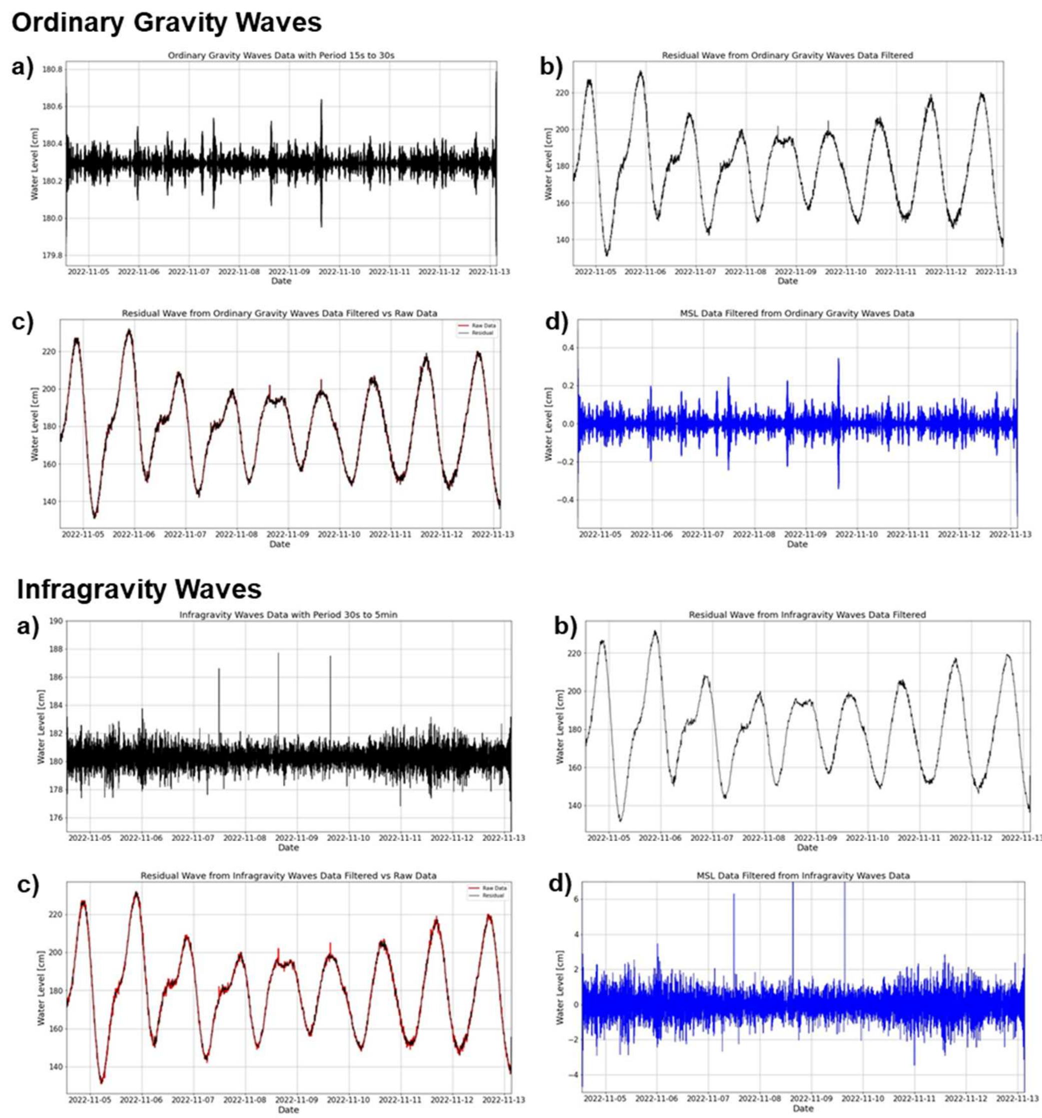
