Tidal Datum Consistency for Marine Cadastre Littoral Zone Commencement in Malaysia

Rasheila RAHIBULSADRI, Abdullah Hisam OMAR, Ashraf ABDULLAH, Wan Muhammad Aizzat WAN AZHAR, CHAN Keat Lim , TENG Chee Hua, TAN Ah Bah, and Hasan JAMIL, Malaysia

Key words: tidal datum, Lowest Astronomical Tide (LAT), littoral zone, marine cadastre

SUMMARY

Marine cadastre is the key in managing a complex marine administration. The rapid development of coastal areas in Malaysia for economic generation activities and public interests has triggered the needs for a new system of marine administration. A tidal datum is a standard elevation defined by a certain phase of the tide. Tidal datum is also the basis for establishing privately owned land, state owned land, territorial sea, exclusive economic zone, and high seas boundaries. This paper reviews some concepts and issues pertaining to the delineation of the tidal line for marine cadastre in Malaysia. This study will assess the use of Lowest Astronomical Tide (LAT) as reference datum in marine cadastre. Tide data acquired from Department of Survey and Mapping Malaysia (DSMM) will be processed using Total Tide Solution (TOTIS) to compute the LAT as the reference datum for marine cadastre. From the tidal data observed, tidal analysis can be made on sea levels, chart datum, types of tide and tidal constituents. This paper aims to produce the tidal lines and littoral zone for use in marine cadastre procedures and practices. Based on the analysis, it can be concluded that the LAT is consistent and can potentially be used for marine cadastre reference level in order to improve the effectiveness of implementing the marine cadastre.

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1. INTRODUCTION

A marine cadastre is a 3D marine parcel administration system with respect to the legal and systematic technical arrangement of marine spatial rights, restrictions and responsibilities for marine space activities (Ashraf et. al, 2013). The littoral zone is the region that lies between the lines of high tide and low tide. The physical location of the coastline is commonly referred to as the line of intersection between a specified tidal datum and the terrain. The exact tidal datum used for this purpose will lead to a different realization of the coastline (Nathan, 2008).

Mean Sea Level (MSL) is normally used as a reference level for various land development applications while a low water level is applied as the reference level. The vertical datum used as a reference level in the marine environment is called chart datum. A chart datum is usually related to the mean of low ocean surfaces, such as Mean Lower Low Water Spring (MLLWS), Mean Lower Low Water (MLLW), Mean Low Water (MLW), Low Water (LW), Mean Low Water Spring (MLWS) or Lowest Astronomical Tide (LAT) and not all countries in the world is using the same level as chart datum for their marine administration.

Malaysia is a federal state with marine jurisdiction and management responsibility split between the states and the federal government. Following the Emergency (Essential Powers) Ordinance, No.7 1969, now loosened and replaced by Territorial Water Act 2012, territorial water shall be constructed as a reference to such part of the sea that is adjacent to control the coast there of not exceeding 3 nautical miles measured from low water mark. In this situation, the states control up to 3 nautical miles from low water mark whilst the federal government has jurisdiction and management responsibility from the said 3 nautical miles limit to the outer edge of the EEZ and continental shelf. Through this specific jurisdiction by United Nations Convention on the Law of the Sea (UNCLOS), Malaysia enacted numerous acts related to the sea zone (Ashraf, 2011).

In addition, Article 3(1) of the Emergency (Essential Powers) Ordinance, No. 7/1969 mentioned territorial water shall be measured in accordance with the principle of the Geneva Convention on the Territorial Sea and Contiguous Zone (1958), therefore accordingly whatever maritime baseline applied by Malaysia to define its international maritime boundary, the same baseline shall be used to define the local states maritime boundary. Legally empowered by this Ordinance, if Malaysia applies a straight baseline, theoretically it's State also have its marine jurisdiction measure from a straight baseline (Robin, 2013). The base points for the determination of baseline using GPS as shown in Figure 1. According to Malaysia National Land Code, the limit of Land Cadastre administration is referred to the level of Highest Astronomical Tide (HAT). This description will create an uncertainty of jurisdiction of space between HAT and to the low water mark.

