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Seafloor Morphology and Bathymetric Data Quality Evaluation Around Panjang Island, Banten Bay

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Abstract

Gathering accurate bathymetric data in shallow coastal waters proves to be difficult due to the environmental issues and operational constraints, especially in a semi-enclosed water like Banten Bay. This research intends to examine the seafloor morphology, in addition to assessing the quality of hydrographic data acquired through the use of single-beam echosounder (Odom Echotrac CV100) around Panjang Island Waters. The main line and cross line surveys of the survey were carried out using RTK-GNSS positioning and tidal corrections using 30 day observations relative to mean sea level. The bathymetric data show a gradual depth transition from 8 m nearshore to more than 20 m offshore. Ridges and basins are evident in the data indicating spatial variability. According to the results of a data quality assessment based on the IHO S-44 standard, 94.07% of data belonged to Order 2, 76.67% to Order 1a/1b, 56.30% to Special Order and 38.52% to Exclusive Order with data errors below 7%. As the above results suggest, the general hydrographic mapping by the dataset is of reliable accuracy, which does not achieve highest accuracy consistently. The study's main contribution is the demonstration of performance and practical limitations of single beam echosounder surveys in shallow water environment with a quantification of data quality compared to IHO standard. This study provides a validated methodology for low-cost bathymetric mapping of other similar semi-enclosed coastal water.

Keywords: Banten Bay, bathymetric data quality, order classification, single-beam echosounder, S-44 IHO standards

1. Introduction

The mapping of bathymetry in shallow waters is important for safe navigation. The accurate bathymetric data can assist in identifying potential natural and man-made hazards that can threaten navigation safety. Similarly, bathymetric data can also help in determining the condition of water that meets a safe depth criterion, especially in the port and commercial shipping area (Specht et al., 2021). Bathymetric mapping not only looks at safety but it is also a work that forms an important base for coastal zone management and maritime transportation planning, especially settings that have a rich biodiversity such as coral reef (Li et al., 2021).

To assure accuracy and reliability of bathymetric data, hydrographic survey standards that stipulate the tolerances of horizontal and vertical positioning errors are issued by International Hydrographic Organization. Standards in survey methodologies for the use of unmanned aerial vehicle (UAV) and unmanned surface vehicles (USV) for bathymetric measurements was referred (Zwolak et al., 2021; Lewicka et al., 2022). Mapping techniques that meet IHO standards are essential for navigational safety and for better data-driven environmental management (Bio et al., 2020). A measure of Total Vertical Uncertainty (TVU) is defined and classification of order is laid down within the IHO S-44 standard. This provides an objective standard for measurement of the quality of bathymetric data. All measures incorporate the hydrography of areas which are not the same (Stateczny et al., 2021).

In addition to navigation support, bathymetric mapping contributes to achieving Sustainable Development Goal (SDG) 14: Life Below Water. Once there is reliable and standardized bathymetric data available, marine and coastal ecosystem management will be enhanced, thus protecting marine resources and accelerating a blue economy in coastal regions (Kaloop et al., 2022; Ji et al., 2023). More accurate mapping creates the potential for ecologically based planning to help maintain the balance between exploitation and preservation of the marine environment (Mohammadloo, 2020). The effectiveness of hydrographic data quality standards including IHO S-44 when implementing these applications is likely to vary based on the reliability and validation of the bathymetric data acquired.

Bathymetric mapping in shallow waters is nevertheless complicated by rapid seabed morphological changes, limited access for field surveys and turbid water conditions that can degrade data accuracy (Caballero and Stump, 2020; Kulbacki et al., 2024). A range of contemporary technologies, including bathymetric mapping using satellites and advanced acoustic devices, has been devised to address these challenges and facilitate high-resolution mapping in these complex environments (Sagawa et al., 2019; Liu et al., 2023). Many coastal areas cannot effectively utilise these methods due to their sensitivity to complex processing, high operational costs, or a particular environment. As such, single-beam echosounders (SBES) are still widely used for shallow water survey due to their low cost, ease of operation and suitability for field condition. There have not been any studies that have critically assessed SBES derived bathymetric data against hydrographic quality criteria.

