Accuracy Assessment of the Geospatial Information Agency's Tidal Prediction

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Abstract: Bathymetric survey requires tide data to reduce sounding data to the preferability vertical datum. A tidal observation is performed in the vicinity of the survey area to achieve the tide correction for the depth measurement. In order to obtain vertical references, it is necessary to conduct a direct tide observation for at least 15 days period. An in-situ tidal observation takes high operating cost and needs a lot of effort to install a tide gauge in the survey area. Thus, to reduce the time and the cost for tide observation, tidal prediction data can be used as an alternative solution. This research attempted to perform the accuracy assessment of the tidal prediction model from Geospatial Information Agency (BIG). There are 128 tidal stations from BIG which spread across Indonesia archipelago. These stations provide real time tide observation. Based on the data, BIG established a tidal prediction model for Indonesia waters. The research examined the BIG tide model with direct tidal observation data from two locations (Ambon and Cilacap). The results show the accuracy of tidal prediction from BIG is 0.085m for Ambon and 0.385m for Cilacap. The residual of MSL, HHWL, and LLWL between tidal prediction and in-situ data in Ambon are -0.022m, -0.063m and +0.020m, and in Cilacap are -0.147m, -0.122m, and -0.173m, respectively.

1 INTRODUCTION

A hydrographic surveyor has to be able to associate all measured depths with respect to a vertical datum, regardless of the water surface variation along the time of sounding. A water level datum can be a 'tidal datum' when defined in terms of a certain phase of tide. The datum to which depths on a chart are referred is known as the chart datum (IHO, 2005). In Indonesian coastal waters, Mean Sea Level (MSL) is used for topographic map and Lowest Low Water Level (LLWL) is used for hydrographic map (Republik Indonesia, 2011) are computed from tabulation of the observations of the tide, in this case the average of the tidal waters everyday over a 19 year period.

The tide plays an important role both in the land and sea surveying. In Indonesian's Constituent No. 4 2011 about Geospatial Information Law, states that (Republik Indonesia, 2011):

1) The Indonesian base map must consist of coastline (Article 12),
2) The coastline is a adjoint line between the land and the sea which is affected by the tides (Article 13, paragraph 1).
3) There are three types of coastlines: a Lowest Low Water Level (LLWL) is used as nautical chart reference, Mean Sea Level (MSL) is used as topographic reference and the Highest High Water Level (HHWL) (Article 13, paragraph 2).

Tides are the phenomenon of rising and falling of sea surface caused by the attraction between earth and celestial bodies such as the Moon and the Sun (IHO, 2005; Triatmojo, 1999; Parker, 2007). Although the mass of the moon is smaller than the mass of the sun, but because its distance to the earth is much closer, the influence of the moon's attraction on the earth is greater than the influence of the sun. Tidal generating forces vary inversely as the cube of the distance from the tide generating object. Gravitational attractive forces only vary inversely to the square of the distance between two objects (Thurman, 1994). The attraction of the moon that affects the tides is 2.2 times greater than the sun attraction.

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The observation of sea surface variation can be applied in the following areas (IHO, 2005): a. water level requirement planning; b. preliminary water level zoning development; c. control water level station operation; d. supplemental water level station installation, operation, and removal; e. data quality control, processing, and tabulation; f. datum computation and datum recovery; g. generation of water level reducers and the final tidal zoning. The observation of the water level variation is also essential for supporting hydrographic survey. However, the development of a tidal station in fields, either permanent or temporally, is unintelligible. The complication of developing a tidal station depends on the topography of the shore and the accessibility of the survey area, especially if it is located in a remote area.

The Geospatial Information Agency (BIG) is the government institution that responsible for providing geospatial data in Indonesia. One of the responsibility of BIG is providing tidal data across the country with an online tide prediction service (BIG, 2018). Yet, this tide prediction is lack of information related to the tide data (i.e.: the vertical reference of downloaded data is unclear). Thus, the data cannot be directly applied for determining vertical reference and depth correction in hydrographic survey. This study aims to examine the accuracy of tidal prediction data downloaded from tides.big.go.id with in-situ data in two locations of tidal observations. Furthermore, the study also analyzed the feasibility of this tidal prediction for depth correction during the hydrographic survey.