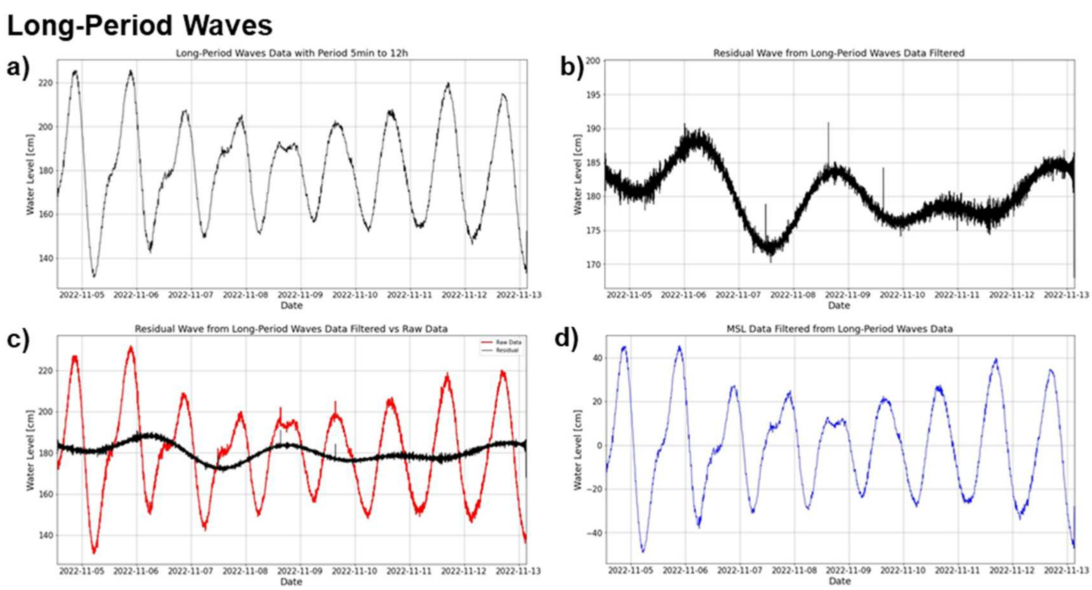