The bathymetric mapping has previously been used for navigation, habitat mapping and coastal studies (Kearns and Breman, 2010). Nevertheless, earlier studies have generally concentrated only on desirable morphological interpretation or mapping outputs without a significant emphasis on quantitative data quality validation based on international hydrographic standards. In the context of Indonesia and tropical coastal, such gaps become extremely relevant as most surveys utilize low-cost instruments without a thorough investigation of the measurement error and uncertainties (Manessa et al., 2022). Bathymetric datasets are often not explicitly evaluated for their reliability or uncertainty in novel scientific analyses including coastal management and planning (Khazaei et al., 2026).

Located in Banten Bay, Panjang Island is a shallow water which contains an important state with active sediment, coastal ecosystem, and shipping activity (Harahap et al., 2021). Bathymetric information is essential for supporting fishing, coastal shipping and ecosystem services, but not quality-controlled and detailed. The complexity of the environment and human pressure mean that bathymetric data must not only be descriptive, but also quantitatively verified (Nadzir and Munthe, 2025).

With reference to this, this study aims to (1) describe the morphology of the seafloor in the waters around Panjang Island; and (2) assess the quality of the bathymetric data acquired with a SBES according to IHO S-44. By explicitly combining morphological analysis with standardized quality assessment of data, this study aims to fill a gap in existing research. The originality of this research work is that it has been done as a geomorphological interpretation, as well as a quantitative assessment of the accuracy of hydrographic data. This contribution provides a practical and scientific reference to assess the efficacy of a cost-effective bathymetric survey using unmanned aerial vehicles (UAVs) in shallow coastal areas of Indonesia.

2. Materials and Methods

2.1. Tools and Materials

The device utilized for depth measurement was the Teledyne Odom CV100 Singlebeam Echosounder (SBES) along Hypack 2015 acquisition software. The sounding activities employed an RTK positioning system. A Trimble R8 Base GPS installed at the hydro pillar point powered this. A Trimble PDL HPB 450 Radio Link system connected this Base GPS to the R8 Rover GPS installed on the Sounding Boat. The position achieved was a Fixed RTK position. The instruments of this study are presented in **Table 1**.

Table 1. The particular hardware and technical instruments utilized to perform the hydrographic survey and tidal observation around Panjang Island. It comes equipped with a Teledyne Odom CV100 echo sounder for measuring depths along with GNSS Trimble positioning systems for high-precision positioning.

Instrument	Description
Teledyne Odom CV100 Single Beam Echosounder	Bathymetry observation
GNSS (Trimble R8 Base)	Base station positioning on the hydro pillar point
GNSS (Trimble R8 Rover)	Rover positioning on the boat
Trimble PDL HPB 450 Radio Link	Connect the base and the rover
Theodolite (T2)	Levelling to *Thalimedes/Tide Master* position
Waterpass	Collimation (prior step to levelling)
Thalimedes	Tidal observation at Pasir Putih Port

2.2. SBES Instrument Calibration and Configuration

The sounding activity was done using a local fishing boat, a wooden boat of dimension 9 m x 3 m x 3 m fitted with diesel engine. The echosounder transducer and GPS positioning are mounted on one axis. The setup of the sounding equipments and the sounding boat is shown in **Figures 1** and **2**.

