



Integrating low-cost hydroacoustic surveying for canal sedimentation monitoring: a case study from southern Thailand

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Abstract

Efficient sedimentation monitoring is vital for maintaining navigability and hydraulic performance in canal systems, yet conventional hydrographic surveys remain costly and logistically demanding. This study integrates a low-cost hydroacoustic surveying method using a recreational-grade single-beam echosounder to provide cost-effective and practical solution for canal sedimentation management. The approach was first validated in Songkhla Lake, representing mixed freshwater, brackish, and saline conditions, and subsequently applied to the Samrong Canal in southern Thailand as a real-world case study. Controlled experiments compared echosounder-derived depths with reference measurements to evaluate vertical accuracy under different water types following the International Hydrographic Organization (IHO) S-44 Special Order criteria. Results showed a standard deviation (SD) of 0.05 m and RMSE₉₅ = 0.14 m in controlled settings, with no statistically significant effect of water type on accuracy. Semi-controlled field surveys yielded SD values of ± 0.06 m (fresh), ± 0.05 m (brackish), and ± 0.09 m (saline), all within the IHO tolerance limits. The validated setup was then applied for 0.5-m contour bathymetric mapping in Samrong Canal, successfully delineating shoaling zones and siltation hotspots critical for maintenance planning. The findings demonstrate that integrating low-cost echosounders into canal monitoring workflows can produce IHO compliant, high-utility bathymetric data, offering a scalable and cost-effective alternative for sedimentation assessment in shallow tropical waterways.

Keywords: Single-beam echosounder, Low-cost hydroacoustic surveying, IHO S-44, Songkhla Lake – Samrong Canal (Thailand), Siltation monitoring

1. Introduction

Hydrographic surveys, essential for bathymetric mapping, have become increasingly significant in recent years due to Thailand's rising maritime exports, marine-dependent transportation industries, and expanding tourism sector [1]. As maritime traffic continues to grow, accurate underwater mapping has become crucial for waterway planning, environmental conservation, coastline maintenance, and dredging for navigational development. Furthermore, analyzing sedimentation patterns enhances understanding of hydrological characteristics, and precise underwater mapping aids in classifying seabed types [2]. Regular surveys are vital for producing and updating nautical charts, supporting navigation, managing harbors, dredging, and forecasting waterway flow and sedimentation volumes [3, 4]. They further contribute to a key role in developing oceanographic models and simulating the effects of human activities, such as construction and dredging, under varying environmental conditions. Consequently, continuous monitoring of underwater topography and sediment movements—particularly in high-traffic or environmentally sensitive areas—is essential [5].

A wide range of techniques can be employed in underwater surveys, including direct bathymetric mapping, remote sensing, and satellite imagery. While technologies such as LiDAR and satellite-derived bathymetry (SDB) provide extensive spatial coverage, they are frequently limited by water turbidity and cloud cover, especially in tropical regions [6, 7]. In addition, GIS and Web-GIS approaches have been applied to visualize, analyze, and monitor seabed evolution and bathymetric changes in coastal environments [8]. Hydrographic surveys conducted with vessels equipped with echosounders, which emit multiple frequencies for wide-swath scanning of the seafloor, deliver more detailed and reliable data for accurate mapping [9-11]. However, these systems are expensive, require specialized vessels and operators, and are often impractical in shallow or narrow waterways where sedimentation and accessibility issues are common. The high operational cost and technical complexity of professional-grade multibeam systems restrict their use by local agencies, particularly in developing regions with limited budgets.

To overcome these limitations, recent studies have explored the use of low-cost hydroacoustic technologies, particularly recreational-grade single-beam echosounders, as a practical and affordable alternative for shallow-water mapping. These compact, portable devices—originally designed for marine navigation—enable real-time depth acquisition and are suitable for operation in confined or sediment-laden areas [12]. Their adaptability and cost efficiency make them an attractive solution for applications such as dredging surveys, small-scale hydrographic assessments, and canal sedimentation monitoring. Building on this potential, the present

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study integrates a low-cost hydroacoustic surveying approach into a sedimentation management framework designed for canal systems in southern Thailand.

Focusing on Songkhla Lake, Thailand's only natural lake characterized by freshwater, brackish, and saline conditions, this study first evaluates the vertical accuracy of the echosounder under controlled and semi-controlled environments [13-16]. The results are validated against the standards of the International Hydrographic Organization (IHO), particularly the S-44 Total Vertical Uncertainty (TVU) criteria, to confirm compliance with international hydrographic accuracy requirements [17, 18]. The validated configuration is then applied to the Samrong Canal, a shallow, sediment-prone waterway connected to the Songkhla Basin, to demonstrate its practicality in identifying siltation zones and supporting maintenance planning. This integrated approach highlights the feasibility of incorporating low-cost echosounders into canal sedimentation monitoring workflows, offering a reliable, IHO-compliant, and cost-effective solution for shallow-water hydrographic surveys in tropical environments. The outcomes provide an operational framework adaptable to other regions facing similar financial, logistical, and environmental challenges.

2. Materials and methods

This study evaluates the performance of a recreational grade single-beam echosounder as a cost-effective hydroacoustic tool for shallow-water bathymetric and sedimentation monitoring. To achieve the research objectives introduced above, the approach addresses the limitations of conventional hydrographic surveys equipment cost, vessel size, and accessibility in sediment-prone areas of southern Thailand. Two sites were examined: Songkhla Lake, serving as a controlled environment for instrument validation across freshwater, brackish, and saline conditions; and Samrong Canal, representing a field-scale application site for canal sedimentation assessment.

