Shallow-Water Bathymetry Estimation at Pantai Tok Jembal, Terengganu, Malaysia Using Landsat 8 (OLI)

View the article online for updates and enhancements.

Shallow-Water Bathymetry Estimation at Pantai Tok Jembal, Terengganu, Malaysia Using Landsat 8 (OLI)

Nur Syahirah Hashim¹, Wiwin Windupranata², Khairul Nizam Tahar¹, Saiful Aman Hj. Sulaiman¹,

¹ Centre of Studies for Surveying Science and Geomatics, University of Technology MARA, Shah Alam, Selangor, Malaysia, and Geodesy.
² Geomatics Engineering Study Program, Faculty of Earth Science and Technology, Institute Technology of Bandung, Indonesia.

lpiera77@gmail.com

Abstract. Satellite-derived bathymetry (SDB) emerging as a cost-effective that provides high-resolution mapping over a wide area. This method can map shallow water environment, especially that are difficult to access by boat or airplane. SDB is not for replacing the conventional bathymetry method but to assist. The accuracy of SDB does not meet current International Hydrographic Organization (IHO) S-44 standards but still can use when planning hydrographic surveying, i.e., unsurvey areas or areas with old data. In this paper, the SDB method applies to produces bathymetric mapping at Pantai Tok Jembal, Terengganu, Malaysia. Derived from Landsat 8 images and for the bathymetry method use is an empirical-based method, Log-ratio Transform. To diversify the result, utilizing three atmospheric correction approaches: No. atmospheric correction, Dark Object Subtraction (DOS), and Fast Line-of-sight Atmospheric Analysis of Hypercubes (FLAASH). The SDB result then evaluates using Single Beam Echo Sounding (SBES) ground truth data. The result indicates that Log-ratio Transform with DOS atmospheric correction produces the best result based on the error analysis. The error mostly occurs when there is no data available in the particular area due to cloud cover and shallow water area, i.e., inaccessible boat or vessel area. The error also occurs as it goes deeper area where the light is limited. In conclusion, this study successfully produces bathymetric mapping at Pantai Tok Jembal, Terengganu, Malaysia, through the SDB technique. This method strengthens the SBES data by effectively filling the data gaps; however, further research needs to fulfill this support in giving high accuracy and reliability.

1. Introduction

Satellite-derived bathymetry (SDB) is emerging as a cost-effective that provides high-resolution mapping over a wide area [1]. The methods are requiring only single multi-spectral imagery and specific depth measurements [2]. Higher resolution, multi-spectral bands, and open-source availability enhanced its potential for source hydrographic data [3]. The conventional bathymetry method, i.e., Single Beam Echo Sounding (SBES) and Multi-beam Echo Sounding (MBES), provides high accuracy data. However, this method is slow, labour-intensive and constraint by high operating costs significantly limits its frequent repetitions [1], [2], [4]–[6]. Other than that, this method is weather dependent since it is a ground truth measurement [1]. Another alternative method, like an air-borne bathymetry acquisition, Light Detection and Ranging (LiDAR), has proven its ability to measure the topography very detailed.

This technology produces reliable information but very expensive, and projects require more frequent flyover [7]. Satellite altimetry can also determine the water depth based on the linear relationship between the gravity anomaly and the depth's square. However, this method is only suitable for deep-sea (e.g., surveying large seamounts)[8].

SDB is an alternative tool for bathymetry mapping, especially in the shallow water environment [4]. Using satellite imagery allows providing information about difficult areas to access by boat or airplane [9]. It is because ship-based soundings often have a low spatial resolution. This method has trouble navigating shallow waters, which sometimes hazardous, especially at shallow and undulating areas in which possibility risk of stranding, especially for large survey vessels [1], [2], [5], [6], [10]. Other than that, LiDAR operating on air-borne can be limited to boundaries restriction, which is it can only fly in the capable area [9].

However, SDB is not for replacing the conventional bathymetry method but to assist. The accuracy of SDB does not meet current International Hydrographic Organization (IHO) S-44 standards. Nevertheless, it still can use when planning hydrographic surveying of unsurvey areas or areas with old data [11]. An example was done by Earth Observation and Environmental Services (EOMAP) in British Admiralty charts Tuvalu (BA2066), a navigation chart, SDB used to aid navigation for positioning tide gauge [12]. The implementation is as additional data when updating information in the nautical chart.

