REDUCTION OF MEAN SEA LEVEL DEPTH BASED ON TIDE GAUGE DISTANCE-DEPENDENT AT SUNGAI DINDING, LUMUT

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KEY WORDS: Tidal correction, tide gauge, depth reduction, bathymetry, HYDROpro, Surfer.

ABSTRACT:

Tidal correction is vital in shipborne bathymetric survey. This research uses two different tide gauge stations as tidal corrections to reduce the sounding depth. The tide corrections used are from the tidal observation at the survey site and the nearest tide gauge established by the Department of Survey and Mapping Malaysia (DSMM). The issue that may affect the results is the distance between the tide station used for corrections and the survey site. Are the results obtained by these two distinct tide corrections comparable? And if not, what are the cause for any discrepancies in the results? Thus, this research aims to assess the reduction of Mean Sea Level (MSL) depth using the bathymetric survey data at Sungai Dinding, Lumut relative to two different tide gauge with different distance to the survey site. The two distinct tidal corrections are observed and analysed separately. The tidal data are processed using HYDROpro software, followed by the analysis of the bathymetric plan and the computation of Root Mean Square Deviation (RMSD). The results of different tide corrections are then compared. Furthermore, the reliability of bathymetry data relative to two tide gauges at different distances is also evaluated. For various reasons, the tidal corrections shed new light on the accuracy of depth reduction in the Sungai Dinding area. Besides, using two different tide gauges: on-site tide gauge observation and the nearest DSMM tide gauge (Lumut), provide an insight into the reliability of bathymetry data by comparing the depth derived relative to two different tide gauges at different distances from the survey site. The findings are instructive for future depth reduction, as they will allow for more practical application of the tide corrections. Optimistically, this study will raise awareness of the importance of tide station location in the bathymetry survey area.

1. INTRODUCTION

1.1 Introduction

Tide is a critical component in most of the bathymetric survey application. It is because, tide is used in bathymetry data processing to determine the actual depth of the survey area. Various tide corrections are used to assess the depth reduction. The tide must be reduced to Mean Sea Level (MSL) or Lowest Astronomical Tide (LAT), depending on the purpose of the application. Generally, MSL is used as a sounding datum for engineering works. While for navigation purposes, the sounding datum is reduced to the LAT. Therefore, it is necessary to apply tide corrections when creating a bathymetric plan.

During hydrographic survey, the depth is measured from the water surface to the sea floor. However, the water surface of oceans, seas, rivers, and lakes are not static. It varies due to the meteorological, oceanographic, and tidal effects. Thus, this study focusses more on the tidal effect. The measured depth values of water level must be reduced to a specific vertical datum before constructing hydrographic plan or producing nautical chart. The values of tidal corrections must be determined to accomplish the depth reduction. Normally, the tidal corrections are computed based on the tide observation established near the survey site. A tide gauge (also known as a mareograph, marigraph, or sea-level recorder) is a device that measures the changes in sea level with respect to a vertical datum (Khare et al., 2019).

The tide gauge station used must be at the nearest hydrographic survey area. This is because tidal behaviour might differ at different places. According to Kim et al. (2022), tides do not follow the same patterns everywhere because the Earth's surface is not uniform. The shape of an ocean floor affects the range and frequency of tides. According to Awang et al. (2011) and Zapata et al. (2019), tidal readings are usually obtained at a tidal station established near the survey area. This method is applied to avoid the discrepancy of tidal behaviour in the survey area and the tidal station.

This study aims to assess the reduction of MSL depth based on tide gauge distance-dependent with the bathymetry data at Sungai Dinding, Lumut. The outcome may differ, and the results may be influenced by the differences in tidal corrections used. The nearest Department of Survey and Mapping Malaysia (DSMM) tide gauge station (Lumut) is located slightly far away from the survey area which is approximately more than 10km. Meanwhile, the other tide gauge station is less than 1km within the survey area (hereinafter, on-site tide station). Both data from these stations are used to derive tidal corrections in this study. The tidal data of two different years (2017 and 2018) are used in this study as the bathymetric survey is deployed during the stated years. HYDROpro software is used to process the depth reduction resulting from these tide corrections. The bathymetry plan for 2017 and 2018 with reduced sounding depth relative to in-situ tide gauge and DSMM tide gauge stations are generated. The establishment of the bathymetric plan is visualised using AutoCAD and Surfer software. Then, the Root Mean Square

Deviation (RMSD) is calculated to evaluate the reliability of bathymetric data based on two different distance of each tide stations with the survey area.

2. DATA AND METHODS

2.1 Research Area Identification

According to Tye (2020), Sungai Manjung is one of the major rivers in Perak. It was named after the district of Manjung, previously known as Dinding. Additionally, the river is known as the Dinding River or Sungai Dinding. The study area at Sungai Dinding, Lumut, with a scale of 1:26000, is shown in Figure 1. The study area includes Sungai Dinding and Lumut coastal areas. Table 1 demonstrates the geographical coordinates, the distance from the study area, and the data spans of the DSMM tide gauge station.

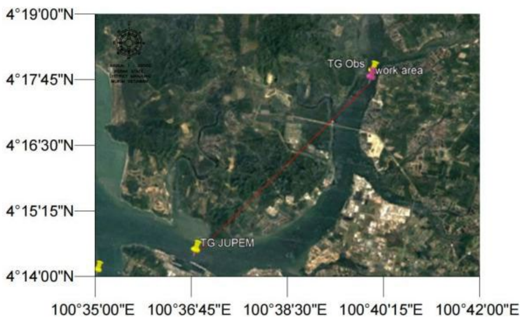

Figure 1. A study area at Sungai Dinding, Lumut (Google Earth, 2022)

Table 1. The coordinates and data period of the DSMM tide gauge station (Hao, 2021)

No	Tide Gauge Station	Latitude	Longitude	Distance from the study area	Period of Data
1	DSMM tide gauge, Lumut	4°14'24"N	100°36'48"E	8.33km	2017
2	DSMM tide gauge, Lumut	4°14'24"N	100°36'48"E	8.33km	2018

2.2 Data Acquisition

Hourly data from each tide gauge station and bathymetry data for year 2017 and 2018 are retrieved from the Hydrography Laboratory, Faculty of Built Environment and Surveying, Universiti Teknologi Malaysia from the Survey Camp data. The depth reduction process uses the hourly tidal data for one to two days—the latest updated and complete data for each station are shown in Table 1.

2.3 Data Processing

Tidal data are acquired and processed using HYDROpro software. In this software, the sounding depths are reduced and the final bathymetry data is generated. Then, the final bathymetric plans are produced using AutoCAD and Surfer software.

2.3.1 HYDROpro Software

A) NavEdit

The NavEdit Tide Editor creates tide files used in the Depth Editor to reduce depth data for tidal effects. This editor allows tide data to be manually entered or by importing the data from ASCII files. In this study, the tide data is manually entered. Figure 2 shows the Tide Editor desktop interface, where the tidal data are plotted in the Tide Graph and the Tide Grid. The primary function of the Tide Editor is to create files consisting tidal data for a specific location, for instance, tide gauge station. The Depth Editor then uses the tide data to reduce the depth data to the local chart datum. Tide data can only be used in the Depth Editor if the tide file is created.

