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Araştırma Makalesi / Research Article

MONITORING SHALLOW COASTAL BATHYMETRY AND SEDIMENT DYNAMICS WITH MODERN FISHFINDER BATHYMETRY DATA: A CASE STUDY IN THE ARDEŞEN FISHING HARBOR (RİZE, TÜRKİYE)

Modern balık bulucu batimetri verileriyle sığ kıyı batimetrisi ve sediment dinamiklerinin izlenmesi: Ardeşen Balıkçı Barınağı (Rize, Türkiye) örneği

Abdulkadir DURAN[a], **Hüseyin TUROĞLU**[b]

[a] Sorumlu Yazar / Corresponding Author
İstanbul Üniversitesi, Sosyal Bilimler Enstitüsü, Coğrafya ABD, İstanbul, TÜRKIYE
duranakadir@gmail.com https://orcid.org/0000-0001-6267-8798
[b] İstanbul Üniversitesi, Edebiyat Fakültesi, Coğrafya Bölümü, İstanbul, TÜRKIYE
turogluh@istanbul.edu.tr https://orcid.org/0000-0003-0173-6995

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ÖZET

Kıyıdaki sediment dinamikleri ve morfolojik değişimlerin izlenmesi, sürdürülebilir kıyı yönetimi açısından önem taşımaktadır. Bu çalışmada, Ardeşen Balıkçı Barınağı'nda düşük maliyetli sonar tabanlı modern balıkbulucu kullanarak sediment dinamikleri ve batimetrik değişimlerin incelenmesi amaçlanmıştır. 2007 ve 2024 yıllarına ait batimetrik verilerin Coğrafi Bilgi Sistemi (CBS) ortamında karşılaştırılması sonucunda, 602.373 m³ hacminde sediment birikimi tespit edilmiştir. Bu birikim, Karadeniz Sahil Yolu Projesi kapsamında gerçekleştirilen dolgu uygulamaları ve Dolona Deresi'nin yönünün değiştirilmesi gibi mühendislik müdahalelerinin bir sonucudur. Sediment birikimi sonucunda kıyı çizgisi 85 metre ilerlemiş ve 5.100 m²'lik yeni birikim alanı oluşmuştur. Barınak ağzına doğru gerçekleşen bu birikim, barınağın giderek sığlaşmasına ve işlevselliğinin azalmasına yol açabilecek ciddi bir tehlike oluşturmaktadır. Çalışmanın bulguları, mühendislik müdahalelerinin kıyı morfolojisi üzerindeki uzun vadeli etkilerine dikkat çekmekte ve düşük maliyetli sonar tabanlı batimetrik izleme yöntemlerinin, kıyı süreçlerinin düzenli ve etkin şekilde izlenmesine katkı sağlayarak sürdürülebilir kıyı yönetimi için uygulanabilir bir araç olduğunu göstermektedir.

ABSTRACT

Monitoring coastal sediment dynamics and morphological changes is important for sustainable coastal management. This study aimed to examine sediment dynamics and bathymetric changes in the Ardeşen Fishing Harbor using a low-cost, sonar-based modern fishfinder system. A comparison of bathymetric data from 2007 and 2024 using Geographic Information System (GIS) tools revealed a sediment accumulation of 602,373 m³. This accumulation is the result of engineering interventions, including land reclamation activities carried out as part of the Black Sea Coastal Highway Project and the redirection of the Dolona Stream. As a result of sediment deposition, the shoreline migrated seaward by 85 meters, creating a new sediment deposit area of 5,100 m². This accumulation progressing toward the harbor entrance poses a significant threat of increasing shoaling and a potential reduction in harbor functionality. The findings draw attention to the long-term impacts of engineering interventions on coastal morphology and demonstrate that low-cost, sonar-based bathymetric monitoring methods provide an effective tool for the regular and efficient monitoring of coastal processes, thereby contributing to sustainable coastal management.

1. INTRODUCTION

Coasts are dynamic environments continually shaped by both natural and anthropogenic processes. Understanding these processes requires the accurate and regular acquisition of bathymetric data revealing the morphological and morphodynamic characteristics of the seafloor. Bathymetric data are critically important for monitoring sediment accumulation and erosion trends, modeling wave and current regimes, and assessing hazards such as storm surges and coastal flooding. With increasing population and development pressure on coastal zones, activities such as fishing, sand and gravel mining, port construction (including coastal filling), and uncontrolled coastal construction can disrupt the natural sediment circulation of coastal systems (Bird, 2008; Davidson-Arnott, 2010; Huang & Jin, 2018). Therefore, the ability to foresee coastal hazards and risks and to ensure effective coastal management and planning directly depends on the quantitative assessment of bathymetric characteristics. Structures such as ports and fishing harbors—particularly those near river mouths—can accumulate sediment, resulting in shoaling from marine and fluvial sources. This phenomenon increases the costs associated with infrastructure maintenance and development. In the narrow coastal zones of the Black Sea region where population growth, construction, and economic activities are steadily intensifying, this issue becomes more pronounced, thereby making the regular monitoring of bathymetric changes essential (Turoğlu et al., 2004; Süme & Yüksek, 2018; Duran & Turoğlu, 2021).

Sonar technologies are used to detect submarine topography and objects on the seafloor. Single-beam and multi-beam sonar are two technological approaches commonly used in submarine mapping and depth measurement. Multi-beam sonar systems enable detailed mapping of large areas by collecting multiple depth points simultaneously (Kearns & Breman, 2010). However, due to their size and weight, multi-beam sonar systems are often unsuitable for, expensive, and complex shallow-water surveys conducted with small boats. On the other hand, single-beam sonar enables the detection of underwater objects and depth by sending a single sound wave. The single-beam sonar systems used in modern fish finders are lightweight, cost-effective, and simple solutions for small boats, vessels, and unmanned surface vehicles used in shallow-water surveys (Uchida et al., 2008; Yamasaki et al., 2017).