In this paper, the SDB method applies to produces bathymetric mapping at Pantai Tok Jembal, Terengganu, Malaysia. The bathymetry derived from Landsat 8 images, and the method used is the empirical-based method, Log-ratio Transform. To diversify the result, utilizing three types of atmospheric correction approach: No. atmospheric correction, Dark Object Subtraction (DOS) [6], and Fast Line-of-sight Atmospheric Analysis of Hypercubes (FLAASH) [13], [14]. The SDB result then evaluates using the Evaluation dataset consist 18283 SBES point. Furthermore, Figure 1 briefly illustrates and summarises the light penetration theory and associate with the objective and analysis in this paper.
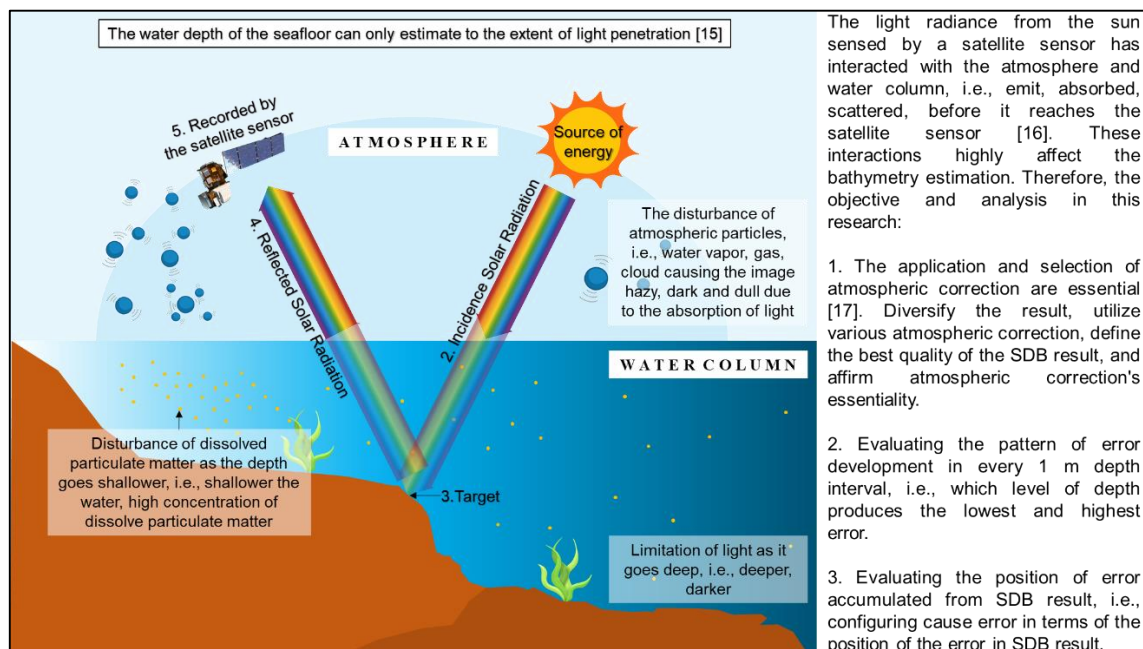
Figure 1. The illustration behind the theory of SDB associate with light penetration, atmospheric effects, and dissolve particulate matter, along with the objective and analysis in conducting the research.

2. SPEAR Relative Water Depth: Log-ratio Transform

SPEAR: Relative Water Depth is a rapid processing tool in determining water depth. This is a built-in tool in ENVI 5.3 that automatically can compute SDB, developed by Harris Geospatial. There are three

types of bathymetry algorithms available in the method selection option, but this study will use the Log-ratio Transform algorithm.

Theoretically, of the concept Log-ratio Transform, every band has a different level of water body absorption. The different absorption levels conceptually will generate the ratio between bands, and this ratio will simultaneously change when depth changes. When the ratio increases, the depth will increase. The band higher level of absorption will continually decrease when the depth increase. The Log-ratio model is more robust and has demonstrated more accurate depth estimation, especially for shallow habitats with low reflectance and in the area of deeper benthic habitat compared to others. Furthermore, Log-ratio transform is an albedo free algorithm that means that seafloor sealed with dark seagrass or light sand showed simultaneously when both are at the same depth [7]. The equation (1) as follows;

$$Z = m_1 * \frac{\ln[nL(\lambda_2)]}{\ln[nL(\lambda_1)]} - m_0 \qquad (1)$$

Where;
Z: Depth Estimation
n, m_1 & m_0: the constant-coefficient for the model
$L(\lambda_1)$ & $L(\lambda_2)$: reflectance for spectral λ_1 & λ_2

Depth estimation of Log-ratio algorithm is beginning with rationing of ln Blue band with ln Green band. Once the band ratio value obtains, linear regression will perform where known depth against this value and as the m_0 and m_1 value determined from the regression process, the depth, Z can compute.