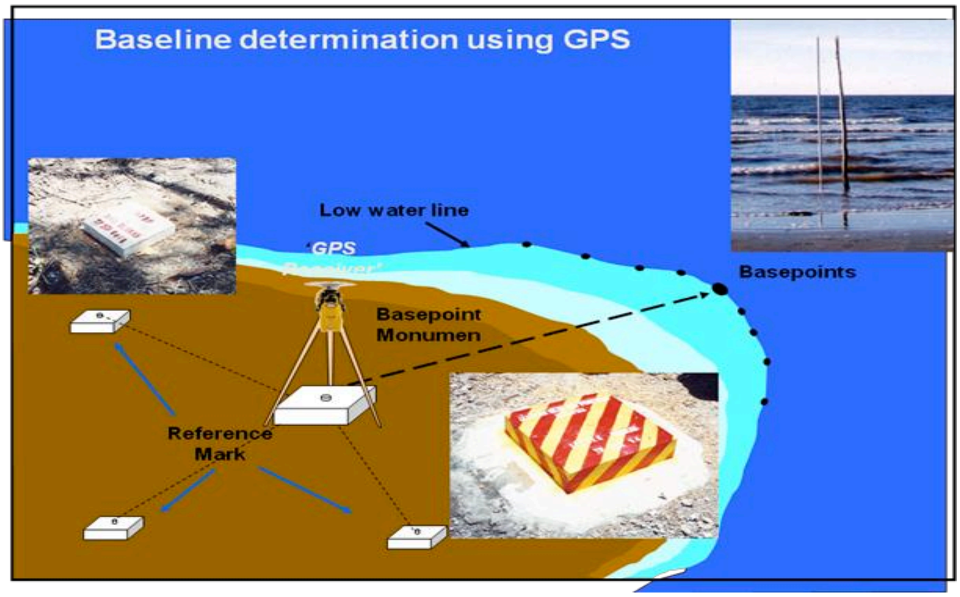

Figure 1 Baseline determination using GPS method (JUPEM 2007; Robin 2013)

Based on the above mentioned acts, the determination of LAT as the reference level for marine cadastre is crucial. This study is an attempt to present the tidal datum consistency and the use of Lowest Astronomical Tide (LAT) and Highest Astronomical Tide (HAT) for marine cadastre littoral zone commencement in Malaysia.

The objective of this paper is to present some fundamental principles that can be applied to produce the tidal line and analyze the consistency of LAT to use as a reference level in marine cadastre. It is proposed a computational technique of tidal datum to obtain the water level value based on LAT. In order to delineate the littoral zone, several of datasets have been identified to derive the tidal line.

2. TIDAL DATUM

Tides are the periodic vertical movement of water on the Earth's surface. It is also defined as the periodic variation in the surface level of the oceans and of bays, gulfs, inlets, and estuaries, caused by gravitational of the moon and the sun. It also can be defined as the rise and fall of sea level. The measurement of the tide is called tide observation and the equipment used for the observation is called tide stations. Tide gauge is the device that we use to measure the changes in sea level.
A tidal datum is a standard elevation defined by a certain phase of the tide. Tidal datum is used as a reference level for measuring local water levels and should not be extended into

areas having differing oceanographic characteristics without substantial measurements. The definition of tidal datum for Lowest Astronomical Tide and Highest Astronomical Tide is given in Table 1.

Table 1 Definition of International Hydrographic Organization (IHO) tidal datum (IHB, 2010)

Level	Definition
LAT(HAT)	LAT (HAT) is defined as the lowest (highest) tide level which can be predicted to occur under average meteorological conditions and under any combination of astronomical conditions. It is recommended that LAT and HAT be calculated either over a minimum period of 19 years using harmonic constants derived from a minimum of one year's observations or by other proven methods known to give reliable results. Tide levels should, if possible, reflect the estimated error values obtained during the determination of these levels.

IHO resolves that Lowest Astronomical Tide (LAT) shall be adopted as chart datum where tides have an appreciable effect on the water level. A tidal datum is essentially the average of all the water elevations (high, low or mean) over an 18.6 year period. This eliminates most meteorological effects on water level. It is defined more simplistically as averaged stages of the tide such as Mean Sea Level (MSL), Mean High Water (MHW) and Mean Lower Low Water (MLLW). Tidal datum elevations vary significantly with geographic distance especially in shallow water. They are used as references to measure local water levels and should not be extended into areas having differing oceanographic characteristics without substantiating measurements. In order that they may be recovered when needed such as datum are referenced to bench mark (FIG, 2006).

2.1 Consistency of Tidal Datum

Tides data from 12 Department of Survey and Mapping, Malaysia (DSMM) tide gauge stations have been acquired to assist the determination of tidal datum as shown in Figure 2. Tides data period is started from the year 1993 to 2012. The computation of tidal datum is carried out using Total Tides Station (TOTIS) tidal analysis software. The software is able to compute the tidal datum based on the number of tidal constituents in relation to the number of months. The computation of tidal datum will focus on the study area Langkawi Island. The type of tides in Langkawi Island is semi-diurnal, consisting of two high tides and two low tides of nearly equal level of the lunar day. Langkawi Island has been chosen as a study case because it has the nature of business such as infrastructure, development and tourism. This area was selected as it has a lot of marine institutional and related agencies to support on marine administration.