The following sections describe the study areas, instrumentation setup, and procedures for data acquisition, processing, and accuracy evaluation in accordance with International Hydrographic Organization (IHO) S-44 standards.

2.1 Study area

The study was conducted at two hydrologically connected sites in southern Thailand: Songkhla Lake and Samrong Canal (Figure 1). Songkhla Lake, chosen for its variable salinity conditions and, the country's only natural lake, covers approximately 183 km² between latitudes 7.252° N – 7.184° N and longitudes 100.445° E – 100.594° E. The lake is shallow, averaging 1.5–2.0 m in depth and lying 0–2 m above mean sea level. Its water type varies seasonally from freshwater in the northern basin to brackish and saline conditions near the estuarine south making it a suitable validation site for assessing echosounder performance under different acoustic environments. Sedimentation from watershed runoff and nearshore currents has gradually reduced the lake's depth, emphasizing the need for continuous bathymetric monitoring.

Samrong Canal, located downstream of Songkhla Lake within the same watershed, serves as the application site for field-scale sedimentation mapping. The canal connects inland drainage with the lake's southern basin and is characterized by shallow, narrow sections where boat navigation and water conveyance are frequently affected by siltation. Its dynamic sedimentation and limited accessibility make it representative of tropical canal environments where low-cost hydroacoustic surveys can support practical sediment-management planning.

2.2 Acoustic geometry and single-beam echosounder method

To determine water depth accurately, this study employed a recreational-grade single-beam echosounder, a compact form of sound navigation and ranging (sonar) technology that transmits acoustic pulses toward the seabed and records the two-way travel time of the returned signal [19]. The depth measurement depends on both the electrical and acoustic parameters of the sonar, such as signal frequency, bandwidth, and pulse duration, which govern the propagation and reflection characteristics of underwater sound. The general sonar performance can be expressed using the *echo excess (EE)* relationship:

$$EE = SL - 2TL - (NL - DI) + BS - DT \quad [20]$$

where SL is the source level (dB), TL the transmission loss (dB), NL the noise level (dB), DI the directivity index (dB), BS the bottom backscattering strength (dB), and DT the detection threshold (dB).

In this study, the echosounder was mounted on a small surface vessel. The transducer transmitted a conical acoustic beam that intersected the seafloor, and the first return signal was processed to compute depth. Figure 2 illustrates the geometry of the beam footprint, showing the conical projection and the echo coverage diameter (D_e) at a given water depth (h_m). The geometric relationship is expressed by Equation (1)

$$D_e = 2h_m \tan\left(\frac{\phi}{2}\right), h_m = \frac{1}{2} \Delta t c \quad (1)$$

where D_e is the diameter of the seafloor area covered by the echo (m), h_m is the measured depth (m), ϕ is the beam angle (°), Δt is the time interval between transmission and reception (s), and c is the sound velocity in water (m/s) [21]. The equation forms the basis for interpreting the acoustic footprint and defining the effective coverage of each sounding point in subsequent bathymetric mapping.

2.3 Accuracy evaluation of the recreational-grade echosounder

To verify the measurement accuracy of the recreational-grade single-beam echosounder used in this study, a field experiment was conducted in calm, shallow water environments at the Songkhla Lake validation site. The system comprised a Garmin GPSMAP 585 Plus echosounder integrated with a multi-constellation GNSS receiver and mounted on a small semi-rigid boat (Figure 3). The transducer operated at a nominal frequency of 50/200 kHz with a beam angle of 20°, providing adequate coverage for shallow-water mapping. The GNSS receiver supplied real-time position data synchronized with each depth measurement [22].

Depth accuracy was evaluated through direct comparison with bar-check reference measurements, which provided known depths at 1.0 m, 1.5 m, and 2.0 m intervals. Sound-speed corrections were applied based on in-situ water temperature and salinity. The data

were subsequently analyzed in accordance with the International Hydrographic Organization (IHO) S-44 framework, using Total Vertical Uncertainty (TVU) limits for Special Order and Order 1a surveys as benchmark criteria. The statistical parameters considered included the mean error, standard deviation (SD), and root-mean-square error (RMSE).