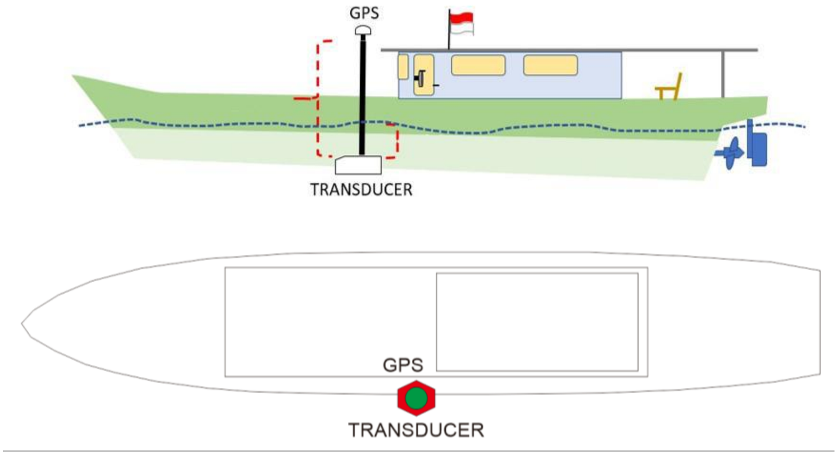

Figure 1. Specific arrangement of the Single Beam Echo Sounder (SBES) sounding equipment used to acquire depth measurements during the survey. The configuration ensures that the GPS positioning instruments and the echosounder transducer are aligned on a single axis to maintain accuracy during data logging.

Figure 2. Sounding boat that served as the primary vessel for the hydrographic survey around Panjang Island. This vessel was equipped with a diesel engine and provided the necessary platform for mounting the SBES and RTK positioning systems.

The calibration of the SBES was conducted using a barcheck to estimate correct values of sound velocity and frequency gain. The barcheck procedure was performed daily prior to data acquisition. It was also repeated whenever a sudden weather change occurred, for instance, a shift from almost blazing sunlight to heavy cloud cover and rain. Such weather changes would affect water temperature and salinity which, in turn, can impact the sound velocity (Rahman et al., 2013). The depths of 2 m and 6 m were selected for the barcheck since the study area average water depth is in the range of 2 m to 10 m.

2.3. Data Acquisition

2.3.1. Tidal Data Acquistion

Tides, an oceanographic component, need to be considered when implementing a bathymetric survey (Yang et al., 2015). Measurements of depths are corrected using tidal data during the multibeam data processing stage. By entering the tidal values in the Load Tide menu of the Caris HIPS & SIPS 9.0 software, the correction is performed automatically.

The Thalimedes equipment and a tide staff were used for tidal data collection with data recording intervals of every 5 minutes. Tidal observation referred to S-44 (IHO, 2020) which states that the measurements should be taken for at least 29 tidal cycles (30 days) for an accurate assessment of tidal data. The tidal information was collected between 9th July to 7th August. The tidal station at Pasir Putih Port is shown in **Figure 3**.

Figure 3. The tidal station established at Pasir Putih Port, which was used to monitor water level fluctuations throughout the study period. The station utilized Thalimedes equipment and a tide staff to record data every five minutes for 30 days to meet IHO standards.

2.3.2. Bathymetric Data Acquisition

Bathymetric data in the waters around Panjang Island were collected using Single Beam Echo Sounders (SBES), specifically the Teledyne Odom CV100. Before putting into place for data acquisition, preparation stage was a crucial phase involving the design of main and cross-track survey lines in the target areas. The intended track lines were then imported to the Hypack and used to navigate the survey. The use of the pre-designed track lines seen on the survey map allowed for a more systematic, efficient, as well as accurate data acquisition. **Figure 4** shows the location of the study area and the layout of the bathymetric data acquisition tracks.