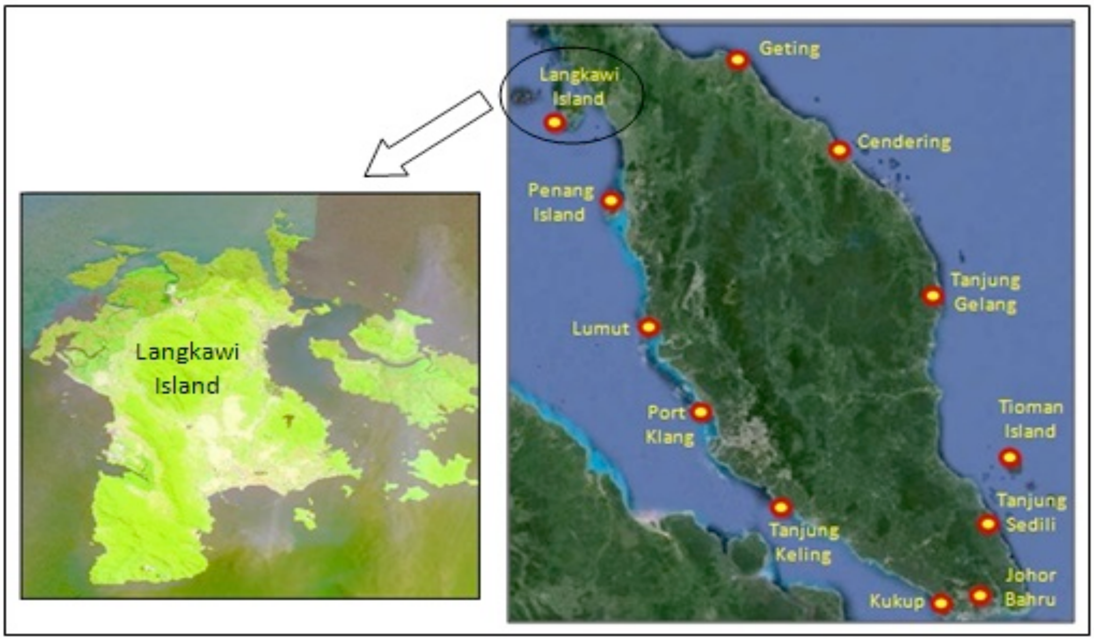

Figure 2 Tide gauge stations location in Peninsular Malaysia. Case study location, Langkawi Island.

The computation of water level value is based on LAT. The number of constituents will reflect the result. The analysis will cover the following periods: 15 days, 1 month, 3 months, 8 months, 1 year and 18.6 years. Table 2 tabulates the tide analysis period for 2012. Figure 3 show consistency of zero LAT based on MSL.

Table 2 Day of Analysis for DSMM Tide Gauge Station in Langkawi Island based on Lowest Astronomical Tide (LAT) system

Period of Observation		LAT	MLWS	MLWN	**MSL**	MHWN	MHWS	HAT
15 Days	1/1/2012 – 16/1/2012	Zero LAT	0.350	1.201	**1.555**	1.909	2.760	2.991
1 Month	1/1/2012 – 31/1/2012		0.429	1.323	**1.683**	2.043	2.938	3.315
3 Months	1/1/2012 – 31/3/2012		0.443	1.476	**1.760**	2.043	3.076	3.499
8 Months	1/1/2012 – 1/9/2012		0.531	1.411	**1.778**	2.144	3.024	3.557
1 Year	1/1/2012 – 31/12/2012		0.532	1.428	**1.790**	2.151	3.047	3.542
18.6 Years (Ideally)	15/12/1992 –24/7/2011		0.560	1.451	**1.792**	2.133	3.024	3.509

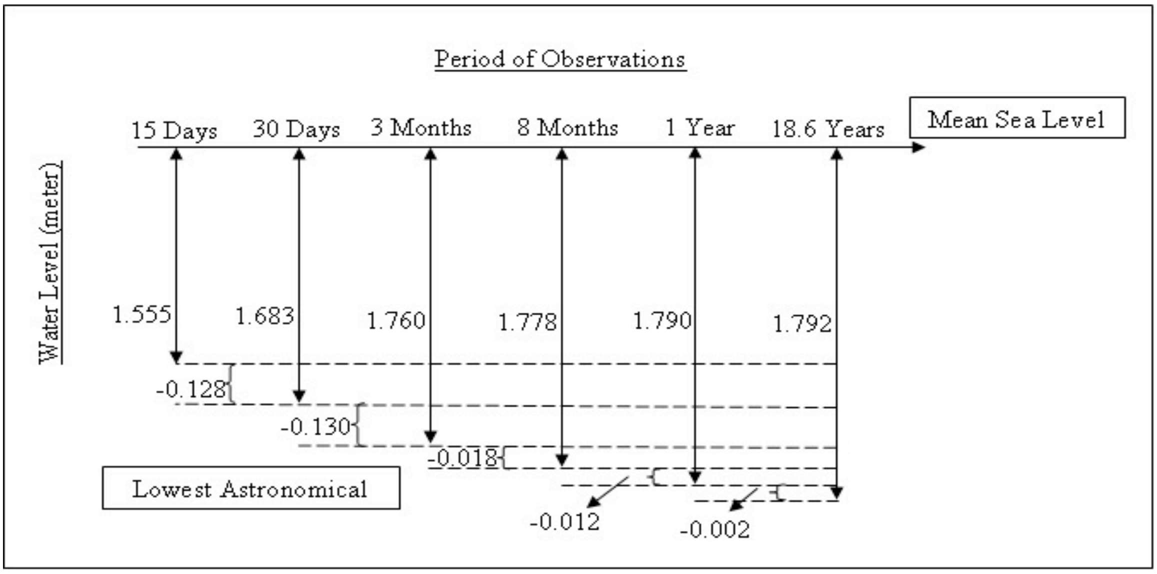

Figure 3 Consistency of zero Lowest Astronomical Tide (LAT) based on Mean Sea Level (MSL)

Table 3 Standard deviation value for MSL

	15 Days	1 Month	3 Month	8 Month	1 Year	18.6 Years
Standard Deviation MSL	3.09 x 10^{-6}	1.10 x 10^{-6}	2.46 x 10^{-6}	0.36 x 10^{-6}	0.21 x 10^{-6}	0.09 x 10^{-6}

Table 4 and 5 show the day of analysis for 11 stations based on LAT system.

