Generating of Cotidal Dataset by Spatial Interpolation Techniques

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Abstract

Tidal observation is the main requirement in depth reduction to a specific vertical datum thus ensuring safe navigation prerequisite is met. The determination of water level (e.g. highest astronomical tide and mean sea level) can be achieved through tidal analysis which is crucial for the application of hydrographic and sustainable coastal development. Due to severity of the site conditions and resource constrains, not all areas can be represented just by one tidal station dataset. Significance changes in tidal characteristic from one location to another limit the application of single tide station to represent an entire observed area. Previously, it was recommended that series of tide stations were erected to properly represent and justify the reliability of the tidal data over the entire observed area. However, this approach requires great resources in providing multiple tide stations. Therefore an alternative approach in the estimation of tidal data; which is the concept of cotidal data needs to be introduced in order to provide tidal dataset. This is due to the fact that cotidal datasets does not require physical tide gauge to be positioned at a location as well as the need for observing tide data for a long period of time. Interpolation techniques are required in cotidal approach by analysing tidal data from multiple tide station networks. Typically, a number of real observed tidal data are used in generating the cotidal data. However, to further the cost-effective measures, real observed tidal data were being replaced with predicted tidal data published by Malaysian Navy. Therefore, this paper evaluates the reliability of cotidal data generated through predicted tides instead of real observed tide. A comparative study of the tide levels between real observed tides against cotidal data through statistical analysis was conducted. Three interpolation techniques were carried out at two locations of the coastal of Peninsular Malaysia as testing grounds. Final analysis will indicate the best interpolation method based on acceptable limits drawn by the International Hydrographic Organization (IHO). The application of cotidal will definitely save in terms of time; cost and effort to acquire reliable tide information especially for hydrographic and sustainable coastal development.

Keywords: Tide, Cotidal, Spatial Interpolation, Sustainable Coastal Sustainable, Hydrography

1.0 Introduction

Observation of tide is a primary requirement in hydrography survey to reduce the depths so that the user will know the lowest sea surface at a specific time. Water level can be determined by doing some tidal analysis using tide data which is crucial for navigation as it provides the information about the safe depth of the sea to the navigators and also for the use of coastal development.

Generally, establishment of tide gauge at desired place is needed in order to acquire real tide data. Currently, there are 33 tide ports established along coastal of Peninsular Malaysia and 31 tides ports along Sabah and Sarawak coastal (RMN, 2015). Those tide observational locations were established by Royal Malaysian Navy, International Tidal Survey and Department of Survey and Mapping Malaysia; and are very important to provide real tide data in order to produce tide predictions as well as tidal level (e.g. mean sea level and highest astronomical tide). However, those tide observational locations do not cover all observed coastal areas. There are locations far from any tide gauge and there is no tide observation being done. Typically, the observation of tide needs to be carried out for a long period of time. This consumes numerous resources to obtain the required tide data at unoberved location. Instead of doing observation of tide for sufficiently long over a period of time, estimation of tidal data; which is a concept of cotidal can be done. This concept does not require physical tide gauge to be placed on location. This method can also be applied when there are limited existing tide observational locations.

The concept of cotidal is to save time and cost to gain tidal information. Cotidal as spatial data is used purposely to support hydrography survey as well as coastal development either back shore or shore front areas. The most important purpose is to determine the water levels in order to support the coastal sustainable development; this development needs tidal information especially in aspect of land use for back shore sustainable development such as recreation, residential and tourism, light and heavy industry, agriculture (including aquaculture) and Environmental Sensitive Area (KSAS).

Estimation of oceanographic variables especially at coastal areas such as tidal data can be difficult. Spatial interpolation is the most convenient way of meeting this need i.e. to produce the irregularly-spaced geospatial data (Hess, 2002). Estimation of tide data which involve interpolation of tidal data from multiple tide station networks is presented here. This study concentrates on doing interpolation of tidal data from three reference tide ports. The selection of three reference tide ports is based on interpolation method of triangular network.

Predicted tidal data published by Malaysian Navy were being used in the interpolation process; instead using real observed tidal data for cost and time effectiveness. In this study, cotidal results generated by predicted tidal data then being evaluate for the reliability.