3. Material & Methods

3.1. Study Area
Pantai Tok Jembal, Terengganu, Malaysia located roughly at 5º24'00" N, 103º00'00" E (refer to Figure 2), which is nearly located to Sultan Mahmud Airport and University Malaysia of Terengganu (UMT). Besides, based on Figure 2, the SBES data has covered about 13.4% of the study area.
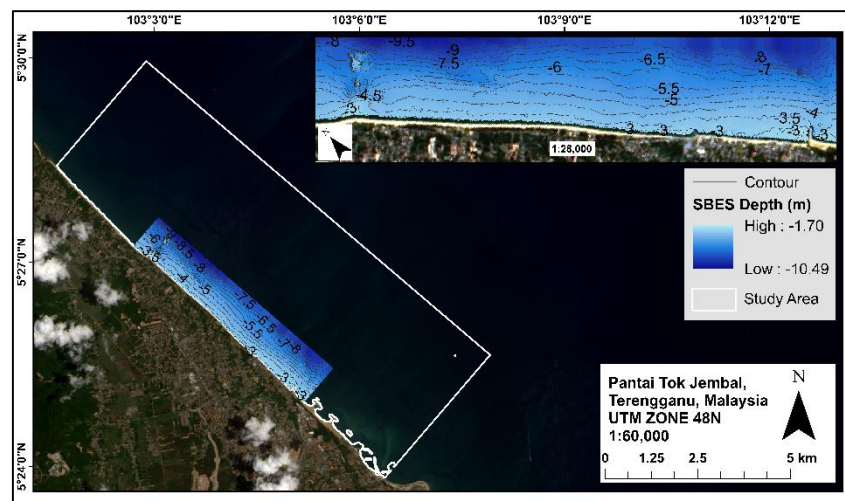
**Figure 2.** Study Area: Pantai Tok Jembal, Terengganu, Malaysia

Pantai Tok Jembal is one of the exciting and beautiful in the state of Terengganu. This location is already famous among locals and tourists as one of the exciting places in Terengganu. Apart from local or tourist attractions, this area is also a residence of the local people and 400 households near the coastal area from Pantai Tok Jembal to Batu Rakit three-kilometer distance. Other than that, this area is prone

to coastal erosion due to the position of this area fronting to the vast South China Sea that is always vulnerable to the strong winds, widespread waves, and ocean current [15]. Comprehensive bathymetric data is essential in this area, which can apply in hydrodynamic modelling or monitoring.

3.2. Data used
The SBES data collected by using SONARLITE Portable Single Beam Echo Sounder and Astech SP80 GNSS receiver. This data obtained from the Department of Irrigation and Drainage Malaysia (DID) and surveyed in April – May 2017. The expectation horizontal and vertical accuracy of this bathymetric data is ±0.3cm [16] and ±2.5cm [17]. The total 18283 SBES points with a range of depth between 1.70 m to 10.49 m below land survey datum. This data used as ground truth data divided into two datasets: the calibration dataset consists of 11191 SBES points, and the evaluation dataset consists of whole SBES points (18283 points).

Then, based on Figure 3, a multi-spectral images data Landsat 8 (extent: 56-row x 126 columns), source from Malaysian Space Agency (MYSA) with date acquisition 29th June 2017 at 03:21:23 (GMT) and is also available at United States Geological (USGS) website free downloadable. This product is a Landsat Level-1 Data Product (L1TP). The image was radiometrically calibrated and orthorectified using ground control points (GCP). This GCP derives from the Global Land Survey 2000 (GLS 2000). The LITP product calibrates and orthorectified using the Digital Elevation Model (DEM) to correct relief displacement. Landsat 8 (OLI) band designation has 11 spectral bands [18]. Spatial resolution for bands is 30 m for multi-spectral images and 15 m for panchromatic images.
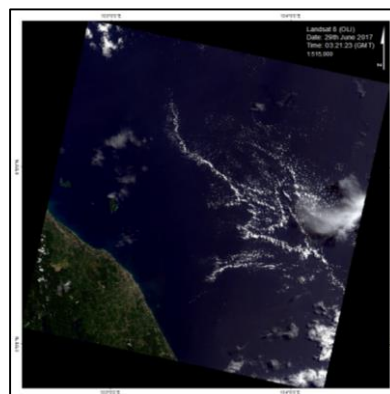
Figure 3. Landsat 8, 29th June 2017 at 03:21:23 (GMT)

3.3. Processing
The bathymetry derivation process begins with the pan-sharpening process: transforming Landsat images from 30 m to 15 m resolution. This process conducts by merging high-resolution panchromatic data (15 m) with medium-resolution multi-spectral data (30 m). The author considers this step is essential, especially in improving information extraction [19].