Table 4 Tidal analysis for semi-diurnal station

Station	Period of Observation	Type of Tide	LAT	MLWS	MLWN	MSL	MHWN	MHWS	HAT
Penang Island	10/7/1995 – 14/3/2013	Semi-diurnal	Zero LAT	0.707	1.378	1.601	1.825	2.495	2.950
Port Klang	15/12/2008 – 20/3/2013			1.112	2.440	3.148	3.857	5.185	6.028
Lumut	15/12/2009 – 11/3/2013			0.672	1.352	1.761	2.170	2.850	3.367
Johor Bahru	15/12/2005 – 18/3/2013			1.056	1.733	2.266	2.798	3.476	4.006
Kukup	11/12/2003 – 18/3/2013			0.390	1.254	1.747	2.240	3.104	3.903
Tanjung Keling	15/12/2006 – 20/3/2013			0.315	0.902	1.230	1.558	2.145	2.740

Table 5 Tidal analysis for diurnal station

Station	Period of Observation	Type of Tide	LAT	MLLW	MHLW	MSL	MLHW	MHHW	HAT
Cendering	15/12/2010– 20/1/2012	Diurnal	Zero LAT	0.418	1.015	1.490	1.965	2.561	3.082
Geting	14/8/1994 – 19/3/2013			0.176	0.390	0.648	0.906	1.120	1.511
Tanjung Gelang	15/12/2009 – 18/3/2013			0.547	1.627	1.911	2.195	3.274	3.823
Tanjung Sedili	15/12/2001 – 19/3/2013			0.535	1.614	1.762	1.910	2.990	3.343
Tioman Island	25/5/1994 – 16/12/2012			0.472	1.636	1.919	2.201	3.365	3.795

Table 6 shows the constituents value for 18.6 years at DSMM tide gauge station in Langkawi Island.

Table 6 Constituents value of M2, S2, N2, K2, K1, O1, P1, Q1 for 18.6 years observation at Langkawi.

	Amplitude	Phase
M2	0.786985	359.349945
S2	0.445315	36.221198
N2	0.144344	353.303280
K2	0.124387	50.304571
K1	0.167017	1.768064
O1	0.050599	294.273881
P1	0.050425	354.727930
Q1	0.008412	236.493450

3. TIDAL MODEL FOR MARINE CADASTRE COMMENCEMENT

There are a number of tidal lines in littoral zone. In order to delineate the littoral zone, the location of the tidal line needs to be defined clearly. Tidal line describes the line of intersection between a specified tidal datum and the foreshore terrain (Nathan, 2001). The tidal datum calculated from the hydrodynamic model and it involves the computation of the harmonic constituents. The harmonic constituents from tide observation can be derived using TOTIS software.

The model of LAT surfaces has been discussed and derived using various strategies. LAT will be modelled relative to a geoid, after which the ellipsoid heights of LAT will be obtained by adding geoid heights to the model LAT values. Modeling LAT relative to a geiod is realized by referencing the hydrodynamic model to the chosen geoid (Slobbe et. al, 2012). Terrain Irregular Network (TIN) and Digital Elevation Model (DEM) are needed to view the 3D model of seabed profile. The set of constituents used to derive the observed LAT values is that set for which the RMS of the differences between the observe water levels and the reconstructed astronomical tide is lowest. The tidal lines can be derived from the integration of various datasets as follows:

–Topography data
–Bathymetry data (multi-beam sonar)
–Seabed topography data
–Tide data
–Light Detection and Ranging (LIDAR)
–High resolution satellite image

There are two methods in creating tidal model. The first method is by interpolating the tide height between tide gauges. But this method only works well along open coastlines. It suffers major limitations in complex foreshore like bays, islands and rivers. So in this case, the second method is introduced. This method is localized the hydrodynamic model. Hydrodynamic model represent the movement of water at the sea and solving governing equations for oceanic movement. This models derived by using bathymetry data to get the depth, solving the LTE numerically, and ocean tidal constants observed by tide gauges as the boundary conditions. The examples of global tidal model are FES2004, GOT4.8 and ORI96. The final data or result of tidal model contains the constituents and the constituents will separate by phase and amplitude. The amplitude and phase contain the longitude, latitude and the value of the respective constituents. Figure 4 and Figure 5 shows the phase and amplitude of the S2 constituent from the model Ori96.