The number of scientific studies utilizing bathymetric data collected via modern fishfinders has increased significantly thanks to their affordability, practicality, ease of measurement, applicability, testability, and reliability. Examples include studies on coral reef habitat mapping (Heyman et al., 2007), glacial environments (Sugiyama et al., 2015; Purdie et al., 2016), geological and landslide research (Yamasaki & Kamai, 2015), river and estuary mapping (Sacarny et al., 2018; Halmai et al., 2020; Bio et al., 2022), lake surveys (Giambastiani et al., 2020; Škodová & Solár, 2023), and sediment accumulation monitoring (Bradbury et al., 2022). These pioneering studies have demonstrated the scientific potential of fishfinder-based single-beam sonar technology for bathymetric mapping.

The Ardeşen Fishing Harbor (Rize, Türkiye) (Lat. 41.1948°, Lon. 40.9896°) is one of the region’s key coastal structures used for fishing activities and coastal security (Fig. 1). Despite its importance, the harbor faces sedimentation problems caused by uncontrolled coastal use. The accumulation of sand within the harbor leads to the obstruction of the harbor entrance, causing the facility to become non-operational, and sometimes preventing fishing boats from accessing open waters for extended periods (URL 1).

This study aims to assess the applicability of modern fishfinder-based bathymetric data in determining the spatial and temporal variations in the depth profiles of the Ardeşen Fishing Harbor and in understanding sediment dynamics. Furthermore, the reliability of fishfinder data is evaluated by comparing it with manual measurements obtained using a plumb line. The potential of low-cost sonar systems for monitoring bathymetric changes in coastal areas is also explored.

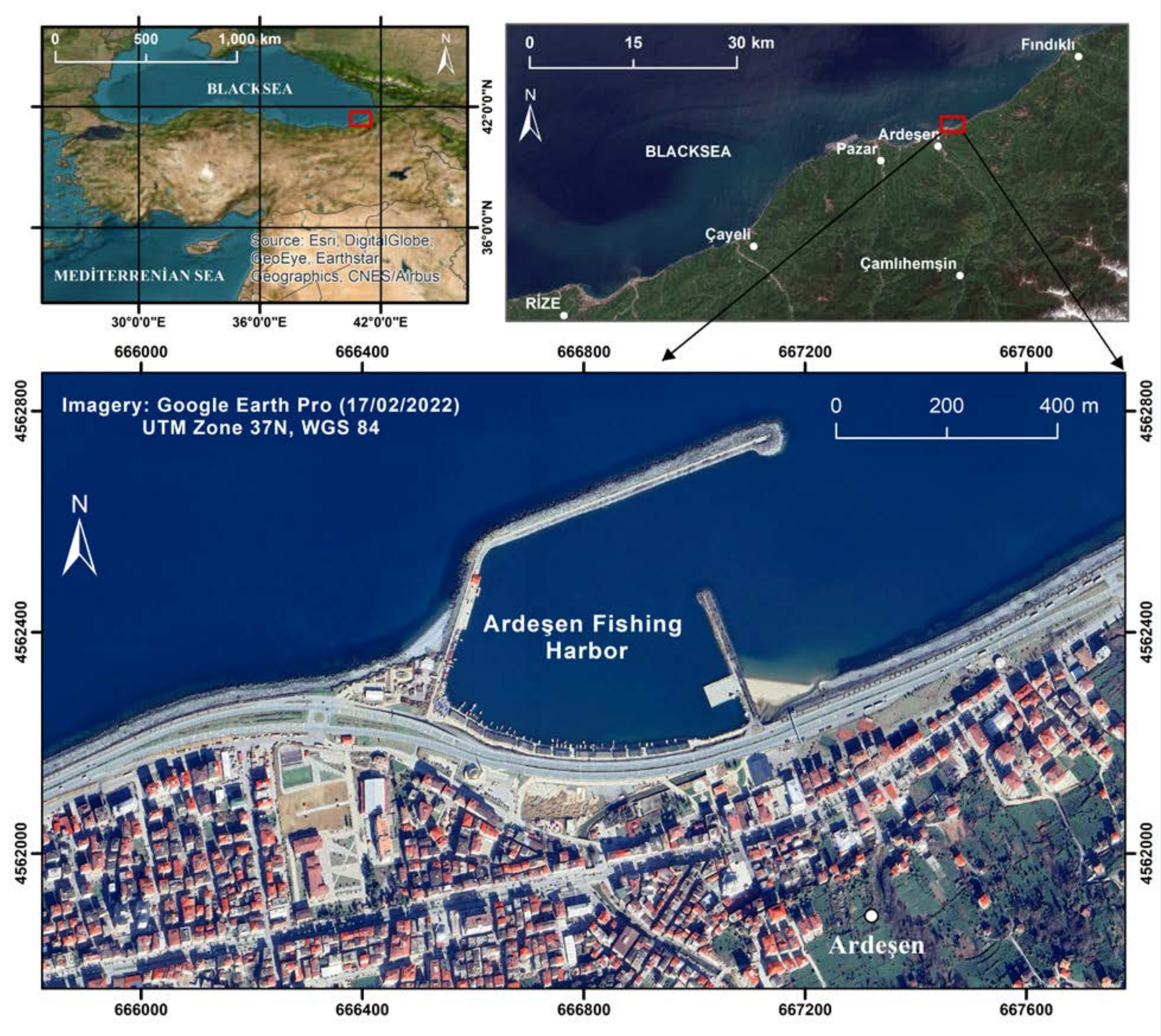

Figure 1: Location map of the study area.

Hydrodynamic forces such as waves, currents, and turbulence are limited in relatively sheltered, stable water bodies such as ports and fishing harbors. Therefore, bathymetric measurements in such areas are anticipated to yield more stable and reliable results. In particular, the accuracy of sonar signals in shallow coastal zones can vary depending on the level of water column movement. For this reason, coastal environments like ports and fishing harbors are ideal, calm, and controlled shallow-water settings where the system can be applied and reliable results can be obtained.

The Ardeşen Fishing Harbor has characteristics that ensure data reliability. These include calm water conditions, the possibility of repeated measurements, and easy access, which allow fieldwork to be conducted in a more planned, safe, and cost-effective manner. In addition, the availability of historical bathymetric data for Ardeşen Fishing Harbor allows for comparative analyses with current data, thereby enhancing the study's scientific value. For all these reasons, Ardeşen Fishing Harbor has been selected as a suitable study site for evaluating the effectiveness of modern fishfinder technology.

