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UTILIZATION OF MULTIBEAM ECHOSOUNDER DATA FOR BATHYMETRY MAPPING: EVALUATION WITH INTERNATIONAL STANDARD

UTILISASI DATA MULTIBEAM ECHOSOUNDER DALAM PEMETAAN DASAR LAUT: EVALUASI TERHADAP STANDAR INTERNASIONAL

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Abstract. Bathymetric mapping is crucial for understanding seabed conditions, especially in maritime countries like Indonesia. This study evaluates the quality of bathymetric data acquired using Multibeam Echosounder (MBES) in Jakarta waters. The acquired data was processed and analyzed based on the international standard IHO S-44. The results show that most acquired bathymetric data met the specified accuracy standard. However, some data did not meet the standard, especially in areas with varying depths. Bathymetric maps and seabed slope classification maps were successfully produced. The bathymetric map shows the complex morphology of the seabed, while the slope classification map indicates the dominance of flat areas. This research contributes significantly to efforts to improve the quality of bathymetric data in Indonesia.

Abstrak. *Pemetaan batimetri merupakan aktivitas penting untuk memahami kondisi dasar laut, terlebih di negara maritim seperti Indonesia. Penelitian ini bertujuan untuk mengevaluasi kualitas data batimetri yang diperoleh menggunakan Multibeam Echosounder (MBES) di perairan Jakarta. Data yang diperoleh kemudian diproses dan dianalisis berdasarkan standar internasional IHO S-44. Hasil penelitian menunjukkan bahwa sebagian besar data batimetri yang diperoleh memenuhi standar akurasi yang ditetapkan. Namun, terdapat beberapa data yang tidak memenuhi standar, terutama pada daerah dengan kedalaman yang bervariasi. Peta batimetri menunjukkan detail morfologi dasar laut yang kompleks, sedangkan peta klasifikasi profil menunjukkan dominasi daerah datar. Penelitian ini memberikan kontribusi penting dalam upaya meningkatkan kualitas data batimetri di Indonesia.*

1. INTRODUCTION

The process of mapping the seabed (bathymetry, from the words bathy - depth and metry - the science of measurement (Ayu et al., 2020)) in detail and accurately is essential to fulfill the concept of sustainable development (Nadzir, 2024). In addition, bathymetric mapping is also helpful for marine activities, such as navigation, natural resource management, and understanding climate change's effects (Hammerstad et al., 1993). The bathymetric survey consists of observations on the sea surface to obtain data on the depth and topographic conditions of the seabed and its classification (Soeprapto, 1999). The results of high-quality bathymetric mapping are an important basis for making two- or three-dimensional marine maps (Poerbandono & Djunarsjah, 2005). However, obtaining accurate data that meets international standards is often challenging, especially in complex waters such as Indonesia.

Indonesia is one of the archipelagic countries with the most significant number of islands in the world, according to data from the Indonesian Navy Hydrographic and Oceanographic Center in 2018, totaling 16,056 islands. In addition, sea conditions throughout Indonesia have different tendencies and make the complexity of Indonesian sea conditions relatively high (Wicaksana et al., 2015). This geographical condition, in the context of national defense, makes it quite tricky for related parties to manage, utilize, and supervise resources from within (Syahuri & Sitompul, 2020). This makes the need for accurate and up-to-date sea maps very important as the beginning of a sustainable process, such as border management, security, and exploration of natural resources in the exclusive economic zone (EEZ) (Shidarta & Agoes, 2008), as well as economic activities in big cities like Jakarta, especially in the Jakarta Bay area and Tanjung Priok.

Studies related to the processing of seabed observation data in Indonesia tend to use SBES sensors and also focus on applicative uses, such as classification of seabed features (Wicaksana et al., 2015), planning of rig locations and uses in the chemical and biological fields (Febrianto et al., 2016; Fuad et al., 2016; Jasmin et al., 2019). In addition, findings in locations other than Indonesia, such as Ireland (Fonseca et al., 2009), Turkey (Dupré et al., 2015), and Belgium (Montereale-Gavazzi et al., 2018) show that MBES is an efficient tool for producing high-accuracy bathymetric data. However, factors such as environmental conditions, system configuration, and pre-processing methods used on MBES data affect the level of accuracy, especially in the context of compliance with the IHO S-44 standard, which is the primary reference in quality control of MBES observations in the world (Calder & Mayer, 2003; Hellequin et al., 2003; Roberts et al., 2005). This is reinforced by the routine updates of the S-44 document, carried out 7 times in the last 40 years.

