JOURNAL OF APPLIED GEOSPATIAL INFORMATION

Vol 5 No 2 2021

http://jurnal.polibatam.ac.id/index.php/JAGI
ISSN Online: 2579-3608

Tides Measurement and Tidal Analysis at Jakarta Bay

Hollanda Arief Kusuma[1,*], Muhammad Zainuddin Lubis[2], Nadya Oktaviani[3], Dwi Eny Djoko Setyono[3]

[1] Universitas Maritim Raja Ali Haji, Jl. Politeknik Senggarang, Kampus UMRAH, Tanjungpinang Kota, Tanjungpinang, Kepulauan Riau, Indonesia
[2] Politeknik Negeri Batam, Jl. Ahmad Yani Batam Kota. Kota Batam. Kepulauan Riau, Indonesia
[3] Research Division, Badan Informasi Geospasial, Jl. Raya Jakarta Bogor Km. 46 Cibinong, Kabupaten Bogor, Indonesia
[4] Research Unit for Natural Product Technology - LIPI, Jln. Yogya - Wonosari km 31,5 Gading, Playen, Gunungkidul, DIY, Indonesia
*Corresponding author e-mail : hollandakusuma@umrah.ac.id

Received: January 15, 2021
Accepted: September 06, 2021
Published: September 08, 2021

Abstract

Tides observation conducted for these purposes such as real-time depth of water, determination mean sea level and other tidal datums to establish a system of tidal benchmarks and data for production of tide and tidal current predictions. Center for Marine and Coastal Mapping – Geospatial Information System used water level and tides data mainly to correct the water depth measurement to chart datum. This study uses sea level observation data conducted from 20th February 2018 until 4th April 2018 at Marina Batavia, Jakarta. This study found that tidal types at this location is mixed diurnal using formzahl number. Astronomical and shallow water possible constituent were derived from the harmonic analysis. Fourier analysis gives clearly visual interpretation in frequency perspective. Several constituents inseparable because of short duration records.

Keywords: *Tides, Formzahl Number, Harmonic Analysis, Fourier Analysis*

1. Introduction

Tides are the periodic motion of seawater caused by the combined gravitational effects of the moon and the sun as they change position relative to the rotating earth. Tide is the superposition of hundreds of tidal constituents, each having a frequency that is the sum and difference of five fundamental frequencies. Tides observation are important for navigation; they influence accurate geodetic measurements; and they change the orbits and rotation of planets, moons, and stars in galaxies (Stewart, 2008).

Tides data derived from water level measurement. Water level measurements conducted for these purposes such as real-time depth of water available in harbors, estuaries, and lakes; determination mean sea level and other tidal datums to establish a system of tidal benchmarks; representation of the shoreline; sea level rise; and data for production of tide and tidal current predictions (NOAA, 2001; Talke et al., 2018; Trageser, 1995). One of existing technology to measure sea level is pressure system (Intergovernmental Oceanographic Commission, 2006). Tidal records from this system in few months duration can be used to predict tides many years into the future (Stewart, 2008).

Doodson (as cited in Flinchem & Jay, 2000) identified 400 tidal constituents in the gravitational potential with magnitudes >10-4 relative to the largest factor, including periods as long as 19 years. Tides have 146 components usually referred as harmonic constituent. These constituent derived into two type: 45 astronomical and 101 shallow water constituents (Pawlowicz et al., 2002). Usually only 6-12 astronomical constituents used to determine the tidal type and used in tides prediction because they have the largest amplitude. The model that has been derived for the Equilibrium Tide provide the knowledge that the tide is composed of a finite number of constituents of calculable frequency. It also provides a measure of their relative amplitudes so that we have an idea which constituents are important in the real tide (Intergovernmental Oceanographic Commission, 2006).

Tidal analysis and tidal prediction are next step after retrieving tides data. These steps can be looked in the time domain and frequency domain. Tidal analysis used to find amplitude

Jakarta as capital city of Indonesia located on the north coast of the island of Java in the Indonesian archipelago. Jakarta is prone from coastal tidal flood.

Several areas along the coast of Jakarta already have experienced tidal flooding during high tide periods (Abidin et al., 2012). (Takagi et al., 2016) demonstrate tidal flooding could potentially reach several kilometers inland in Jakarta Based on this simulation, tide measurement is very important to give sea level data that can help government manage coastal flood risk and flood mitigation system.

The purposes at this study are : (1) to find out the tidal datum from tides observation; (2) to determine tidal constituent from harmonic analysis and compare tidal prediction from astronomical, shallow-water, and all constituents; (3) to show dominant frequencies from tides observation based on Fourier analysis; (4) to determine the tidal type using formzahl number.