2. MATERIALS AND METHODS

This study used the modern Garmin Striker Vivid 5cv fishfinder model (Figure 2; Table 1), which operates at a frequency of 200 kHz. In fishfinder systems, frequency selection is crucial and should be based on the characteristics of the study area. Low-frequency sonar systems (50 kHz) are advantageous for scanning wider areas and deeper waters but provide lower resolution when detecting seafloor details. Conversely, high-frequency sonar systems (200 kHz) can scan narrower areas but capture bottom features with greater clarity. For this study, a frequency of 200 kHz was selected to obtain precise bathymetric data in a shallow-water environment (Yamasaki & Kamai, 2015; Yamasaki et al., 2017; Sacarny et al., 2018).

Depth data were collected from 341 measurement points, and the geographic coordinates were recorded using the Navionics Boating mobile application (version 21.0.2). To validate the depth data obtained via the modern fishfinder, reference measurements were taken using a plumb line at 17 locations. The depth data from 341 points were interpolated using the 'Topo to Raster' tool in ArcGIS 10.8, creating a bathymetric map. Bathymetric data from 2007 were obtained from the Ministry of Transport and Infrastructure and used for comparison with the current data. These historical bathymetric data were digitized in the ArcGIS environment, and the 'Topo to Raster' method was applied to generate a historical bathymetry map (Turoğlu, 2020; ESRI, 2024).

Table 1: Garmin Striker Vivid 5cv Technical Specifications (Garmin, 2024)

Feature	**Value**
Sonar Frequency	50/77/200 kHz
Maximum Depth (Freshwater)	700 ft (213 m)
Maximum Depth (Saltwater)	330 ft (100 m)
GPS Integration	Built-in GPS
Screen Size	5 inches
Screen Resolution	800 x 480 pixel
Data Recording and Transfer	Waypoint and route recording
Saltwater Durability	IPX7 waterproof rating
Connectivity Options	NMEA 0183, Wi-Fi, and Bluetooth

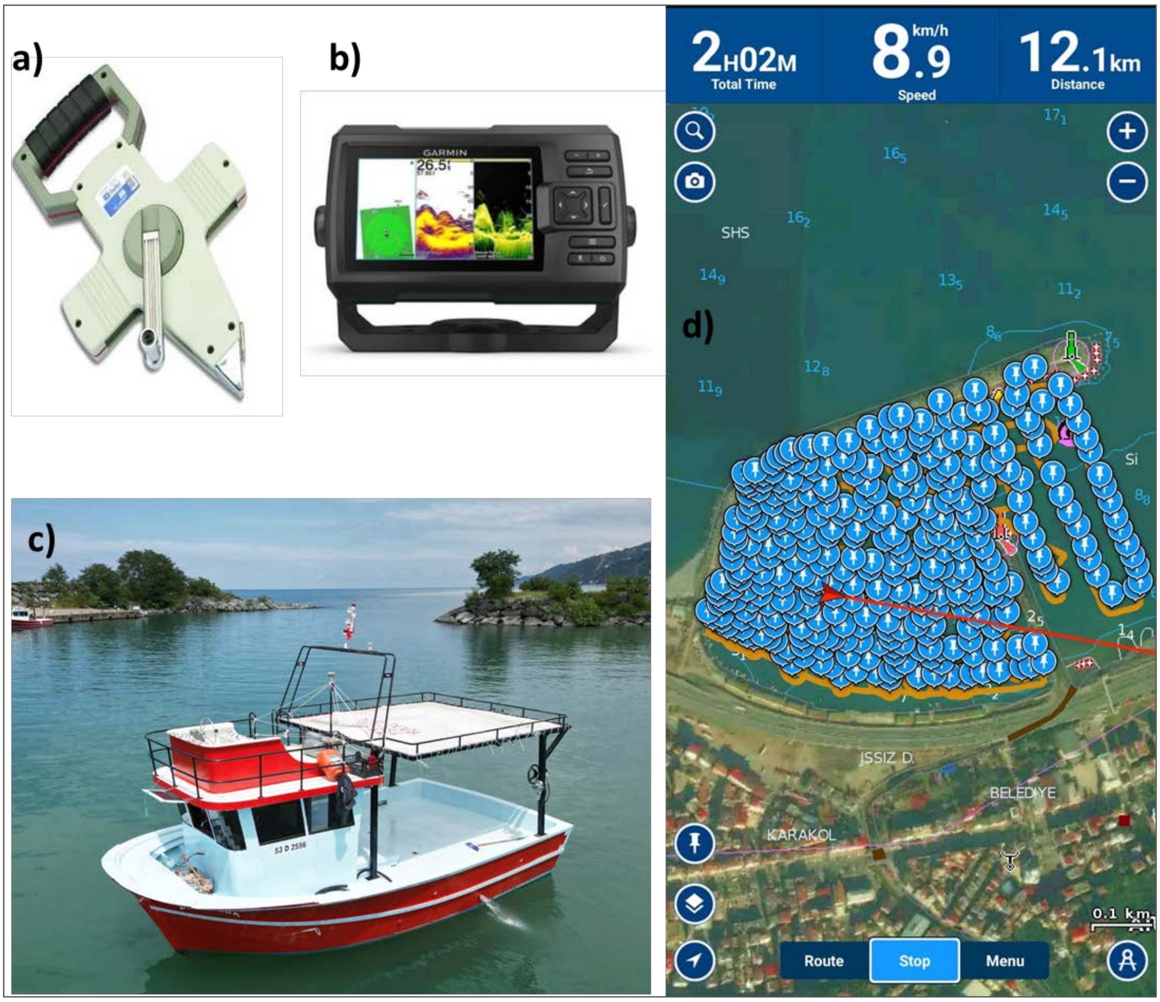

Figure 2: (a) Plumb line used in the study, (b) modern fishfinder, (c) boat, (d) Navionics Boating, version 21.0.2 mobile application.

To evaluate spatial changes in and around Ardeşen Fishing Harbor, orthophotos from 2004 and 2013 were obtained from the Directorate General for Mapping (DGM). Additionally, satellite imagery from 2022 (Google Earth) and unmanned aerial vehicle (UAV) images were used as part of the study.