The main objective of this paper is to produce the cotidal using methods in spatial interpolation. A special focus is set on the evaluation of processed cotidal results from methods in spatial interpolation. The evaluation of cotidal results is based on the acceptable limit drawn by International Hydrographic Organization (IHO).

2.0 Materials and methods

2.1 Study area

In this study, two study areas were selected. Both study areas were located at coast of Peninsular Malaysia which experienced different type of tide. First study area located at West Coast of Peninsular Malaysia experienced semi diurnal tide where predominantly have two high waters and two low waters each day. This study area involved interpolation of tide data at three reference ports which are Teluk Ewa port, Kuala Perlis port and Kedah Pier port in order to produce cotidal for Kuah port.

Meanwhile, second study area sited at East coast of Peninsular Malaysia. The tide characteristic of second study area is diurnal where experienced one high water and one low water each day. Second study area involved interpolation process of tide data at three reference ports which are Endau port, Teluk Tekek port and Tanjung Sedili port to produce cotidal for Mersing port.

2.2 Data gathering and preparation

Typically, real observed tide data is used in interpolation process. However, in this study, real observed tide data is replaced with predicted tide data published by Malaysian Navy. Here, the reliability of cotidal results generated by predicted tide will be evaluated.

One month of predicted tide data at every reference port are used in the interpolation process. Acquiring the same period of predicted tide data at Kuah port and Mersing port is also needed in order to carry out comparing process with cotidal results of both ports. Tide data obtained from Malaysian Navy was stored in spreadsheet program which then is stored in notepad format with column in hour, longitude, latitude and height of water. This data is for interpolation process in Geographical Information System (GIS) tool.

2.3 Interpolation process

Three method of interpolation that use predicted tide data were applied. They were Inverse distance weighting (IDW), kriging and natural neighbors. These interpolation methods were carried out at height of water for every hour at reference ports. This process will generate cotidal data at every hour for Kuah port and Mersing port.

Inverse distance weighting (IDW) is a widely used and easy to implement interpolation method (Paul et al, 2012). It is one of the simpler interpolation techniques that do not require pre-modeling like kriging (Tomczak, 1998). IDW method also shows points closer to the predicted area have more influence than points of further distance (Johnston et al, 2001). In our case, the influence of the measured cotidal data is weighted according to the distance between tide data of reference ports. Furthermore, distance between reference ports does not being set during the processing due to measured cotidal data are acquired base on interpolation method of triangular network.

Second method of interpolation being used in this study is kriging. Kriging is synonymous with optimal prediction as kriging attempts to make inferences on unobserved values (Cressie, 1993). Kriging is a stochastic technique similar to inverse distance weighted averaging in that it uses a linear combination of weights at known points to estimate the value at an unknown point (Fred, 1996). It is differs from other interpolation methods because it can assess the quality of prediction with estimated prediction errors (Chang, 2010).

Third method of interpolation being used to generate cotidal is natural neighbor. This method assumes that any point within a polygon is closer to the polygon’s known point than any other known points. It does not use an interpolator but require initial triangulation for connecting known points (Chang, 2010).

Geographical Information System (GIS) has been used as set of tool for the interpolation process. GIS is a computer-based tool for mapping and analyzing things that exist and events that happen on Earth. It is capable to analyze and display the dataset into the computer. In GIS application, spatial interpolation is typically applied to a raster with estimates made for all cells (Chang, 2010).

2.4 Comparing the water levels

Once the cotidal are generated, then the comparing process between cotidal and predicted tide data are carried out. Cotidal of Kuah port will be compared with Kuah predicted tide data and same process goes to cotidal of Mersing port where will be compared with Mersing predicted tide data. Comparing water levels take part for mean height of tide, lowest tide and highest tide.

2.5 Comparing the standard deviation

The root mean square error (RMSE) is used to assess which interpolation method can generate cotidal with accuracy within the acceptable limits drawn by International Hydrographic Organization (IHO). The procedure is to calculate the error between the cotidal data and the predicted tide data so as to measure the precision of the interpolation methods. The standard deviation or root mean square error (RMSE) can be calculated as follows:

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(Z_i - Z)^2} \qquad (1)$$

where Z is the mean of estimated data; Z_i is the estimated data for every hour i ($i = 1, \ldots, n$); and n is the number of data used for the estimation.