2. Materials and Methods

2.1. Field Survey

Tides observation conducted from 20 February 2018 until 4 April 2018 at Marina Batavia Sunda Kelapa Port, Jakarta (Figure 1). Tides observation used Valeport Tide Master to retrieve sea water level data. The sensor installed at the bottom of tide staff and tied using ties cable. Data interval was set for one minute logging interval with 30 seconds burst. Sea water level data will be used for tidal analysis.

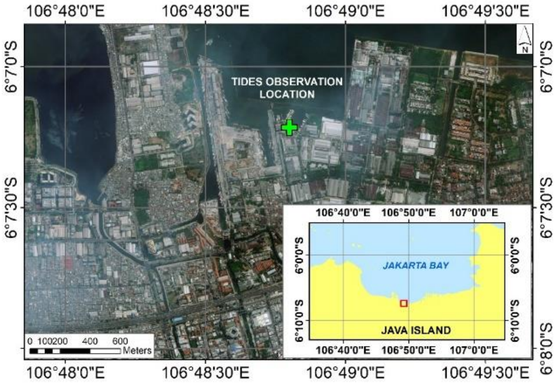

Figure 1. Tides observation station at Marina Batavia Sunda Kelapa Port, Jakarta (shown in red point)

Water level data retrieved from Valeport Tide Master using R232 Communication to the computer. Data downloaded using TideMaster Express software. Logged data saved in text file format. This instrument always creates a new file each time interrupted and set into a run mode or turned on (Valeport Limited, 2009). Every two days, tides data downloaded to the computer and give a blank data around 15 until 30 minutes.

This data gaps filled using interpolation and curve-fitting techniques. We used Piecewise Cubic Hermite Interpolating Polynomial. This interpolation used to obtain smoother fit to a given set of n points while preserving data points curve (Can, 2013; Yang and Huiyan, 1996). This interpolation done in Matlab. All data derived through gap-filling procedures are marked.

2.2. Harmonic Analysis

Harmonic analysis is one of the methods to predict future tides (Stewart, 2008). This method decomposed tides signal into harmonic constituents. Before doing harmonic analysis, all possible tidal constituents were calculated based on Nyquist frequency. List all possible tidal constituents based on (Pawlowicz et al., 2002) using *t_constituent*. Nyquist frequency is defined as twice the highest frequency that exists within time-varying, periodic signal. Determination of Nyquist frequency or Nyquist criterion use this equation (Gilat and Subramaniam, 2013) :

$$f_{nyquist} = \frac{1}{2f_{sample}}$$

The basis for the Nyquist frequency is a practical guideline for exact reconstruction of a signal by sampling. The signal can be reconstructed without distortion, from samples, provided that the sampling frequency must larger than Nyquist frequency (Gilat and Subramaniam, 2013). Nyquist frequency used to determine the lowest tidal constituent period based on sampling period/frequency.

Before harmonic analysis is conducted, determination of period (t_f) every possible tidal constituent from its frequency (f) was done using this equation :

$$t_f = \frac{1}{f} \tag{2}$$

If t_f less than observation sampling period (t_{obs}), tidal constituents frequency (f) was compared with the observation data sampling rate (f_{obs}) to check whether or not a tidal frequency is aliased. Aliasing occurs when the time step is allowed to exceed a certain limit. If t_{obs} is less than 2 (two) t_f or usually called as Nyquist frequency, tidal constituent has an original frequency. If aliased, then the corresponding aliasing frequency (f_a) calculated using this governing equation (Fu and Cazenave, 2001) :

$$f_a = \frac{|f \times t_{obs} - (f \times t_{obs}) + 0.5|}{t_{obs}} \tag{3}$$

Nodal correction in amplitude and phase accounts for slow modulations of the tidal forcing over the nodal period of 18.61 years. Nodal correction needed to truncate harmonic constituent. This procedure allows the Doodson series to be reduced from about 400 constituents to only a few tens (Fu and Cazenave, 2001). Nodal correction perform using calculation by Pawlowicz et al., (2002).

The harmonic analysis method of least squares is set up with harmonic constituents (m) to predict tide height (h) at any time (t) relative to mean water level (h_0) in the series by its amplitude (A) and phase (φ) (Boon, 2011) :

$$h_t = h_0 + \sum_{j=1}^{m} A_j \cos(\omega_j t - \varphi_j) \tag{4}$$

Harmonic analysis will give result in amplitude and phase for each tidal constituents. Amplitude of main luni-solar diurnal constituent (K1), main lunar diurnal constituent (O1), main lunar constituent (M2), and main solar constituent (S2) used to determine tidal type.