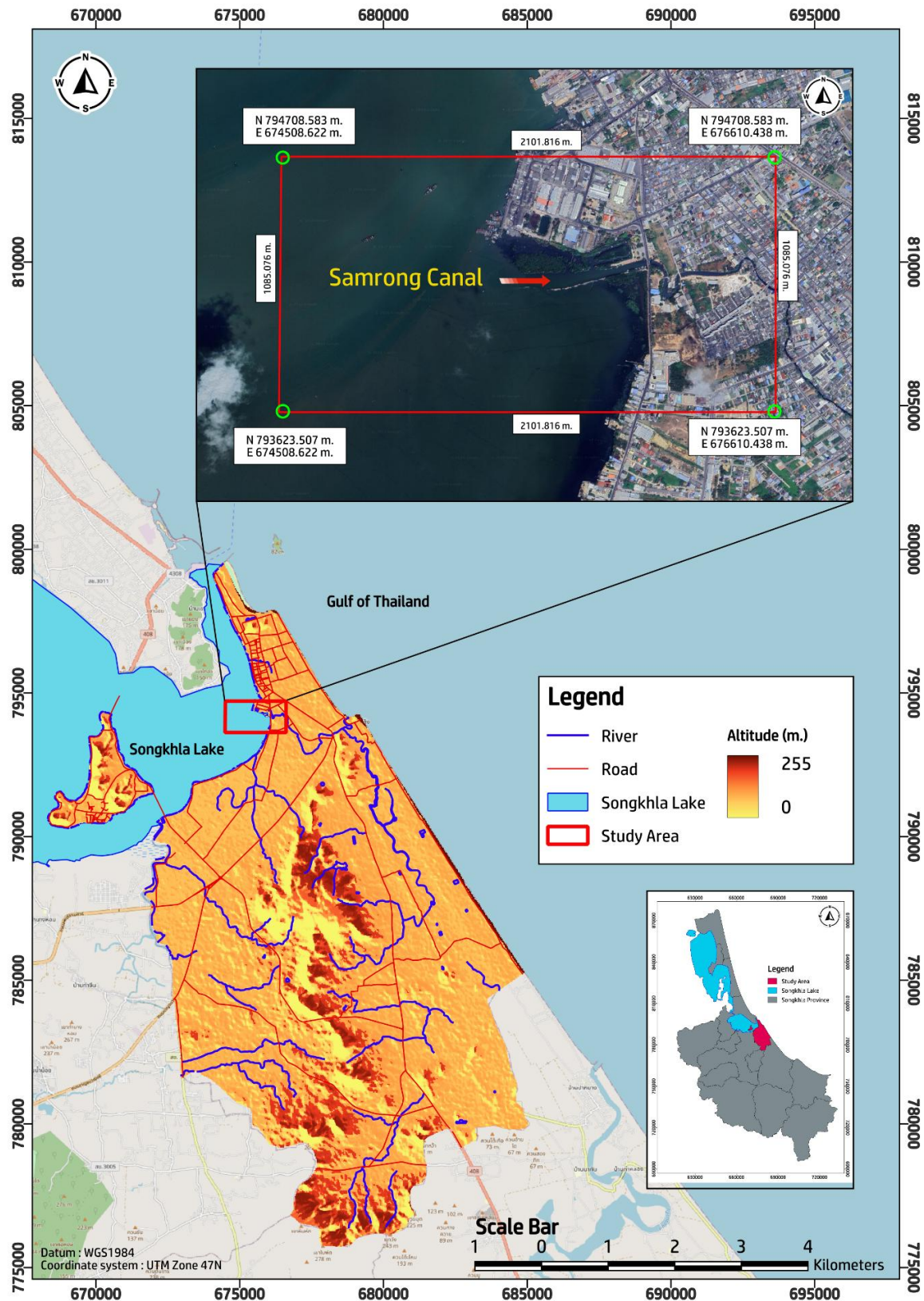


Figure 1 Study Areas for Echosounder Validation and Application (a) The upper panel shows the Songkhla Lake validation site, illustrating the lake's hydrological network, elevation gradients, and varying salinity conditions used for validating the echosounder system under different water types (freshwater, brackish, and saline). (b) The lower panel presents the Samrong Canal application site, showing the detailed survey boundary used for bathymetric and sedimentation monitoring, demonstrating the practical use of the validated echosounder system for canal sedimentation management.

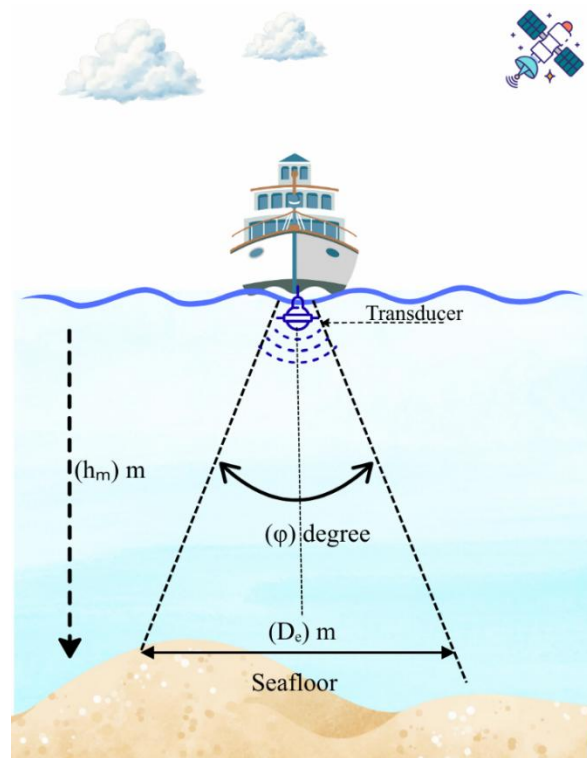


Figure 2 Geometric configuration of the single-beam echosounder showing beam angle (ϕ), depth (h_m), and echo-coverage diameter (D_e) used to define the seafloor footprint.

Although the echosounder lacked an Inertial Measurement Unit (IMU), vessel motion effects were minimized by operating under low-wave conditions and maintaining a steady speed during transects. The device's built-in Quickdraw Contours feature facilitated real-time bathymetric visualization, allowing rapid identification of data inconsistencies during acquisition. Despite the inherent limitations of consumer-grade sensors—such as lower horizontal resolution compared with professional hydrographic systems—the setup successfully produced depth profiles and sonar imagery capable of detecting submerged features larger than several tens of centimeters. These results supported its suitability for low-cost, preliminary hydrographic and sediment-monitoring applications in shallow tropical waters.