2 DATA AND METHOD

2.1 Data and Research Area

The research used tidal prediction data downloaded from tides.big.go.id/pasut. The data are adjusted to the location and time of in-situ data measurement. There are two in-situ tidal observation used in the research: Cilacap and Ambon. The geographical coordinates of these locations and the date when the data were taken be seen in Table 1. The aerial image of the in-situ stations is shown in Fig 1).

2.2 Method

The downloaded tidal prediction is in ASCII format comprises geographical positions of the station, the date and the time observation, and the water elevation (Fig 2). The time is recorded in UTC (Universal Time Coordinate). The time is converted to the local time, which is in Ambon is UTC + 9 (Eastern Indonesia Time) and in Cilacap is UTC + 7 (Western Indonesia Time). The tidal prediction and in-situ data, then, were plotted overlaid each other to see the difference between the tidal prediction and in-situ data. The accuracy of the tidal prediction is represented by Root Mean Square error (RMSe).

Table 1: Geographical coordinates of the tidal staff.

No	Location	Latitude (S)	Longitude (E)	Date
1	Cilacap	7°44'37.34"	108°59'57.24"	12 July – 26 July 2017
2	Ambon	3°39'42.34"	128°10'43.05”	14 August – 28 August 2018

Figure 1: The location of the tidal staff in Cilacap (top) and Ambon (bottom).

Table 2: Tidal prediction data in UTC.

Latitude	Longitude	Date	Time	Z (m)
-7.743	108,9992	8/14/2018	0:00:00	0,211
-7.743	108,9992	8/14/2018	1:00:00	0,601
-7.743	108,9992	8/14/2018	2:00:00	0,866
-7.743	108,9992	8/14/2018	3:00:00	0,936
-7.743	108,9992	8/14/2018	4:00:00	0,787
-7.743	108,9992	8/14/2018	5:00:00	0,452
-7.743	108,9992	8/14/2018	6:00:00	0,009
-7.743	108,9992	8/14/2018	7:00:00	-0,436
-7.743	108,9992	8/14/2018	8:00:00	-0,777
-7.743	108,9992	8/14/2018	9:00:00	-0,933
-7.743	108,9992	8/14/2018	10:00:00	-0,87
-7.743	108,9992	8/14/2018	11:00:00	-0,607
-7.743	108,9992	8/14/2018	12:00:00	-0,213

The tide analysis was performed using least square estimation to predict the variation of the water level over the time which is shown in the following mathematical equation (Stephenson, 2016):

$$\hat{y}(t) = Z + \sum_{n=1}^{N} A_n \cos\left(\frac{\pi}{180}(\omega_n t - \psi_n)\right) \quad (1)$$

where:

y(t) = water level at time t

Z = Mean Sea Level

N = number of tide components, from n=1 to n=N

An = Amplitude of the average harmonic components

ωn = angular speed of tidal wave component.

t = time based on GMT.

ψn = Greenwich phase of tidal component n at t = 0 which varies before corrected.

Figure 2: shows the tide prediction and in-situ data overlaid at the same time reference and the height of the tide prediction is adjusted to the same reference of the in-situ data.

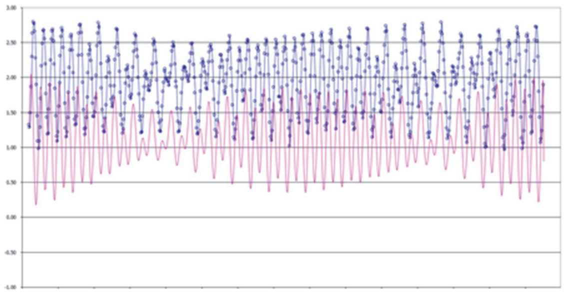

Figure 2: The tide prediction (blue) and in-situ (blue) graph use the same reference.

The difference between the tide prediction and in-situ data is computed to get the accuracy. Here the accuracy is represented by root mean square error. RMSe is a frequently used measure of the difference between values predicted by a model and the values observed from the environment that is being modelled. These individual differences are also called residuals, and the RMSe serves to aggregate them into a single measure of predictive power. The RMSe of a model prediction with respect to the estimated variable Xmodel is defined as the square root of the mean squared error (FEMA, 2016):

$$E_{rms} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(p_i - m_i)^2} \quad (2)$$

where Erms is dimensional RMSe, pi is tidal prediction data, mi is tidal in-situ observed values the time i. In this case pi is the tidal heights of BIG tidal prediction and mi is the tidal heights of in-situ observation. The accuracy of the amplitude of tidal constituents can also be computed by Eq. 2.