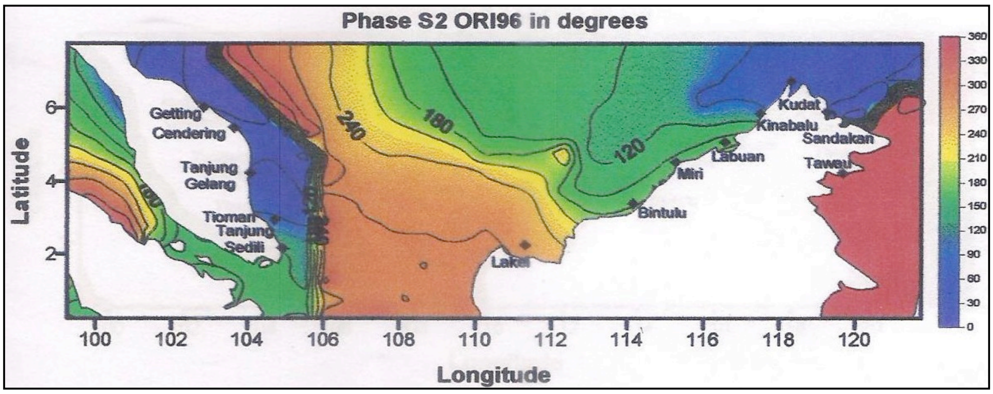

Figure 4 Phase of the S2 constituent from the model Ori96 (Vella, 2000)

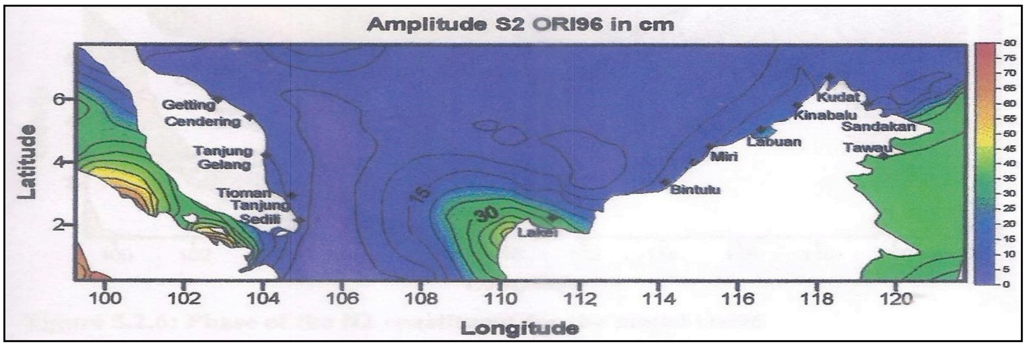

Figure 5 Amplitude of the S2 constituent from model Ori96 (Vella, 2000)

4. LITTORAL ZONE GENERATION

The littoral zone is the region that lies between the lines of high tide and low tide. The tidal lines are formed by the intersection of the tidal datum and the foreshore terrain. A technique to delineating the littoral zone is by using the digital model the coastal terrain and digital model of the ocean tides. The first step of delineating the littoral zone is deriving the foreshore terrain model and tidal models. Then the LAT and HAT line can be compute by using bathymetric and topographic DEMs from the terrain model. The LAT line is derived from the bathymetric data and the HAT line derived from bathymetric data (Nathan, 2008). Figure 6 to Figure 9 show the shoreline from all sources of data. Figure 10 shows the littoral zone boundaries as delineate from terrain and tidal models.

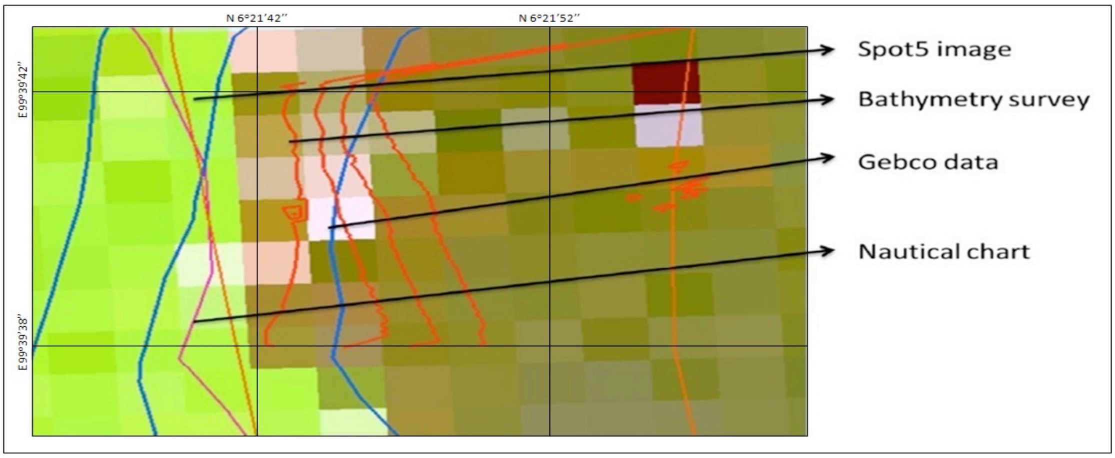

Figure 6 Shoreline from all the sources of data.