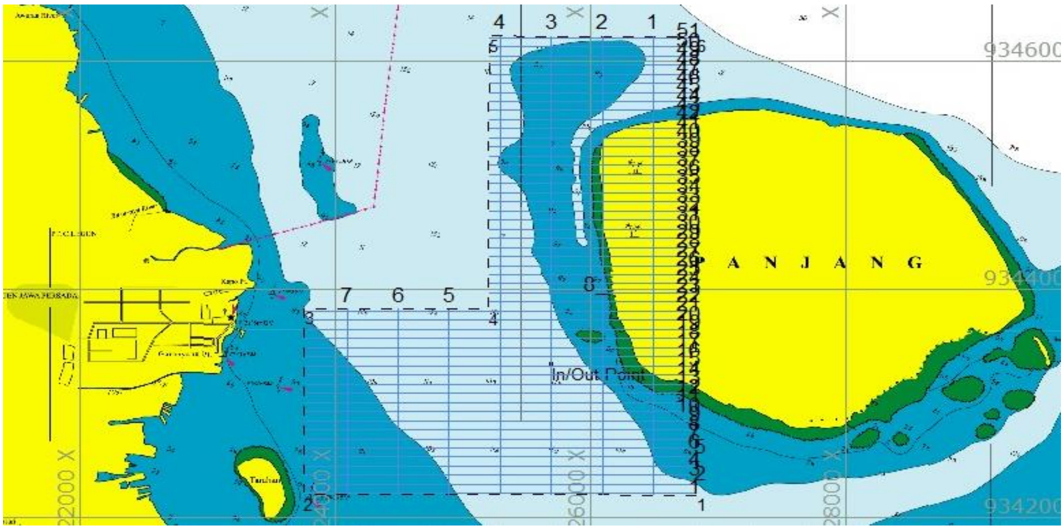

Figure 4. The geographical location of the study area and the systematic layout of the planned survey tracks around Panjang Island. These predesigned main and cross-track lines were imported into navigation software to ensure efficient and accurate bathymetric data collection.

SBES sounding acquisition was performed using Teledyne Odom Hydrographic SBES ODOM CV100 software to link SBES readings to Hypack 2015 Automatic Data Logging (ADL) software. For easy file management, data logging was carried out for each file according to main lane file and cross lane file. The resulting sound data was saved to a daily folder. Upon completion of sounding data, the sounding data was downloaded for processing with Hypack 2015 processing software.

2.4. Bathymetric Data Quality

To ensure that the acquired bathymetric data meet the IHO S-44 (2020) standards, a Quality Control (QC) procedure involving bathymetric correction is required. This correction process is mandatory in every bathymetric survey, as it determines the level of accuracy in representing the true depth of the survey area and is essential for assessing data quality according to the designated order classification.

The correction was performed by comparing depth values at cross-check points between the main (longitudinal) and cross (transverse) survey lines, from which the depth deviation value (s) was obtained. Prior to calculating the deviation, the bathymetric data were processed through a gridding procedure using a weighted moving average method. The extracted dataset included geographic coordinates (latitude and longitude) and the depth differences at each intersection point. The depth deviation was then computed using the Equation 1:

$$s = d_l - d_b \tag{1}$$

where s is the depth deviation; d_l is the depth on the main survey line; and d_b is the depth on the cross-check survey line.

The IHO (2020) standard defines four levels of bathymetric survey accuracy (orders). A summary of the minimum survey accuracy requirements is presented in **Table 2**, representing the maximum allowable vertical measurement uncertainties (total vertical uncertainties/TVU) at 95% confidence level.

Table 2. Minimum accuracy requirements for bathymetric surveys as defined by the IHO S-44 standards. It specifies the maximum allowable Total Vertical Uncertainty (TVU) for different survey categories, ranging from the high-precision Exclusive Order to the more general Order 2.

Criteria	Exclusive Order	Special Order	Order 1a/1b	Order 2
TVU of reduced depth	a = 0.15 m b = 0.0075 m	a = 0.25 m b = 0.0075 m	a = 0.5 m b = 0.0013 m	a = 1.0 m b = 0.23 m

After completing the bathymetric sounding, post-processing activities were carried out. The procedure began with surveying the main track lines, followed by cross-track lines to validate the previously collected depth data. The quality control processing for the SBES data in this survey operation was performed using calculations processed in Microsoft Excel. The relevant IHO requirements are stated in the S-44 standard and formulated as follows (Equation 2).

$$TVU_{max} = \sqrt{a^2 + (b\ x\ d)^2} \tag{2}$$

where ***a*** represents that portion of the uncertainty that does not vary with the depth; ***b*** is a coefficient which represents that portion of the uncertainty that varies with the depth; and ***d*** is the depth.