A subset tool is then applied to focus the study area by sub-setting the area of interest from the whole Landsat image. Apart from focusing on the study area, the subset image gives conveniences in reducing the workload carrying from one whole image [7].

After that, the application of radiometric correction and atmospheric correction. The application of radiometric correction is to reduce or correct errors in a digital number of images. This process improves the interpretability and quality of satellite images [20]. Meanwhile, the removal of scattering and absorption effects from the atmosphere to the images applies atmospheric correction. Utilizes three types of atmospheric correction approach: No. atmospheric correction, DOS, and FLAASH in the methodology cause the bathymetry derivation process broken down into three types of processes.

Next, SDB will produce using SPEAR Relative Water Depth: Log ratio transform, and then the regression is applied, the relationship between depth index with Calibration dataset that has been

corrected tides. After that, to obtain the final SDB, the SDB needs to go through tidal correction again. The Calibration dataset used in the calibration process added tide-value since the Landsat image capture during the tide presence. After the SDB obtain, the tide needs to reduce to bring the depth back into Mean Sea Level. The SDB result will then mask the land area since bathymetry mapping focuses only on the water area.

Finally, for the final step, all of the SDB results will validate using the Evaluation dataset consist of 18283. A comparative analysis will undertake between three SDB results conducted with different atmospheric correction approach. This paper also conducts the error development analysis pattern from the three SDB results in every 1 m depth interval and the analysis of position error accumulated from the SDB results.

4. Result and Discussion
Three SDB results were generated from Landsat 8 images using SPEAR Relative Water Depth: Log-ratio Transform performing without atmospheric correction (refer Figure 4 (a)) and with an atmospheric correction: DOS (refer Figure 4 (b)) and FLAASH (refer to Figure 4 (c)).
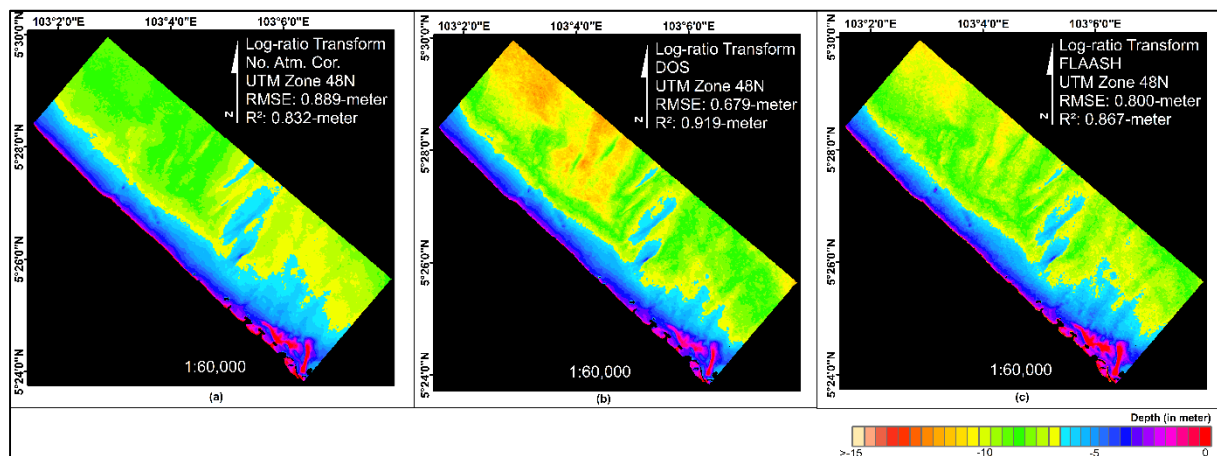
Figure 4. SDB result: (a) Log-ratio Transform with No. atmospheric correction, (b) Log-ratio Transform with DOS and (c) Log-ratio Transform with FLAASH

The accuracy of SDB then assess using two statistical indices, R-squared (R^2) and Root Mean Square Errors (RMSE), and the result present in Table 1 below. As summarised in Table 1, the SDB result generated using SPEAR Relative Water Depth: Log-ratio Transform, performing with three different atmospheric corrections. Based on the result, for the regression model Log-ratio Transform with three atmospheric corrections gives a strong positive linear relationship between SDB and SBES. The highest R^2 is when Log-ratio Transform performs with DOS: 0.919 m, follow by FLAASH: 0.867 m and No. atmospheric correction 0.832 m.