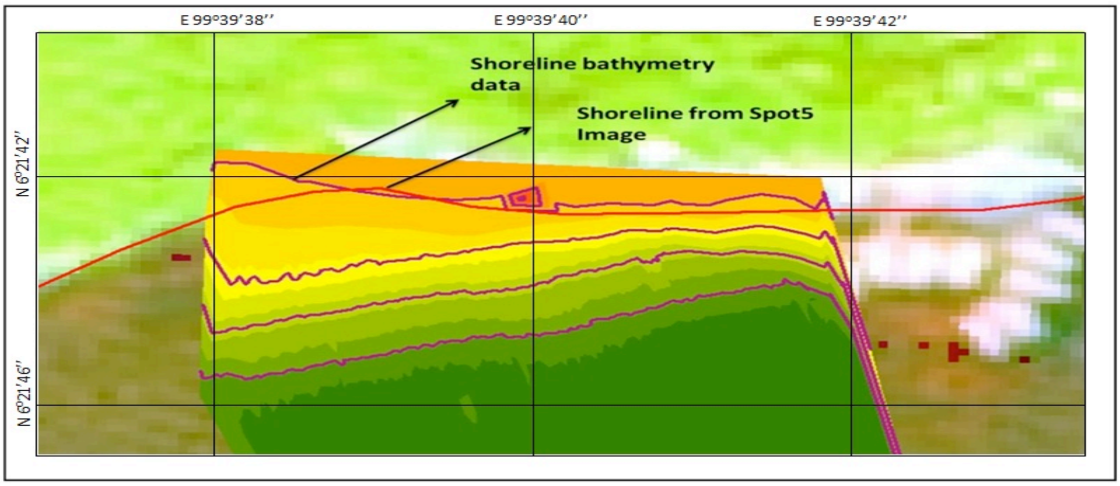

Figure 7 Shoreline from bathymetry data and Spot5 Image.

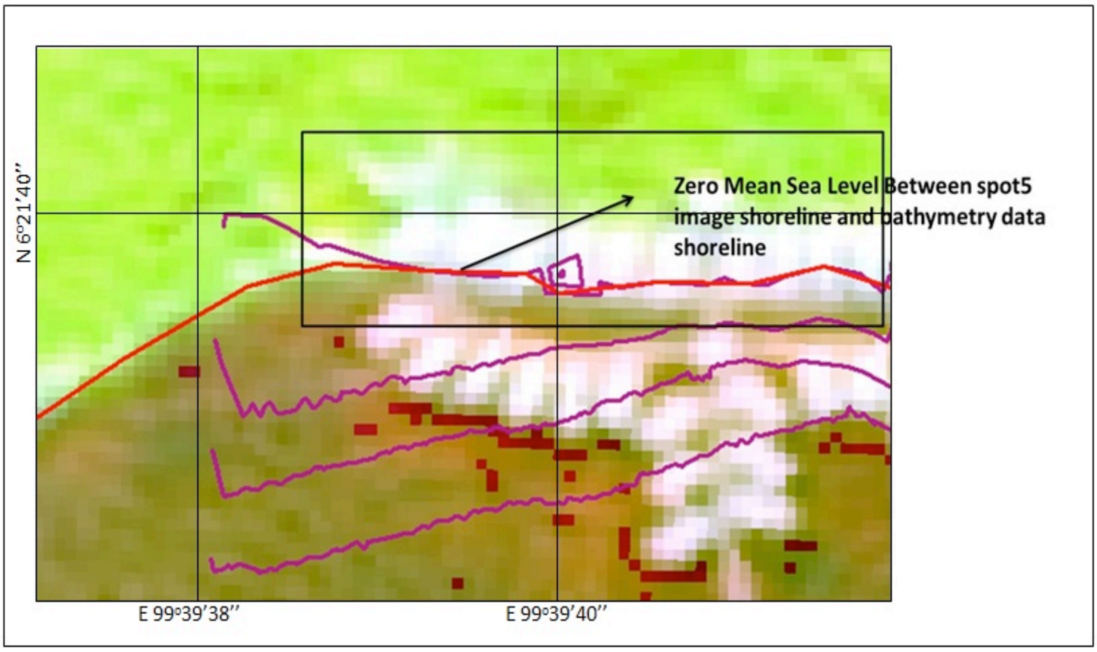

Figure 8 Zero elevation from line bathymetry and spot5 maps.