Vertical references that are often used in topographic and hydrographic mapping are computed from the amplitude of each tidal component that has been determined by least square method based on Eq. 1. According to (Latief, et.al, 2018), highest high water level and lowest low water level can be determined by these equations:

$$HHWL = Z0 + (M2 + S2 + P1 + K2 + O1 + K1 \quad (3)$$

$$LLWL = Z0 - (M2 + S2 + P1 + K2 + O1 + K1) \quad (4)$$

3 RESULTS AND DISCUSSION

The analysis of the accuracy was performed at two locations which will be explained more detail at the following section.

3.1 Ambon

The tide prediction from BIG and the tide observation at Ambon waters can be seen in the tide graph in Figure 3. Based on the graph, the tidal prediction has a similar pattern with tidal in-situ (in-situ is blue and prediction is red in the Fig 3). The residual for each tidal elevation from time to time can be seen in a green color. The Erms on Eq. 2, the accuracy of BIG tidal prediction is ± 8.5 cm. Based on the tidal constituents produced by least square method in Table 3 the residual of the amplitude of the 9 (nine) tidal prediction and in-situ less than 13 cm. The accuracy of tidal prediction amplitude to in-situ is 5.3 cm computed by Erms. The phase of M2, N2, K2, M4 and MS4 tidal prediction are slower than tidal in-situ and otherwise for other phases.

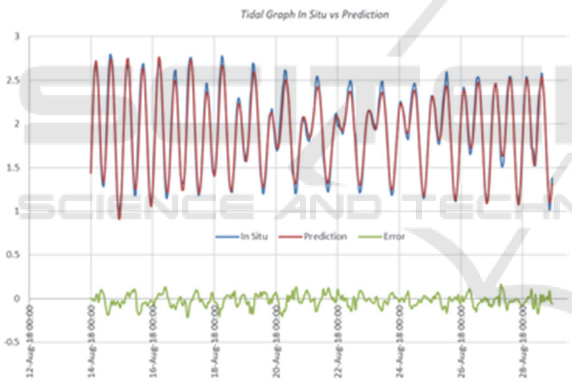

Figure 3: Tidal prediction and in-situ graph at Ambon.

According to the results of the tidal component calculation for data prediction and in-situ, the vertical reference such as Mean Sea Level (MSL), High Highest Water Level (HHWL) and Lowest Low Water Level (LLWL) which are used in the hydrographic mapping can be computed from Eq. 3 and Eq. 4. The height difference of MSL, HHWL and LLWL between tidal prediction and in-situ can be seen on Table 4. It shows that the height residual of MSL (-2.2 cm), HHWL (-6.3 cm) and LLWL (2 cm) are very small.

Table 3: Amplitude and Phase of tidal constituents at Ambon.

Constituents	Symbol	Phase (degree)		Amplitude (m)	
		In-situ	Prediction	In-situ	Prediction
Main lunar constituent	M_2	234.4557°	230.8995°	0.5657	0.5604
Main solar constituent	S_2	208.3771°	217.7096°	0.1055	0.2322
Lunar constituent, due to Earth-Moon distance	N_2	206.3367°	195.3842°	0.1058	0.1178
Soli-lunar constituent, due to the change of declination	K_2	209.7330°	47.8323°	0.0750	0.0646
Soli-lunar constituent	K_1	223.3428°	237.4431°	0.2739	0.1885
Main lunar constituent	O_1	112.9094°	123.5641°	0.1718	0.1343
Main solar constituent	P_1	7.3897°	240.0212°	0.0575	0.0569
Main lunar constituent	M_4	263.2144°	119.0107°	0.0078	0.0001
Soli-lunar constituent	MS_4	296.2383°	129.8310°	0.0173	0.0001

Table 4: Vertical references which can be derived from tidal constituents.