The two main reasons for this research are the need for accurate sea maps in Jakarta and the regional aspect of MBES data accuracy. The evaluation process of the MBES data accuracy level based on the predetermined scheme of the IHO S-44 standard, coupled with a comparison of mapping results with existing data and the classification process of seabed feature slopes based on Van Zuidam's slope theory (Zuidam, 1982) were carried out. This research is expected to improve the quality of bathymetric data, especially from MBES, in Indonesia, thus contributing well to Hydrography in Indonesia. Bathymetric data with good accuracy will be helpful for various related parties such as hydrographic agencies, local governments, and the marine industry.

2. LITERATURE REVIEW

One of the technologies commonly used in bathymetric observations is the Multibeam Echosounder (MBES). This tool has a basic principle, namely vertical distance (Z) observation using the time difference (Δt) between the transmission of sound waves from the transducer and the reception of reflections from the sound waves (Clarke, 2018), represented by Equation 1 with V as the soundwave velocity (±1,500 m/s). MBES has a fundamental difference with

Singlebeam Echosounder (SBES) in the scope of observation. SBES is represented by data at one point on the path, while MBES observations are one lane (swath) perpendicular to the path. This happens because MBES in the swath system can emit many beams from the transducers, as shown in **Figure 1**. In contrast, the sweep system combines several SBES transducers installed in parallel (Chaussard et al., 2013).

$$Z = \frac{V.\Delta t}{2} \tag{1}$$

$$Tolerance = \pm\sqrt{a^2 + (b * d)^2} \tag{2}$$

Every bathymetric observation process, following the uncertainty of sea surface conditions, experiences errors which are generally divided into 3: blunders, systematic and random (Ghilani & Wolf, 2008). These three sources of error need to be minimized in harmony, one of which is adjusted to the international standard of the International Hydrographic Organization (IHO) with number S-44 (International Hydrographic Organization (IHO), 2022). This document provides comprehensive guidelines to meet the requirements of the quality of sounding data (observations) from the seabed. The threshold of the S-44 document used is the measurement tolerance parameter written in Equation 2 with a and b as uncertainty tolerance contstant provided by the document while d represents the depth.

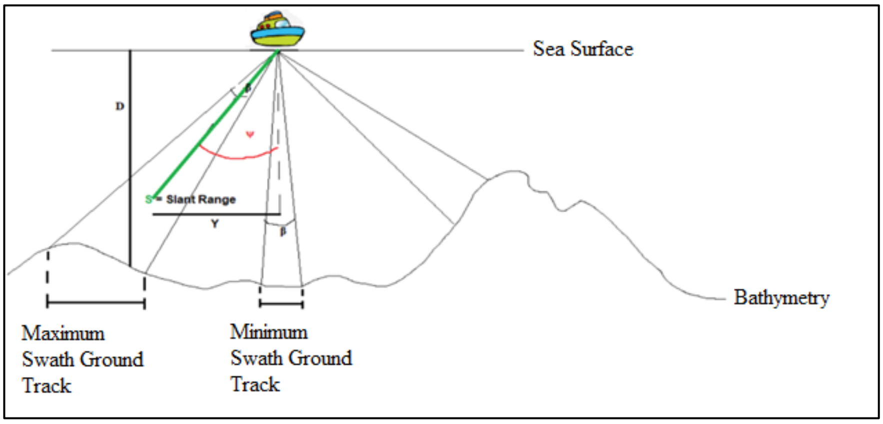

Figure 1. Swath scheme on MBES (de Jong et al., 2010).

3. METHODS

3.1. Data and Research Location

The location used in this study is in the Jakarta Bay Coast area, at coordinates 06°04'37" South Latitude and 106°49'52" East Longitude, covering an area of 41,400 m^2. Observations were conducted for 7 consecutive days in November 2018 and are depicted in **Figure 2**.

