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TIDAL CHARACTERISTICS ANALYSIS UTILIZING RADAR TIDE GAUGE IN CIREBON SEAWATER

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ABSTRACT
Radar-based tide gauge is an approach in measuring tidal offering much more easier installation and maintenance than that commonly tide staff or pressure tide gauge. Here, a radar tide gauge was installed at Cirebon port, northern coast of Java, to investigate the tidal characteristics in the region. The instrument recorded water elevation every 15 minutes from July 2022 to November 2023. The tidal component is analyzed using the least squares method, and the tidal type is determined with the Formzahl number. It is found that the dominant tidal component in the study area consists of semidiurnal components (M2, S2, N2, K2, 2N2), diurnal components (K1, O1, P1, Q1, J1, TAU1), and shallow water component (SSA) components with amplitude (in cm) of 11.98, 5.58, 2.91, 2.11, 1.45, 11.80, 3.89, 6.11, 2.08, 1.56 and 3.11, respectively. Tidal type in the study area is mixed prevailing semidiurnal. The tidal range is approximately 0.8-1 m high with high-tide conditions at local time between 6.00-9.00 and 18.00 - 21.00, while low tide conditions are between 11.00 - 14.00 and 01.00 - 04.00. Elevation height calculation based on datum is done by combining the tidal components. This radar-based tidal elevation measurement could be an alternative dataset to support and complement tidal data record in Cirebon and may could be consider for development and other maritime activities.
Keywords: datum, harmonic constituents, radar tide gauge, tidal analysis

Analisis Karakteristik Pasang Surut Menggunakan Radar Tide Gauge di Air Laut Cirebon

ABSTRAK
Pengukur pasang surut (pasut) berbasis radar merupakan salah satu pendekatan dalam mengukur elevasi muka air yang mudah diinstal dan dipelihara dibandingkan menggunakan palem pasut atau pressure tide gauge pada umumnya. Disini radar tide gauge dipasang di pelabuhan Cirebon, bagian utara pesisir Jawa, untuk mengamati karakteristik pasut di wilayah ini. Instrumen merekam elvasi muka air setiap 15 menit dari bulan Juli 2022 hingga November 2023. Komponen pasut dianalisa menggunakan metode least square dan tipe pasut ditentukan melalui bilangan Formzahl. Diketahui bahwa komponen dominan pasut di area kajian terdiri dari komponen semidiurnal (M2, S2, N2, K2, 2N2), komponen diurnal (K1, O1, P1, Q1, K1, J1, TAU1), dan komponen perairan dangkal (SSA) dengan amplitudo (dalam cm) secara berurutan sebesar 11.98, 5.58, 2.91, 2.11, 1.45, 11.80, 3.89, 6.11, 2.08, 1.56, dan 3.11. Tipe pasang surut di area kajian adalah campuran condong semidiurnal. Tunggang pasut di daerah studi diperkirakan setinggi 0.8-1 m dengan waktu lokal kondisi pasang saat pukul 6.00-9.00 dan 18.00 - 21.00, sedangkan kondisi surut pada rentang pukul 11.00 - 14.00 dan 01.00 - 04.00. Perhitungan tinggi elevasi berdasarkan datum dilakukan dengan mengkombinasikan komponen pasang surut. Data pengukuran pasut menggunakan radar dapat menjadi data alternatif untuk mendukung dan melengkapi data yang terekam di Cirebon serta dapat menjadi pertimbangan untuk pembangunan dan kegiatan maritim lainnya.
Kata kunci: *datum, komponen harmonik, radar tide gauge, analisis pasang surut*

INTRODUCTION

Tidal knowledge is crucial for marine and coastal structure development, for example the highest water level is very important in determining the elevation of the tops of coastal buildings and port facilities, while the depth of shipping lanes or port is determined by the lowest tide (Triatmodjo, 2003; 2010). The purpose of observing tides is to provide water elevation data for forecasting tides and to provide information regarding tide conditions for certain activities. The results of tidal observations can be used as a basis or reference in determining appropriate actions in the process of making pond construction, especially brackish water ponds in Cirebon Regency (Arnol *et al.,* 2016).

Measuring tidal or water elevation can be done conventionally using tide staff (record manually) or automatically using a tide gauge instrument. Low cost radar tide gauges have become available from several manufacturers which offer easier installation and maintenance than float, pressure, and acoustic tidal gauges. Radar tide gauges are commonly positioned several meters above the surface of the sea, or river or lake. Some radars measure changes in sea level by monitoring the time-of-travel of a radar pulse from a transmitter/receiver unit to the surface and back to the unit, while others use transmitted radar waves mixed with signals which are reflected from surface in determining the phase shift between two waves and its range (Woodworth and Smith, 2003).