3.0 Result and analysis

Predicted tide data of Teluk Ewa port, Kuala Perlis port and Kedah Pier port was interpolated using IDW method, kriging method and natural neighbor method in order to acquire cotidal data for Kuah port. Mean height of tide, lowest tide and highest tide of cotidal result had been compared with predicted tides data of same period. Based on comparison results at Kuah port, the differences are range from 0 m to 0.3 m (Table 1). The error reading of 0.3 m is denotes by kriging method of interpolation for Kuah port.

Meanwhile, cotidal data at Mersing port are acquired from interpolation of Endau port, Teluk Tekek port and Tanjung Sedili port which also using IDW method, kriging method and natural neighbor method. The range of differences for mean height of tide, lowest tide and highest tide are from 0 m to 0.1 m (Table 1). The range of differences at Mersing port shows slightly better range for all method of interpolation than at Kuah port.

Table 1: Comparison of water levels between cotidal and predicted tide

Cotidal port	**Interpolation method**	**Amplitudes**	**Height (m)**		**Difference**
			Cotidal	**Predicted tides**	
Kuah	IDW	Mean	1.6	1.5	0.1
		Lowest	0.1	0.1	0.0
		Highest	3.2	3.0	0.2
	Kriging	Mean	1.6	1.5	0.1
		Lower	0.3	0.1	0.2
		Higher	3.3	3.0	0.3
	Natural neighbor	Mean	1.7	1.5	0.2
		Lower	0.2	0.1	0.1
		Higher	3.2	3.0	0.2
Mersing	IDW	Mean	2.1	2.2	0.1
		Lower	0.5	0.5	0.0
		Higher	3.6	3.6	0.0
	Kriging	Mean	2.1	2.2	0.1
		Lower	0.5	0.5	0.0
		Higher	3.5	3.6	0.1
	Natural neighbor	Mean	2.1	2.2	0.1
		Lower	0.5	0.5	0.0
		Higher	3.5	3.6	0.0

For further analysis, the focus is set on the cotidal RMSE results. The range for RMSE results is from 0.0421 m to 0.0819 m for all method of interpolation at Kuah port and Mersing port (Table 2). Based on the standard deviation, kriging method shows better result than the other two methods. However, IDW method performs better standard deviation result at Mersing port. The standard deviation for IDW method and kriging method at Mersing port performs quite similar result with slightly differences. The natural neighbor method does not perform better RMSE result at both cotidal ports. It has been shown that the interpolation for cotidal data do not rely as much on neighboring tides data.

Table 2: Standard deviation of cotidal result for method of interpolation

Method of interpolation	***RMSE* (m)**	
	Kuah port	**Mersing port**
IDW	0.0778	0.0421
Kriging	0.0685	0.0423
Natural Neighbor	0.0819	0.0520

4.0 Conclusions and Recommendations

As a conclusion, all spatial interpolation method can generate cotidal with the accuracy and precision within the acceptable limits drawn by IHO. This is indicated by water levels and RMSE results for every method of spatial interpolation used in this study (Table 1, Table 2). By comparing the RMSE results, all results provide standard deviation results in accordance to the accuracy allowance. This accuracy allowance is proved by referring to *Chapter 5, Page 275, subsection 2.2.1 (a), Manual on Hydrography, Publication M-13, International Hydrographic Organization* which state that the allowable error or tolerance of tides is 0.2 m where the total error comprises of 0.1 m for measurement error of the gauge/sensor and 0.1 m for processing error. This is also confirms that one month predicted tide data can be used for interpolation process to generate cotidal as the error does not exceed the allowable 0.2 m limitation.

There is still some weaknesses and inadequacy in this study that can be improved. Further studies on several elements could improve the analysis and results of this study. It is recommended that this study to be carried out for interpolation using more than one month (e.g. 3 months, 6 months and 12 months) tide data to observe the various results. Furthermore, it is recommended that interpolation of tide data at the multiple tide stations network is carried out for other locations along the coastal of Peninsular Malaysia as well as Sabah and Sarawak.

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