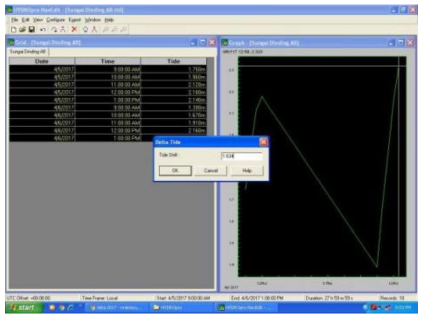

Figure 2. The Tide Grid and Tide Graph display

B) Disk Operating System (DOS) Processing

NavEdit can export a variety of file formats using the Export command. Then, the exported file can be used in DOS Processing to process the bathymetry data, as shown in Figure 3.

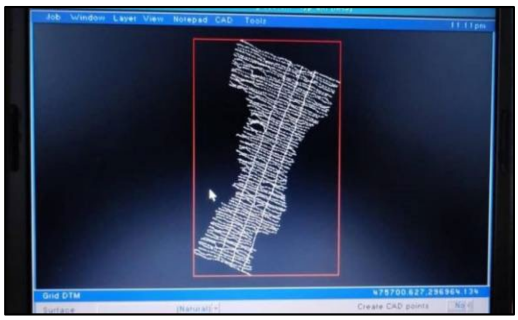

Figure 3. The interface of DOS Processing while editing the bathymetry data

2.4 Bathymetric Plan

A) AutoCAD Software

In DOS Processing, the final bathymetry data can be exported into DXF file formats as illustrated in Figure 4. This DXF file is used in AutoCAD to perform final editing and produce the complete bathymetric plan. The complete bathymetry plan usually consists of legend, location plan, key plan, the north direction, and etc (See Figure 5). For the bathymetric plan in 2017, the scale used is 1:12000 in A4 size, while in 2018, the scale used is 1:8000. The bathymetric plan in this study uses the Geocentric Datum of Malaysia 2000 (GDM2000) as a reference datum and Rectified Skew Orthomorphic (RSO) Geocentric for map projection.

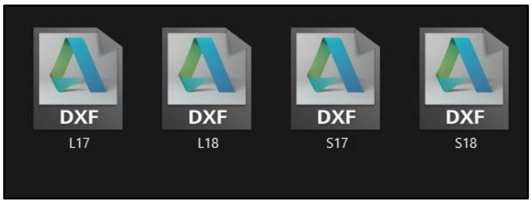

Figure 4. The DXF file formats

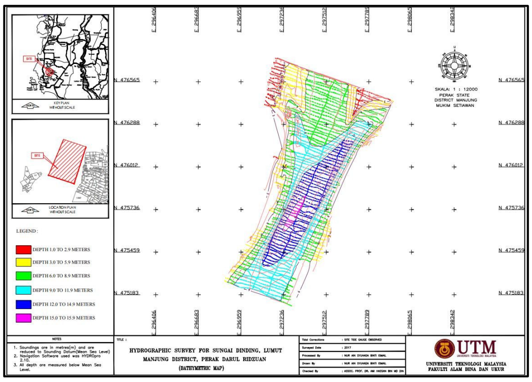

Figure 5. A complete bathymetric plan

B) Surfer Software

Surfer software also has an ability to generate bathymetric plan. Nevertheless, the output is slightly different from AutoCAD. Surfer is used to interpolate the scattered bathymetric data into gridded data. In this study, Kriging is selected to generate a 3-Dimensional bathymetric plan. This is due to the flexibility of gridding method. Depending on the user-specified parameters, Kriging can either be an exact or a smoothing interpolator in Surfer. It incorporates anisotropy and underlying trends efficiently and naturally. Next, the grid spacing selected is based on the comparison of several values. The comparison is based on the smoothest map produced. Figure 6 shows the grid data set for the plot. Grid files are necessary for Surfer to create grid-based map types. Generally, the data files are randomly spaced files and these data must be converted into an evenly spaced grid before any other features in Surfer is used. Grid files are produced from East, North, and Depth data from the HYDROpro. A 3D surface clearly shows the terrains of river bed compared to a 2D surface (see Figures 7 and 8).

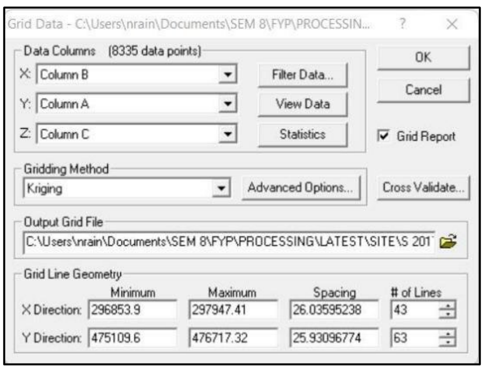

Figure 6. The interface of Grid Data Setting

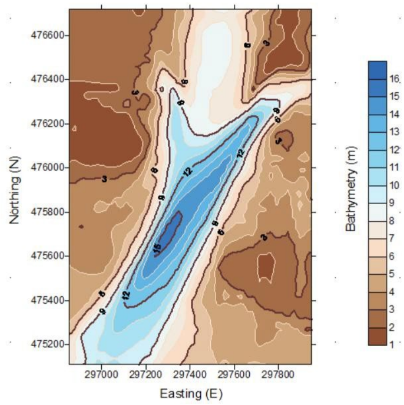

Figure 7. Bathymetric plan in 2D surface

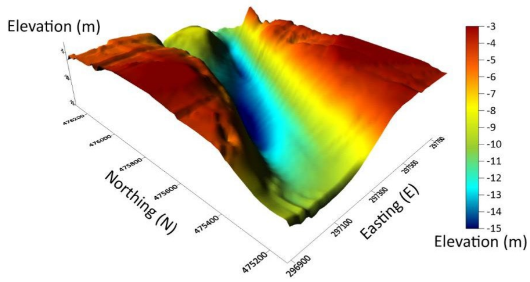

Figure 8. Bathymetric plan in 3D surface

2.5 Data Evaluation

The RMSD is one of the statistical analyses used for data validation between the reduced sounding depth relative to the site tide gauge and the nearest DSMM tide gauge. It is often used in mathematical computations to assess the reliability of results. According to Glen (2021), the Root Mean Square Error (RMSE) measures how evenly distributed these residuals are. In other words, it indicates how robust the data is around the best fit line. The RMSD of the results can be used to determine the reliability of the bathymetry data between two different distance of tide gauge stations. The formula to calculate RMSD is identical to the RMSE formula and is shown in equation (1) (Ćalasan et al., 2020)

$$\mathrm{RMSD} = \sqrt{\sum_{i=1}^{n} \frac{(X_i - P_i)^2}{n}} \qquad (1)$$

where i is the variable value, X_i is the DSMM tide gauge data, P_i is the on-site tide gauge data, and n is the total number of data points. After obtaining the RMSD of reduced sounding depth relative to both tide gauge stations, these values are compared to the International Hydrographic Organization (IHO) S-44 Standard guidelines to determine the uncertainties of bathymetry. Generally, the IHO S-44 Standard aims to provide a set of standards for hydrographic surveys primarily used to compile navigational charts essential for navigation safety, particularly for LAT sounding datum. Although the reduced depth in this study is referred to MSL, the assessment is still corresponding to the IHO S-44 standard. This is due to the limited validation sources. The formula of Total Vertical Uncertainties (TVU) is used to calculate the maximum allowable vertical measurement uncertainty (International Hydrographic Organization Standards for Hydrographic Surveys, 6th edition). In order to calculate the maximum allowable TVU, the parameters "a" and "b", as well as the depth "d" must be included in the formula, as shown in equation 2:

$$\mathrm{TVU}_{\max}(\mathrm{d}) = \sqrt{\mathrm{a}^2 + (\mathrm{b} \times \mathrm{d})^2}, \tag{2}$$

where a represents the portion of the uncertainty that does not vary with the depth, b is a coefficient, which represents the portion of the uncertainty that varies with the depth, and d is depth. Table 2 tabulates the minimum bathymetry standard.