This study aims to introducing the measurement of water elevation utilizing radar tide gauge in the Cirebon area and analyze the data using T_TIDE method in determining tidal type and tidal harmonic constituent. Cirebon has many lowlands, beaches, mangroves, salt ponds, fish or shrimp ponds, traditional harbors, mussel aquaculture, and coastal fishing spots which can be influenced by tidal patterns. This region is located on the highway and railroad tracks connecting this port city and many cities in its surrounding (Hermawan, 2017). However this region faces erosion-sedimentation even some flooded areas are affected by tides (Abdurrahman *et al.,* 2021; Suhendar, 2022). Therefore tidal information is necessary for marine and coastal activities. Several works had been done to observe tidal characteristics in this area. However most of the works were done using conventional methods or using tide gauges with limited time (Ismail and Taufiqurohman, 2012; Leksono *et al.,* 2013; Tarunamulia, 2016; Haidar *et al.,* 2021). Tidal components which have longer periods may not be considered in the short measurement time. The national agency, namely the Geospatial Information Agency (BIG) also records water elevation regularly in Kejawanan port, Cirebon. However, the tidal data obtained using a sensor from pressure tide gauge. The utilization of radar gauge may have opportunities to support national data services or complement the national BIG dataset.

RESEARCH METHODS

The radar tide gauge CEETIDE™ Mk IV consists of an electronic Control Unit connected to a distance sensing instrument or probe installed above water (Figure 1). This probe will measure the distance to the water surface and be collected in the Control Unit. The Control Unit then processes the data and converts it to tide height relative to a given datum that is stored. To measure the position, Real Time Kinematic Global Navigation Satellite System (RTK GNSS) Leica GS18 is utilized to have horizontal and vertical position with high accuracy. There are no moving parts or submerged installations and no metal parts exposed on the probe, thus corrosion is negligible. The probe must be installed above the water,

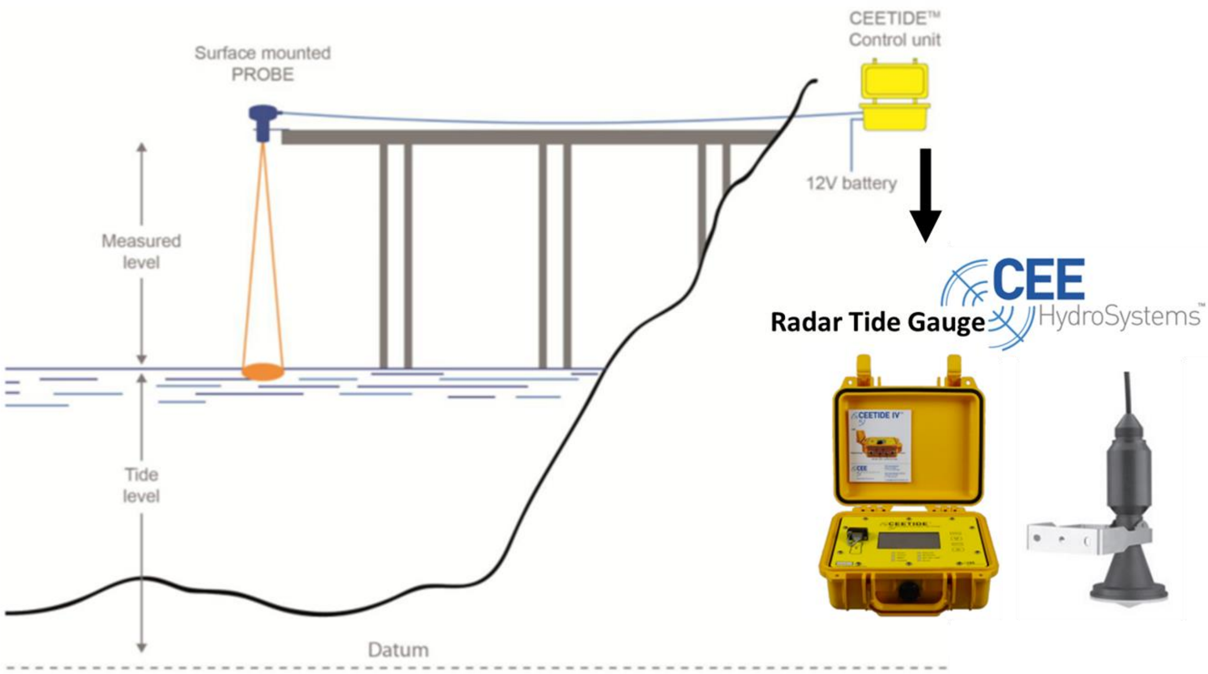

Figure 1. Basic CEETIDE instruments and system installation (Bruttour International, 2014).

facing vertically down to the water surface. It must be positioned so that there are no obstructions in the path to the water surface, and be fixed to a solid structure. The probe should be installed at least 50 cm above the highest spring tides and wave action. Also the location should be such that the water underneath and does not dry-out at low water (Bruttour International, 2014). Following the guidance, tide gauge sensor is put in small pier inside Pelindo port. The distance between land and sensor point is approximately around 6.5 m. The control unit is separated from sensor and put in the box and be protected to rain. Electricity source is from solar panel connected by cable to control unit.