2.3. Error Estimation

Differences between observed water level (h) and predicted tide (h_t) from all data (n) was determined using root mean square error (RMSE). RMSE used as a standard statictical metric to measure model performance or prediction in this study and t e error distribution. Root mean square error (R) can be stated using this equation (Chai and Draxler, 2014) :

$$RMSE = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(h-h_t)^2} \tag{5}$$

2.4. Fourier Analysis

A Fast Fourier transform (FFT) is an algorithm that samples signals in time domain and divides it accordingly to its frequency components. The aim of most spectral methods is to analyze the energy spectrum of a signal after transformation from the time domain to the frequency domain (Boon, 2011). With Fourier analysis, we could make it possible to find all the main tidal frequencies and the difference between the original and the processed data. Fourier transform can be expressed as (James, 2002) :

$$F(t) = A_0/2 + \sum_{n=1}^{\infty} A_n \cos(n\omega_0 t) + B_n \sin(n\omega_0 t \tag{6}$$

2.5. Tidal Datum and Tidal Types

The principal tidal datums used in this study include Highest High Water Level (HHWL), Lowest Low Water Level (LLWL), and Mean Sea Level (MSL). MSL defined as the average of all high and low water levels. Tidal range defines as differences between Highest Water Level and Lowest Water Level (Boon, 2011).

Tidal type can be determined using the formzahl number. Formzahl number (F) is a convenient way to define the tidal type. It is computed as the sum of the main two diurnal amplitudes divided by the sum of the main two semidiurnal amplitudes using the formula below (Boon, 2011) :

$$F = \frac{A_{K1} + A_{O1}}{A_{M2} + A_{S2}} \tag{7}$$

where:

F = Formzahl number
A = amplitude
K1 = Main luni-solar diurnal constituent
O1 = Principle lunar diurnal constituent
M2 = Principal lunar constituent
S2 = Principal solar

When the formzahl number is less than 0.25, the tidal type is semidiurnal tides. Between 0.25 and 1.5, tidal type is mixed semidiurnal. Tidal type is mixed diurnal when formzahl number between 1.5 and 3.0. Above 3.0, the tidal type is fully diurnal.

3. RESULTS

3.1. Tides Observation

Tides observation at Marina Batavia shown in Figure 2. In this location, MSL was 134.2591 cm, HHWL was 190.3 cm, and LLWL was 88.5 cm. Tidal range was 101.8 cm. Total blank data periods were 16 hours 22 minutes. Blank data periods were smaller than observation time (42 days 15 hours and 59 minutes). Observation data shown in green and gap fill shown in red. From this observation, K1 amplitude was 18.91 cm, O1 amplitude was 12,55 cm, M2 amplitude was 6.70 cm, and S2 amplitude was 5.95 cm. Using tides formzahl number it was found that this location had mixed diurnal type (F= 2.49).

3.2. Harmonic Analysis

Based on observation data, 42 astronomical and 101 shallow water possible constituents can be derived using the Nyquist rule. All possible astronomical constituents derived for harmonic analysis shown in Figure 2. Table 1, From this analysis we can get the shortest astronomical tidal consituent frequency every 31.81 cycle per day (MSM) and the longest astronomical tidal constituent frequency every 0.35 cycle per day (M3) All possible shallow water constituents shown in Table 3. Shallow water constituents vary from 0.09 cycle per day to 0.94 cycle per day. SSA and SA constituent couldn’t derived because observation time was 42 days. We need 2193.43 hours or 91.31 days to derive SSA and 4381.088 hours or 182.55 days to derive SA (Safi’I and Rudiastuti, 2019).

All possible tidal constituents used in harmonic analysis method of least squares to reconstruct tide height. Tidal analysis using astronomical constituents (Figure 3), shallow water constituents (Figure 4), and all constituents (Figure 5) give different approximation from observation data. Tidal analysis using astronomical constituents give RMSE = 5.2 cm, shallow water constituents give RMSE = 16 cm, and all constituents (combining astronomical and shallow water constituents) give RMSE = 4.2 cm.