Fig. 6. Decomposition of Ordinary gravity waves and Infragravity waves



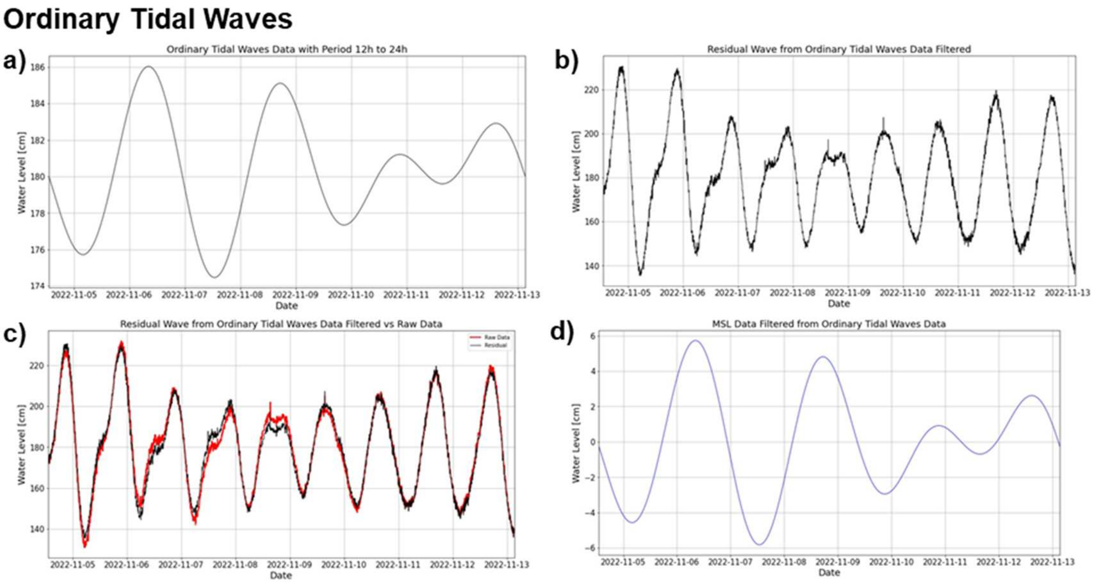


Fig. 7. Decomposition of Long-period waves and Ordinary tidal waves

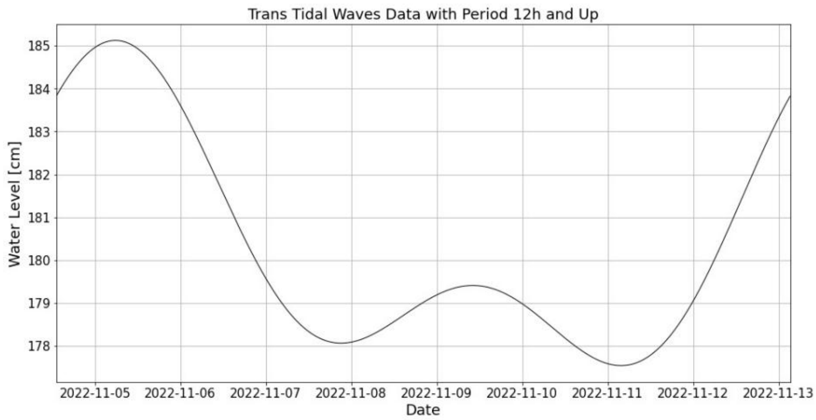


Fig. 8. Decomposition of Trans Tidal waves

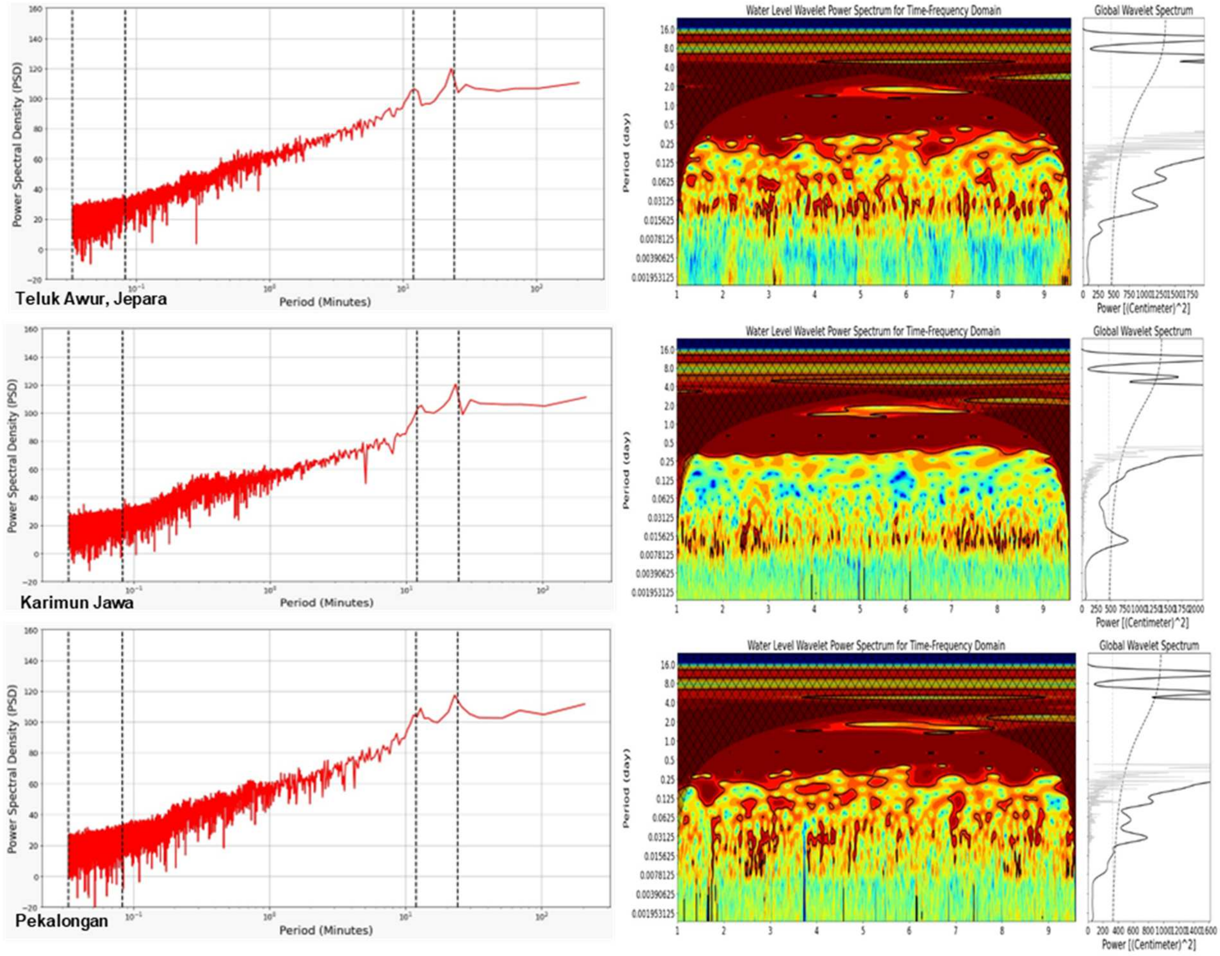


Fig. 9. Power Spectral Density (PSD) and Continuous Wavelet Transform (CWT) from 3 stations

C. *Power Spectral Density (PSD) and Continuous Wavelet Transform (CWT) Analysis*

The results of Power Spectral Density (PSD) and Continuous Wavelet Transform (CWT) can be seen in "Fig. 10". It is known that the wave decomposition results from the FFT method from tidal data using the A01NYUB ultrasonic sensor have the same decomposition results from other comparison stations, namely Karimun Jawa and Pekalongan. The results of the distribution of Power Spectral Density (PSD) in Fig. 9 shows that the classification of wave types in these waters consists of ordinary gravity waves (15s – 30s), Infragravity waves (30s – 5min), long-period waves (5min – 12h), ordinary tidal waves (12h – 24h), and trans tidal waves (12h – more).

Power Spectral Density (PSD) is needed for stochastic time series data [13]. CWT results show wave decomposition based on frequency and time domain. The three results of the Continuous Wavelet Transform (CWT) for each tidal station show a similar pattern. The classification of wave types recorded at tidal stations also shows variations. The classification of ordinary tide waves is the most dominant wave type in Teluk Awur waters, this