Radar tide gauge was installed at Pelindo II, Cirebon since July 2022 (Figure 2). More specifically, the instrument was located in the geographical coordinate of 108° 34' 21.0301" E and 6° 42' 58.2174 S or in cartesian coordinates of -2017624.7250 m and 6004780.0066 m in UTM 49 S. This point has a height of 23.6802 m counted from ellipsoid height. The data that will be used for analysis are between 18 July 2022 and 6 November 2023 (1 year 3 months time -series dataset).

The instrument records water elevation with sampling interval time every 15 minutes. Raw data (csv or ASCII file format) retrieved from instrument every week by connecting USB drive to the control unit. Data is sort neatly and filter to avoid any blank or error data. Blank data may be found if there is any instability form electricity sources, but commonly only 1-2 data (15-30 minutes) is missing and can still be compensated by interpolating between hour interval. The data then processed using T_TIDE approach to obtain tide harmonic component or constituent. The T_TIDE is a Matlab toolbox of harmonic analysis using least squares method developed by Rich Pawlowicz together with Steve Lentz and Bob Beardsley (Pawlowicz *et al.*, 2002; Ichsari *et al.*, 2020). T_TIDE fits a set of sinusoidal functions to the observed sea level data to identifies and extracts tidal constituents based on their frequencies and amplitudes, and then computes the phase and tidal parameters (such as amplitude, phase, and speed) for each constituent

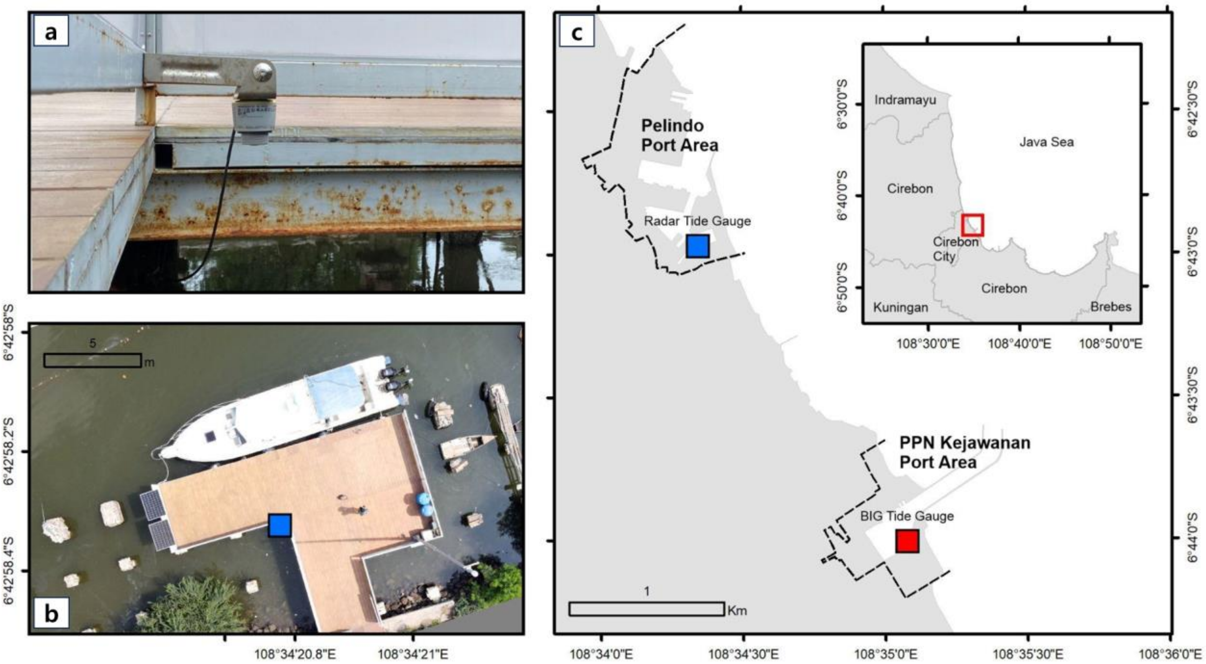

Figure 2. Radar tide gauge location in Pelindo II port, Cirebon. a) tide gauge sensor installed, b) tide position (blue square) in aerial view, c) location of radar tide gauge in Pelindo port area (blue square) compare with BIG tide gauge location in PPN Kejawanan (red square).

(Pawlowicz *et al.*, 2002). To identify the tidal type on study area, Formzahl number is commonly used and calculated as the sum of the main two diurnal amplitudes divided by the sum of the main two semidiurnal amplitudes (Ongkosongo, 1989; Fadilah *et al.*, 2014; Waluyo *et.al.*, 2021). Formzahl number can be obtained as the equation below:

$$F = \frac{K1+O1}{M2+S2} \quad \text{.................................(1)}$$

where, *F* is Formzahl or tidal form factor. The K1, O1, M2, and S2 are amplitudes for components of luni-solar diurnal, principal lunar diurnal, principal lunar, and principal solar, respectively. Formzahl number is obtained by dividing the total of two diurnal (K1+O1) with semidiurnal compnent (M2+S2). The category of Formzahl can be seen in Table 2.