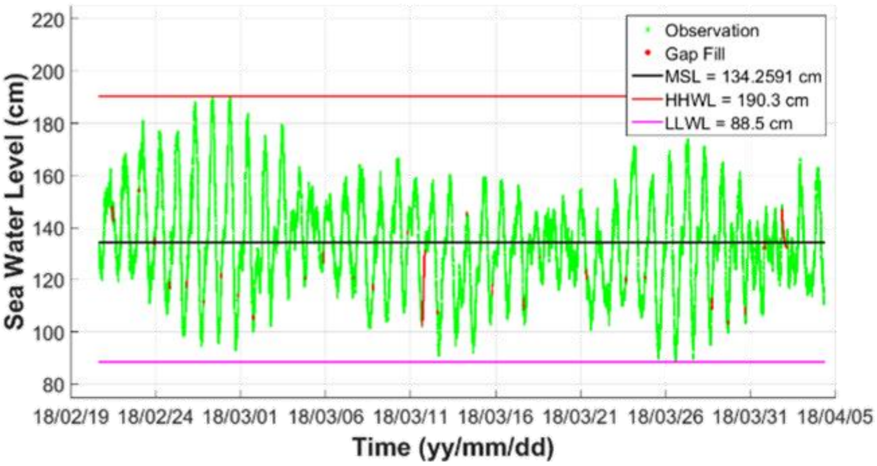

Figure 2. Tide height observation in Marina Batavia Station, Jakarta. Observation data shown in green point and red point indicate gap filled data using interpolation

Table 1. List of possible astronomical tidal constituents according to nyquist rule (CONS = name of constituent; f = frequency in cycle/day)

CONSTITUENT	FREQUENCY	CONSTITUENT	FREQUENCY	CONSTITUENT	FREQUENCY
MSM	31.81	**PI1**	1.01	**N2**	0.53
MM	27.55	**K1**	1	**NU2**	0.53
MSF	14.77	**P1**	1	**GAM2**	0.52
MF	13.66	**S1**	1	**H1**	0.52
ALP1	1.21	**PHI1**	0.99	**H2**	0.52
2Q1	1.17	**PSI1**	0.99	**M2**	0.52
SIG1	1.16	**THE1**	0.97	**L2**	0.51
Q1	1.12	**J1**	0.96	**LDA2**	0.51
RHO1	1.11	**OO1**	0.93	**K2**	0.5
O1	1.08	**UPS1**	0.9	**R2**	0.5
TAU1	1.07	**EPS2**	0.55	**S2**	0.5
BET1	1.04	**OQ2**	0.55	**T2**	0.5
CHI1	1.03	**2N2**	0.54	**ETA2**	0.49
NO1	1.03	**MU2**	0.54	**M3**	0.35

Table 2. List of possible shallow water tidal constituents according to nyquist rule (CONS = name of constituent; f = frequency in cycle/day)

CONSTITUENT	FREQUENCY	CONSTITUENT	FREQUENCY	CONSTITUENT	FREQUENCY
2PO1	0.94	**N4**	0.26	**ST41**	0.17
SO1	0.93	**SN4**	0.26	**ST42**	0.17
ST36	0.57	**ST10**	0.26	**3MK7**	0.15
2NS2	0.56	**ST39**	0.26	**M7**	0.15
ST1	0.56	**ST40**	0.26	**ST14**	0.15
ST37	0.56	**ST9**	0.26	**ST15**	0.15
ST2	0.55	**MK4**	0.25	**ST16**	0.15
O2	0.54	**MS4**	0.25	**ST17**	0.15
ST3	0.54	**S4**	0.25	**3MK8**	0.13
SNK2	0.53	**SK4**	0.25	**3MN8**	0.13
MKS2	0.52	**SL4**	0.25	**3MS8**	0.13
OP2	0.52	**2MK5**	0.21	**M8**	0.13
ST4	0.52	**2MO5**	0.21	**ST18**	0.13
ST5	0.51	**2MP5**	0.21	**ST19**	0.13
ST6	0.51	**3MP5**	0.21	**ST20**	0.13
2SK2	0.5	**MNK5**	0.21	**ST21**	0.13
MSN2	0.49	**MNO5**	0.21	**ST22**	0.13
ST7	0.49	**2SK5**	0.2	**ST23**	0.13
2SM2	0.48	**3KM5**	0.2	**ST24**	0.13
2SN2	0.48	**MSK5**	0.2	**ST25**	0.12
SKM2	0.48	**ST11**	0.18	**ST26**	0.12

ST38	0.48	**2MK6**	0.17	**4MK9**	0.11
MO3	0.35	**2MN6**	0.17	**ST27**	0.11
NO3	0.35	**2MS6**	0.17	**M10**	0.1
MK3	0.34	**2NM6**	0.17	**ST28**	0.1
NK3	0.34	**2SM6**	0.17	**ST29**	0.1
SO3	0.34	**M6**	0.17	**ST30**	0.1
SK3	0.33	**MKN6**	0.17	**ST31**	0.1
SP3	0.33	**MSK6**	0.17	**ST32**	0.1
ST8	0.27	**MSN6**	0.17	**M12**	0.09
3MS4	0.26	**NSK6**	0.17	**ST33**	0.09
KN4	0.26	**S6**	0.17	**ST34**	0.09
M4	0.26	**ST12**	0.17	**ST35**	0.09
MN4	0.26	**ST13**	0.17		