is shown in the 0.5-1-day time domain in the Continuous Wavelet Transform (CWT). From the results of the FFT and CWT analysis that has been carried out, the tidal data from the A01NYUB ultrasonic sensor monitoring results show accurate results and have the same wave type characteristics as standardized tidal observations belonging to BIG Indonesia.

Waves from the lowest period, namely ordinary gravity waves, to the highest period, namely trans tidal waves, can be recorded by the sensor. This shows that the quality of measurement data can be used to support the process of developing and improving coastal and disaster mitigation efforts in Teluk Awur, Jepara.

IV. Conclusions

Based on the analysis and the methodology applied in this research, the ultrasonic sensor A01NYUB can record the tidal and wave data with good results. The results show that the waters of Teluk Awur have a tidal type named mixed tide prevailing semi-diurnal. The wave decomposition methods using Fast Fourier Transform (FFT) and Continuous Wavelet Transform (CWT) show that the A01NYUB ultrasonic sensor can record wave data with the lowest period which is Ordinary Gravity Waves, and the highest period which is Trans Tidal Waves. These results can improve the understanding of waves and tidal characteristics in Teluk Awur, Jepara. It will contribute to the disaster mitigation planning from oceanographic aspects, and helps the authority to set the right policies to conserve and protect the coastal areas of Teluk Awur, Jepara.

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