RESULTS AND DISCUSSION

Tide Gauge Measurement

The tidal measurements in the Pelindo port showed the tidal range is around 0.8 -1 m. It aligns with the result of Purnama *et al.*, (2015), Arnol (2016), in other places around the Cirebon area such as in Suranenggala and Losari. High tide and low tide time in this area is not the same exact time on each day. It can be seen in sampling data within 7 – 15 December (Figure 3), the low tide is shifted a bit at increasing day. Earlier date has low tide before 12.00 and at the later date, the low tide found after 12.00 local time. High tide appears on 6.00-9.00 and 18.00 - 21.00 in local time (UTC+7), meanwhile lowtide commonly found within 11.00 - 14.00 and 01.00 - 04.00 also in local time, and this pattern will always repeat itself everyday. Spring and neap tide occur each month but the date is shifted. The forces responsible for generating tides are

Table 1. CEETIDE installation description

Installation	Description
	Tide gauge sensor is put in pier, above the water (>50 cm) and give some distances from land. The sensor probe surface is positioned so it face down to the water. Probe cable then is connected to control unit.
	Solar panel is put as the source of electricity for instrument. Then it is connected to accu then to tide gauge's control unit. The cable connection is made neatly, safely, and unobtrusively. Alternatively, other electricity sources (from Pelindo port) had been applied to avoid power outages from solar panel.
 	The control unit is put inside the box to prevent and secure from direct heat and rain. Inside the box is also put accu batteries (main electricity), Solar Charge controller (solar panel contol unit), power inverter (solar panel to electricity), Automatic Transfer Switch (for 1st and 2nd electricity sources), and fan (reducing heat).
	Tide gauge is set up its configuration (time reference, position, measurement time, etc.). Then, tide gauge started to measurement. Tide gauge is checked every day and data retrieved every week. Data retrieved through USB drive and produce in csv (ASCII) file format

Table 2. Fromzahl number category

Fohmzal number	Tidal type	Description
$0 < F \leq 0.25$	Semidiurnal	Two high tides and two low tides in a day.
$0.25 < F \leq 1.5$	Mixed tide prevailing Semidiurnal	Two high tides and two low tides in a day with different height and period. Occasionally, there is only one high tide and one low tide.
$1.5 < F \leq 3$	Mixed tide prevailing Diurnal	One high tides and one low tides in a day. Occasionally, there are two high tides and two low tides with different height and period.
$F > 3$	Diurnal	One high tides and one low tides in a day

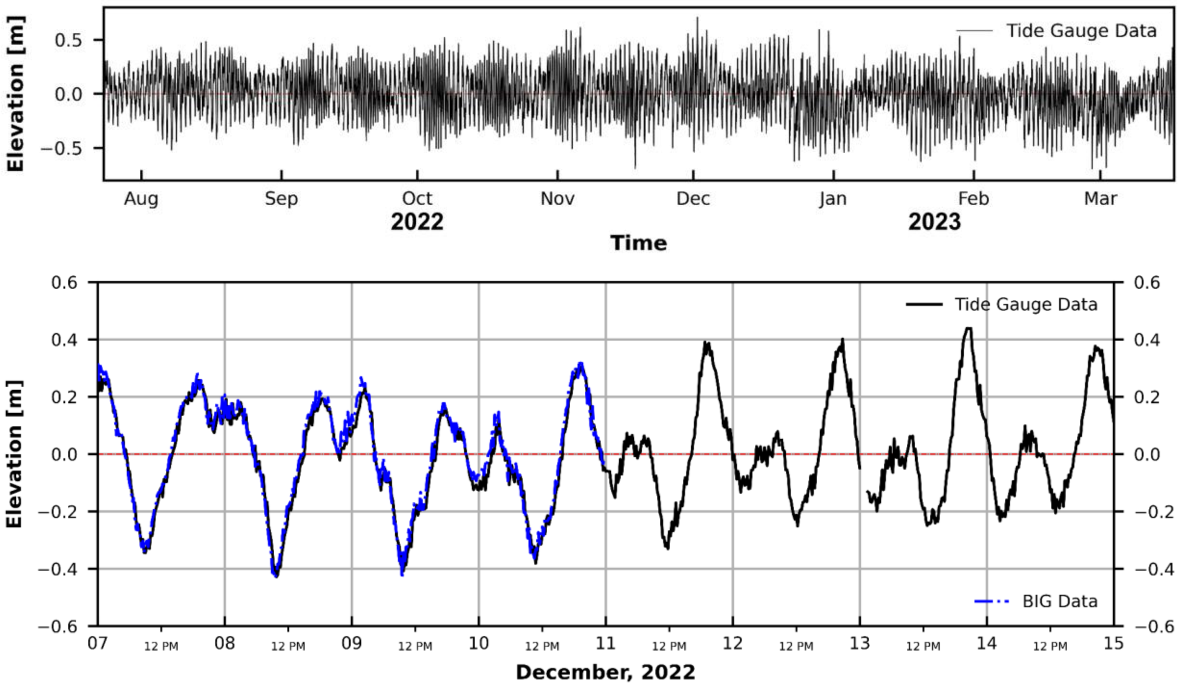

Figure 3. Tide chart for measurement (upper panel) and sampling data in comparison with BIG tide data on 7-15 December 2022 (lower panel).