The primary data consists of 6 main-sounding lanes marked in orange in **Figure 2** and **1** correction-sounding lane marked in black in **Figure 2**. In addition, tidal information and sound velocity profile (SVP) are also used as additional data.

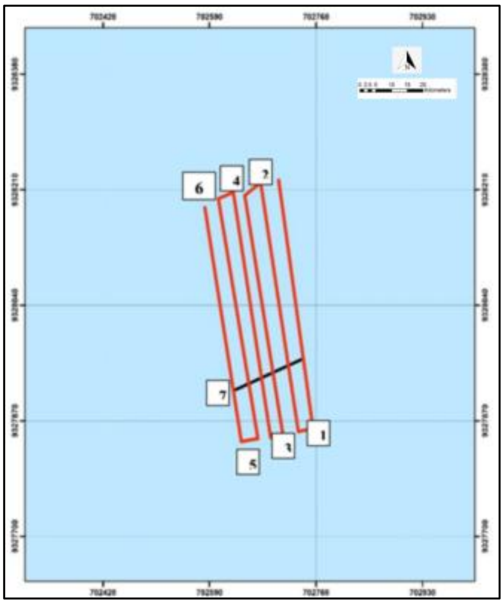

Figure 2. Research location map.

3.2. Data MBES Calibration

The calibration process of MBES data is the first step taken, with the input of primary MBES observation data and additional data, namely SVP and tidal information. Tidal data with an average instantaneous sea level calculation of 1.52 meters and a sound speed profile with an average speed value of 1,544.959 m/s and an average depth of 2.985 meters are used to normalize the observation data so that it is free from tidal effects by determining the chart datum (CD) and the effect of wave refraction due to the speed of sound which is different from the default sound speed value. After the combination of the three data occurs, the datum and projection system of the observations are set, which are helpful as a reference for global positions and coordinates.

The MBES observation data that has been globally referenced and corrected from tides and SVP then undergoes a static offset and patch test process (Li et al., 2008). These two corrections aim to normalize ships' behavior during measurements, considering that the sea surface is a dynamic surface that is constantly moving. Static offset calibration is carried out to start spatially connecting the transducer and the location of the GPS receiver system. Technically, a search for a local survey reference point (Central Reference Point - CRP) and offset numbers from related instruments is carried out, as shown in **Figure 3**.

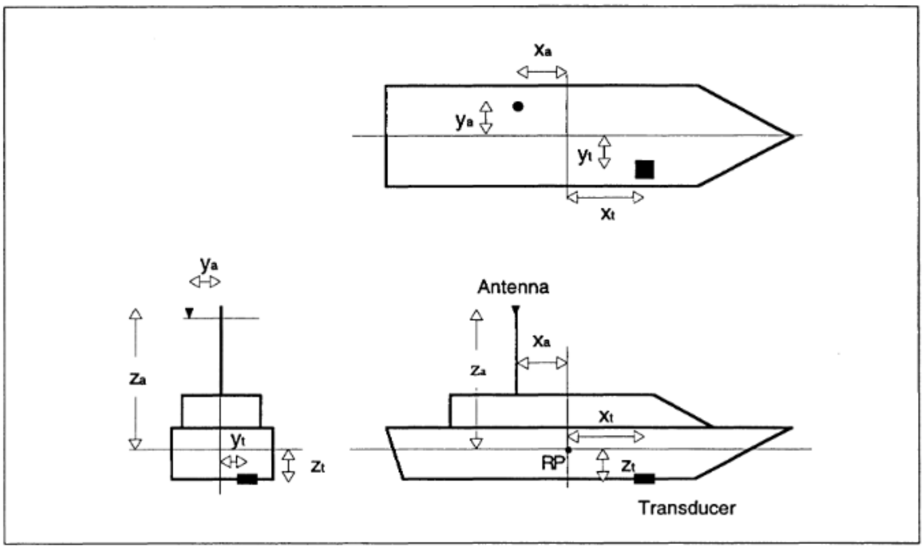

Figure 3. Static offset correction scheme (Godin, 1998).