Table 2. Minimum bathymetry standard (International Hydrographic Organization Standards for Hydrographic Surveys, 6th edition)

Criteria	Order 2	Order 1b	Order 1a	Special Order	Exclusive Order
Area description (Generally)	Areas where a general description of the sea floor is considered adequate.	Areas where underkeel clearance is not considered to be an issue for the type of surface shipping expected to transit the area.	Areas where underkeel clearance is considered not to be critical but features of concern to surface shipping may exist.	Areas where underkeel clearance is critical.	Areas where there is strict minimum underkeel clearance and manoeuvrability criteria.
Depth TVU (a) [m] and (b)	a = 1.0 m b = 0.023	a = 0.5 m b = 0.013	a = 0.5 m b = 0.013	a = 0.25 m b = 0.0075	a = 0.15 m b = 0.0075

2.6 Data Analysis

The processed results from each tidal correction of HYDROpro software are evaluated based on the bathymetric plan. The results are analysed by interpreting the bathymetric plan in AutoCAD and Surfer, both in 2D and 3D surfaces. The bathymetric plans for 2017 and 2018 are also compared. In addition, the bathymetric data are compared based on the distance of tide measurement to the survey area. Since the DSMM tide gauge is slightly far from the survey area, the results might give more unreliable output compared to the on-site tide gauge station as the tidal behaviour are not be the same. The calculation of RMSD will facilitate in validating the DSMM tide gauge data. It determines whether DSMM tidal data can still be used as tidal corrections for the hydrographic survey.

3. RESULTS AND DISCUSSION

3.1 Bathymetric Plan

3.1.1 Establishment of a Bathymetric Plan in AutoCAD

After processing the raw depth data at Sungai Dinding in Lumut, a bathymetric plan is created. Based on the bathymetric plan of 2017 reduced relative to the on-site tide gauge data, as shown in Figure 9, the plan with a scale of 1:12000 shows the highest depth of 15.55 metres and the lowest depth of 1.26 metres based on the colour gradient. However, the bathymetric plan of 2018 reduced relative to the on-site tide gauge data, the plan with a scale of 1:8000 shows the highest depth of 15.52 metres and the lowest depth of 2.66 metres based on the colour gradient, as shown in Figure 10.

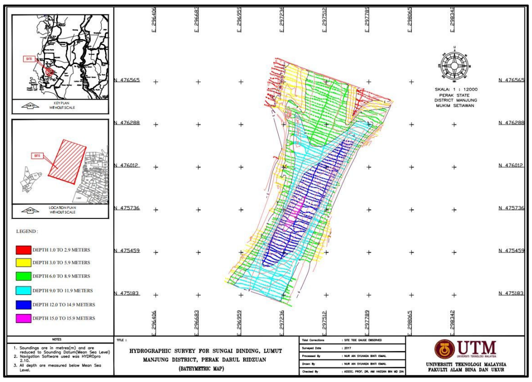

Figure 9. Bathymetric plan relative to the on-site tide gauge in 2017 plotted using AutoCAD

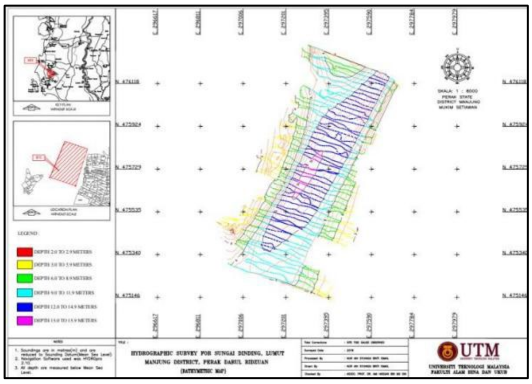

Figure 10. Bathymetric plan relative to the on-site tide gauge in 2018 plotted using AutoCAD

Meanwhile, the bathymetric plan (scale 1:12000) for year 2017 reduced relative to the DSMM tide gauge data shows the highest depth of 15.43 metres and the lowest depth of 1.15 metres (Figure 11). Furthermore, the bathymetric plan (scale of 1:12000) for year 2018 reduced relative to the DSMM tide gauge data shows the highest depth of 15.42 metres and the lowest depth of 1.28 metres, as displayed by Figure 12.

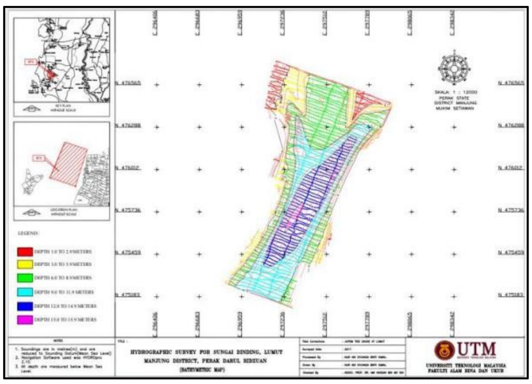

Figure 11. Bathymetric plan relative to the DSMM tide gauge in 2017 plotted using AutoCAD

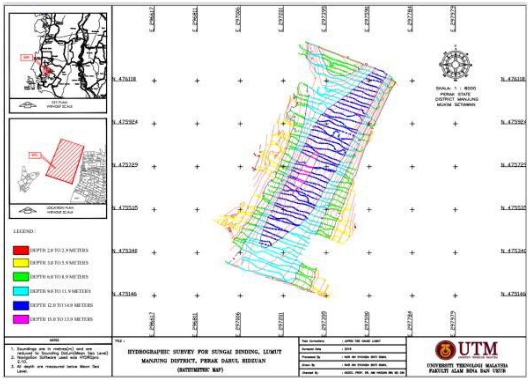

Figure 12. Bathymetric plan relative to the DSMM tide gauge in 2018 plotted using AutoCAD

3.1.2 Establishment of a Bathymetric Plan in Surfer

According to Golden Software (2017), robust 2D and 3D mapping, modelling, and analysis programs are designed to facilitate a deeper understanding of geospatial data. Surfer is a leading competitor in data modelling software. Surfer software can produce the bathymetric plan both on 2D and 3D surfaces.

3.1.2.1 Bathymetric Plan

The bathymetric plan shows the depth of each tide gauge data in 2017 and 2018. (See Figures 13 to 16). The major contour line is dark brown, where the line width is slightly thicker than the minor contour. The dark brown colour also indicates the lowest depth, while the dark blue indicates the highest depth. The interval of the major contour is 3 meters.