Table 1. SDB result generated from Landsat 8 (OLI) using SPEAR Relative Water Depth: Log-ratio Transform performing with No. atmospheric correction, DOS, and FLAASH.

	(a) No Atm. Cor	(b) DOS	(c) FLAASH	SBES
RMSE	0.889	0.679	0.800	
R^2	0.832	0.919	0.867	
Min	7.144	0.092	0.389	-1.70
Max	-7.588	-8.782	-8.227	-10.49
Mean	-5.034	-5.164	-5.092	-5.52

The obtain high value of R^2 is because the regression model accounts for more of the variance, in which the data points are closer to the regression line. Therefore, it can conclude that the closer the

points to the regression line, the higher the R² value obtained, the better the result. Based on Figure 5, the fitted line plots the association between Bathy-sounding and Bathy-SDB, b shows the best example where most of the data point is linearly close.
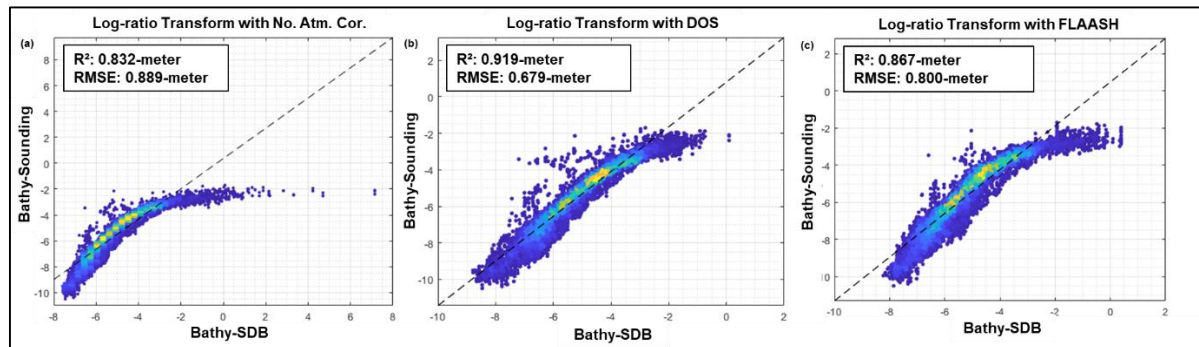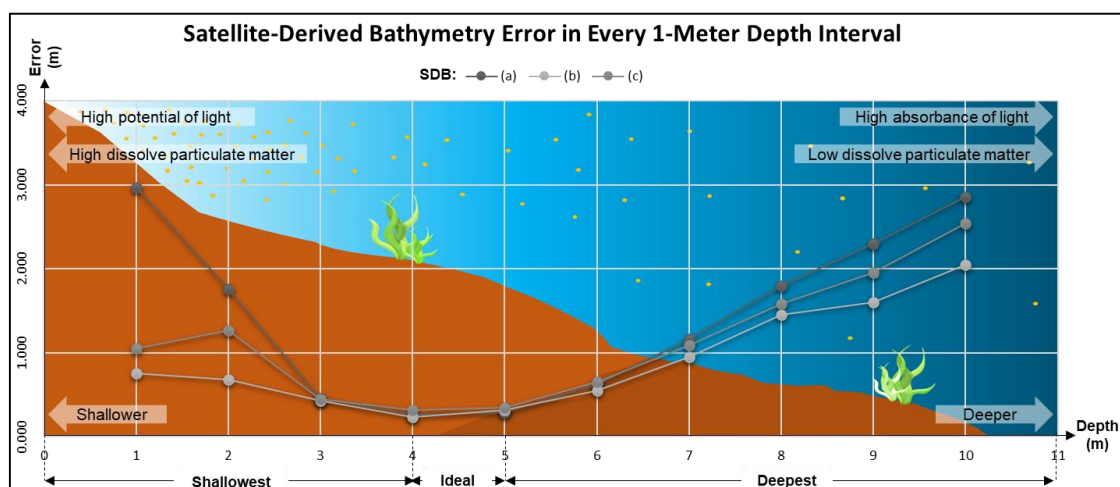

Figure 5. Linear graph of Bathy-Sounding against Bathy-SDB: a) Log-ratio Transform with No. atmospheric correction, (b) Log-ratio Transform with DOS, and (c) Log-ratio Transform with FLAASH

On the other side, the result of RMSE analysis, as shown in Table 1 and Figure 5, Log-ratio transform performance with DOS produces the lowest RMSE: 0.679 m and the highest R²: 0.919 m, which indicates the best result overall. The second-best, followed by Log-ratio Transform, performs with FLAASH, produces RMSE: 0.800 m and R²: 0.867 m. Then, Log-ratio Transforms performs with No. atmospheric correction, gives the highest RMSE and the lowest R² result: 0.889 m and 0.832 m, make as the third-best result.