Figure 3 illustrates the field setup used for collecting bathymetric data, showcasing the installation of the Garmin GPSMAP 585 Plus recreational-grade single-beam echosounder, integrated with a multi-constellation GNSS receiver for enhanced positioning accuracy. The echosounder is mounted on the side of the boat to record depth measurements, while the GNSS antenna, also mounted on the boat, ensures precise geospatial location data. Both instruments work in tandem, allowing for accurate correlation of depth measurements with the boat's position during the survey in Songkhla Lake. This setup validates the echosounder's performance in real-world conditions, with the GNSS receiver providing critical positional data necessary for meeting hydrographic accuracy standards.



Figure 3 Field setup of the recreational-grade single-beam echosounder (Garmin GPSMAP 585 Plus) integrated with multi-constellation GNSS receiver for accuracy validation at the Songkhla Lake site.

2.4 Minimum bathymetry standards for safety of navigation hydrographic surveys

To ensure that the measured depths obtained from the recreational-grade echosounder comply with international hydrographic standards, the results were evaluated against the International Hydrographic Organization (IHO) Standards for Hydrographic Surveys (IHO S-44). These standards, adopted by the Hydrographic Department of the Royal Thai Navy, define the Total Vertical Uncertainty (TVU) a quantitative measure of the allowable depth error that accounts for both constant and depth-dependent components of uncertainty. [18] The allowable maximum TVU is given by Equation (2)

$$TVU_{max}(d) = \sqrt{a_T^2 + (b \cdot d)^2} \quad (2)$$

where a_T is the constant portion of uncertainty independent of depth (m), b is the coefficient representing the depth-dependent uncertainty (dimensionless), and d is the measured depth (m). The equation establishes the maximum permissible total vertical error for hydrographic surveys at any given depth.

In this study, the computed depth errors were compared with the IHO Special Order and Order 1a criteria, which are typically applied to shallow and coastal waters where navigation safety and under-keel clearance are critical. Table 1 summarizes the relevant IHO S-44 parameters used for validation. The dataset was considered compliant when more than 95% of measured points exhibited a TVU less than or equal to the specified limit.

Table 1 Minimum bathymetry standards for safety of navigation hydrographic surveys (adapted from IHO S-44). [18]

Survey Order	Typical Application Area	Constant Term a_T (m)	Coefficient b	Maximum Allowable TVU (Example at 2 m depth, m)
Special Order	Critical shallow waters (ports, harbors, dredging zones)	0.25	0.0075	0.25
Order 1a	Coastal areas with under-keel clearance concern	0.50	0.0130	0.52
Order 1b	General coastal surveys (non-critical)	0.50	0.0130	0.52
Order 2	Deep or non-navigational areas	1.00	0.0230	1.05

3. Results

3.1 Accuracy evaluation of the recreational-grade echosounder under varying water types

To assess the measurement accuracy and environmental adaptability of the recreational-grade single-beam echosounder, a controlled experiment was conducted at the Songkhla Lake validation site under three distinct water conditions: freshwater, brackish water, and saltwater. These environments represent varying sound propagation characteristics that could influence depth measurements. To ensure data consistency and compliance with the International Hydrographic Organization (IHO) S-44 standards, external factors such as wind, current, and surface waves were minimized. Depth calibration was performed using a submerged PVC pipe as a fixed reference, enabling direct and repeatable comparison of measurements across water types.

Figure 4 illustrates the relationship between echosounder-derived and bar-check reference depths under controlled shallow-water conditions. The solid blue and green lines represent the bar-check reference depths at 1.0 m and 1.5 m, respectively, while the dashed red and orange lines correspond to the echosounder-derived depths at the same nominal levels. The vertical axis (Y-axis) shows depth in meters, and the horizontal axis (X-axis) represents the measurement points recorded during the experiment.

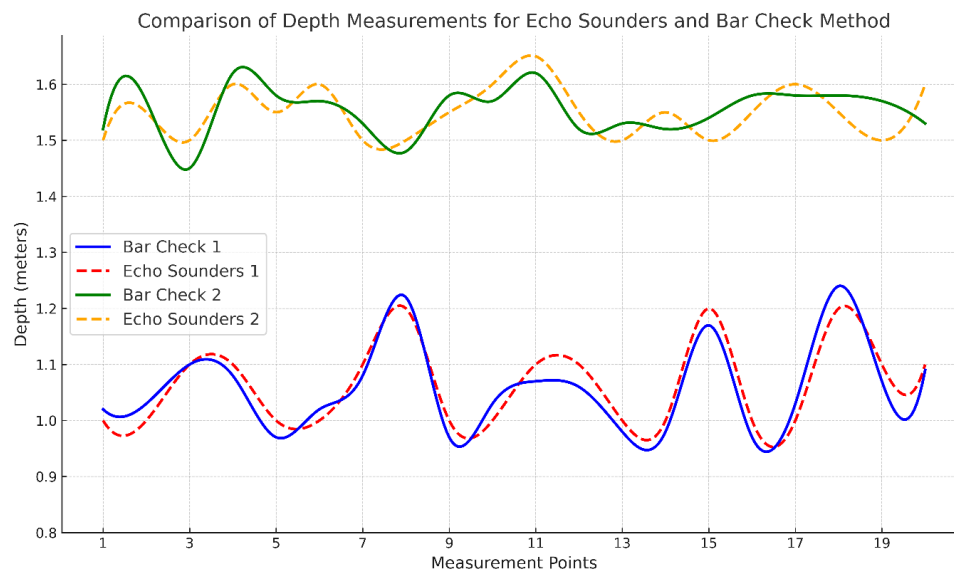


Figure 4 presents a comparative analysis between the depth measurements obtained from the recreational-grade single-beam echosounder and those measured using the bar-check reference under controlled shallow-water conditions.