brought about by the gravitational pull between the earth, moon, and sun, as stated by Triatmodjo (2012). The gravitational pull from the moon and sun creates a cohesive system between the earth and the moon/sun, resulting in their mutual revolution called common acis of revolution (Ongkosongo, 1989). Moreover, it is explained that the creation of ocean tides is significantly impacted by the primary motions of the sun and the moon, including the moon's orbit around the earth taking approximately 27.3 days, the earth's orbit around the sun taking about 365.25 days, and the earth's rotation taking approximately 24 hours. The gravitational influence of the moon causes the timing of the tides to shift by a few minutes each day as the moon completes its orbit around the Earth roughly in 28 days. The daily occurrence of two high tides and two low tides, approximately six hours apart, is attributed to the Earth's 24-hour rotation. However, the timing of these tides varies due to the Moon's changing position on a daily basis.

The tidal data is not smooth as it seems though the pattern is clearly shown (Figure 3). The data shows real conditions inside the port including boat activities and wind that can temporarily influence the water level condition. The sudden high water level can occur due to extreme waves or weather conditions. Moreover, port activities when they lower the ship from deck after boat repairment may create high waves close to the measurement area.

The result of radar tide gauge measurement has close value with BIG data (after normalized with each mean sea level). Tidal measurement at BIG station is located in Kejawanan port which is a neighbor to Pelindo II port where the radar tide gauge is installed. In this case, the BIG tide station has three kinds of sensor to measure the water level, however two of the sensors may not function well since the data only shows one value without any variation of water elevation. Unfortunately, the main sensor sometimes records strange data where the elevation was far from the tidal pattern or has a spike value suddenly. There is missing data found in tide gauge located in PPI kejawanan (BIG dataset) started from 11 December 2022 (blue line at lower panel in Figure 3) since the instrument might stop recording within this time. This radar based tidal dataset may complement the gap in case the blank data occurred in the BIG data.

Tidal Component Analysis

Based on tidal analysis through the T_TIDE approach, harmonic constituents can be seen in Table 3. The total of tidal components generated by T_TIDE can reach 62 constituents. However several major and minor components with small amplitude are not included in the list. Major constituents commonly used or provided in tidal component study are M2, S2, N2, K2, K1, O1, and P1 (Tarunamulia *et al.,* 2015; Ichsari *et al.,* 2020) or even consist of shallow water components such as M4 and MS4 (Subono *et al.,* 2017; Suhana *et al.,* 2023). Minor constituents included in this study are included in fortnight tide and monthly tide.

Tidal constituents, obtained from the analysis, are then used to calculate tidal datums which can then be used as a reference for measuring water levels in local. It is also used to calculate the Formzahl number which determines the tidal type in the area. Based on the tidal constituents obtained, the Formzahl number is 0.89 which makes the waters in the study area have a mixed tide prevailing semidiurnal type. This number is close to other results such as from Gurning *et al.* (2016), Dwianti *et al.* (2017), and Subono

Table 3. Tide harmonic constituent at the study site

Harmonic constituent		Amplitude (cm)	Phase (°)	Period
Semidiurnal tide				
M2	*Principal lunar*	11.98	101.13	12.42 hour
S2	*Principal solar*	5.58	317.45	12.00 hour
N2	*Larger lunar elliptic*	2.91	65.46	12.65 hour
K2	*Principal lunar*	2.11	19.26	11.96 hour
2N2	*Lunar elliptical semidiurnal 2nd-order*	1.45	61.49	12.90 hour
Diurnal tide				
K1	*Luni-solar diurnal*	11.80	310.19	23.93 hour
O1	*Principal lunar diurnal*	3.89	68.09	25.81 hour
P1	*Principal solar diurnal*	6.11	299.80	24.06 hour
Q1	*Larger lunar elliptic diurnal*	2.08	34.96	26.86 hour
J1	*Smaller lunar elliptic diurnal*	1.56	26.78	23.09 hour
TAU1		1.61	344.05	25.66 hour
Fortnightly tide				
MSF*	*Lunisolar synodic fortnightly*	1.24	106.41	14.7 day
MF	*Lunisolar fortnightly*	1.77	34.98	13.6 day
Monthly tide				
MSM*		0.81	225.70	1 month
MM*	*Lunar monthly*	0.87	346.68	~1 month
Semiannual tide				
SSA	*Solar semi annual*	3.11	160.58	6 month