In continuation, the comparison in these findings to findings of earlier studies [6] reveals that when performing Log-ratio Transform with DOS atmospheric correction consistently gives a good result. This study's findings also strengthen the study's findings [21], which is DOS atmospheric correction proved to be an excellent first approach for the correction of the atmospheric influence.

4.1. The error development analysis in every 1 m depth interval

The error development analysis pattern conducted from three SDB results in every 1 m depth interval, and this pattern illustrates in the graph. Based on Figure 6, the pattern of the error development divide into three classes: shallowest (0 – 4 m), ideal (4 – 5 m), and deepest (5 – 10 m).

Figure 6. Graph of error development in every 1 m depth interval from three SDB result: (a) Log-ratio Transform with No. atmospheric correction, (b) Log-ratio Transform with DOS, and (c) Log-ratio Transform with FLAASH

The first class: shallowest (0 – 4 m), is where the development of error high start at the initial number of depths, and this area is the shallowest water area, has a high potential of light more than the seafloor's depth. At Pantai Tok Jembal, since this area prone to coastal erosion, i.e., exposes to the widespread wind, waves, and ocean currents, the dissolved particulate matter (e.g., suspended sediment) quickly accumulates, especially in the shallowest water area. Therefore, when the light emits at dissolved particulate matter, it quickly appears like sand or shoal, and this situation leads to 'false bathymetry' as stated in [22] studies.

The second class: ideal (4 – 5 m), is where the development error is minimal. In this class, light penetration is close to optimal enough to penetrate the amount of water depth. Furthermore, the dissolved particulate matter in this class lesser.

Finally, the third class: deepest (5 – 10 m), is the highest development of error as it reaches the highest depth interval. This class has low dissolved particulate matter. However, as the depth goes deeper, limiting the light energy to penetrate water. Therefore, it can conclude that the increase of depth, decreasing the rate of light penetration.

4.2. The position of error accumulated analysis

The position of error accumulated analysis conducted from the best performance, Log-ratio Transform, performs with DOS atmospheric correction. Based on Figure 7, the green tone (i.e., 0 to more than 3 m depth interval) and purple tone (i.e., 0 to more than -3 m depth interval) indicate underestimation overestimation, respectively.
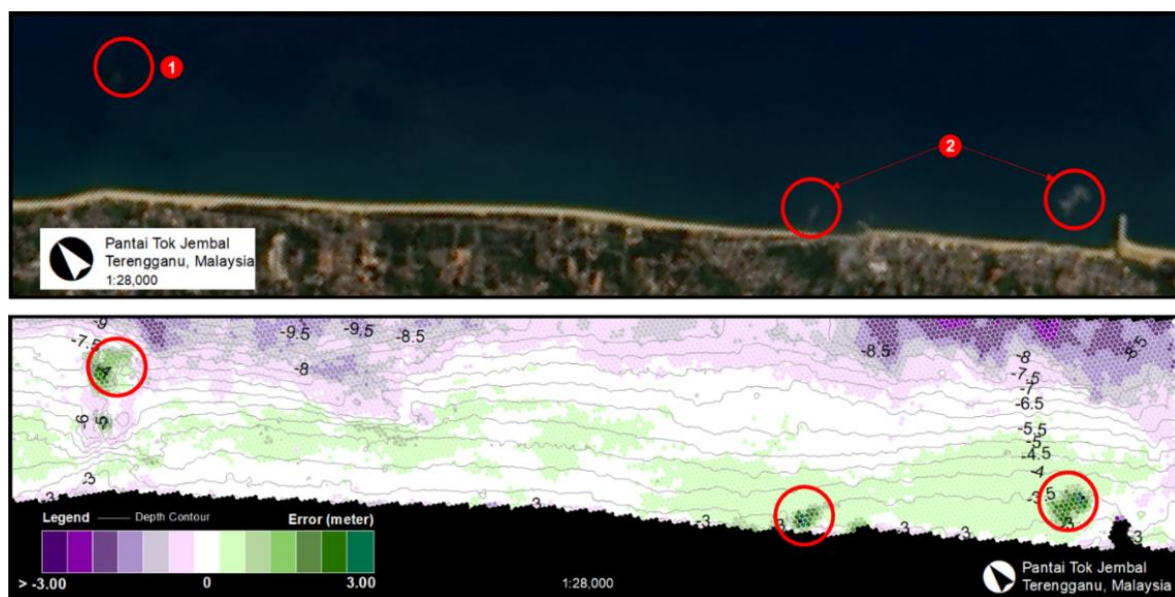
Figure 7. Analysis of the position of error accumulated from the SDB result.