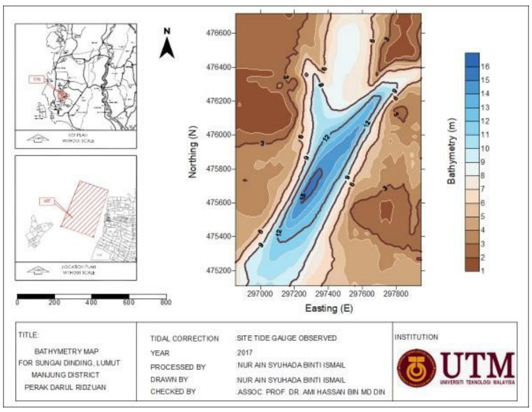

Figure 13. Bathymetric plan relative to the on-site tide gauge in 2017 generated using Surfer

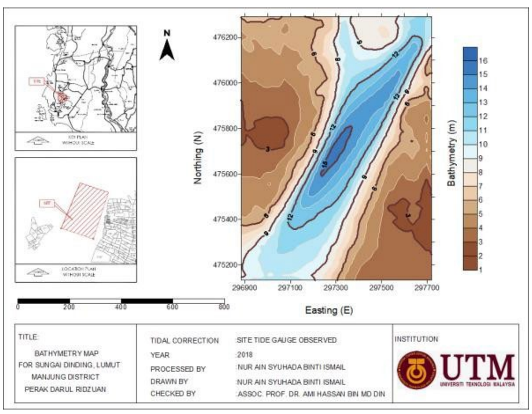

Figure 14. Bathymetric plan relative to the on-site tide gauge in 2018 generated using Surfer

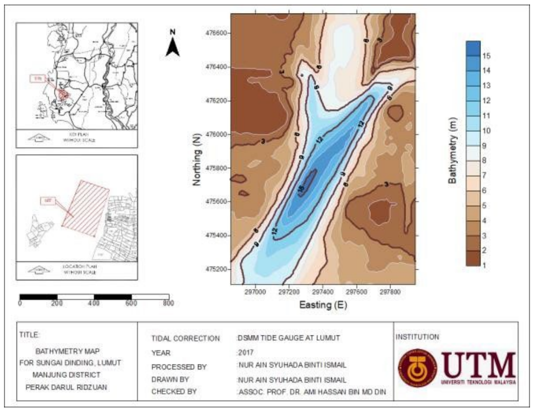

Figure 15. Bathymetric plan relative to the DSMM tide gauge in 2017 generated using Surfer

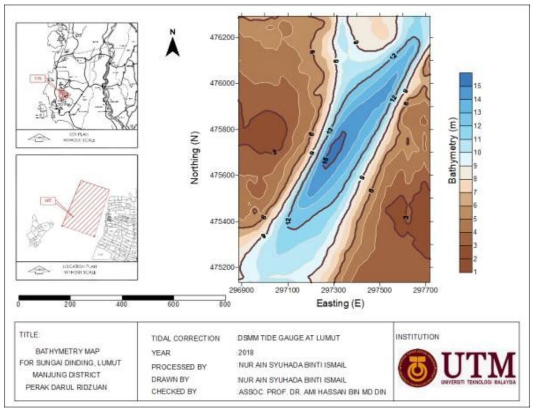

Figure 16. Bathymetric plan relative to the DSMM tide gauge in 2018 generated using Surfer

3.1.2.2 3-Dimensional Model

The bathymetric plan is also created in 3D model, as shown in Figures 17 to Figure 20. The deepest depth is blueish, while the shallowest are red to orange. The depth interval is 1 metre. The map projection has a 45° field of view, 45° rotation, and 30° tilt. The latitude and longitude scales are proportional.

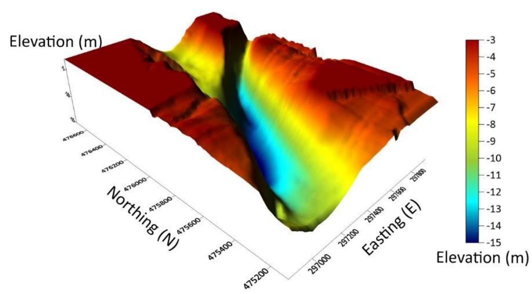

Figure 17. A 3D bathymetric plan relative to the on-site tide gauge in 2017

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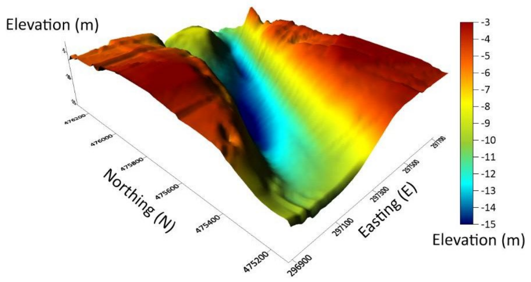

Figure 18. A 3D bathymetric plan relative to the on-site tide gauge in 2018

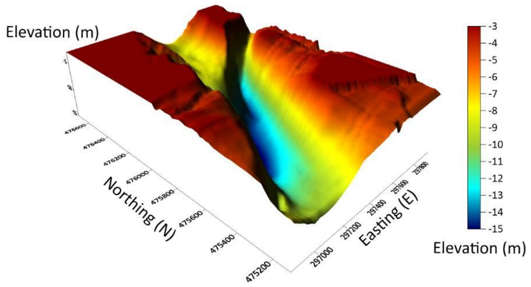

Figure 19. A 3D DSMM bathymetric plan relative to the DSMM tide gauge in 2017

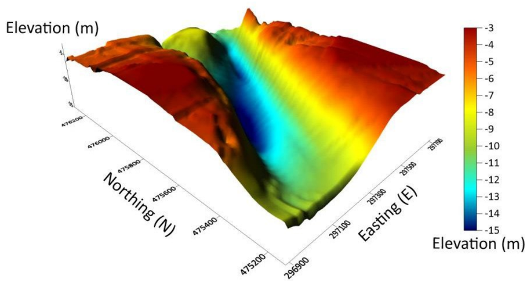

Figure 20. A 3D DSMM bathymetric plan relative to the DSMM tide gauge Plan in 2018

3.2 Analysis of Bathymetric Plan

3.2.1 Comparison of Reduced Sounding Depth Relative to the On-site Tide Gauge

Table 3 shows the exact observation points between the 2 years of the bathymetric plan relative to the on-site tide gauge. Figure 21 compares reduced sounding depths relative to the on-site tide gauge in 2017 and 2018 with a scale of 1:7000. The depth of 48 points from both years are compared and the differences are calculated. The highest depth difference is 0.8 metres, while the lowest is 0 metres. Data in Table 2 are illustrated as indicates in Figure 22. Figures 23 and 24 illustrate the comparison between the depth observed in 2017 and 2018 relative to the on-site tide gauge using Surfer.

Table 3. Depth comparison between 2017 and 2018 relative to the on-site tide gauge