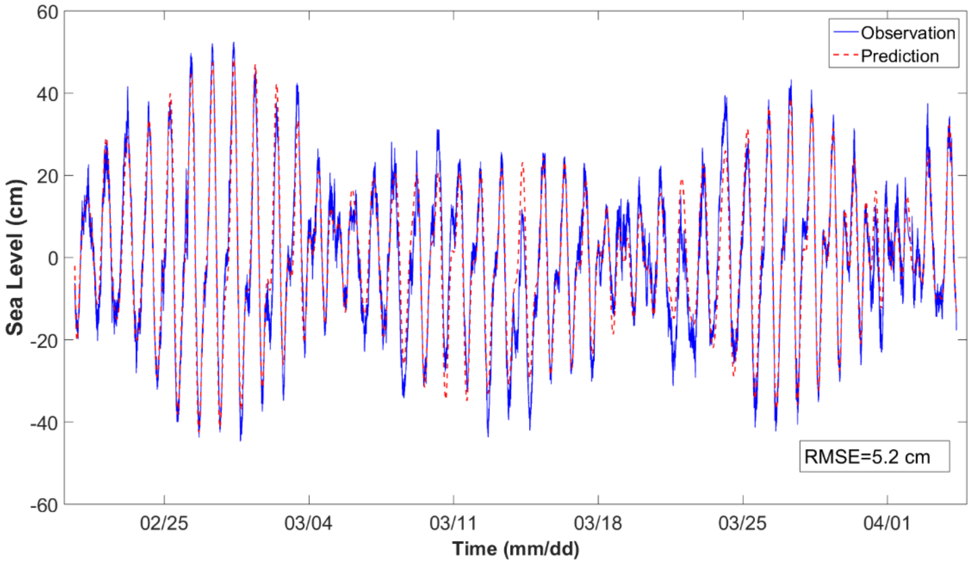

Figure 3. Tidal analysis using astronomical constituents and comparison with observation data

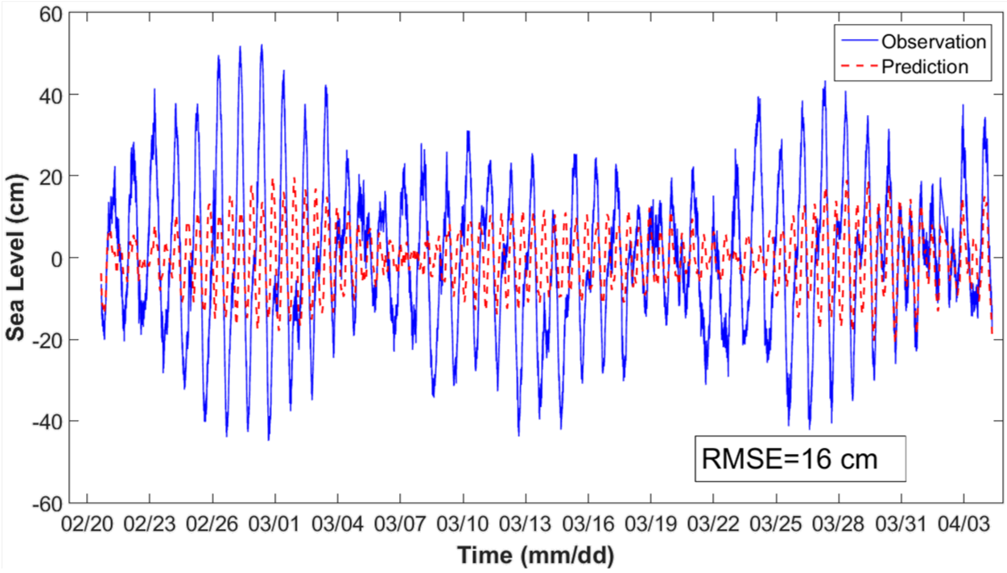

Figure 4. Tidal analysis using shallow-water constituents and comparison with observation data