3. Results and Discussion

3.1. Tidal Observation in Panjang Island

The tidal observations at Panjang Island have been done for 30 days or 29 tidal cycles. The tidal graphs for the Pasir Putih Port station are illustrated in **Figure 5**. Over the observation period, water level in Pasir Putih Port station reach as high as 248 cm and as low as 159 cm. The difference in maximum and minimum water levels which is tidal range was found out to be 89 cm and mean sea level (MSL) was found to be 209 cm.

Subsequently, the calculated Formzahl value was used to determine the tidal type of the area. Based on the value obtained from the Formzahl calculation (F=2.017) at both stations, it can be concluded that the tidal type at Panjang Island is mixed tide prevailing diurnal.

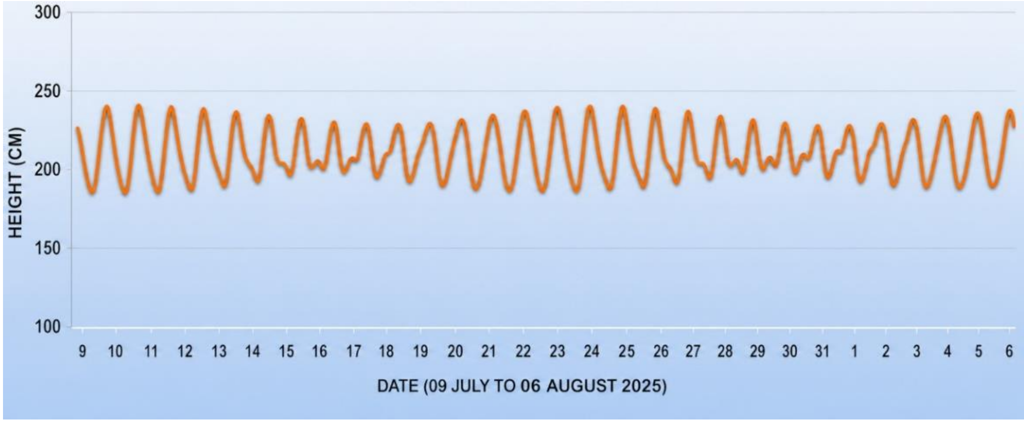

Figure 5. Visual tidal graph representing the water level changes recorded at the Pasir Putih Port station over 29 tidal cycles. The data indicates a mixed tide prevailing diurnal type, with recorded water levels ranging between a minimum of 159 cm and a maximum of 248 cm.

A harmonic tidal analysis was additionally executed to obtain the tidal reduction value (Z_0). Pasir Putih Port station was calculated as Z_0 = 50 cm so that the vertical datum (Chart Datum, CD) used in this study is MSL – Z_0 = 159 cm.

3.2. Bathymetric Data Visualization

The bathymetric survey results surrounding Panjang Island indicate that the research area is characterized as shallow-water (<50 m depth). Tidal-corrected bathymetric map shown in **Figure 6**. The bathymetric map indicates a variation in depth from 2 to 4 m of the seafloor. Relative proximity or spacing of contours is an indication of a steep or gentle slope respectively. The map shows depths about 8 m from the shore to more than 20 m at the centre of the mapped area, with darker shades of blue indicating greater depth. The spacing of contour lines and colors help view seabed morphology, such as a narrow central trough with shallow raised features on the eastern shoreline next to land.