No	Northing (m)	Easting (m)	Depth 2017 (m)	Depth 2018 (m)	Depth Difference (m)
1	475960	297217	6.0	6.2	0.2
2	475960	297277	7.6	7.6	0.0
3	475960	297337	11.2	11.2	0.0
4	475960	297397	12.8	12.5	-0.3
5	475960	297457	13.9	13.7	-0.2
6	475960	297517	14.3	14.5	0.2
7	475900	297217	5.1	4.8	-0.3
8	475900	297277	8.8	8.6	-0.2
9	475900	297337	12.1	12.6	0.5
10	475900	297397	14.1	13.9	-0.2
11	475900	297457	14.5	14.5	0.0
12	475900	297517	14.0	13.9	-0.1
13	475840	297217	5.6	5.4	-0.2
14	475840	297277	10.1	10.0	-0.1
15	475840	297337	13.6	14.1	0.5
16	475840	297397	14.7	14.7	0.0
17	475840	297457	13.8	13.8	0.0
18	475840	297517	11.4	11.8	0.4
19	475780	297217	6.9	6.7	-0.2
20	475780	297277	11.9	12.5	0.6
21	475780	297337	15.2	15.2	0.0
22	475780	297397	14.3	14.3	0.0
23	475780	297457	13.1	13.1	0.0
24	475780	297517	9.8	9.0	-0.8
25	475720	297217	8.9	9.0	0.1
26	475720	297277	14.9	14.9	0.0
27	475720	297337	15.0	15.0	0.0
28	475720	297397	13.4	13.7	0.3
29	475720	297457	11.2	11.3	0.1
30	475720	297517	7.7	7.4	-0.3
31	475660	297217	12.8	12.3	-0.5
32	475660	297277	15.5	15.3	-0.2
33	475660	297337	14.1	14.0	-0.1
34	475660	297397	12.5	12.5	0.0
35	475660	297457	9.2	9.1	-0.1
36	475660	297517	5.6	5.7	0.1
37	475600	297217	14.5	14.9	0.4
38	475600	297277	14.4	14.4	0.0
39	475600	297337	13.0	13.1	0.1
40	475600	297397	10.8	11.0	0.2
41	475600	297457	7.8	7.3	-0.5
42	475600	297517	5.1	5.6	0.5
43	475540	297217	14.7	14.7	0.0
44	475540	297277	13.1	13.0	-0.1
45	475540	297337	12.2	12.1	-0.1
46	475540	297397	9.5	9.3	-0.2
47	475540	297457	6.7	6.3	-0.4
48	475540	297517	4.8	4.6	-0.2

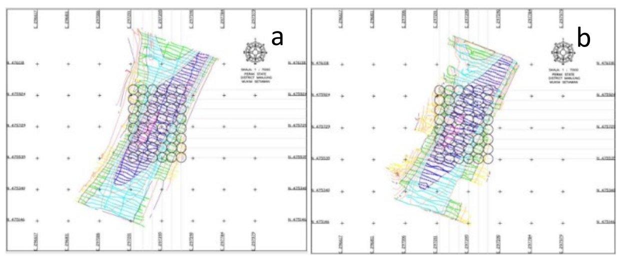

Figure 21. The bathymetric plan plotted using AutoCAD. a) The bathymetric plan in 2017 and b) the bathymetric plan in 2018

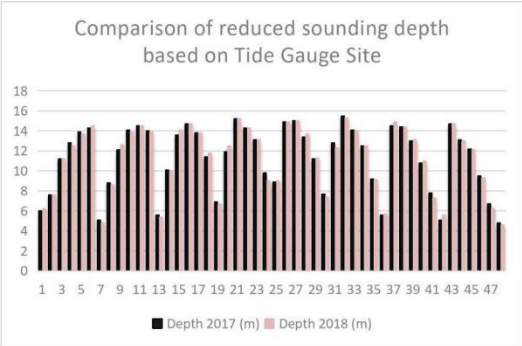

Figure 22. The depth comparison between 2017 and 2018 relative to the on-site tide gauge

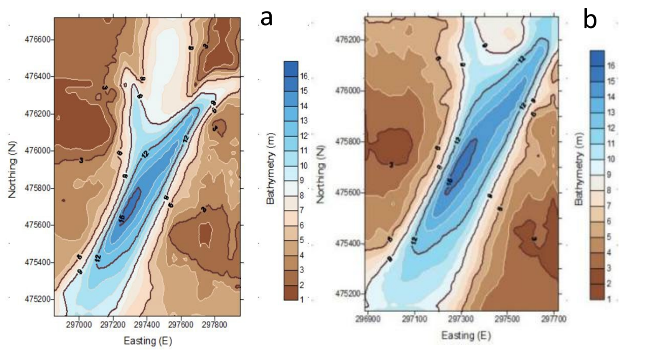

Figure 23. The bathymetric plan generated using Surfer in 2D. a) The bathymetric plan in 2017 and b) the bathymetric plan in 2018

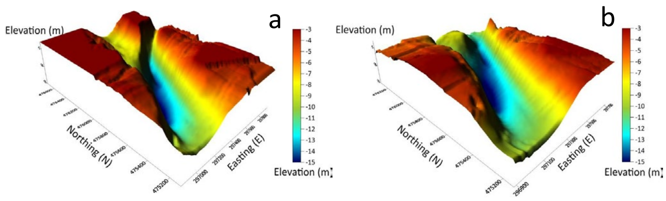

Figure 24. The bathymetric plan generated using Surfer in 3D. a) The bathymetric plan in 2017 and b) the bathymetric plan in 2018

Figure 24 shows the bathymetry between 2017 and 2018, where they are slightly different. The river floor in 2018 is smoother than in 2017. The changes in bathymetry are due to the sedimentation. According to Sousa et al. (2022), sediment accumulation affects cross- sectional and longitudinal bathymetric profiles. Sungai Dinding is quite a busy place. Lumut is reached via the River Passage along the Sungai Dinding (Jojo, 2011). The primary function of the port is for the use of the Lumut Naval Base, the Malayan Flour Mill, and to access the small pier in Lumut used by coasters at high tide. The ocean traffic is dominated by the fishing boats and ferries. With the complicated situation, the water flow affects the sedimentation. Furthermore, Sakhaee & Khalili (2021) also agree that the marine structures and traffic affect the sedimentation.

3.2.2 Comparison of Reduced Sounding Depth Relative to DSMM Tide Gauge

The exact observation points between the 2 years of the bathymetric plan relative to the DSMM Tide Gauge is shown in Table 4. The depth of 48 points is compared between the years and the difference are calculated. The highest depth difference is 0.86 metres, while the smallest is 0.01 metres. Figure 25 illustrates the comparison of reduced sounding depths relative to the DSMM tide gauge in 2017 and 2018 with a scale of 1:7000. The data tabulated in Table 4 is interpreted in Figure 26. Figures 27 and Figure 28 illustrate the comparison between the depth observed in 2017 and 2018 relative to the DSMM tide gauge.

Table 4. Depth comparison between 2017 and 2018 relative to DSMM tide gauge

No.	Northing (m)	Easting (m)	Depth 2017 (m)	Depth 2018 (m)	Depth Difference (m)
1	475960	297217	5.92	6.27	0.35
2	475960	297277	7.47	7.43	-0.04
3	475960	297337	11.13	11.08	-0.05
4	475960	297397	12.68	12.34	-0.34
5	475960	297457	13.84	13.56	-0.28
6	475960	297517	14.26	14.32	0.06
7	475900	297217	5.05	4.71	-0.34
8	475900	297277	8.69	8.48	-0.21
9	475900	297337	12.04	12.43	0.39
10	475900	297397	14.06	13.78	-0.28
11	475900	297457	14.37	14.33	-0.04
12	475900	297517	13.86	13.75	-0.11
13	475840	297217	5.47	5.32	-0.15
14	475840	297277	9.97	9.91	-0.06
15	475840	297337	13.48	13.96	0.48
16	475840	297397	14.64	14.6	-0.04
17	475840	297457	13.72	13.65	-0.07
18	475840	297517	11.32	11.68	0.36
19	475780	297217	6.75	6.60	-0.15
20	475780	297277	11.80	12.45	0.65
21	475780	297337	15.08	15.11	0.03
22	475780	297397	14.18	14.17	-0.01
23	475780	297457	12.96	13.03	0.07
24	475780	297517	9.74	8.88	-0.86
25	475720	297217	8.76	8.93	0.17
26	475720	297277	14.73	14.77	0.04
27	475720	297337	14.84	14.95	0.11
28	475720	297397	13.27	13.63	0.36
29	475720	297457	11.12	11.23	0.11
30	475720	297517	7.61	7.27	-0.34
31	475660	297217	12.67	12.24	-0.43
32	475660	297277	15.37	15.22	-0.15
33	475660	297337	14.02	13.93	-0.09
34	475660	297397	12.42	12.38	-0.04
35	475660	297457	9.11	8.98	-0.13
36	475660	297517	5.46	5.60	0.14
37	475600	297217	14.35	14.76	0.41
38	475600	297277	14.29	14.31	0.02
39	475600	297337	12.86	13.05	0.19
40	475600	297397	10.64	10.88	0.24
41	475600	297457	7.70	7.22	-0.48
42	475600	297517	4.94	5.49	0.55
43	475540	297217	14.57	14.58	0.01
44	475540	297277	12.98	12.87	-0.11
45	475540	297337	12.10	12.01	-0.09
46	475540	297397	9.34	9.22	-0.12
47	475540	297457	6.58	6.23	-0.35
48	475540	297517	4.63	4.49	-0.14