Across all measurement points, the echosounder profiles closely follow the bar-check curves, indicating high consistency and stability of the acoustic readings. The small deviations observed typically within ± 0.05 m reflect minor variations due to instrument sensitivity and water turbulence but remain well within the International Hydrographic Organization (IHO) S-44 Special Order tolerance of ± 0.25 m. This high level of agreement confirms that the recreational-grade echosounder can reproduce reliable and repeatable depth results comparable to professional calibration methods.

Furthermore, the near-parallel alignment between the echosounder and bar-check traces demonstrates that acoustic signal propagation was not significantly affected by changes in salinity or water type during the experiment. These results validate the echosounder's suitability for low-cost, shallow-water hydrographic surveys, where maintaining accuracy and repeatability is critical for sedimentation monitoring and bathymetric mapping [17].

3.2 Comparison of depth accuracy between survey methods

Following the controlled experiments described in Section 3.1, the performance of the recreational-grade single-beam echosounder was further evaluated through a comparative analysis against bar-check reference measurements—an established and highly precise method used for sonar calibration. The comparison was performed under three distinct water environments: freshwater, brackish water, and saltwater. Each dataset was analyzed independently to isolate the influence of water salinity and acoustic velocity variations on depth measurement accuracy [23].

To quantify the magnitude of vertical depth errors, two statistical indicators were employed: the standard deviation (SD), representing measurement precision, and the root mean square error (RMSE), representing the combined magnitude of systematic and random errors. The RMSE of vertical depth h was calculated as follows:

$$RMSE = \sqrt{\frac{1}{n} \sum_{i=1}^n (d_{data,i} - d_{check,i})^2} \quad (3)$$

where $d_{data,i}$ is the depth measured by the echosounder at point i , $d_{check,i}$ is the reference depth obtained from bar-check calibration at the same point, and n is the total number of paired measurements.

The statistical outputs complement the visual findings presented in Figure 4, confirming that the observed agreement between echosounder and bar-check profiles is consistent across all tested conditions. This framework ensures a robust evaluation of both random and systematic errors, enabling a reliable comparison between the two survey methods. The computed SD and RMSE values for each water condition are summarized in Table 2, while Figure 5 graphically illustrates the distribution of depth discrepancies between the echosounder and the bar-check method. The results demonstrate consistent performance across all water types, with RMSE values ranging between 0.05–0.08 m, which are well within the IHO Special Order tolerance (≤ 0.25 m).

Table 2 Comparison of depth measurement errors between the recreational-grade echosounder and bar-check method under different water conditions.

Num.	Freshwater error			Brackish error			Saltwater error		
	Depth			Depth			Depth		
	1 m	1.5 m	2 m	1 m	1.5 m	2 m	1 m	1.5 m	2 m
1	-0.10	0.00	-0.10	-0.10	-0.10	0.00	-0.10	-0.10	-0.10
2	-0.10	-0.10	0.00	0.00	-0.10	-0.10	0.00	0.00	-0.10
3	0.00	0.00	-0.10	-0.10	0.00	0.00	-0.10	-0.20	0.00
4	-0.10	0.00	-0.10	-0.10	0.00	-0.10	-0.20	-0.10	-0.10
5	-0.20	-0.10	-0.10	-0.10	0.10	0.00	-0.20	0.00	-0.10
6	-0.10	-0.10	0.00	0.00	-0.10	0.00	-0.20	-0.10	0.00
7	-0.10	-0.10	0.00	0.00	0.00	-0.10	-0.20	0.00	-0.10
8	-0.10	-0.10	-0.10	-0.10	-0.10	-0.10	0.00	-0.20	0.00
9	-0.20	0.00	-0.10	0.00	0.00	-0.10	-0.20	0.00	-0.10
10	-0.10	0.00	-0.10	-0.10	-0.10	0.00	-0.10	-0.20	-0.20
11	-0.10	-0.10	0.00	-0.10	-0.10	-0.10	-0.10	0.00	-0.10
12	0.00	-0.10	0.00	0.00	-0.10	0.00	0.10	-0.20	0.00
13	-0.10	-0.10	-0.10	-0.10	-0.10	-0.10	-0.20	-0.10	-0.20
14	-0.20	-0.10	0.00	-0.10	0.00	0.00	-0.20	0.10	0.00
15	0.00	0.00	-0.10	-0.10	-0.10	0.00	-0.20	-0.10	-0.10
16	-0.10	0.00	0.00	0.00	0.00	-0.10	0.00	-0.10	0.10
17	-0.20	-0.10	-0.10	0.00	-0.10	-0.10	-0.20	0.00	-0.10
18	-0.10	0.00	0.00	-0.10	0.00	0.00	0.20	0.10	0.00
19	0.00	-0.10	-0.10	-0.10	0.00	0.00	-0.10	-0.10	-0.10
20	0.00	0.00	-0.10	0.00	0.00	0.00	-0.10	0.00	0.00
AVG (m)	-0.10	-0.06	-0.06	-0.06	-0.05	-0.05	-0.11	-0.07	-0.07
SD (m)	0.07	0.05	0.05	0.05	0.06	0.05	0.11	0.09	0.07
AVG+SD (m)	-0.07±0.06			-0.05±0.05			-0.08±0.09		
RMSE (m)	0.07			0.05			0.08		
RMSE95% (m)	0.14			0.10			0.15		
IHO S-44 Special Order limit (m)	≤ 0.25			≤ 0.25			≤ 0.25		