Information: asterisk (*) behind the constituent in this study is consider as minor constituent.

et al. (2017). This study result is similar with tide prediction analysis by PUSHIDROSAL but different in some components shown from measurement in eastern Cirebon as work of Tarunamulia *et al.* (2016). Although the tidal type is still the same, they found higher amplitudes for S2, K2, K1, and P1 with values of 42, 47, 39, and 26 (in cm), respectively. The reason may be due to local behavior on different measurement locations since they show tides chart in coastal water nearby farming area in Losari district. Different location measurement neighboring with Cirebon area such as in Indramayu (Waluyo *et al.,* 2021) and Brebes (Wijaya *et al.,* 2019) have different tidal amplitude and phase. The phase between this three cities give insight of the tidal propogation. For M2 and S2, the tidal propagates from Indramayu (3.3933° and 94.1429°) direction to Cirebon (101.13° and 317.45°) then to Brebes (155.7° and 321.8°). However, for K1 and O1 seems have a propagation from west part and east part of Indonesia then meet at Java sea. A big picture of tidal wave propagation in Java sea, including Cirebon, had been investigate by inspecting tide gauge spread surround this sea (Putra and Pratomo, 2017). Most of major tidal harmonic constituent propagate from west (South China Sea, Malacca strait, and Karimata strait) and east (Makassar strait, Nusa Tenggara). As a result, the occurrence of tidal waves in the western Java shows a complex tidal system which is evidenced by the irregular distribution of the co-phase lines (Ding *et al.,* 2012).

The tidal datum components are obtained by combining tidal constituents and are designated for their respective uses (Table 4). For example, Mean High Water Level (MHWL) is used to refer to cadastral (boundary) purposes in some jurisdictions, Highest High Water Level (HHWL) is used to refer to the peak height of breakwaters, piers and boat chains, Lowest Low Water Level (LLWL) is used to refer to the depth of shipping lanes and harbor pools, Lowest Astronomical Tide (LAT) is used to refer maritime boundaries, and so on. In this study calculated tidal datum relative to sensor is presented as shown in Figure 4.

Table 4. Water elevation on each datum

Datum	Value (m)	Description
HAT	-0.64	Highest Astronomical Tide
HHWL	-0.75	Highest High Water Level
MHHW	-0.80	Mean Highest High Water Level
MHWS	-0.91	Mean High Water Springs
MHWL	-0.91	Mean High Water Level
MHWN	-1.02	Mean High Water Neaps
MLHW	-1.04	Mean Lower High Water
MSL	-1.08	Mean Sea Level
MHLW	-1.12	Mean Higher Low Water
MLWN	-1.15	Mean Low Water Neaps
MLWS	-1.26	Mean Low Water Springs
MLWL	-1.26	Mean Low Water Level
MLLW	-1.36	Mean Lowest Low Water Level
LLWL	-1.41	Lowest Low Water Level
LAT	-1.53	Lowest Astronomical Tide