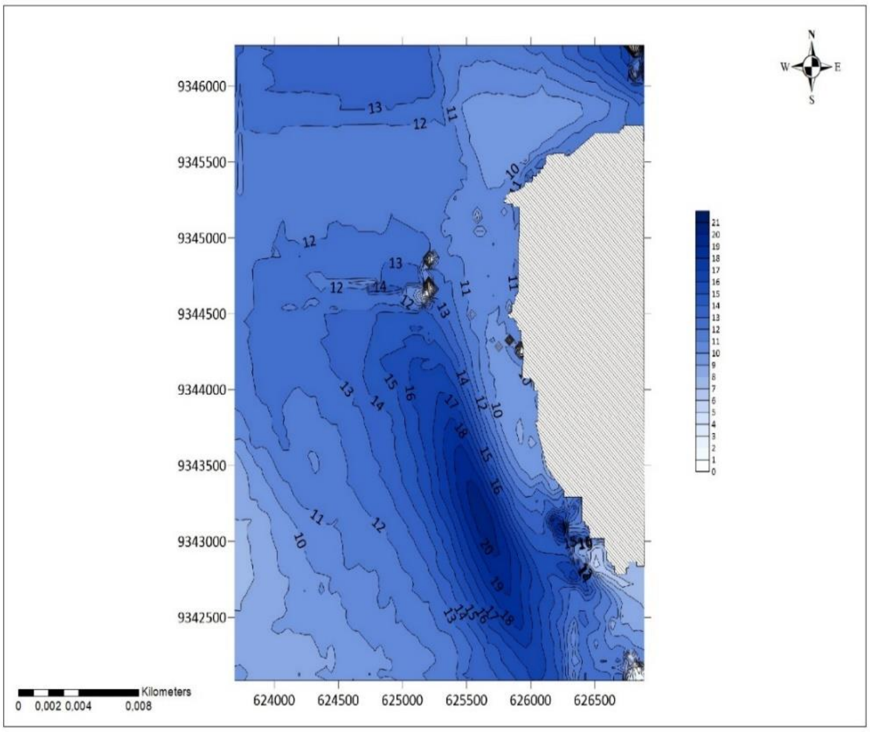

Figure 6. Two-dimensional visualization of the tidal-corrected bathymetry, showing seafloor depths that range from 8 meters to over 20 meters. The map uses contour intervals and colour gradients to highlight geomorphological features such as a narrow central trough and steep seabed slopes.

The overall depth pattern reveals a fairly gentle slope of the seafloor, which descends from the eastern coastal margin towards southwest. The slopes are representative of the natural geomorphology of the area. In the central sector, there are also a number of local depressions or small basins, possibly the result of seabed erosion due to bottom currents, but perhaps geological in nature (Wenau et al., 2021). The vast and quite shallow strip along all coastlines is a transition area between coastal ecosystems and deeper offshore waters (Goes et al., 2019).

The bathymetric data obtained will have environmental and ecological benefits that will help in identifying the different benthic habitat zones like sandy substrate, rocky outcrop, and muddy depression, which support different communities (Harris and Baker, 2020). Central troughs could act as traps for sediments and habitats for benthic organisms while the shallow eastern areas are likely natural barriers against wave force and shoreline erosion (Diaz et al., 2004). The fine-scale characterization of the seabed helps to prepare coastal hazard-mitigation strategies, such as demarcating zones for mangrove protection and coral reef conservation.

The 3D bathymetric model of Panjang Island is illustrated in **Figure 7**. Light to dark blue gradients indicate variations in depth, with deeper areas portrayed in darker shades. The topography of the ocean floor is irregular, with strong vertical features that may correspond to hard geological structures, such as coral reefs ecosystem (Savini et al., 2021). Conversely, the lighter-shaded areas with a gentle slope on the hills indicate shallow water nearer the shore.