3. FINDINGS

3.1. Validation of Bathymetric Data

The depth values obtained using the fishfinder were compared with plumb-line measurements at 17 reference points, and error values were calculated for each point (Table 2). The results showed that the differences between fishfinder and plumb-line measurements ranged from 0.02 m to 0.38 m. The most significant difference (0.38 m) was observed at Points 1 and 17, near the harbor entrance. The error remained within the range of 0.10–0.20 m at most points. The mean absolute error (MAE) across all points was calculated as 0.183 m, while the root mean square error (RMSE) was found to be 0.211 m, indicating that the measurement errors were randomly distributed and that no systematic bias was detected. The standard deviation of the error values was relatively low, at ±0.109 m. This finding demonstrates that the device provided consistently accurate measurements. The relationship between modern fishfinder measurements and reference values is illustrated in Figure 3. The two depth datasets generally showed a strong parallel pattern, with no significant deviations observed between them.

The relationship between the depth values based on reference measurements and the absolute error values of sonar measurements was examined using a simple linear regression analysis (Figure 4). The resulting regression equation was $y = 0.17951 - 0.00046x$. The coefficient of determination (R^2) obtained from the regression analysis was calculated as 0.00007. This indicates that only 0.007% of the variation in absolute error can be explained by changes in depth, demonstrating that there is virtually no linear relationship between the two variables.

Table 2: Reference data and location information.

Point	Altitute	Latitute	Plumb-line (Reference)	Fishfinder	Absolute error (m)
1	41°11.729' N	40°59.312' E	-8.72	-9.1	0.38
2	41°11.729' N	40°59.296' E	-6.08	-6.4	0.32
3	41°11.684' N	40°59.497' E	-2.96	-2.8	0.16
4	41°11.644 N	40°59.434' E	-4.07	-4.2	0.13
5	41°11.646 N	40°59.325' E	-6.02	-6	0.02
6	41°11.647 N	40°59.314' E	-8.42	-8.6	0.18
7	41°11.722 N	40°59.224' E	-9.27	-9.5	0.23
8	41°11.798 N	40°59.343' E	-10.17	-10.3	0.13
9	41°11.811 N	40°59.405' E	-7.42	-7.6	0.18
10	41°11.754 N	40°59.497' E	-6.62	-6.8	0.18
11	41°11.688 N	40°59.469' E	-6.42	-6.6	0.18
12	41°11.709 N	40°59.424' E	-7.52	-7.6	0.08
13	41°11.733 N	40°59.368' E	-8.52	-8.5	0.02
14	41°11.753 N	40°59.293' E	-9.62	-9.7	0.08
15	41°11.899 N	40°59.603' E	-10.22	-10.4	0.18
16	41°11.802 N	40°59.546' E	-8.12	-8.4	0.28
17	41°11.770 N	40°59.556' E	-6.72	-7.1	0.38

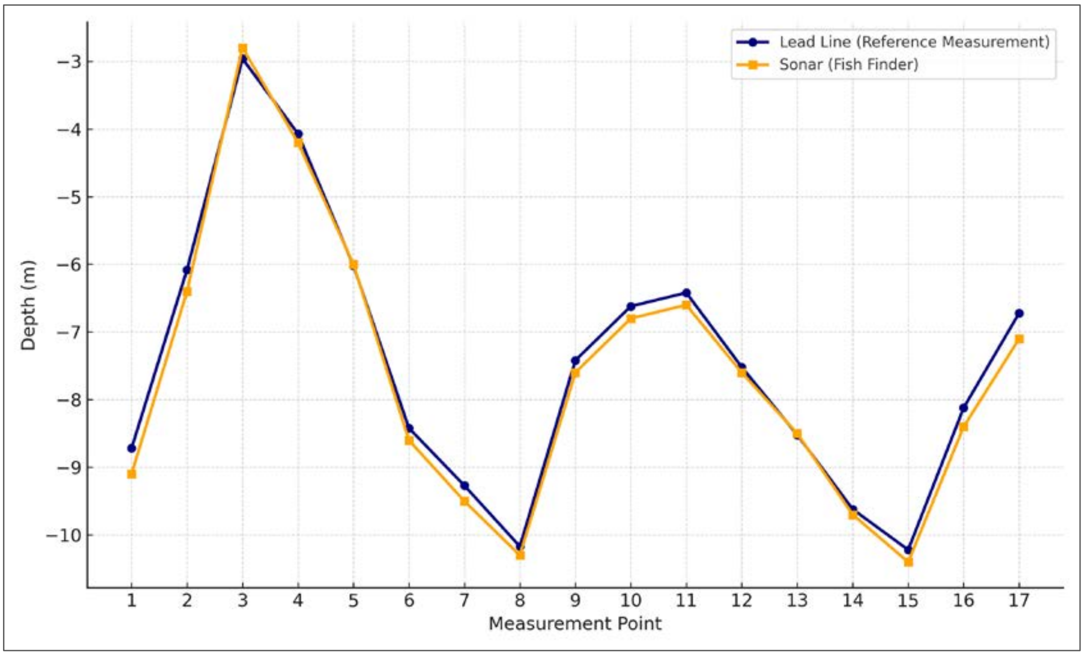

Figure 3: Comparison of Plumb line and Modern Fishfinder Data.