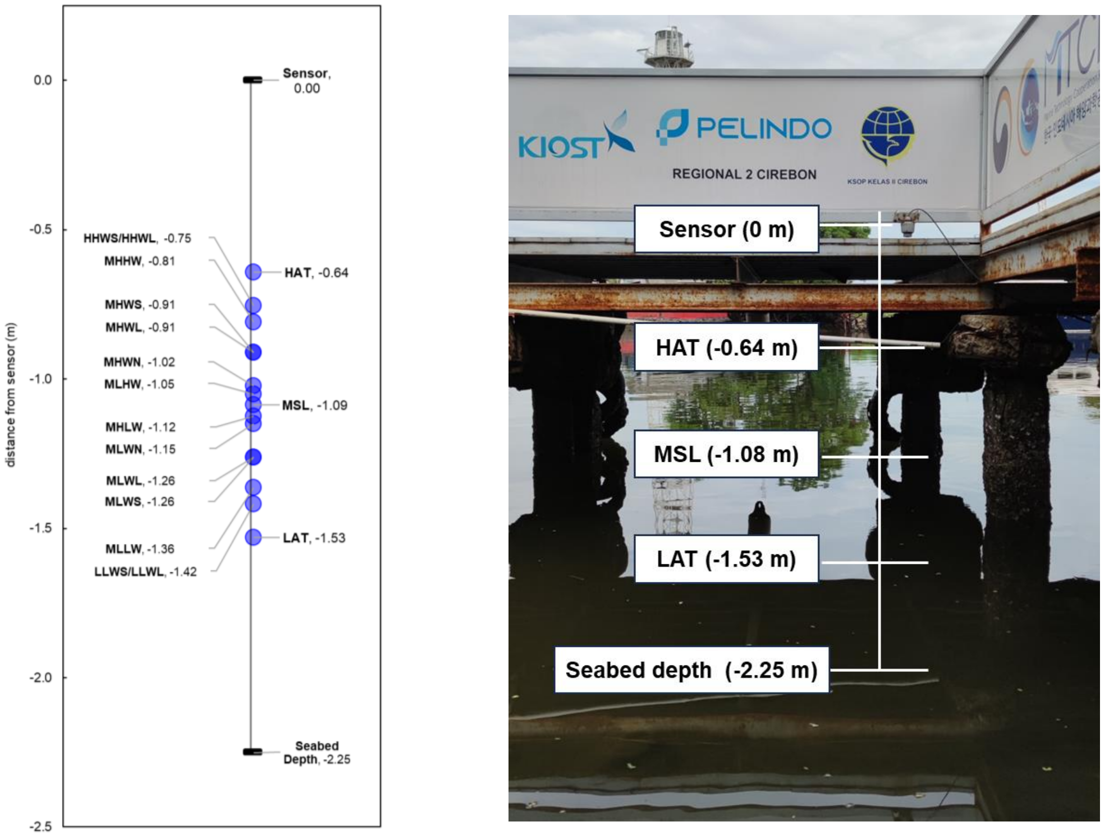

Figure 4. Water level elevation in study area.

Haidar *et al.* (2021) calculated the tidal data in Bondet estuaries which is close to this study area. Although the mean sea level reference is different, the gap of HHWL and LLWL is similar, which both in estuary have a delta value of 56 cm, while in this port is around 33 cm.

CONCLUSION

Based on the data and calculation, the tidal type in Cirebon seawater is mixed semidiurnal type with tidal range of 1 m. It is known the major harmonic tides consist of M2, S2, N2, K2, 2N2, K1, O1, P1, Q1, K1, J1, and SSA. Formzahl number shows value of 0.89. The measurement is well fit with national data which located in different port, indicating the radar based tide have good performace for long temporal. The information of sea level height can be beneficial for harbor development, ship activities, and fishing spots in the surrounding area. Additionally the data from the radar measurement approach can be an alternative data to support filling the gap of Cirebon data measured regularly by BIG.

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REFERENCES

Abdurrahman, U., H. Diastomo, Avrionesti, M. Y. Surya, M. R. Badriana, T. Suprijo, and H. Park. 2021. Comprehensive analysis of coastal dynamics in Cirebon Coastal Area

(CCA), Indonesia. *Journal of Coastal Research*, *114*, 444-448. https://doi.org/10.2112/JCR-SI114-090.1

Arnol, M., R. Sabang, and R. Rahmiyah. 2016. Analisis Karakteristik Pasang Surut di Kabupaten Cirebon Provinsi Jawa Barat. *Buletin Teknik Litkayasa Akuakultur*, *14*(1), 65-68. http://dx.doi.org/10.15578/blta.14.1.2016.65-68

Bruttour International. 2014. *CEETIDE*™ *User Manual Version 1.34.01*. NSW: Bruttout International Pty Ltd.

Ding, Y., X. Bao, H. Yu, and L. Kuang. 2012. A numerical study of the barotropic tides and tidal energy distribution in the Indonesian seas with the assimilated finite volume coastal ocean model. *Ocean Dynamics*, *62*, 515-532. https://doi.org/10.1007/s10236-011-0518-0

Dwianti, R. F., S. Widada, and H. Hariadi. 2017. Distribusi Sedimen Dasar Di Perairan Pelabuhan Cirebon. *Jurnal Oseanografi*, *6*(1), 228-235. https://ejournal3.undip.ac.id/index.php/joce/article/view/16200

Fadilah, Suripin, and D. P. Sasongko. 2014. Menentukan tipe pasang surut dan muka air rencana perairan laut Kabupaten Bengkulu Tengah menggunakan metode admiralty. *Maspari Journal: Marine Science Research*, *6*(1), 1-12.

Gurning, R. H., B. Rochaddi, and S. Widada. 2016. Pengaruh arus terhadap muatan padatan tersuspensi di muara sungai dan sekitar perairan kesunean, Cirebon. *Jurnal Oseanografi*, *5*(4), 512-522. https://ejournal3.undip.ac.id/index.php/joce/article/view/16096

Haidar, A. Z., G. Handoyo, and E. Indrayanti. 2021. Sebaran Salinitas secara Horisontal di Muara Sungai Bondet, Cirebon, Jawa Barat. *Journal of Marine Research*, *10*(2), 275-280. https://doi.org/10.14710/jmr.v10i2.30461

Hermawan, H. 2017. The development of intermodal transportation in Cirebon. *International Conference on Coastal and Delta Areas, 3*, 119-128. http://jurnal.unissula.ac.id/index.php/ICCDA/article/view/1991

Ichsari, L. F., G. Handoyo, H. Setiyono, A. Ismanto, J. Marwoto, M. Yusuf, and A. Rifai. 2020. Studi Komparasi Hasil Pengolahan Pasang Surut Dengan 3 Metode (Admiralty, Least Square Dan Fast Fourier Transform) Di Pelabuhan Malahayati, Banda Aceh. *Indonesian Journal of Oceanography*, *2*(2), 121-128. https://doi.org/10.14710/ijoce.v2i2.7985