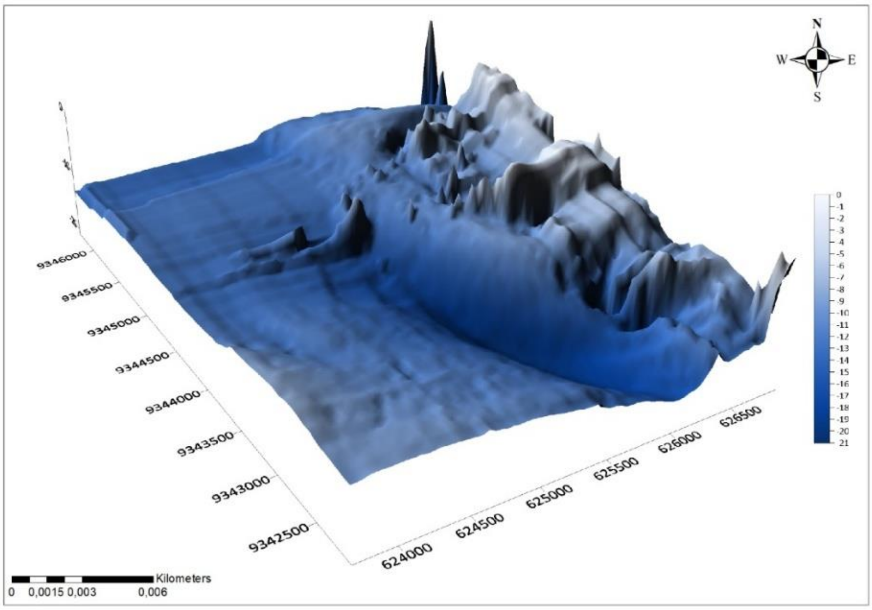

Figure 7. Three-dimensional bathymetric model that captures the irregular topography and vertical features of the seafloor. This 3D representation enhances the interpretation of sediment dynamics and seabed slopes by showing the transition from shallow coastal zones to deeper offshore basins.

Geomorphologically, the coastal zone displays a seabed slope and sediment dynamics in 3D representation. Steep portions are areas of active erosion or strong bottom current transports (Shimozono et al., 2024). Flat areas are zones of sediment deposition (Gao, 2019). The Panjang Island area has a better understanding of coastal geomorphology and sediment transport mechanisms as a result of these insights.

3.3. Bathymetric Data Quality

The quality of the bathymetric data based on hydrographic survey order standards is presented in **Figure 8**. The highest proportion of data falls under Order 2, accounting for 94.07%, indicating that the majority of the dataset meets the accuracy requirements suitable for general mapping and medium-precision survey applications.

Figure 8. The quality of the bathymetric data according to IHO S-44 survey order standards. The chart shows that while 94.07% of the data meets Order 2 standards, only 38.52% reaches the high-precision Exclusive Order level required for the most demanding maritime applications.

Meanwhile, Order 1a/1b comprises 76.67%, and Special Order contributes 56.30% of the dataset. Only 38.52% of the data meets the Exclusive Order criteria, which represent the highest level of hydrographic survey accuracy. In contrast, 6.30% of the data are categorized as errors, indicating a small portion of observations that failed to meet the expected quality threshold due to technical disturbances or measurement deviations.

Overall, this quality distribution demonstrates that the majority of the collected bathymetric data satisfies the minimum requirements for coastal mapping and general spatial analysis, although it does not fully achieve the precision level required for high-accuracy hydrographic applications such as navigation channel determination or offshore construction planning. The predominance of Order 2 data signifies stable and reliable survey performance, supporting coastal-related studies such as zoning, sediment dynamics assessment, and monitoring of seafloor morphological changes (Feygels et al., 2016). However, the relatively low percentage of Exclusive Order data suggests that improvements in sensor calibration, survey line density, tidal correction, and sound-velocity adjustment are still needed to meet higher-order hydrographic standards required for navigation safety and maritime engineering. An example of the bathymetric data quality calculation is presented in **Table 3**.