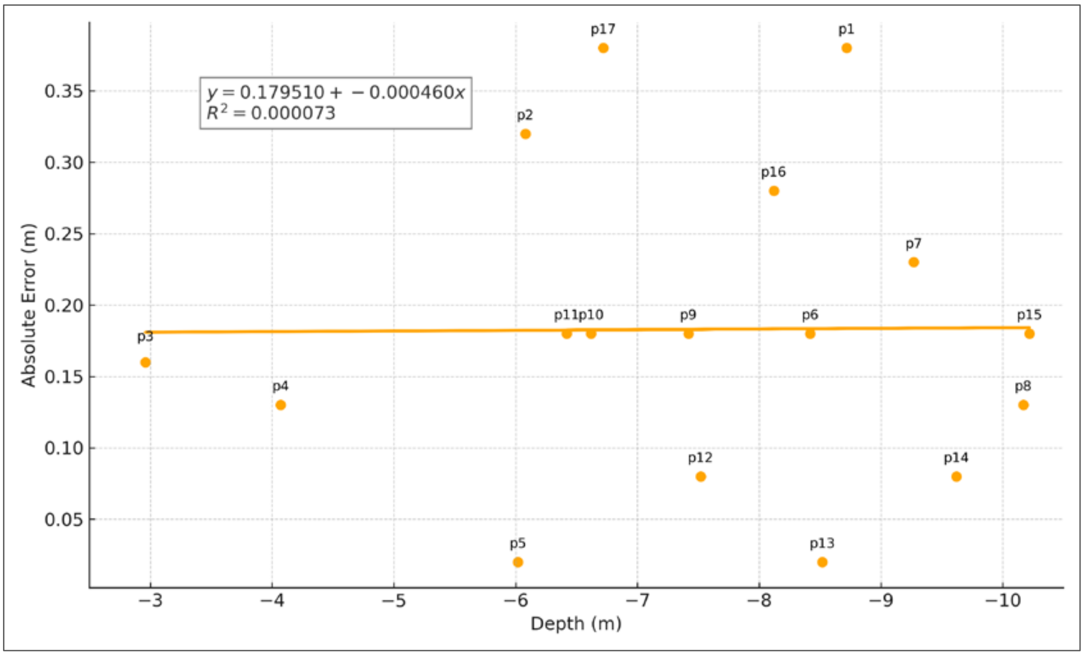

Figure 4: Depth and Absolute Error Regression Chart.

No increase in error was observed with increasing depth. The absolute error was approximately 0.10–0.20 m in shallow zones between 2 and 4 meters, and similar levels were found in deeper areas between 8 and 10 meters (Figure 4). The obtained MAE value of 0.183 m corresponds to a measurement accuracy of over 98% for the depth data collected with the device. While evaluating the relationship between depth and absolute error, it should be noted that the deepest point measured in the study area (P15) was −10.22 meters. Therefore, error values may vary at greater depths beyond this range. However, within the 0–10 m depth interval, the results demonstrate the reliability of measurements obtained using a modern fishfinder.

3.2. Comparison of Bathymetric Mapping and Changes in Depth Profiles

Using historical (2007) and current (2024) bathymetric data, bathymetric maps were generated (Figure 5a, b), and depth profiles were extracted along three cross-sections (A–A′, B–B′, and C–C′) to analyze sediment accumulation. The profile data obtained along these cross-sections reveal both the horizontal distribution of sediment accumulation and vertical depth changes that have occurred over time. According to the digital surface difference analysis, a net sediment accumulation of approximately 602,373 m^3 was detected throughout the harbor over 17 years. This volume difference indicates that sediments transported from the open sea and the Dolana Stream have been retained within the harbor basin over this period.

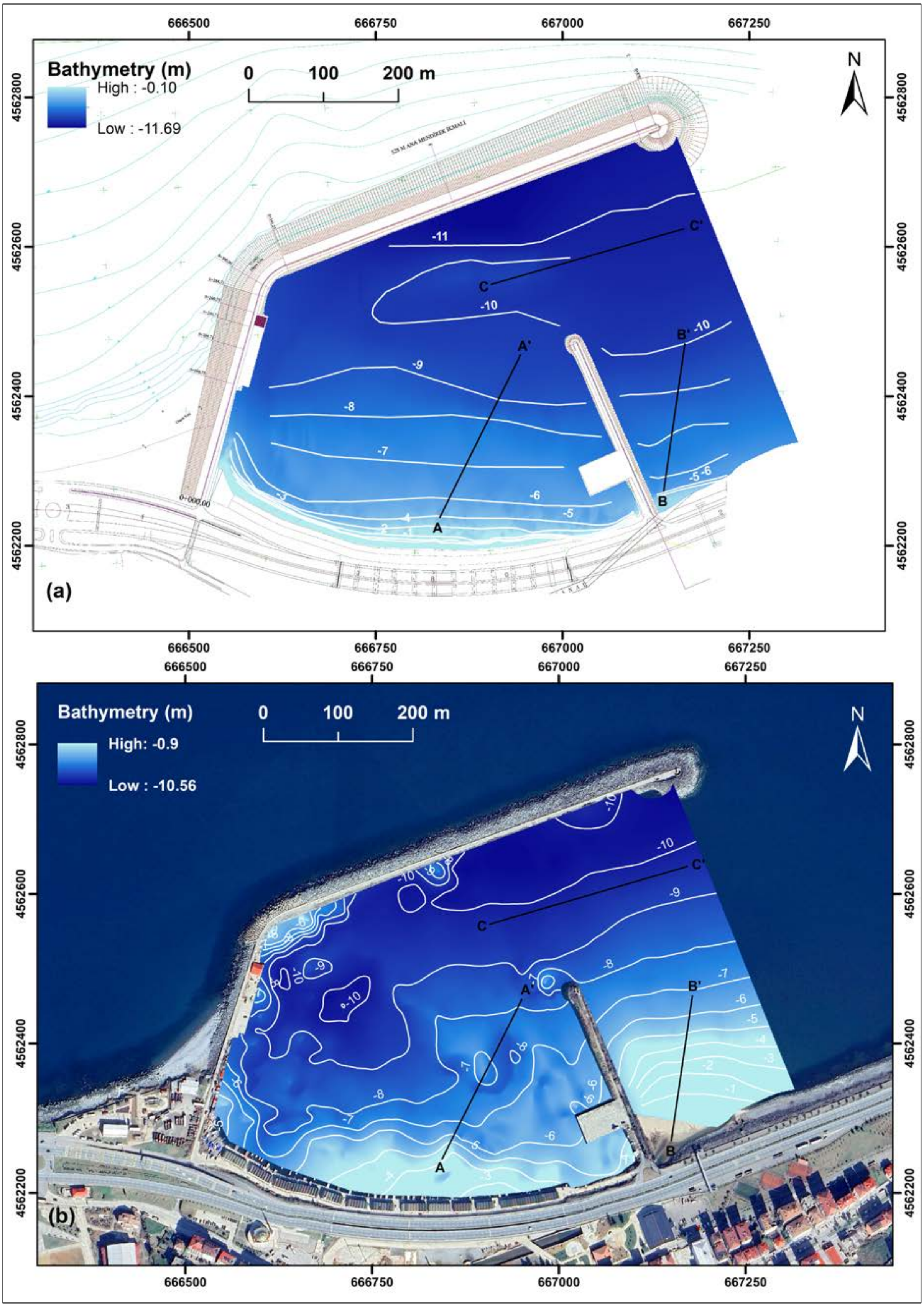

Figure 5: (a) Bathymetric map of Ardeşen Fishing Harbor for 2007, (b) bathymetric map of 2024.