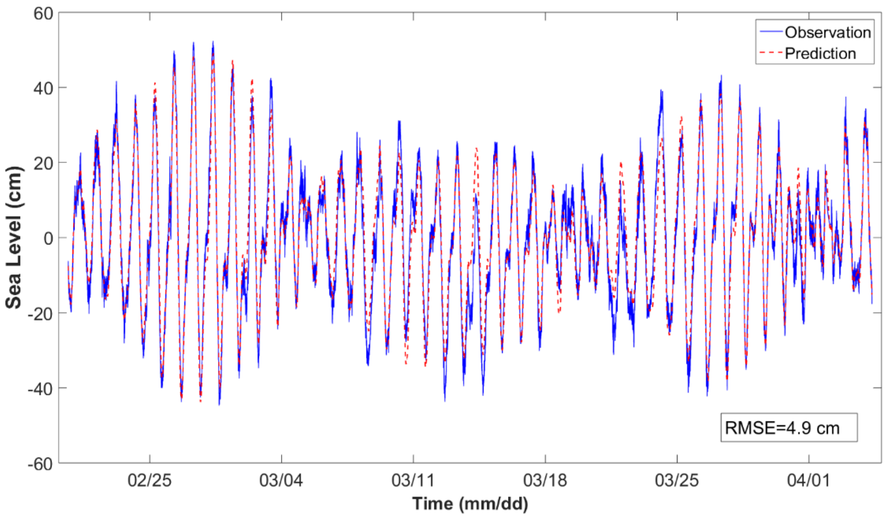

Figure 5. Tidal analysis using all constituents and comparison with observation data

3.3. Fourier Analysis

Figure 6 shows the result of the fourier transformation of tides observation data. From this figure, we can see that low frequency gives big effect (frequency < 3 cycles per days). The most influent tidal frequency is the K1 constituent (f=1.0027 cycle per day, amplitude = 13.16 cm) followed by O1 constituent (f=0.92954 cycle per day, amplitude = 12,66 cm). Attaching diurnal constituents (Q1, O1, K1, J1, OO1), semidiurnal constituents (N2, M2, L2, S2, K2), and shallow water constituents (M4, M6, MK3, S4, S6, SP3, M3, M8, MS4) to fourier transformation give better interpretation (Figure 7). From this observation, it shown that shallow water constituents give a small effect in tide height compared to diurnal and semidiurnal constituents based on amplitude value. Figure 8 shown the diurnal constituents and its amplitude. Figure 9 shown the amplitude of semidiurnal constituents.

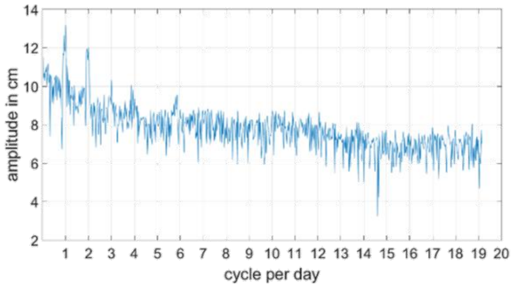

Figure 6. Fast Fourier Transform (FFT) from observation data at Marina Batavia

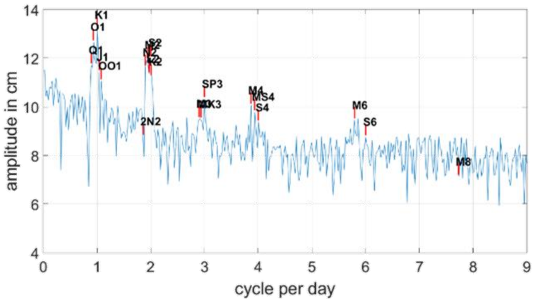

Figure 7. 20 constituents (M4, M6, MK3, S4, S6, SP3, M3, M8, MS4, M2, S2, N2, K2, L2, 2N2, K1, O1, J1, OO1, and Q1) identified from tides observation