The analysis can summarise that the error happens when the prediction data underestimate and overestimate the observation value. The underestimation occurs when the prediction value over observation is usually at the area with no data available. The first area locates near the shallow water area. This area is usually inaccessible for the boat to take a measurement. Then, the second area is wherein the cloud area. The cloud usually covers up important information underneath. To avoid wrong information extraction, SBES points overlaid on cloud pixels need to be removed as the cause of a shortage of SBES points in the area. In contrast, overestimation occurs when the prediction value lower than the observation value. It happens in the area where the depth reaches up to 10 m due to the limited light energy to penetrate the water column.

5. Conclusion

SDB method applied to produces bathymetric mapping at Pantai Tok Jembal, Terengganu, Malaysia. Bathymetry derived from Landsat 8 images and the bathymetry method use is an empirical-based method, Log-ratio Transform. To diversify the result utilizes three atmospheric correction approaches: No. atmospheric correction, DOS, and FLAASH. The SDB result then evaluates using the Evaluation dataset. Based on the overall analysis, it can conclude that:

1. Log-ratio transform performs with DOS produces the lowest RMSE: 0.679 m, which indicates the best result overall since it also produces the highest R^2. This study's findings strengthen the study's findings [21], which is DOS atmospheric correction proved to be an excellent first approach for the correction of the atmospheric influence.

2. In the evaluation of error development pattern in every 1 m depth interval analysis, the cause of the error is first to associate with the disturbance of dissolved particulate matter, i.e., shallower the depth, a higher concentration of dissolved particulate matter, a higher disturbance will be. Second, the absorbance light distributes with depth, i.e., the deeper, the darker will be. Third, light and depth must be optimal for an accurate water depth penetration, i.e., the ample amount of light for the seafloor's ample amount of water depth.

3. In evaluating position error analysis, it can conclude that the error mostly occurs where the area is no data available due to cloud cover and shallow water area, i.e., inaccessible for boat and vessel. The error also occurs as it goes deeper area where the light is limited.

Next, the method can improvise using Landsat 8 Coastal Aerosol band because this band can estimate aerosols' concentration in the atmosphere, which may refine atmospheric correction procedures such as DOS. This band is also advisable for advanced research in the inland water region to provide closer inspection of the coastal and inland waters since the inland water area mostly contributes a high error production in this research [23].

Then, the limitation of this study is the lack of supporting data suchlike water turbidity. It would be useful to determine the water condition of the continental shelf of Pantai Tok Jembal if it includes the water quality aspects since this area prone to ocean dynamics and natural disasters. By providing the support may make the analysis more stable.

In conclusion, this study successfully produces bathymetric mapping at Pantai Tok Jembal, Terengganu, Malaysia, through the SDB technique. This method is effectively strengthening the SBES data by effectively filling the data gaps. However, in giving high accuracy and reliability, further research needs to undertake to fulfil this support.

References

[1]   C. Cahalane, A. Magee, X. Monteys, G. Casal, J. Hanafin, and P. Harris, "A comparison of Landsat 8, RapidEye and Pleiades products for improving empirical predictions of satellite-derived bathymetry," *Remote Sens. Environ.*, vol. 233, no. March, 2019.

[2]   A. Kanno, Y. Koibuchi, and M. Isobe, "Shallow water bathymetry from multispectral satellite images: Extensions of Lyzenga's method for improving accuracy," *Coast. Eng. J.*, vol. 53, no. 4, pp. 431–450, 2011.

[3]   M. Ashphaq, "Bathymetry estimation in turbid water using SENTINEL 2 image," *38th INCA Int. Congr. Hyderabad.*, no. February, pp. 1–7, 2018.