In the A−A′ cross-section, a notable increase in sediment accumulation was observed in 2024 compared to 2007, particularly in nearshore areas. This accumulation is concentrated between 0−50 meters and 150−250 meters along the profile. Due to this accumulation, the depth difference between the two profiles reaches up to 2 meters. In the B−B′ cross-section, the area between 0 and 25 meters had a depth of approximately −6 meters in 2007, but by 2024, it has transformed into land due to sediment deposited by the Dolana Stream. This indicates a significant shoreline shift. The depth difference between the two profiles reaches approximately 7 meters in the area between 25 and 75 meters. The C−C′ cross-section represents a deeper part of the harbor and shows relatively less sediment accumulation. Here, the average difference between the depth profiles is around 1.5 to 2 meters, and the sediment appears more homogeneously distributed (Figure 6).

Overall, all cross-sections indicate significant changes in bathymetric conditions over time within Ardeşen Fishing Harbor. In particular, in the B−B′ section, shallowing due to sediment accumulation is observed more distinctly in terms of both volumetric increase and spatial extent, especially near the downstream part of the Dolana Stream (Figures 5 and 6).

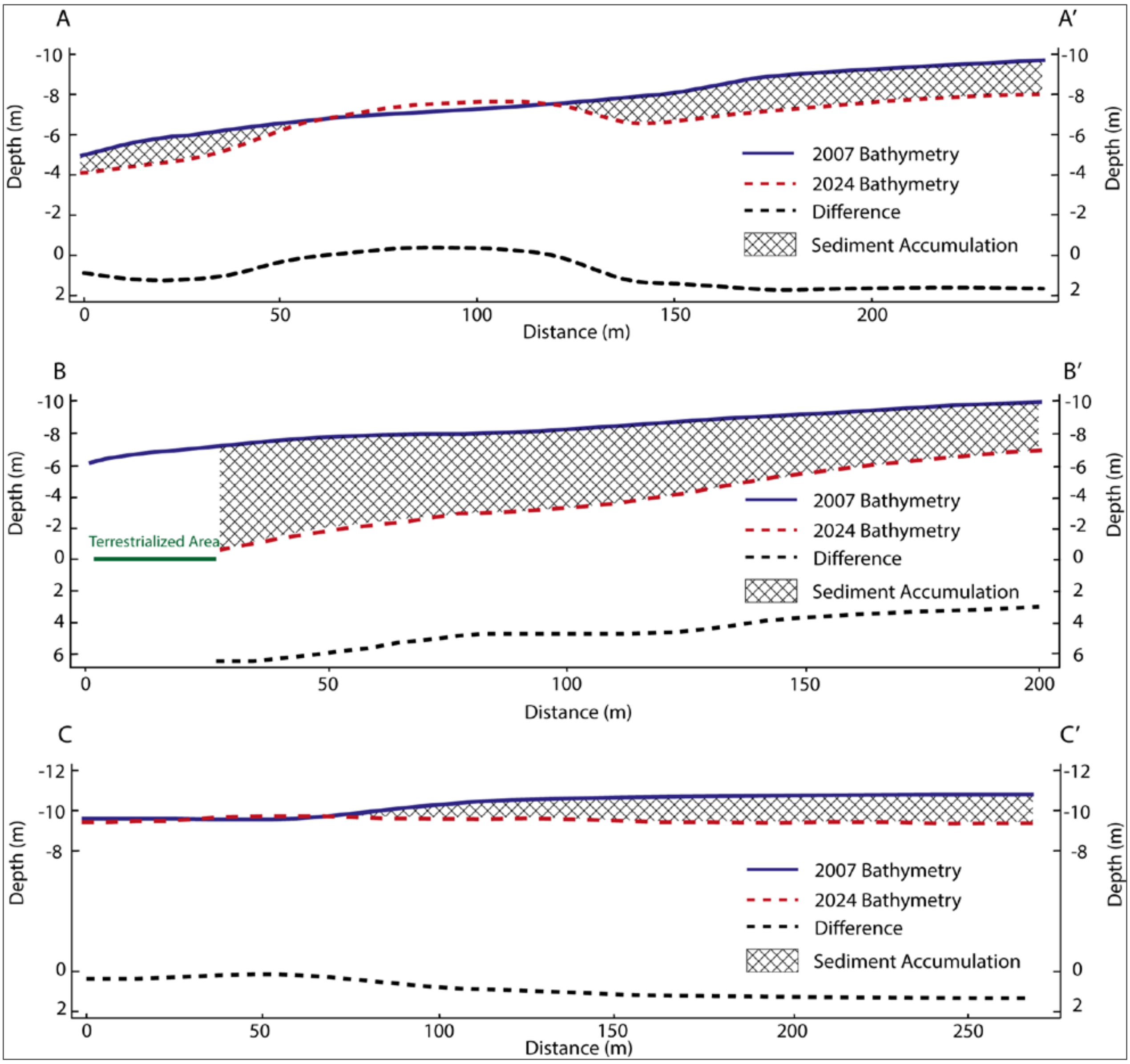

Figure 6: Depth profiles of Ardeşen Harbor.

3.3. The Impact of Changes in the Downstream Part of Dolona Stream on Bathymetry and Shoreline Changes.

Ardeşen Fishing Harbor was constructed in the mid-1980s at the mouth of the Dolana Stream. This location choice is highly problematic from a physical planning perspective, as clearly evidenced in the 2004 orthophoto provided by the Directorate General for Mapping (Figure 7a). Within the scope of the Black Sea Coastal Highway Project—added to the national investment program in 1983, tendered in 1987, finalized during the 1990s (Turoğlu, 2005a), and opened to traffic in 2007—additional engineering interventions were implemented in the vicinity of the harbor (Turoğlu, 2005a). One such intervention involved artificial land reclamation, which encroached upon part of the harbor. This fill extends seaward along the coastline, reaching a maximum distance of 137 meters, representing the furthest extent of coastal infill in this area. Furthermore, the downstream section of the Dolana Stream, which originally discharged into the harbor, was redirected approximately 323 meters eastward via an artificial canal (Figures 7a, 7c). The stream now reaches the sea just east of the harbor, adjacent to the eastern breakwater.