Vertical Reference	Abbreviation	In-situ (m)	Prediction (m)	Residual (m)
Mean Sea Level	MSL	1.9337	1.9121	-0.0216
Highest High Water Level	HHWL	3.2121	3.1489	-0.0632
Lowest Low Water Level	LLWL	0.6553	0.6752	0.0199

3.2 Cilacap

The same method used for Ambon was performed for analyzing tidal prediction and in-situ data at the Cilacap waters. This is described on tidal chart (Figure 4). From the graph, we can see that the tidal prediction and in-situ have the same pattern. However, the amplitudes of some points are very different. Generally, the height difference of tidal prediction and in-situ is between -0,5 m and 1 m. Using Erms formula on Eq. 2, the accuracy of BIG tidal prediction in Cilacap is ± 38.5 cm. Based on the tidal constituents produced by least square method in

Table 5, the residual of the amplitude of the tidal prediction and in-situ less than 3 cm and the accuracy of amplitude of tidal prediction to in-situ is 1.4 cm. The phase of M2, N2, K2, and S2 are faster than tidal in-situ and otherwise for other phases.

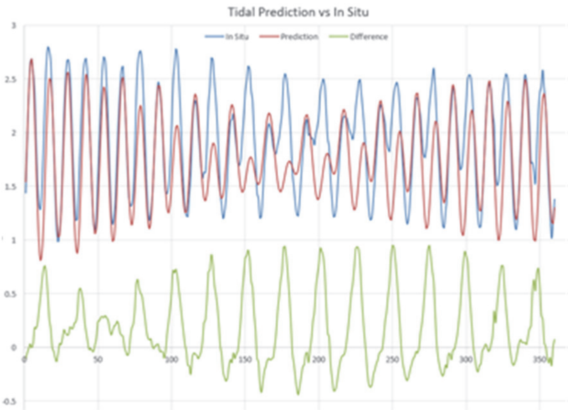

Figure 4: Tidal prediction and in-situ chart at Cilacap.

According to the results of the tidal component calculation for data prediction and in-situ, the height difference of MSL, HHWL and LLWL between tidal shows that the difference of height of MSL (-14.7 cm), HHWL (-12.2 cm) and LLWL (-17.32 cm) are relatively small.

Table 5: Amplitude and phase of tidal constituents at Cilacap.

Constituents	Symbol	Phase (degree)		Amplitude (m)	
		In-situ	Prediction	In-situ	Prediction
Average water level	Z_0			2.2360	2.0886
Main lunar constituent	M_2	47.1235°	30.7097°	0.4948	0.5024
Main solar constituent	S_2	36.1647°	13.2859°	0.2583	0.2906
Lunar constituent, due to Earth-Moon distance	N_2	209.5123°	202.0489°	0.1241	0.1204
Soli-lunar constituent, due to the change of declination	K_2	161.1427°	153.9478°	0.1032	0.1111
Soli-lunar constituent	K_1	122.5043°	286.9136°	0.2003	0.1776
Main lunar constituent	O_1	7.7426°	186.8371°	0.1161	0.1162
Main solar constituent	P_1	41.9251°	218.2835°	0.1121	0.1127
Main lunar constituent	M_4	294.0919°	319.4123°	0.0001	0.0002
Soli-lunar constituent	MS_4	281.3738°	328.9046°	0.0001	0.0002

Table 6: Vertical reference which can be derived from tidal constituents at Cilacap.

Vertical Reference	Abbreviation	In-situ (m)	Prediction (m)	Difference (m)
Mean Sea Level	MSL	2.2360	2.0886	-0.1472
Highest High Water Level	HHWL	3.5207	3.3992	-0.1215
Lowest Low Water Level	LLWL	0.9512	0.7780	-0.1732

4 CONCLUSIONS

In this study, an accuracy assessment has performed to examine the tide model from Geospatial Information Agency and in-situ observations from two areas, Cilacap and Ambon. Based on the study, both data have similar pattern in hourly basis for 15 days period. The residual height of water level between tidal prediction and in-situ in Ambon is 0.085m and in Cilacap is 0.385m. The differences of MSL, HHWL, and LLWL between tidal prediction and in-situ data in Ambon are -0.022m, -0.063m and +0.020m and in Cilacap are -0.147m, -0.122m and -0.173m.

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