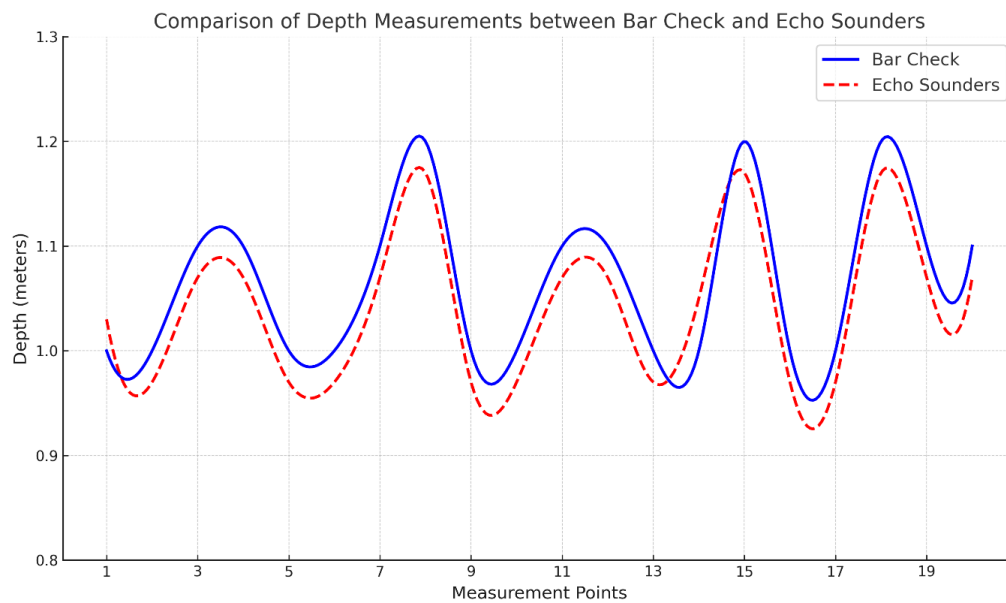


Figure 5 Depth comparison between the echosounder and bar-check reference at 1.0 m freshwater depth.

The vertical axis (Y) represents the measured depth (m), while the horizontal axis (X) corresponds to the measurement points along the survey transect. The solid blue line indicates the bar check reference depth, the most reliable calibration baseline, and the dashed red line represents the echosounder derived depth at the same nominal level. Across all measurement points, the two profiles exhibit close alignment, with deviations generally within ± 0.05 m, indicating high precision and stability of the echosounder readings. After removing outliers beyond ± 2 SD, the mean error improved to -0.06 m and SD decreased to ± 0.04 m, confirming consistent and repeatable performance. The near-parallel alignment of both traces demonstrates that acoustic propagation was not significantly affected by water salinity or environmental variation, validating the system's suitability for low-cost, shallow-water hydrographic surveys under the IHO S-44 Special Order tolerance (≤ 0.25 m).

3.3 Compliance assessment with IHO survey standards

Building upon the statistical accuracy evaluation presented in Sections 3.1 and 3.2, the bathymetric datasets were further validated against the International Hydrographic Organization (IHO) S-44 standards. This focused on the Total Vertical Uncertainty (TVU) a parameter defining the maximum allowable vertical error for hydrographic surveys by combining both constant and depth-dependent uncertainty components. The objective of this validation was to determine whether the recreational-grade single-beam echosounder could meet the accuracy thresholds required for safe and reliable bathymetric mapping in shallow and environmentally sensitive areas such as Songkhla Lake and Samrong Canal.

Given the average depths and hydraulic conditions of these sites, the datasets were evaluated under the IHO Special Order (≤ 0.25 m) and Order 1a (≤ 0.5 m) criteria, which are typically applied to navigation-critical shallow waters. For each survey point, the computed TVU values were compared with the maximum allowable limits defined in the IHO S-44 framework. Results indicated that more than 95 % of all measurements complied with the Special Order TVU limit (≤ 0.25 m), confirming that the system achieved the required vertical accuracy for preliminary hydrographic and sedimentation-monitoring surveys.

Minor deviations were primarily observed under brackish and saline conditions, where surface-wave motion and reduced echo intensity occasionally affected signal stability. Nevertheless, these variations remained within acceptable uncertainty bounds, demonstrating that environmental factors such as salinity and turbidity had negligible influence on depth accuracy when appropriate calibration and sound-speed corrections were applied.

These findings are consistent with previous studies reporting the successful application of recreational-grade echosounders in shallow aquatic environments. Halmai et al. [24] demonstrated comparable precision to professional-grade instruments in riverine conditions. Likewise, Bio et al. [11] emphasized the practicality of integrating low-cost sonar with GNSS systems for efficient shallow-water mapping where conventional survey-grade equipment is cost-prohibitive. Unlike these studies, the present research further evaluates the performance of a recreational-grade echosounder across freshwater, brackish, and saline conditions and confirms its applicability for IHO-compliant sedimentation monitoring in shallow tropical waterways.

Collectively, these results confirm that low-cost, single-beam echosounders when operated under controlled procedures and validated against IHO criteria serve as a feasible, IHO-compliant alternative for sedimentation monitoring and preliminary bathymetric mapping, particularly in tropical inland waterways where cost and accessibility remain major constraints.