Once the spatial information of all instruments on the ship is known from the static offset correction, a patch test can be performed. This process is one of the most important in the MBES data calibration scheme because it is at this stage that the data is normalized to the ship's movement (Gueriot et al., 2000). The movement of the ship is divided into three axes, represented by **Figure 4**: the x-axis (roll), the y-axis (pitch), and the z-axis (yaw). Information on the movement on the three axes is obtained from motion sensors or accelerometers/ gyrometers. The sensitivity of the patch test process is proportional to the depth (D); the more significant the error (e), the deeper it is, as shown by Equation 3 where θ indicates the rotation angle on all three axis. Time data from GPS is used to maintain the quality of the observation time data. In the patch test process, selecting observation lanes used as a calibration process and other observation lanes as validation is necessary. The lane is determined as close as possible to the cross-over area of the two overlapping lanes. The patch test result is one cumulonimbus correction value for each axis (roll, pitch, and yaw), shown in **Table 1**.

$$e = D * \tan\theta \quad (3)$$

The fourth part of the MBES data calibration process is data cleaning, which eliminates observation values considered anomalies. This process is carried out in stages, starting with automatic cleaning, which uses the maximum and minimum data from MBES observations as thresholds. After that, the next level is semi-automatic cleaning, which uses different limits, such as x-sigma, with x representing the standard deviation multiplier constant (sigma). The selection of this constant value is determined by the level of data quality that we obtain, which is generally two (~95%). The third level is manual cleaning, which must be done to clean up the remaining anomalies that have not been removed from the previous two levels.

Table 1. Patch test result parameter values.

Axis	Block	Area	Result
Time	N01 + N02	-	0 s
Pitch	N03+ N05	504,31 m^2	19,21°
Roll	N01 + N02	848,25 m^2	1,76°
Yaw	N04 + N06	322,14 m^2	-1,08°

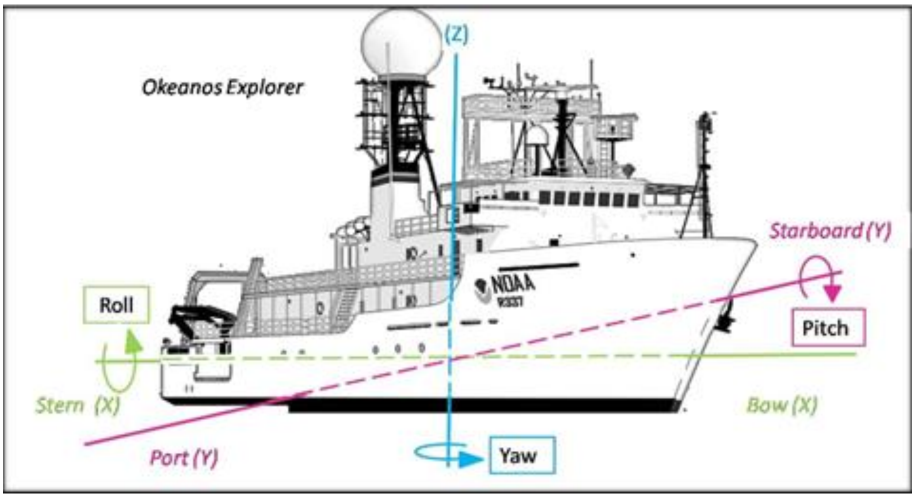

Figure 4. Roll, pitch, and yaw scheme (Hoy & Kissinger, 2010).

3.3. MBES Data Processing and Visualization

After the MBES observation data has been corrected and selected (filtered) through the previous process, the MBES data can be combined to become the desired output, namely a surface representing the seabed at the observation location and its contours. This section begins with the merging of data from various sounding lanes. This data merger is divided into three parts: 1) overlapping main lanes, 2) main lanes and cross lanes, and 3) cross lanes and main lanes that are treated like SBES data. This division is intended to ensure that the following process, namely the interpolation process using the Kriging method (Nadzir, 2024) and smoothing, can be carried out properly.