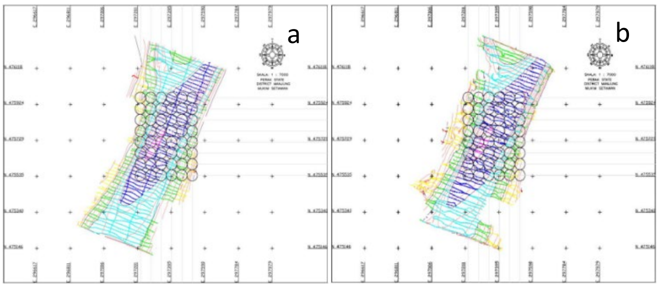

Figure 25. The bathymetric plan plotted using AutoCAD. a) The bathymetric plan in 2017 and b) the bathymetric plan in 2018

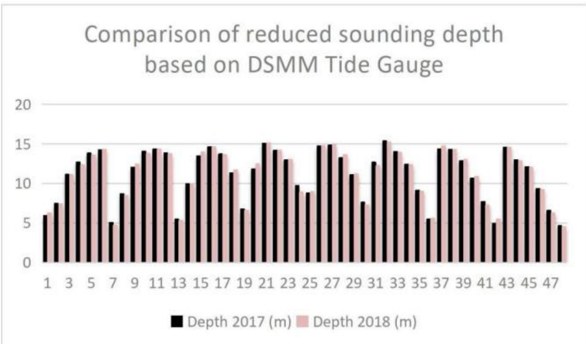

Figure 26. The comparison between depth observed in 2017 and 2018 relative to the DSMM tide gauge

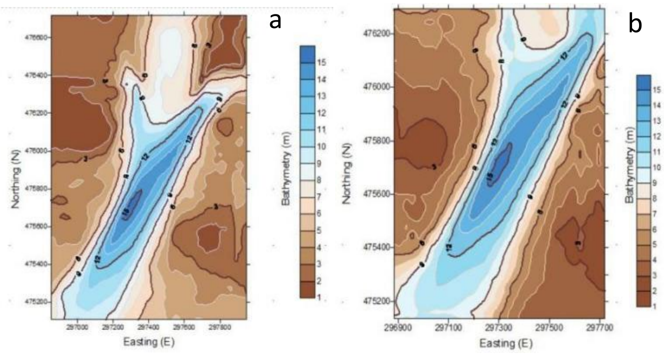

Figure 27. The bathymetric plan generated using Surfer in 2D. a) The bathymetric plan in 2017 and b) the bathymetric plan in 2018

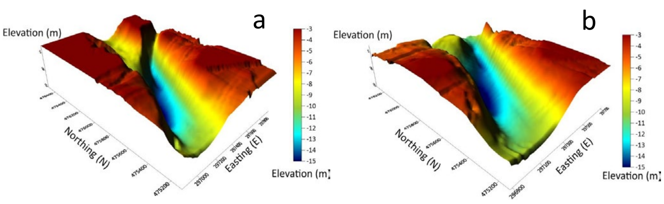

Figure 28. The bathymetric plan generated using Surfer in 3D. a) The bathymetric plan in 2017 and b) the bathymetric plan in 2018

The river floor of 2017 and 2018 bathymetric plan relative to DSMM tide gauge is identical to the bathymetric plan relative to the on-site tide gauge. The difference in river floor between the 2 years is also due to the same causes. The sedimentation that affects the bathymetric plan relative to the on-site tide gauge is in the same way that it affects the bathymetric plan relative to the DSMM tide gauge.

3.3 Assessment of Bathymetric Data Based on the Distance of Tide Measurement

3.3.1 Statistical Comparison of Reduced Sounding Depth in 2017

Table 5 and Figure 29 show the comparison of reduced sounding depth in 2017. The difference between sounding depths is calculated by comparing the depth at 48 points. The highest depth difference is 0.17 metres and the lowest is 0.04 metres.

Table 5. Depth comparison of reduced sounding depth relative to on-site and DSMM tide gauge in 2017

No.	Northing (m)	Easting (m)	Depth On-Site (m)	Depth DSMM (m)	Depth Difference (m)
1	475960	297217	6.00	5.92	-0.08
2	475960	297277	7.60	7.47	-0.13
3	475960	297337	11.20	11.13	-0.07
4	475960	297397	12.80	12.68	-0.12
5	475960	297457	13.90	13.56	-0.28
6	475960	297517	14.30	14.32	0.06
7	475900	297217	5.10	4.71	-0.34
8	475900	297277	8.80	8.48	-0.21
9	475900	297337	12.10	12.43	0.39
10	475900	297397	14.10	13.78	-0.28
11	475900	297457	14.50	14.33	-0.04
12	475900	297517	14.00	13.75	-0.11
13	475840	297217	5.60	5.32	-0.15
14	475840	297277	10.10	9.91	-0.06
15	475840	297337	13.60	13.96	0.48
16	475840	297397	14.70	14.6	-0.04
17	475840	297457	13.80	13.65	-0.07
18	475840	297517	11.40	11.68	0.36
19	475780	297217	6.90	6.60	-0.15
20	475780	297277	11.90	12.45	0.65
21	475780	297337	15.20	15.11	0.03
22	475780	297397	14.30	14.17	-0.01
23	475780	297457	13.10	13.03	0.07
24	475780	297517	9.80	8.88	-0.86
25	475720	297217	8.90	8.93	0.17
26	475720	297277	14.90	14.77	0.04
27	475720	297337	15.00	14.95	0.11
28	475720	297397	13.40	13.63	0.36
29	475720	297457	11.20	11.23	0.11
30	475720	297517	7.70	7.27	-0.34
31	475660	297217	12.80	12.24	-0.43
32	475660	297277	15.50	15.22	-0.15
33	475660	297337	14.10	13.93	-0.09
34	475660	297397	12.50	12.38	-0.04
35	475660	297457	9.20	8.98	-0.13
36	475660	297517	5.60	5.60	0.14
37	475600	297217	14.50	14.76	0.41
38	475600	297277	14.40	14.31	0.02
39	475600	297337	13.00	13.05	0.19
40	475600	297397	10.80	10.88	0.24
41	475600	297457	7.80	7.22	-0.48
42	475600	297517	5.10	5.49	0.55
43	475540	297217	14.70	14.58	0.01
44	475540	297277	13.10	12.87	-0.11
45	475540	297337	12.20	12.01	-0.09
46	475540	297397	9.50	9.22	-0.12
47	475540	297457	6.70	6.23	-0.35
48	475540	297517	4.80	4.49	-0.14

According to Zach (2021), the lower the value of RMSD, the better a model can "fit" to a dataset. The range of the dataset must be considered when determining whether the given RMSD value is "low" or not. In 2017, the RMSD between the reduced sounding depth relative to on-site and the reduced sounding depth relative to DSMM tide gauge is 0.1171m, as tabulated in Table 6. This RMSD value is relatively low. When refers to the IHO S-44 standard (TVU), the RMSD is acceptable as the value is within the tolerance in all Level Order (See Table 7). It implies that the model difference is reliable. Thus, the reduced sounding depth relative to the DSMM tide gauge still can be used.