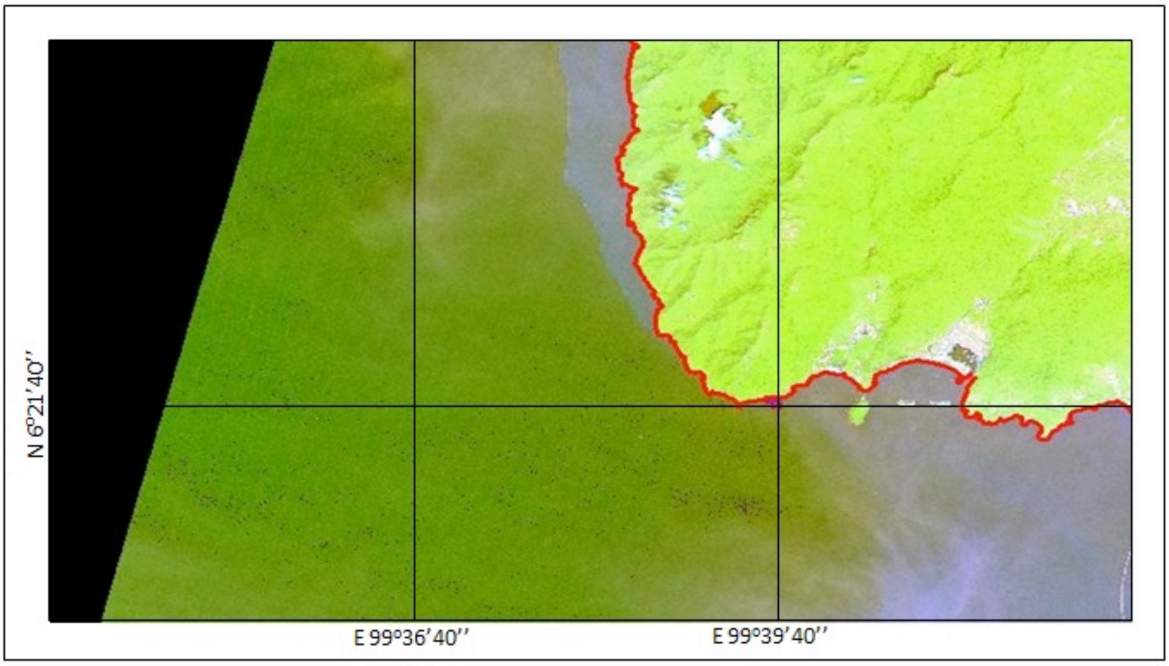

Figure 9 Shoreline model part of Langkawi Island.

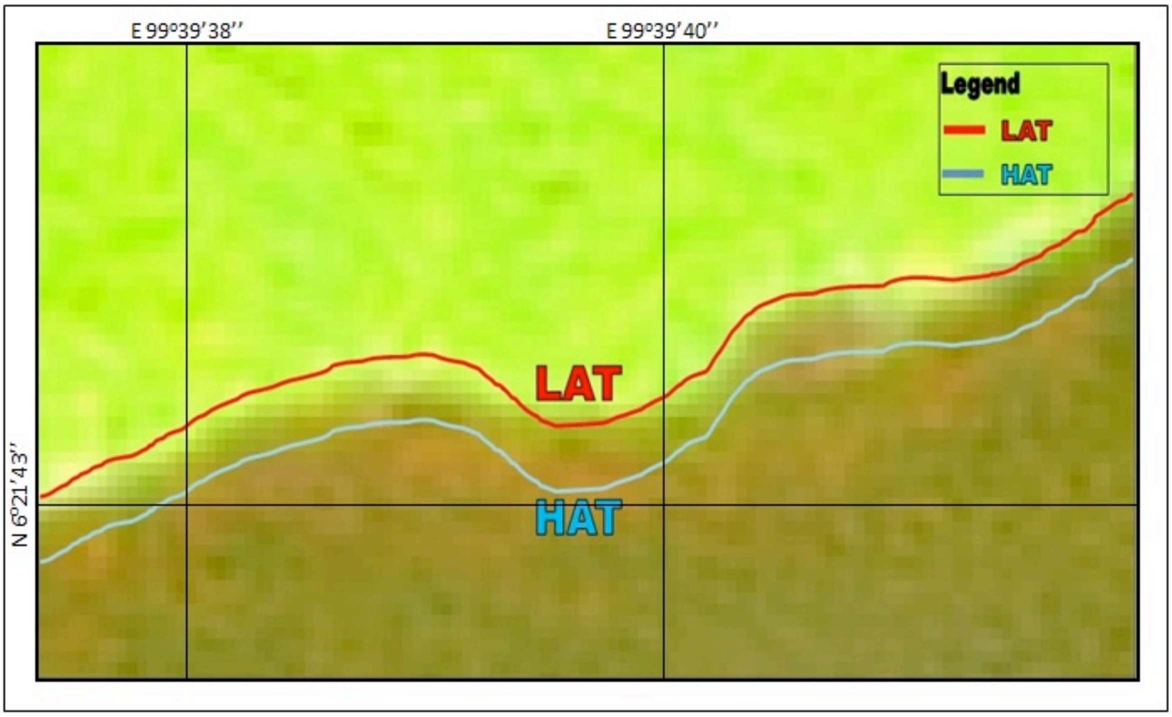

Figure 10 The littoral boundaries (LAT and HAT)

5. CONCLUSION

A tidal datum is a standard water level defined by a particular phase of the tide. Tidal datum is used as a reference level for measuring local water levels and should not be extended into areas having differing oceanographic characteristics without substantial measurements. A number of techniques and datasets are available to delineate the littoral zone. Littoral zones are crucial components that supported by a legal. The bathymetric and topographic data are used to define the terrain model. Meanwhile, the tides observation data are used to derive the tidal model and tidal line.