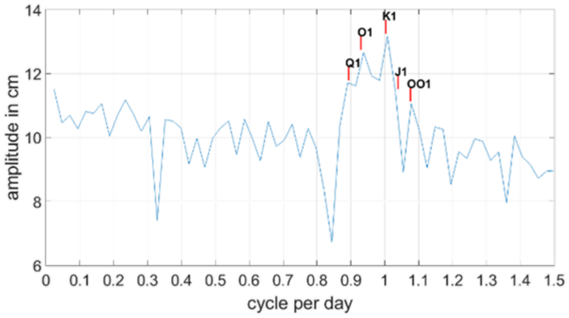

Figure 8. Diurnal constituents identified from tides observation

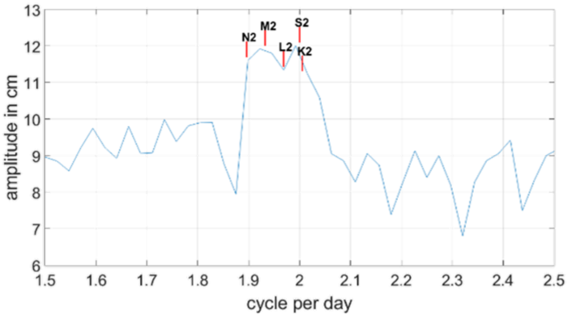

Figure 9. Semidiurnal constituents identified from tides observation

4. DISCUSSION

Tidal type in Jakarta Bay based on observation is similar with (Wyrtki, 1961). Different tidal type occur in this location based on several research. Christon, Djunaedi, and Purba (2012) observed tidal type in this location was diurnal. Haryono and Narni (2004) states tidal type was mixed semidiurnal. Indriani, Kurniawati, and Hendri (2010) showed that tidal type in Jakarta was diurnal. It was assumed that different formzahl number occur because observation time is different and duration of observation is too short.

Based on harmonic analysis, the combination between astronomical and shallow constituents give more accurate approximation than others. Boon (2011) states that adding additional tidal constituents increase the final accuracy of a given day's predictions. However, adding right constituents with wrong amplitude and/or phase will add disinformation to the prediction. Much of the remaining percentage is due to non-tidal variations caused by weather - winds and changes in atmospheric pressure. Tidal analysis using shallow-water constituents give high RMSE because combined sum from these shallow water constituents wave signal gives small amplitude based on Figure 7 compared to observation data. Tidal analysis using shallow water constituents only gives a poor result although our tides observation location is at the harbour.

Based on Figure 3 and Figure 4, Tidal height from harmonic analysis have a different value significantly in neap and spring tide compared to observation data. This value difference can be reduced by adding more record length. A record of one or more years allows a considerable number of tidal constituents to be determined accurately (Boon, 2011). Emery and Aubrey (1991) said that improvements in prediction accuracy can be done by 1) analysis of longer recordings to eliminate effects of "noise" caused by local weather, (2) addition of further harmonic components to account for effects of local seiches, or reflections of long-period waves caused by local topography, and (3) additional harmonic constituents for longer-term changes of Earth-Moon-Sun geometry or more complex tidal interactions.

The tidal frequencies used in harmonic analysis were not fit perfectly with the frequencies in fourier analysis. This occur because fourier analysis tidal frequency derived from duration observation using Eq 2 and harmonic analysis tidal frequency defined from *t_constituent* in Pawlowicz et al., (2002). Tidal frequency in fourier analysis was depended on the length of data record. This difference between tidal frequencies in fourier analysis and harmonic analysis occur because observation time length were not exactly same with tidal constituents period (Thomson and Emery, 2014). Tidal analysis using fourier analysis can show that it is possible to find all the main tidal frequencies (Holinde et al., 2015) and shows the spectral amplitude of the tide waves (Manzano-Agugliaro et al., 2011).

5. CONCLUSION

This study shown that the Mean Tide Level was 134.2591 cm, Highest High Water Level was 190.3 cm, and Lowest Low Water Level was 88.5 cm. Tidal analysis using Harmonic analysis and Fourier analysis provide a general evaluation of the harmonic components and their amplitude. 42 astronomical and 101 shallow water possible constituents can be derived from harmonic analysis. Tides height reproduction from harmonic analysis gives the best error of 4.2 cm using combination astronomical and shallow water constituents. Harmonic analysis using astronomical constituents gives RMSE of 5.2 cm and using shallow water constituents only give RMSE of 16 cm. Based on Fourier analysis, tidal frequencies occur in our tides observation data. The most influent tidal frequency is the K1 and followed by O1 constituent. Tidal type at Jakarta Bay is mixed diurnal type.

ACKNOWLEDGEMENT

This study was supported primarily by DIPA BIG 2018. We are indebted to Mr. Dudy D Wijaya and his team for helping and providing sources codes; We thank you to Mr. Dwi Eny Djoko Setyono for his valuable and constructive suggestions and Mr. Ibnu Sofian for his guidance in this study.

REFERENCES

Abidin, H.Z., Hadi, S., Andreas, H., Gumilar, I., Nurmaulia, S.L., Fukuda, Y., 2012. Coastal Flooding of Jakarta (Indonesia): Causes and Impacts. p. 393.

Boon, J.D., 2011. Secrets of the Tide: Tide and Tidal Current Analysis and Applications, Storm Surges and Sea Level Trends, Secrets of the Tide: Tide and Tidal Current Analysis and Applications, Storm Surges and Sea Level Trends. Woodhead Publishing Limited, Cambridge.