3.4. Accuracy Test and Determination of Slope Class

The surface of the seabed in the observation area then undergoes an accuracy test process to see the level of fulfillment of the S-44 document. In its implementation, 4 observation orders can be selected in the initial phase, and their accuracy is calculated according to Equation 2, whether or not they are included in the accuracy order. These are special orders, order 1a, order 1b, and order 2, listed in **Table 2**. The main difference between the four orders is using the resulting bathymetric data. The special order is intended for data in port areas and areas with critical levels of need. While orders 1 and 2 are used for locations that are not too critical. The two orders above are distinguished by their depth, where order 1 is specifically for locations with a depth of <100 meters and vice versa, and order 2 is designed for locations with a depth of> 100 meters. Furthermore, the difference between order 1a and order 1b lies in the bathymetric coverage, where order 1a requires 100% coverage, while order 1b does not require 100% coverage.

Table 2. Types of observation orders according to document S-44 (International Hydrographic Organization (IHO), 2022).

Order	Area	Depth	Tolerance
Special	100%, Critical	0 – 40 m	2 m
1a	100%	0 – 100 m	5 m + 5% D
1b	not 100%	0 – 100 m	5 m + 5% D
2	not 100%	> 100 m	20 m + 10% D

The process begins with checking the intersecting and overlapping paths from the central and correction lanes. After that, the number of samples (n) involved in the accuracy test is determined, according to Equation 4 with N as population and X is the sampling constant. Determining the number of samples is necessary to determine the sample value representing the population data, which is proportional to the amount of data. The location of the sample point is determined through a randomized, simple sampling process. After that, the standard error value (SE) in Equation 5 with SD as standard deviation is used to determine the level of fulfillment of data standards. The main criteria for the S-44 document fulfillment process are based on the SE parameters of the sample points. If the tolerance value, called TVU, is more significant than SE in Equation 6, then the data is said to be in the expected order.

$$sample\ (n) = {N * X}/{(X + N - 1)} \quad (4)$$

$$SE = \frac{SD}{\sqrt{n}} \quad (5)$$

$$TVU\ \geq SE\ \approx qualify \quad (6)$$

Slope classes, according to van Zuidam in 1985, are divided into 7 classes, starting from flat (0° to 2°) to steep classes (more than 55°). This class division is practically carried out independently in the hillshade-making process.

4. RESULT AND DISCUSSION

The tidal data obtained during the observation amounted to ~500, spaced 1 minute apart, starting from November 7, 2018, at 00:07 WIB to 15:05 WIB. The period of the data cannot yet be used to obtain the average sea level value. Therefore, the calculation process of the momentary average from the observation period was carried out, which had a value of 1.52 meters, following that stated in sub-chapter 3.2.

Furthermore, the observed sound speed values are depicted in **Figure 5,** obtained using the CTD (Conductivity, Temperature, and Density) instrument with a depth of between 0 meters and 10,777 meters. The average value produced was 1,544.959 m/s. In addition, it was found that the maximum sound speed value was at a depth of 0.116 meters, with a value of 1,545.72 m/s. Conversely, the minimum value was obtained at a depth of 10,777 meters with a speed of 1,544.29 m/s. This finding follows the concept of dividing pseudo-layers in the sea, surface layers, and thermocline (Makar, 2022). 3 factors influence the differences in these pseudo-layers: a) temperature, b) salinity (salinity, conductivity), and c) depth (depth, density). These results show that regionally, the research location has characteristics similar to the average worldwide (global).

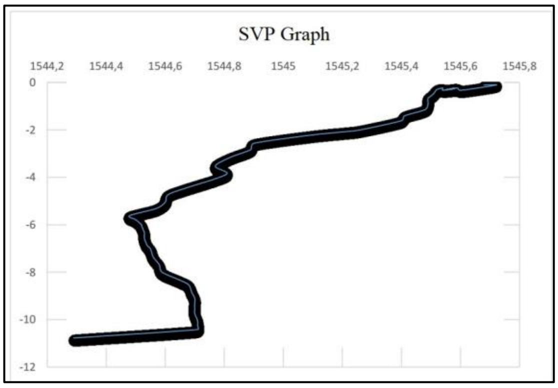

Figure 5. SVP graph.