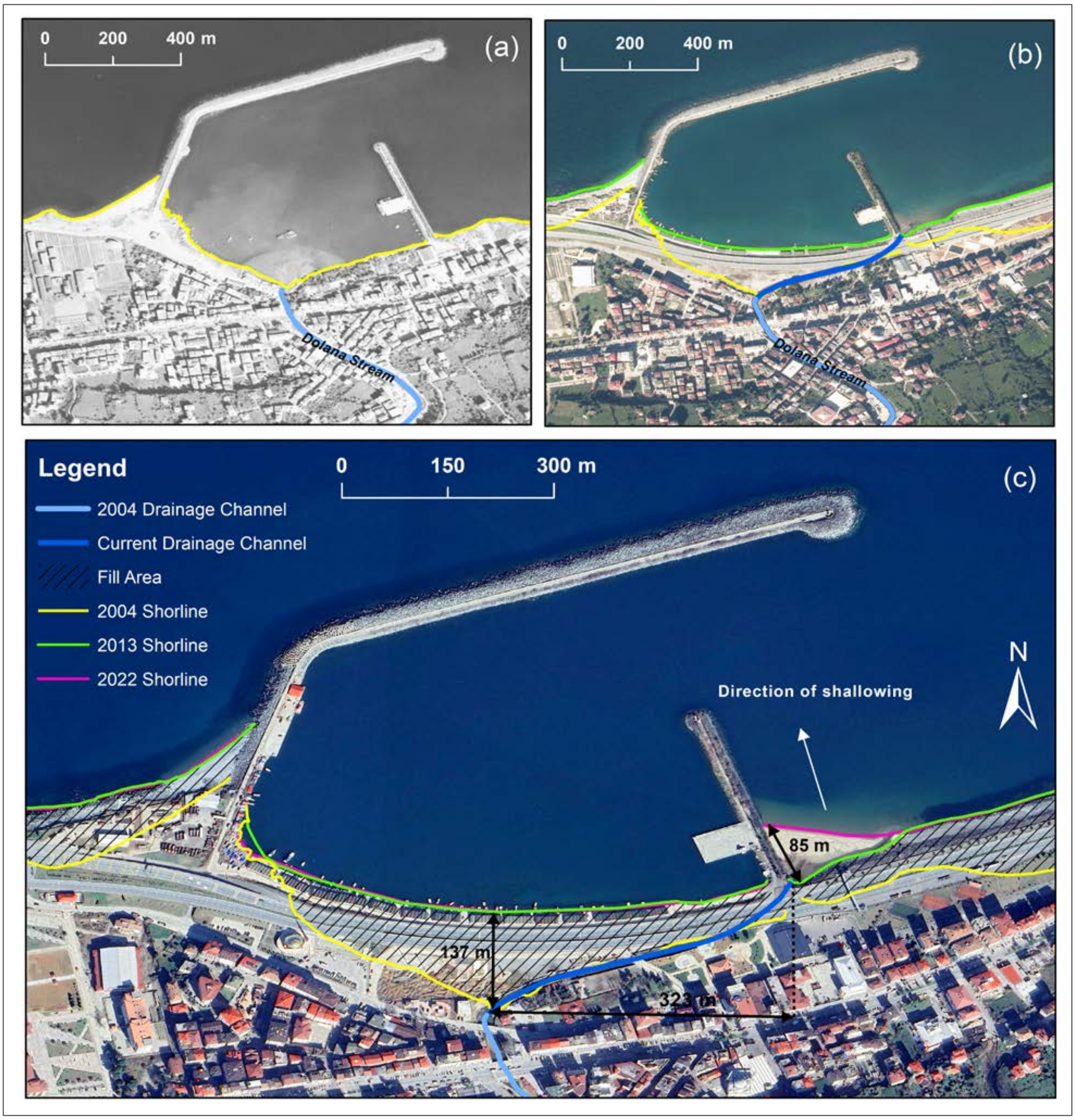

Figure 7: (a) Ardeşen Fishing Harbor 2004 DGM Orthophoto Image, (b) 2013 DGM Orthophoto Image, (c) 2022 Google Earth Satellite Image.

As a result of these physical modifications, sediment transported by the stream has begun to accumulate near the eastern breakwater. Analysis of orthophotos and satellite imagery from 2004 and 2022 (Figure 7) indicates that the shoreline to the east of the harbor has advanced seaward. Specifically, near the new stream outlet east of the harbor, the shoreline has extended approximately 85 meters seaward, forming a new landmass of around 5,100 m² (Figure 7c). If this sedimentation continues, the entrance to the harbor is likely to become increasingly shallow and narrow. UAV imagery obtained in 2024 as part of this study (Figure 8) clearly illustrates the ongoing shallowing in this area. If left unaddressed, this process may ultimately lead to complete infill of the harbor entrance, rendering the facility inoperable in the long term.

A commonly employed approach to mitigate the closure of harbor entrances is periodic dredging and removal of accumulated sediments. However, this method is both costly and operationally unsustainable. In the case of Ardeşen Fishing Harbor, the underlying issue stems from poor site selection and planning errors made during the initial construction phase (Turoğlu, 2000; Turoğlu, 2005b). Therefore, to ensure effective sediment management, it is essential to implement preventive planning measures that restrict stream-borne sediments from entering the harbor—such as diversion structures, sediment traps, or other similar engineering solutions.

Figure 8: Drone Image of Ardeşen Fishing Harbor dated 08/08/2024.