[4]   M. D. M. Manessa, M. Haidar, M. Hartuti, and D. K. Kresnawati, "Determination of the Best Methodology for Bathymetry Mapping Using Spot 6 Imagery: a Study of 12 Empirical Algorithms," *Int. J. Remote Sens. Earth Sci.*, vol. 14, no. 2, p. 127, 2018.

[5]   V. Poliyapram, V. Raghavan, S. Masumoto, and G. Johnson, "Investigation of Algoritham To Estimate Shallow Water Bathymetry From Landsat-8 Images," *Int. Symp. Geoinformatics Spat. Infrastruct. Dev. Earth Allied Sci.*, vol. 4, no. December, pp. 0–5, 2014.

[6]   K. Tang and B. Pradhan, *Converting Digital Number into Bathymetric Depth: A Case Study over Coastal and Shallow Water of Langkawi Island, Malaysia*. 2015.

[7]   Najhan Md Said, Mohd Razali Mahmud, and Rozaimi Che Hasan, "SATELLITE-DERIVED

BATHYMETRY: ACCURACY ASSESSMENT ON DEPTHS DERIVATION ALGORITHM FOR SHALLOW WATER AREA," *ISPRS - Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci.*, vol. XLII-4/W5, pp. 159–164, Oct. 2017.

[8]   X. Monteys, P. Harris, S. Caloca, and C. Cahalane, "Spatial prediction of coastal bathymetry based on multispectral satellite imagery and multibeam data," *Remote Sens.*, vol. 7, no. 10, pp. 13782–13806, 2015.

[9]   T. Sagawa, Y. Yamashita, T. Okumura, and T. Yamanokuchi, "Satellite derived bathymetry using machine learning and multi-temporal satellite images," *Remote Sens.*, vol. 11, no. 10, 2019.

[10] D. J. Poppenga, S.K., Palaseanu-Lovejoy, M., Gesch, D.B., Danielson, J.J, Tyler, "Evaluating the Potential for Near-Shore Bathymetry on the Majuro Atoll, Republic of the Marshall Islands, Using Landsat 8 and WorldView-3 Imagery," *U.S. Geol. Surv. Sci. Investig. Rep. 2018-5024*, p. 14, 2018.

[11] T. D. Leder, N. Leder, and J. Peroš, "Satellite derived bathymetry survey method – Example of hramina bay," *Trans. Marit. Sci.*, vol. 8, no. 1, pp. 99–108, 2019.

[12] EOMAP, "UKHO published first nautical chart with EOMAP Satellite Derived Bathymetry," 2020. [Online]. Available: https://www.eomap.com/ukho-published-first-nautical-chart-eomap-satellite-derived-bathymetry/.

[13] Harris Geospatial Solutions, "Fast Line-of-sight Atmospheric Analysis of Hypercubes (FLAASH)," pp. 1–12, 2020.

[14] ENVI, "ENVI Atmospheric Correction Module: QUAC and FLAASH user's guide," *Modul. Version*, p. 44, 2009.

[15] P. Jaharudin, M. D. Kamarul, T. J. Abu, M. Haslina, and R. Pravinassh, "Impact of coastal erosion on local community: Lifestyle and identity," *Disaster Adv.*, vol. 12, no. 2, pp. 19–27, 2019.

[16] "Spectra Precision SP80 GNSS Receiver." Spectra Precision, p. 4.

[17] "SONARLITE Portable Echo Sounder System." Nautikaris, p. 2.

[18] United States Geological Survey (USGS), "Landsat Level-1 Processing Details." [Online]. Available: https://www.usgs.gov/land-resources/nli/landsat/landsat-level-1-processing-details.

[19] Y. Zhang, *Pan-sharpening for improved information extraction*. CRC Press, 2008.

[20] Humboldt State University, "Radiometric Calibration and Corrections," 2019. [Online]. Available: http://gsp.humboldt.edu/OLM/Courses/GSP_216_Online/lesson4-1/radiometric.html.

[21] W. Hernandez and R. Armstrong, "Deriving Bathymetry from Multispectral Remote Sensing Data," *J. Mar. Sci. Eng.*, vol. 4, p. 8, Feb. 2016.

[22] S. Pe'eri, B. Madore, J. Nyberg, L. Snyder, C. Parrish, and S. Smith, "Identifying Bathymetric Differences over Alaska's North Slope using a Satellite-derived Bathymetry Multi-temporal Approach," *J. Coast. Res.*, vol. 76, pp. 56–63, 2016.

[23] Levy and Przyborski, "Landsat 8: Coastal Aerosol Band," 2013.