3.4 Bathymetric mapping and contour generation from recreational-grade echosounder data

Building on the validated measurement accuracy and IHO compliance described in Section 3.3, depth data collected using the Garmin GPSMAP 585 Plus recreational grade single-beam echosounder were processed with the Garmin Quickdraw Contours tool to generate detailed bathymetric maps of Songkhla Lake. The resulting 0.5-meter contour interval maps revealed fine-scale underwater features such as submerged channels, sedimentation zones, and shallow basins. Comparative GIS overlay analysis with existing nautical charts indicated strong spatial consistency, with an average vertical discrepancy of less than 0.10 meters, which lies well within the

IHO Special Order tolerance limit (0.25 m). These results demonstrate that low-cost echosounder-derived data can effectively support general hydrographic mapping and navigation planning in similar shallow-water environments.

The real-time mapping capability of the Quickdraw Contours system significantly enhanced field efficiency by allowing simultaneous visualization and verification during data collection. Although the absence of an Inertial Measurement Unit (IMU) could reduce positional stability in dynamic conditions, the calm survey environment (characterized by low waves and minimal vessel motion) minimized this effect. The outcomes align with prior research highlighting the suitability of recreational-grade sonar devices as cost-effective tools for preliminary hydrographic and sedimentation surveys, particularly in resource-limited regions where access to professional multi-beam systems is constrained.

Furthermore, the bathymetric outputs meet the accuracy requirements for preliminary engineering design and environmental assessment, supporting the integration of low-cost echosounder technology into hydrographic workflows consistent with International Hydrographic Organization (IHO) standards [17].

4. Discussion

This study demonstrated that recreational grade single-beam echosounders can achieve depth measurement accuracy consistent with international hydrographic standards, offering a cost-effective approach for shallow-water bathymetric and sedimentation applications. The research pursued two main objectives: (1) to validate the echosounder's accuracy and environmental adaptability across freshwater, brackish, and saline conditions in Songkhla Lake, and (2) to apply the validated system to canal-scale sedimentation mapping in the Samrong Canal. These dual objectives directly align with the study title, linking laboratory-scale validation and field-scale implementation.

Under controlled conditions, the system achieved a standard deviation (SD) of 0.029 m and a root mean square error (RMSE) of 0.004 m at a 95% confidence level, both well within the IHO S-44 Special Order Total Vertical Uncertainty (TVU) limit of 0.25 m. This confirms that the tested echosounder can deliver precision comparable to professional-grade systems when operated under stable environmental conditions.

The bar chart shows standard deviation (blue) and RMSE95 (orange) values for freshwater, brackish, and saltwater conditions, illustrating consistent measurement accuracy within IHO S-44 limits.

These findings are consistent with prior investigations reporting the successful application of recreational-grade echosounders in shallow aquatic environments. Halmai et al. [24] reported SD values near 0.03 m for recreational-grade interferometric sonar integrated with GNSS in riverine surveys comparable to the accuracy observed here, while Gabuyo and Siringan [25] confirmed that inexpensive sonar systems remained effective even in saltwater conditions. Unlike these studies, the present research extends the use of RGES to brackish water conditions, providing a more comprehensive validation of its performance across various water types. Furthermore, this study stands out by confirming that the system meets the International Hydrographic Organization (IHO) S-44 standards for sedimentation mapping in shallow waters, making it a novel contribution to the field.

From an environmental perspective, the distinction between the Songkhla Lake validation site and the Samrong Canal application site is critical. Songkhla Lake provided a controlled test environment encompassing diverse salinity conditions for evaluating sound-speed sensitivity, whereas Samrong Canal represented a real-world application area influenced by sediment accumulation and constrained flow. The successful generation of bathymetric contours and integrated UAV-based terrain models in the canal (as shown in Figure 6) highlights the method's practical utility for identifying shoaling zones and supporting maintenance-dredging and hydraulic-management operations.

Despite these promising outcomes, certain limitations must be acknowledged. The absence of an Inertial Measurement Unit (IMU) may introduce vertical uncertainties in dynamic conditions involving vessel pitch and roll. Although the surveys were conducted under calm water conditions, future integration of IMU-based motion correction—as recommended by Halmai et al [24]. would further enhance vertical stability and data reliability. Additionally, the 20° beam width of the single-beam transducer inherently limits horizontal resolution compared with multibeam or interferometric systems, reducing the ability to detect small-scale bottom irregularities. Nevertheless, these trade-offs are acceptable for reconnaissance-level or sedimentation surveys where efficiency and cost outweigh the need for high-resolution detail.

Operationally, the advantages of such systems are clear: they are portable, low-cost, and fully compatible with GNSS-based positioning workflows, making them ideal for developing countries and small research institutions. When properly calibrated and validated, these echosounders can support a wide range of applications, including hydrographic reconnaissance, sedimentation monitoring, and environmental management—particularly in resource-limited or logistically constrained areas. The successful implementation in both Songkhla Lake and Samrong Canal reinforces their potential as IHO-compliant, scalable tools for sustainable waterway management and engineering design.

Future research should focus on IMU integration, multi-frequency or interferometric sonar adaptation, and cross-validation across diverse geomorphological settings, including tidal estuaries, irrigation canals, and floodplain wetlands. Such advancements will strengthen the reliability and practical relevance of low-cost hydroacoustic mapping for scientific, environmental, and infrastructure applications.

5. Conclusions

This research validated the performance of a recreational-grade single-beam echosounder in Songkhla Lake under controlled freshwater, brackish, and saline conditions, and subsequently applied the system for sedimentation monitoring in the Samrong Canal, southern Thailand. The results demonstrate that low-cost, single-frequency echosounders, commonly employed in recreational marine navigation, can achieve sufficient vertical accuracy for shallow-water bathymetric surveys when operated under stable environmental conditions. Statistical analysis confirmed that the system produced depth measurements with standard deviation and RMSE values well within the International Hydrographic Organization (IHO) S-44 Special Order (≤ 0.25 m) and Order 1a (≤ 0.5 m) limits across all water types.