4. DISCUSSION

In this study, the accuracy of bathymetric data collected using a modern fishfinder at Ardeşen Fishing Harbor, located on the Black Sea coast, was compared with that obtained by plumb-line methods. The usability of this technology in monitoring coastal sediment dynamics was also evaluated. The MAE calculated was 0.183 m, the RMSE was 0.211 m, and the standard deviation was 0.109 m. According to the IHO (International Hydrographic Organization) S-44

Standards, the maximum allowable Total Vertical Uncertainty (TVU) for shallow areas less than 100 meters deep should not exceed 0.5 m at a 95% confidence level. The error values of 0.183 m and 0.211 m observed in this study are well within the requirements specified by the IHO (2008) standard.

In the literature, Bradbury et al. (2022) similarly reported that depths measured using fishfinders were, on average, within 5% of those measured with traditional plumb lines, with a standard deviation of 0.034 m. Yamasaki et al. (2015) found that depth measurements using modern fishfinders had an average error margin of approximately 0.20 m compared to known reference depths. Horta et al. (2014) assessed the usability of low-cost fishfinder sonars for coastal bathymetric surveys. Their study showed that these systems, although significantly more affordable than traditional RTK-DGPS methods, provided sufficiently accurate results for shallow-water bathymetric mapping. The differences between the two sonar systems ranged between 0.10 m and 0.16 m and were consistent with the margin of error expected from interpolation methods. The error metrics obtained in our study are consistent with those reported in the literature. These results confirm that low-cost sonar systems represent a practical, cost-effective, and reliable alternative for monitoring shallow and morphologically complex coastal zones.

In this context, the integration of modern fishfinders with unmanned surface vehicles (Yamasaki et al., 2017), unmanned aerial vehicles (Bandini et al., 2018), and small boats or dinghies (Sacarny et al., 2018; Halmai et al., 2020; Bio et al., 2022) offers a promising opportunity for generating high-accuracy bathymetric data in shallow environments. Particularly in small-scale coastal studies, these systems provide a low-cost and practical solution compared to traditional methods. They also hold strong potential for application in areas such as sediment accumulation in dam reservoirs, morphological changes in coastal lagoons, and conservation of coastal habitats.

The 'Topo to Raster' interpolation method used in this study, although possessing some limitations compared to more advanced methods like Kriging, stands out for its ability to maintain hydrological continuity—especially when working with sparse and irregular datasets. Diaconu et al. (2019) noted that Kriging generally yields lower statistical errors. However, the same study also emphasized that the number and spatial distribution of measurement points have a more significant influence on the accuracy of the final model. Therefore, given this study's limited and non-uniform distribution of data points, the Topo to Raster method was considered a much more appropriate choice. Moreover, the ArcGIS-supported implementation of this method enabled the generation of hydrologically consistent and visually smooth surfaces, thus facilitating a sound sediment accumulation analysis (ESRI, 2024).

For future research, it is recommended to increase the number of measurement points, compare different interpolation techniques, and apply similar tests in areas with more complex current and wave conditions. Doing so will help further explore the capabilities and limitations of low-cost sonar-based approaches under various environmental settings. Considering the findings, the usability of modern fishfinder systems for sustainable coastal management and risk assessment has been validated. Their wider application in small-scale bathymetric and sediment monitoring projects will likely yield important scientific and practical benefits.

In artificial coastal environments (Turoğlu, 2019) and coastal areas characterized by rapidly changing sediment dynamics, accurately determining the frequency of bathymetric monitoring is critically important for sustainable coastal management. In regions where coastal morphology is altered by human interventions, conducting bathymetric surveys at least once per year on a regular basis enables effective temporal tracking of sediment processes and timely planning of potential management interventions. Furthermore, it is recommended that additional surveys be carried out following extreme hydrographic and meteorological events, in order to accurately detect sudden morphological changes that may occur as a result of such events. This approach will contribute significantly to maintaining the functionality of harbor infrastructure and to the development of long-term coastal management strategies.

Within this framework, the study investigated the effectiveness of low-cost single-beam sonar devices in generating bathymetric data and tracking sediment dynamics. The results demonstrate the method's potential to monitor changes caused by unsustainable coastal usage and infrastructure development (e.g., excessive land reclamation and unplanned coastal structures). This highlights the role of fishfinder-based monitoring systems in supporting physical planning and coastal management process. Thus, by discussing the strengths and limitations of this approach as an alternative to traditional methods for observing coastal morphology, our study contributes to both academic literature and practical applications aimed at the sustainable management of coastal systems.

5. CONCLUSION

This study demonstrates modern sonar-based fishfinders' applicability in generating bathymetric data and monitoring coastal sediment dynamics in shallow-water environments, using the case of Ardeşen Fishing Harbor, located along the Black Sea coast. The depth data obtained in the sheltered harbor environment, with a MAE of 0.183 m, were deemed sufficient for large-scale bathymetric mapping. These results are consistent with previous accuracy levels reported for similar systems and align with the standards of the IHO.

A comparison of bathymetric data from 2007 and 2024 revealed significant sediment accumulation at the harbor entrance. The calculated volume difference during this period was 602,373 m^3. This finding is particularly important, as it reflects directly the dynamic nature of coastal systems and the spatial-temporal influence of sediment transport processes. Notably, the eastward relocation of the Dolana Stream mouth by 323 meters has resulted in intense sediment accumulation in that area, causing the shoreline to advance approximately 85 meters seaward. Approximately 5,100 m^2 of the marine area has transformed into land due to sediment accumulation, posing a serious threat to the harbor entrance, by leading to progressive shallowing and potential closure.

Monitoring coastal sediment dynamics is vital for understanding changing morphodynamic processes, as well as for coastal land use and physical planning. As observed in Ardeşen Fishing Harbor, the advancement of sediment toward the harbor entrance may cause the harbor to be non-operational shortly. This constitutes a significant threat to the sustainability of investments in regional fisheries infrastructure, such as ports and fishing harbors, which are critical for employment and economic diversification in coastal areas. The method applied in this study offers researchers, coastal planners, and local authorities a low-cost, portable, and repeatable monitoring tool. It also provides valuable data for the sustainable management of coastal areas. This approach can reveal sediment accumulation rates and spatial patterns when conducted at regular intervals, enabling data-driven decision-making for coastal managers. Monitoring the long-term consequences of planning errors contributes to better engineering decisions in the future. Therefore, integrating fishfinder-based measurement systems into broader coastal monitoring programs is strategically important for the adaptive and sustainable management of coastal environments.

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