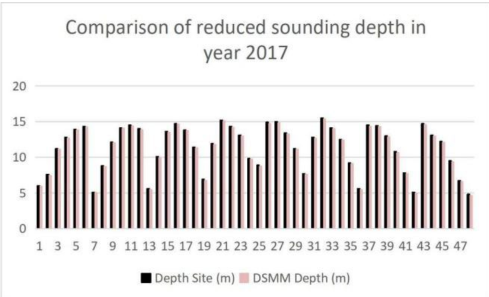

Figure 29. The comparison between depth relative to the on-site and DSMM tide gauge in 2017

Table 6. RMSD between the reduced sounding depth relative to on-site and DSMM tide gauge in 2017

No.	Northing (m)	Easting (m)	Depth Difference (m)	RMSD (m)
1	475960	297217	-0.08	0.0064
2	475960	297277	-0.13	0.0169
3	475960	297337	-0.07	0.0049
4	475960	297397	-0.12	0.0144
5	475960	297457	-0.28	0.0036
6	475960	297517	0.06	0.0016
7	475900	297217	-0.34	0.0025
8	475900	297277	-0.21	0.0121
9	475900	297337	0.39	0.0036
10	475900	297397	-0.28	0.0016
11	475900	297457	-0.04	0.0169
12	475900	297517	-0.11	0.0196
13	475840	297217	-0.15	0.0169
14	475840	297277	-0.06	0.0169
15	475840	297337	0.48	0.0144
16	475840	297397	-0.04	0.0036
17	475840	297457	-0.07	0.0064
18	475840	297517	0.36	0.0064
19	475780	297217	-0.15	0.0225
20	475780	297277	0.65	0.0100
21	475780	297337	0.03	0.0144
22	475780	297397	-0.01	0.0144
23	475780	297457	0.07	0.0196
24	475780	297517	-0.86	0.0036
25	475720	297217	0.17	0.0196
26	475720	297277	0.04	0.0289
27	475720	297337	0.11	0.0256
28	475720	297397	0.36	0.0169
29	475720	297457	0.11	0.0064
30	475720	297517	-0.34	0.0081
31	475660	297217	-0.43	0.0169
32	475660	297277	-0.15	0.0169
33	475660	297337	-0.09	0.0064
34	475660	297397	-0.04	0.0064
35	475660	297457	-0.13	0.0081
36	475660	297517	0.14	0.0196
37	475600	297217	0.41	0.0225
38	475600	297277	0.02	0.0121
39	475600	297337	0.19	0.0196
40	475600	297397	0.24	0.0256
41	475600	297457	-0.48	0.0100
42	475600	297517	0.55	0.0256
43	475540	297217	0.01	0.0169
44	475540	297277	-0.11	0.0144
45	475540	297337	-0.09	0.0100
46	475540	297397	-0.12	0.0256
47	475540	297457	-0.35	0.0144
48	475540	297517	-0.14	0.0289
			Sum (m)	0.6586
			Mean (m)	0.0137
			RMSD (m)	± 0.1171

Table 7. Minimum bathymetry standard (IHO S-44 Standards for Hydrographic Surveys, 6th edition)

Criteria	Order 2	Order 1	Order 1	Special Order	Exclusive Order
TVU for reduced sounding depth in year 2017 between on-site and DSMM tide gauges	1.0329	0.5029	0.5029	0.2639	0.1721

3.3.2 Statistical Comparison of Reduced Sounding Depth in2018

In 2018, Table 8 and Figure 30 show the comparison of reduced sounding depth. The depth at 48 points is used to calculate the difference between the sounding depths. The highest depth difference is 0.18 metres, while the lowest is 0.05 metres.

Table 8. Depth comparison between the reduced sounding depth relative to on-site and DSMM tide gauge in 2018

No.	Northing (m)	Easting (m)	Depth On-Site (m)	Depth DSMM (m)	Depth Difference (m)
1	475960	297217	6.20	6.27	0.07
2	475960	297277	7.60	7.43	-0.17
3	475960	297337	11.20	11.08	-0.12
4	475960	297397	12.50	12.34	-0.16
5	475960	297457	13.70	13.56	-0.14
6	475960	297517	14.50	14.32	-0.18
7	475900	297217	4.80	4.71	-0.09
8	475900	297277	8.60	8.48	-0.12
9	475900	297337	12.60	12.43	-0.17
10	475900	297397	13.90	13.78	-0.12
11	475900	297457	14.50	14.33	-0.17
12	475900	297517	13.90	13.75	-0.15
13	475840	297217	5.40	5.32	-0.08
14	475840	297277	10.00	9.91	-0.09
15	475840	297337	14.10	13.96	-0.14
16	475840	297397	14.70	14.60	-0.10
17	475840	297457	13.80	13.65	-0.15
18	475840	297517	11.80	11.68	-0.12
19	475780	297217	6.70	6.60	-0.10
20	475780	297277	12.50	12.45	-0.05
21	475780	297337	15.20	15.11	-0.09
22	475780	297397	14.30	14.17	-0.13
23	475780	297457	13.10	13.03	-0.07
24	475780	297517	9.00	8.88	-0.12
25	475720	297217	9.00	8.93	-0.07
26	475720	297277	14.90	14.77	-0.13
27	475720	297337	15.00	14.95	-0.05
28	475720	297397	13.70	13.63	-0.07
29	475720	297457	11.30	11.23	-0.07
30	475720	297517	7.40	7.27	-0.13

31	475660	297217	12.30	12.24	-0.06
32	475660	297277	15.30	15.22	-0.08
33	475660	297337	14.00	13.93	-0.07
34	475660	297397	12.50	12.38	-0.12
35	475660	297457	9.10	8.98	-0.12
36	475660	297517	5.70	5.60	-0.10
37	475600	297217	14.90	14.76	-0.14
38	475600	297277	14.40	14.31	-0.09
39	475600	297337	13.10	13.05	-0.05
40	475600	297397	11.00	10.88	-0.12
41	475600	297457	7.30	7.22	-0.08
42	475600	297517	5.60	5.49	-0.11
43	475540	297217	14.70	14.58	-0.12
44	475540	297277	13.00	12.87	-0.13
45	475540	297337	12.10	12.01	-0.09
46	475540	297397	9.30	9.22	-0.08
47	475540	297457	6.30	6.23	-0.07
48	475540	297517	4.60	4.49	-0.11

Table 9. RMSD between the reduced sounding depth relative to on-site and DSMM tide gauge in 2018