Table 3. Detailed sample of the Total Vertical Uncertainty (TVU) calculations and the subsequent order classifications for specific depth data points collected near Panjang Island, by comparing depth measurements from main and cross-track survey lines, the table demonstrates how data points are categorized into standards like Order 1a, Special Order, or Exclusive Order.

Longitude	Latitude	d of main line	d of cross line	Delta d	TVU					Order Classification
					Order 2	Order 1b	Order 1a	Special Order	Exclusive Order	
626486.81	9342370.07	11.502	11.371	0.131	1.034	0.522	0.522	0.264	0.173	Exclusive Order
626492.61	9342451.61	12.520	12.723	0.203	1.041	0.526	0.526	0.267	0.177	Special Order
626498.07	9342517.26	11.861	12.118	0.257	1.037	0.523	0.523	0.265	0.174	Special Order
626488.86	9342682.12	13.384	13.704	0.32	1.046	0.529	0.529	0.269	0.180	Order 1a
626493.65	9346084.11	12.633	13.919	1.286	1.041	0.526	0.526	0.267	0.177	#N/A
626491.73	9345638.59	11.473	11.490	0.017	1.034	0.522	0.522	0.264	0.173	Exclusive Order
626494.15	9345718.81	11.624	11.334	0.29	1.035	0.522	0.522	0.265	0.173	Order 1a
626493.14	9345808.79	10.723	10.515	0.208	1.030	0.519	0.519	0.263	0.170	Special Order
626496.17	9345883.33	10.600	10.430	0.17	1.029	0.519	0.519	0.262	0.170	Special Order
626495.10	9345958.97	11.050	11.430	0.38	1.032	0.520	0.520	0.263	0.171	Order 1a
626496.18	9346049.28	12.110	12.632	0.522	1.038	0.524	0.524	0.266	0.175	Order 1a
626490.95	9346123.26	13.230	13.635	0.405	1.045	0.529	0.529	0.269	0.180	Order 1a
626496.13	9346208.01	14.470	14.830	0.36	1.054	0.534	0.534	0.273	0.185	Order 1a
625289.88	9342204.82	11.269	11.407	0.138	1.033	0.521	0.521	0.264	0.172	Exclusive Order
626766.87	9342203.68	11.360	12.420	1.06	1.034	0.521	0.521	0.264	0.173	#N/A
626686.30	9342205.05	12.249	13.097	0.848	1.039	0.525	0.525	0.266	0.176	Order 2
626610.44	9342198.19	12.010	12.966	0.956	1.037	0.524	0.524	0.266	0.175	Order 2
626523.46	9342203.32	11.830	12.783	0.953	1.036	0.523	0.523	0.265	0.174	Order 2

4. Conclusions

The mapping of seafloor morphology around Panjang Island and the assessment of its bathymetric data quality refer to the IHO S-44 standard. The results reflected the geomorphology of shallow coastal systems with a progressive depth gradient from shallow coastal zone (8 m) to deeper (zone >20 m) toward south west direction. With respect to the quality of the data, most observations fall within Order 1a/1b and Order 2 indicating that the dataset is sufficiently accurate for general hydrographic and coastal mapping applications. The findings achieved the objectives of the study as it was conducted to show that single-beam echosounder surveys provide reliable low-cost bathymetric data in shallow water.

Nevertheless, because Order 2 data take precedence over other data and the other orders take a less dominant status, the dataset may be deployed more suitably for medium precision than high accuracy navigation and engineering design.

As such, the resultant bathymetric data can create a useful baseline for coastal mapping and spatial analysis. The data may be appropriate for other applications such as marine spatial planning or coastal management. However, higher resolution surveys and further assessment of ecological or infrastructure impacts are required to support these applications.

Conflicts of Interest

There are no conflicts to declare.

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AI Writing Statement

During the preparation of this manuscript, the authors used ChatGPT (OpenAI) for language editing and stylistic improvement. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

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