Can, E., 2013. Piecewise Cubic Approximation for Data. Am. J. Appl. Math. 1, 24. https://doi.org/10.11648/j.ajam.20130102.11

Chai, T., Draxler, R.R., 2014. Root mean square error (RMSE) or mean absolute error (MAE)? - Arguments against avoiding RMSE in the literature. Geosci. Model Dev. 7, 1247–1250. https://doi.org/10.5194/gmd-7-1247-2014

Christon, Djunaedi, O.S., Purba, N.P., 2012. Pengaruh tinggi pasang surut terhadap pertumbuhan dan biomassa daun lamun Enhalus acoroides di Pulau Pari Kepulauan Seribu Jakarta. J. Perikan. dan Kelaut. 3, 287–294.

Emery, K.O., Aubrey, D.G., 1991. Sea Levels, Land Levels, and Tide Gauges. https://doi.org/10.1007/978-1-4613-9101-2

Flinchem, E.P., Jay, D.A., 2000. An introduction to wavelet transform tidal analysis methods. Estuar. Coast. Shelf Sci. 51, 177–200. https://doi.org/10.1006/ecss.2000.0586

Fu, L.-L., Cazenave, A. (Eds.), 2001. Satellite Altimetry and Earth Sciences, Volume 69, 1st ed. Academic Press, San Diego.

Gilat, A., Subramaniam, V., 2013. Numerical Methods for Engineers and Scientists, 3rd Edition. John Wiley & Sons, Inc.

Haryono, Narni, S., 2004. Karakteristik Pasang Surut di Pulau Jawa. J. Forum Tek. 28, 1–5.

Holinde, L., Badewien, T.H., Freund, J.A., Stanev, E. V., Zielinski, O., 2015. Processing of water level derived from water pressure data at the Time Series Station Spiekeroog. Earth Syst. Sci. Data 7, 289–297. https://doi.org/10.5194/essd-7-289-2015

Indriani, Kurniawati, N., Hendri, M., 2010. Simulasi Pemodelan Arus Pasang Surut di Luar Kolam Pelabuhan Tanjung Priok Menggunakan Perangkat Lunak. Maspari J. 01, 79–83.

Intergovernmental Oceanographic Commission, 2006. Manual on Sea Level Measurement and Interpretation, Volume IV: An Update to 2006, IOC Manuals and Guides No.14, Vol. IV ; JCOMM Technical Report No. 31. Paris.

Manzano-Agugliaro, F., Corchete, V., Lastra, X.B., 2011. Spectral analysis of tide waves in the

Strait of Gibraltar. Sci. Res. Essays 6, 453–462.

NOAA, 2001. Tidal Datums and Their Applications. Special Publication No. CO-OPS 1. Silver Spring, Maryland.

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

Safi'I, A.N., Rudiastuti, A.W., 2019. Tidal Correlation using Altimetry Satellite. IOP Conf. Ser. Earth Environ. Sci. 284. https://doi.org/10.1088/1755-1315/284/1/012036

Stewart, R.H., 2008. Introduction To Physical Oceanography.

Takagi, H., Esteban, M., Mikami, T., Fujii, D., 2016. Projection of coastal floods in 2050 Jakarta. Urban Clim. 17, 135–145. https://doi.org/10.1016/j.uclim.2016.05.003

Talke, S.A., Kemp, A.C., Woodruff, J., 2018. Relative Sea Level , Tides , and Extreme Water Levels in Boston Harbor From 1825 to 2018. J. Geophys. Res. Ocean. 123, 1–20. https://doi.org/10.1029/2017JC013645

Thomson, R.E., Emery, W.J., 2014. Data Analysis Methods in Physical Oceanography (Third Edition), Third Edit. ed. Elsevier, Boston. https://doi.org/https://doi.org/10.1016/B978-0-12-387782-6.01001-2

Trageser, J.I., 1995. A new family of real-time wave and tide instruments, in: OCEANS '95. MTS/IEEE. Challenges of Our Changing Global Environment. Conference Proceedings. pp. 1760–1768. https://doi.org/10.1109/OCEANS.1995.528850

Valeport Limited, 2009. TideMaster Operating Manual.

Wyrtki, K., 1961. Physical Oceanography of the Southeast Asian Waters, Naga Report 2. La Jolla.

Yang, L., Huiyan, Z., 1996. Shape preserving piecewise cubic interpolation. Appl. Math. 11, 419–424. https://doi.org/10.1007/bf02662881