The values of the patch test results listed in **Table 1** are entered into the MBES observation data system to obtain the error values in the data in the overlapping observation lanes, written in **Table 3**. The results illustrate that the error in the y-axis (pitch) is 2 times greater than the error in the x-axis (roll) and z-axis (yaw), which is 6 centimeters compared to 4 centimeters. In addition, it is also seen that the correction in the y-axis in degrees is 9 times greater than the other two axes. This shows that the conditions at the location during the observation were quite wavy, precisely perpendicular to the direction of the ship's movement. This finding can be a concern that in measurements in the same area, there is an effort to minimize interference in the y-axis.

Table 3. Errors from patch test results.

Axis	SD	Average	Mean
Time	0 s	0 s	0 s
Pitch	6 cm	5 cm	4 cm
Roll	4 cm	3 cm	2 cm
Yaw	2 cm	2 cm	2 cm

In this process, order 1a is selected as the order whose fulfillment level is sought. Order 1a is selected because it meets the urgency criteria of the research location, which is not too critical but still requires 100% coverage. This selection is reinforced by the fact that the research location is quite far from settlements and can still be a shipping route even in the measurement process. The check uses the numbers a, 0.5, and b, 0.013, which reflects order 1a.

The results of the comparison process between the main lanes overlapping with other main lanes are shown in **Table 4**. Of the 5 pairs of lanes, all have SE between 0.0054 - 0.00776. At the same time, the standard deviation value is below 1 meter, worth 10% of the maximum and minimum depth gap. Looking at the relationship between the percentage of overlapping lanes and their standard deviation, it was found that there was no harmonious relationship, either linearly or non-linearly. In addition, it was also found that there was no explicit relationship between the percentage of overlapping lanes and the number of samples (all five had values between 16 thousand). The determination of this number of sample points is based on the Random Simple Sampling approach, following Equation 4, from millions of points to ~16 thousand points with a Margin of Error (MoE) of 1%, or in other words, a Confidence Interval of 99% and a constant Z of 2.58. The results also show that none of the five main lane pairs received a data percentage of more than 70%, indicating that the quality of observations at the research location had not yet reached order 1a, according to document S-44.

Table 4. SE values, overlap for main-main.

Lane	Overlap (%)	SE	SD (m)	n	Yes	%
1 & 2	43.8	0.0076	0.971	16.200	11.200	69.14
2 & 3	43.5	0.0055	0.699	16.050	9.500	59.38
3 & 4	51.6	0.0054	0.694	16.280	8.480	52.09
4 & 5	21.54	0.0066	0.813	15.230	9.780	64.22
5 & 6	40.82	0.0075	0.960	16.120	8.320	51.61

Next, the data between the main lane and the correction lane are compared to obtain the level of accuracy independently from the same observation conditions. There are 6 pairs of lanes shown in **Table 5**. It was found that in terms of SE value, the pair of main lanes and corrections has a value of ~10% than the pair of main lanes (between 0.00034 and 0.0076), as well as in standard deviation (97.1 cm and 4.2 cm). In line with previous results, the comparison between the SE and standard deviation values is 100x smaller. For the comparison of TVU and tolerance, the results obtained are significantly different from the main lane-main lane, with the data received being ~99.5%. The results are similar to the previous comparison, namely that there is no clear correlation between the magnitude of the overlapping value and no clear relationship between the number of sample values and the amount of overlapping data. These findings indicate that a better process for checking the accuracy of MBES data is to form a pair between the primary and cross lanes. In addition, these results also indicate that observations using the MBES instrument depend heavily on a combination of careful measurement to avoid blunders, systematic correction processes (tides, SVP, and patch tests), and visual manual correction processes (smoothing and interpolation), which are in line with studies in other locations, such as (Hewitt et al., 2010; Khomsin et al., 2021; Simmons et al., 2017).

The bathymetry map generated from MBES data processing is shown in **Figure 6**. It can be seen that the depth at the research location does not have significant differences, with some locations being slightly deeper (4 to 5 meters, 50% of the depth range) than others and forming valleys (marked by solid blue). On the other hand, in some locations, not bound by distance/proximity to the coast, they are shallower than their surroundings, forming hills marked by orange.