No.	Northing (m)	Easting (m)	Depth Difference (m)	RMSD (m)
1	475960	297217	0.07	0.0049
2	475960	297277	-0.17	0.0289
3	475960	297337	-0.12	0.0144
4	475960	297397	-0.16	0.0256
5	475960	297457	-0.14	0.0196
6	475960	297517	-0.18	0.0324
7	475900	297217	-0.09	0.0081
8	475900	297277	-0.12	0.0144
9	475900	297337	-0.17	0.0289
10	475900	297397	-0.12	0.0144
11	475900	297457	-0.17	0.0289
12	475900	297517	-0.15	0.0225
13	475840	297217	-0.08	0.0064
14	475840	297277	-0.09	0.0081
15	475840	297337	-0.14	0.0196
16	475840	297397	-0.10	0.0100
17	475840	297457	-0.15	0.0225
18	475840	297517	-0.12	0.0144
19	475780	297217	-0.10	0.0100
20	475780	297277	-0.05	0.0025
21	475780	297337	-0.09	0.0081
22	475780	297397	-0.13	0.0169
23	475780	297457	-0.07	0.0049
24	475780	297517	-0.12	0.0144
25	475720	297217	-0.07	0.0049
26	475720	297277	-0.13	0.0169
27	475720	297337	-0.05	0.0025
28	475720	297397	-0.07	0.0049
29	475720	297457	-0.07	0.0049
30	475720	297517	-0.13	0.0169
31	475660	297217	-0.06	0.0036
32	475660	297277	-0.08	0.0064
33	475660	297337	-0.07	0.0049
34	475660	297397	-0.12	0.0144
35	475660	297457	-0.12	0.0144
36	475660	297517	-0.10	0.0100
37	475600	297217	-0.14	0.0196
38	475600	297277	-0.09	0.0081
39	475600	297337	-0.05	0.0025
40	475600	297397	-0.12	0.0144
41	475600	297457	-0.08	0.0064
42	475600	297517	-0.11	0.0121
43	475540	297217	-0.12	0.0144
44	475540	297277	-0.13	0.0169
45	475540	297337	-0.09	0.0081
46	475540	297397	-0.08	0.0064
47	475540	297457	-0.07	0.0049
48	475540	297517	-0.11	0.0121

			Sum (m)	0.6114
			Mean (m)	0.0127
			RMSD (m)	± 0.1129

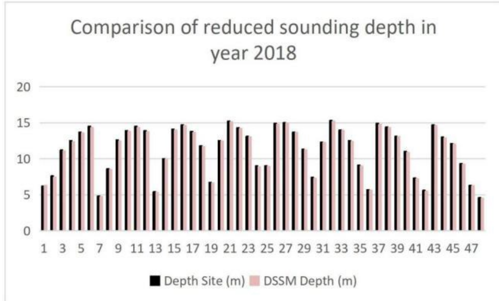

Figure 30. The comparison of depth relative to the on-site and DSMM tide gauge in 2018

Table 10. Minimum bathymetry standard (IHO S-44 Standards for Hydrographic Surveys, 6th edition)

Criteria	Order 2	Order 1	Order 1	Special Order	Exclusive Order
TVU for reduced sounding depth in year 2017 between on-site and DSMM tide gauges	1.0329	0.5029	0.5029	0.2639	0.1721

In 2018, the RMSD values between the reduced sounding depth relative to the on-site and DSMM tide gauge is 0.1129m, as shown in Table 9. This RMSD value is relatively low. Referring to the IHO S-44 standard guidelines (TVU), the RMSD is acceptable because the value is within the tolerance standard in all Level Order, as shown in Table 10. It implies that the model difference is reliable. Thus, the reduced sounding depth relative to the DSMM tide gauge can still be used.

4. CONCLUSION

Tidal corrections based on the on-site and DSMM tide gauge are used to reduce the bathymetry data at Sungai Dinding. It reveals comparable results in bathymetric plans with low RMSD values at cm-level. These findings imply that the DSMM tide gauge at Lumut is reliable for tidal correction in this hydrographic survey area. This study provides guidelines of the selection of tide gauge stations for hydrographic surveys. Furthermore, comparing the distance between tide gauges while using the two tide gauge stations, on-site and the nearest DSMM tide gauge provides insights to the reliability of bathymetry data. In conclusion, this study will raise awareness of the importance of station location in the bathymetry survey area.

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REFERENCES

Awang, N. A. C., & Othman, E. R. (2011). Hydrographic Survey Using Real Time Kinematic Method for River Deepening. Geoinformation Science Journal.
Ćalasan, M., Abdel Aleem, S. H. E., & Zobaa, A. F. (2020). On the root mean square error (RMSE) calculation for parameter estimation of photovoltaic models: A novel exact analytical solution based on Lambert W function. Energy Conversion and Management, 210

Glen, S. (2021). RMSE: Root mean square error. Statistics How To. Retrieved June 29, 2022, from https://www.statisticshowto.com/probability-and-statistics/regression-analysis/rmse-root-mean-square-error/

Golden Software. (2017). *Golden Software releases Surfer® 2D and 3D Mapping, modeling, and Analysis Software. MINING.COM.* Retrieved June 24, 2022, from https://www.mining.com/web/golden-software-releases-surfer-2d-3d-mapping-modeling-analysis-software/

International Hydrographic Organization. (2020). International Hydrographic Organization Standards for Hydrographic Surveys (6th ed.).

Jojo. Lumut Malaysian navy (Perak) (Malaysia). Lumut Malaysian Navy (Perak) (Malaysia). Retrieved June 25, 2022, from https://www.sea-seek.com/en/Lumut-Malaysian-navy-Perak-Malaysia-

Kim, R., Boudreau, D., Hunt, J., Sprout, E., Ramroop, T., Costa, H., Hall, H., Teng, S., & McDaniel, M. (2022, May 20). Cause and effect: Tides. National Geographic Society. Retrieved June 23, 2022, from https://education.nationalgeographic.org/resource/cause- effect-tides

Khare, V., Khare, C., Nema, S., & Baredar, P. (2019). Optimum sizing and modeling of Tidal Energy Systems. Tidal Energy Systems, 189–241. https://doi.org/10.1016/b978-0-12-814881-5.00004-1

Lee, Z. H. (2021). Tidal Modelling of Malaysian Waters using GeoTide and Totis Software (thesis). Dept. Of Geoinformation Science and Engineering, Universiti Teknologi Malaysia, Skudai

Sakhaee, F., & Khalili, F. (2021). Sediment pattern & rate of bathymetric changes due to construction of breakwater extension at Nowshahr Port. Journal of Ocean Engineering and Science, 6(1), 70–84. https://doi.org/10.1016/j.joes.2020.04.002

Sousa, L. S., Raude, J. M., Wambua, R. M., & Mutua, B. M. (2022). Bathymetry changes caused by sedimentation in an unlined canal of the Chókwè Irrigation Scheme, Mozambique. Irrigation and Drainage. https://doi.org/10.1002/ird.2674

Surfer. (n.d.). Kriging. Retrieved June 24, 2022, from https://surferhelp.goldensoftware.com/griddata/idd_grid_data_kriging.htm#:~:text=Within%20Surfer%2C%20Kriging%20can%20 be,an%20efficient%20and%20natural%20manner.

Tye, T. (2020). Sungai Manjung (sg. Dinding), Perak. Penang Travel Tips. Retrieved June 24, 2022, from https://www.penang- traveltips.com/malaysia/perak/sungai-manjung.htm

Zach. (2021). What is considered a good RMSE value? Statology. Retrieved June 25, 2022, from https://www.statology.org/what- is-a-good-rmse/

Zapata, C., Puente, A., García, A., García-Alba, J., & Espinoza, J. (2019). The use of hydrodynamic models in the determination of the chart datum shape in a tropical estuary. Water, 11(5), 902.