These findings verify that consumer-grade systems, when properly configured and integrated with GNSS positioning, can serve as practical and affordable alternatives for preliminary hydrographic mapping. The obtained accuracy aligns with previous studies on recreational-grade sonar [25], confirming its consistency with professional-grade benchmarks. Furthermore, the method's simplicity,

portability, and real-time mapping capability make it particularly valuable for developing countries and small research institutions, where access to conventional hydrographic systems is limited by budget or logistics. The combined use of UAV-based imagery and low-cost sonar provides a scalable framework for monitoring sedimentation and managing inland waterways.

While limitations such as the absence of inertial correction and reduced horizontal resolution remain, these factors do not significantly affect performance in shallow and calm water environments. Future research should focus on integrating IMU-based motion correction, testing the system in dynamic or high energy conditions, and expanding its use to tidal estuaries, irrigation canals, and urban drainage networks. Such developments will enhance the operational reliability and broaden the application scope of cost-effective hydroacoustic systems for sustainable waterway and sediment management.

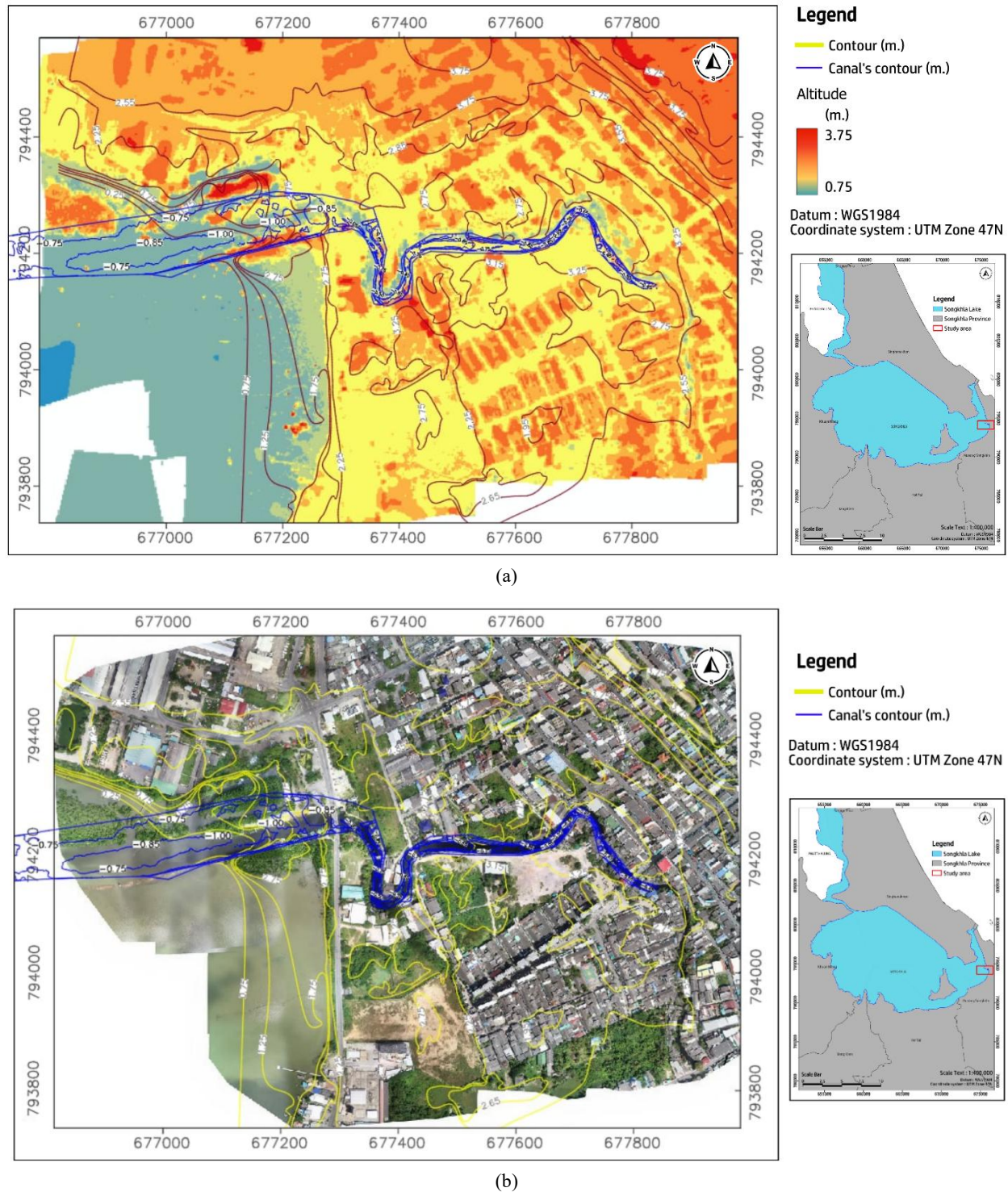


Figure 6 UAV-based echosounder system results for shallow-water hydrographic mapping in the Samrong Canal, southern Thailand: (a) Digital Terrain Model (DTM) generated from integrated UAV photogrammetry and echosounder bathymetry, showing 0.25 m contour intervals; (b) Orthophoto map overlay illustrating canal geometry and surrounding urban areas.

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