In terms of slope, as shown in Figure 7, the research location is dominated by flat areas, with several locations classified as sloping and moderately steep. In detail, by using 3 profiles moving from west to east and north to south (A-A’, B-B’, C-C’), it was found that the profiles from west to east (B-B’ and C-C’) have a slope percentage 2x higher than profile A-A’ (from north to south).

Table 5. SE values, overlap for main-correction.

Lane	Overlap (m)	SE	SD (m)	n	Yes	%
7 &1	39.41	0.00034	0.042	9.360	9.350	99.9
7 &2	39.82	0.00047	0.059	9.400	9.400	99.7
7 &3	38.63	0.00028	0.035	9.450	9.450	99.7
7 &4	40.18	0.00035	0.044	9.300	9.300	99.5
7 &5	41.09	0.00030	0.037	9.500	9.500	99.8
7 &6	40.75	0.00020	0.025	10.000	10.000	99.3

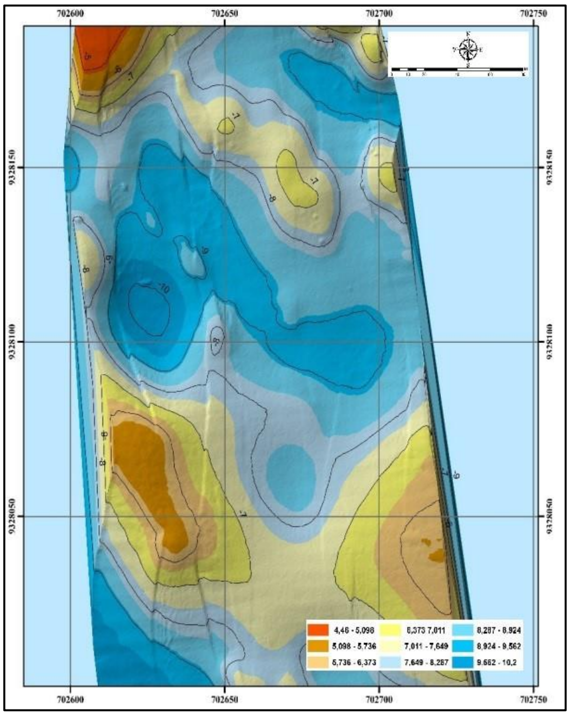

Figure 6. Depth at the research location.

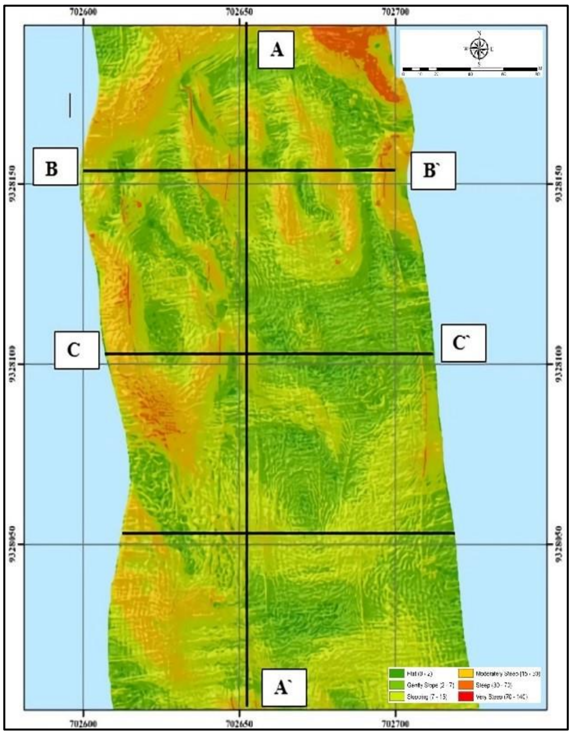

Figure 7. Slope profile at the research location.

5. CONCLUSION

Seabed measurements using MBES cannot be separated from the correction and calibration process, mainly tidal correction, SVP, and patch test. This process is the beginning of an effort to meet international standards in the IHO S-44 document. Accuracy tests of the main lane with the main lane and the central lane with the correction lane at the research location showed that the second approach was better, producing data that met the standard of 99.5% on average, which met the S-44 standard at Order 1a. These results indicate that more attention needs to be paid to holistic efforts to minimize all types of errors in bathymetric observations using MBES.

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