Ismail, M. F. A., and A. Taofiqurohman. 2012. Simulasi Numeris Arus Pasang Surut di Perairan Cirebon. *Jurnal Akuatika*, *3*(1), 1-10. http://jurnal.unpad.ac.id/akuatika/article/view/469

Leksono, A., W. Atmodjo, and L. Maslukah. 2013. Studi Arus Laut Pada Musim Barat di Perairan Pantai Kota Cirebon. *Journal of Oceanography*, *2*(3), 206-213. https://ejournal3.undip.ac.id/index.php/joce/article/view/4554

Ongkosongo, O. S. R. 1989. *Pasang Surut*. Jakarta : Pusat Penelitian dan Pengembangan Oseanologi.

Pawlowicz, R., B. Beardsley, and S. Lentz. 2002. Classical tidal harmonic analysis including error estimates in MATLAB using T_TIDE. *Computers and Geosciences 28*, 929-937. https://doi.org/10.1016/S0098-3004(02)00013-4

Purnama, A. E., H. Hariadi, and S. Saputro. 2015. Pengaruh Arus, Pasang Surut Dan Debit Sungai Terhadap Distribusi Sedimen Tersuspensi di

Perairan Muara Sungai Ciberes, Cirebon. *Journal of Oceanography*, *4*(1), 74-84. https://ejournal3.undip.ac.id/index.php/joce/article/view/7659

Putra, A. Y. N., and D. G. Pratomo. 2017. Pengembangan Co-Tidal Chart Untuk Analisis Karakteristik Pasang Surut Perairan Laut Jawa. *Jurnal Teknik ITS*, *6*(2), G204-G207.

Subono, M., M. Zainuri, and I. B. Prasetyawan. 2017. Distribusi Klorofil-a dan Suhu Permukaan Laut di Perairan Astanajapura Kabupaten Cirebon. *Jurnal Oseanografi*, *6*(2), 377-386. https://ejournal3.undip.ac.id/index.php/joce/article/view/20094

Suhana, M. P., S. D. Nursyahnita, and F. Idris. 2023. Hydrodynamic model approach to study the pattern of sea surface currents around the Tanjungpinang City reclamation site. In *IOP Conference Series: Earth and Environmental Science* Vol. 1148, No. 1, p. 012014. https://iopscience.iop.org/article/10.1088/1755-1315/1148/1/012014

Suhendar, D. 2022. *Analisis Kenaikan Muka Laut dan Luas Genangan di Wilayah Pesisir Cirebon*. Bogor: Institut Pertanian Bogor. https://repository.ipb.ac.id/handle/123456789/110552

Tarunamulia, T., H. Hasnawi, R. A. Suhaimi, A. Mustafa, and M. Paena. 2015. Perspektif Pengembangan Perikanan Budidaya Berdasarkan Karakteristik Pantai di Teluk Gerupuk dan Teluk Bumbang Kabupaten Lombok Tengah Provinsi Nusa Tenggara Barat. *Jurnal Riset Akuakultur*, *10*(1), 117-126. http://dx.doi.org/10.15578/jra.10.1.2015.117-126

Tarunamulia, T., A. Faisal, and H. Hasnawi. 2016. Model Estimasi Potensi dan Arah Pengembangan Lahan Untuk Budidaya Tambak Di Kabupaten Cirebon Provinsi Jawa Barat. *Media Akuakultur*, *11*(1), 47-58. http://dx.doi.org/10.15578/ma.11.1.2016.47-58

Triatmodjo, B. 2003. *Pelabuhan*. Yogyakarta: Beta Offset.

Triatmodjo, B. 2010. *Perencanaan Pelabuhan*. Yogyakarta: Beta Offset.

Triatmodjo, B. 2012. *Perencanaan Bangunan Pantai*. Yogyakarta: Beta Offset.

Waluyo, A.F. Devi, and T. Arifin. 2021. Study of the Coastal Vulnerability in Indramayu Regency, Indonesia. *Journal of Marine Science*, *3*(2). https://doi.org/10.30564/jms.v3i2.2859

Wijaya, P. K., D. N. Sugianto, M. Muslim, A. Ismanto, W. Atmodjo, R. Widiaratih, and H. Hariyadi. 2019. Analisis Genangan Akibat Pasang Air Laut di Kabupaten Brebes. *Indonesian Journal of Oceanography*, *1*(1), 6-12. https://ejournal2.undip.ac.id/index.php/ijoce/article/view/6252/3459

Woodworth, P. L., and D. E. Smith. 2003. A One Year Comparison of Radar and Bubbler Tide Gauges at Liverpool. *International Hydrographic Review*, Vol 4 No. 3, 42-49. https://journals.lib.unb.ca/index.php/ihr/article/download/20630/23792