Based on the analysis of tidal datum that has been conducted, it shows that is a great potential to use LAT as reference level for marine cadastre. This will benefit the realization of marine cadastre in Malaysia due the availability of commencement point for parcel right. However, to develop the homogenous datum for land and sea, there is a need to develop a model for defining the relationship between different vertical reference surfaces. Large scale map of LAT tidal line and littoral zone for Malaysia is important towards the realization of marine cadastre in Malaysia.

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BIOGRAPHICAL NOTES

Rasheila Rahibulsadri is a MSc student of Universiti Teknologi Malaysia. Her research interest focus on the Stability of the Lowest Astronomical Tide(LAT) as a tidal datum for Marine Cadastre in Malaysia. She holds a Bachelor's Degree in Geomatic Engineering from Universiti Teknologi Malaysia.

Abdullah Hisam Omar is a senior lecturer at the Faculty of Geoinformation and Real Estate, Universiti Teknologi Malaysia (UTM) since 2000. He obtained a Bachelor Degree, Master of Science and a Doctor of Philosophy from Universiti Teknologi Malaysia, Malaysia. His research work is in the areas of Land and Marine Cadastre. His current research is on marine legal framework for Malaysia funded by Ministry of Sceince, Technology and Innovation (MOSTI). Abdullah Hisam is a member of the Institution of Surveyors, Malaysia (ISM).

Ashraf Abdullah is a PhD student in Built Environment, Universiti Teknologi MARA with research interest in marine cadastre from legal and technical aspect. He received guidance from supervisors from UiTM and UTM in future marine cadastre project in Malaysia. He holds a Bachelor's and Master's degree from the Universiti Technologi Malaysia, Johor. For the position, he is also a lecturer at Universiti Teknologi MARA, Perlis and teaching marine technology and marine engineering.

Muhammad Aizzat Wan Azhar a master's degree candidate in Geomatic Engineering in Universiti Teknologi Malaysia with research interests primarily in marine cadastre in Malaysia. His research focuses on delineation of boundaries of the littoral zone for marine cadastre in Malaysia. His research interests also include tidal model and digital model of the coastal terrain. He received his bachelor's degree in Geomatic Engineering from the Universiti Teknologi Malaysia in 2012.

Chan Keat Lim graduated from the University of Nottingham with a Master of Science in Geographical Information Systems (Distinction) and Universiti Teknologi Malaysia with a Bachelor of Science in Land Surveying. Currently, he is the Director of Survey (Cadastral Legislation) in the Cadastral Division, Department of Survey and Mapping Malaysia (JUPEM).

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REVIEW	RESPOND TO THE REVIEWER COMMENTS:
On **page 2** is said that the marine cadastre starts from the low water mark seawards, 3 nautical miles for the State, the rest for the Federation. The land cadastre ends at the HAT. So the jurisdiction between HAT and low water mark is unclear. Why then does the paper speak about 'between HAT and shoreline'? By the way: is 'shoreline' synonymous with 'coastline' as used in the first paragraph on this page?	The sentence "jurisdiction of space between HAT and to the shoreline" is incorrect. By the way, the true is low water mark. The correction of the last paragraph on page 2 is: According to Malaysia Land Code, the limit of Land Cadastre administration is referred to the level of Highest Astronomical Tide (HAT). This description will create uncertainty of jurisdiction of space between HAT and to the low water mark.
When -on **page 2**- UNCLOS is mentioned, which treaty uses the concept of 'baseline', wouldn't it be a useful in addition to inform the reader on how Malaysia defines the UNCLOS-'baseline'? May be a little diagram of the vertical coast might visualize the used concepts.	Article 3(1) of the Emergency (Essential Powers) Ordinance, No. 7/1969 mentioned territorial water shall be measured in accordance with the principle of the Geneva Convention on the Territorial Sea and Contiguous Zone (1958), therefore accordingly whatever maritime baseline applied by Malaysia to define its international maritime boundary, the same baseline shall be used to define the local states maritime boundary. Legally empowered by this Ordinance, if Malaysia applies a straight baseline, theoretically it's State also have its marine jurisdiction measure from a straight baseline. The diagram has been shown in the paper.
On **page 4** it appears recommendable to explain why the author(s) choose Langkawi Island as a case in the paper.	There are two reasons why Langkawi Island has been chosen as a case: 1. This area was selected as it has the nature of business such as infrastructure, development and tourism. 2. A lot of marine institutional and

	related agencies to support on marine administration.
May be **pictures 5, 6, 7** can have a less-grid like background, topographical maps?	The pictures have been changed: topographical maps.
On **page 11** it is said that now LAT and HAT have being defined, the littoral zone is known. However, still the land cadastre stops at HAT and the marine cadastres begins at LAT. What in between?	In between HAT and LAT is known as littoral zone. Littoral zones are crucial components that supported by a legal.