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Innovative and Cost-Effective Approaches to the Measurement of Sediment Levels in Small Water Reservoirs

Stanislav Paseka

Institute of Landscape Water Management, Faculty of Civil Engineering, Brno University of Technology, Brno, Czech Republic

Correspondence: Stanislav Paseka (stanislav.paseka@vut.cz)

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ABSTRACT

Sedimentation in small water reservoirs poses a critical challenge with significant environmental, economic, and social implications. To address this issue, this study will employ three measurement techniques—GNSS RTK Trimble R8s, Echolot HDS LIVE 7 with Active Imaging 3-in-1, and the Mivardi Carp Scout bait boat—to assess sediment levels in Žebětínský Pond in Brno, Czech Republic. The research reveals that each method offers distinct advantages and limitations. Through measurement and triangulated networks, the study creates a digital terrain model that facilitates the determination of reservoir volume and sediment levels. The comparison shows that the cost-effective alternatives, Echolot HDS LIVE 7 and Mivardi Carp Scout, provide sufficiently accurate results. The evaluation shows that while the GNSS RTK Trimble R8s has the highest level of accuracy and is unique in its ability to measure both along the shoreline of the reservoir and the hard bottom, it comes with increased costs and logistical challenges. The Echolot HDS LIVE 7 and Mivardi Carp Scout offer efficient, cost-effective solutions that are suitable for a quick estimate of sediment thickness. This research contributes to the use of reliable mathematical models and water management strategies, advocating for a pragmatic approach to the selection of methods based on the project characteristics. The study provides valuable insights into sediment measurement techniques, guiding future endeavors in reservoir management and environmental conservation. It is also used to easily indicate the loss of arable land in the catchment upstream of the reservoir.

1 | Introduction

The processes of erosion of agricultural soils and the resultant sediment found in reservoirs are currently among the major global water issues (Pimentel and Burgess 2013; Walling 2009; Issaka and Ashraf 2017). These processes, involving soil particle transport and the subsequent sedimentation, have significant environmental, economic, and social impacts. It is projected that over the next 30 years, more than 50% of the original storage capacity of the world's reservoirs will be lost to sedimentation (UNESCO 2011). In the Czech Republic, according to the methodology (Novák et al. 2017), it is estimated that approximately one-third of pond volumes are covered by sediment. Siltation of reservoirs leads to a reduction in storage capacity, shorter residence times, increased flow rates, and decreased water abstraction security. Ultimately, these factors result in a reduction in the retained water volume, which also impacts water quality indicators. A decrease in the volume of water stored in reservoirs leads to a faster rise in temperature, which promotes eutrophication processes and increases evaporation. The transport of sediment into reservoirs and sedimentation rates depend on various factors, including rainfall volume distribution, vegetation coverage, its type and distribution, the size of the catchment area, geological and geomorphological conditions, and human interventions within the landscape (Bell 1998).

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While measuring quantities of sediment generally requires an extensive effort, the practical application of expensive measuring equipment at small water reservoirs is often highly challenging. Reasons for this may include a lack of available equipment, shallow water, and a poor cost/benefit equation. In a recent publication (Marval et al. 2018), a comparison of several measurement techniques for assessing the sedimentation of small water reservoirs in the Czech Republic was conducted. Specifically, the study compared the results obtained using acoustic Doppler current profiler (ADCP; RiverSurveyor M9), EcoMapper, and ultrasonic measuring apparatus mounted on a Basin Enterprises measuring barge. The findings demonstrated a high level of agreement between the data acquired through these different approaches.

The main objective of this article is to carry out an empirical analysis of sediment levels in small reservoirs employing three different measuring techniques, each with a different cost level, for a precise determination of the quantity of sediment. This comprehensive approach and subsequent comparisons of the measurements directly answer the pressing need for accurate assessment of sediment levels in small reservoirs. The findings have practical significance in that they should enable swift and economical evaluations of the amount of retained water, thereby streamlining the management of these versatile small reservoirs. The application and validation of these methods of measurement are demonstrated through a detailed case study conducted on the Žebětín reservoir, where the impacts of land degradation will be quantified.

2 | Background

Within the Czech Republic, the “Digital Relief Model of the Czech Republic, 5th generation” (DMR 5G) is used to provide elevation data, and it provides a mean elevation error of 0.18 m in open terrain and 0.3 m in forested areas (ZABAGED—DMR 5G 2023). Although DMR 5G is relatively accurate, it lacks data on depths below the surface of the water as it relies on airborne laser scanning, and the infrared beam does not penetrate below the surface of the water. While this product is effective when used in the design of dams and culverts or in the calculation of bathymetry for proposed reservoirs, from a water management perspective, it does not include crucial data on existing reservoirs, such as reservoir capacities, amount of sediment and storage dynamics. Therefore, it is imperative to acquire appropriate data on the levels of sediment in small reservoirs using available measurements.

The methods used by current depth-measuring techniques range from remotely operated vehicles near the bottom to ships at sea level to satellites orbiting the Earth. Depending on means and mission, these systems utilize acoustics, optics, or radar altimetry to either directly measure or infer bathymetry. Each method provides a different spatial resolution and can probe depths ranging from shallow coastlines to the deepest trenches (Dierssen and Theberge 2014). Bathymetric models available today include the ETOPO1 arc-minute Global Relief Model, shuttle radar topography mission (SRTM) (Tozer et al. 2019) and others that provide direct depth measurement. Remote sensing techniques tend to be widely used to retrieve shallow water depth due to their ability to provide large-scale and continuous monitoring capabilities (Liang et al. 2024). The remote sensing techniques have a significant potential for bathymetry mapping due to their extensive coverage of the area and repeatability (Jagalingam, Akshaya, and Hegde 2015). However, reservoir or lake bathymetric models are either unavailable or difficult to get (Heathcote, del Giorgio, and Prairie 2015; Messager et al. 2016), particularly in remote areas with limited data. These global models lack the necessary resolution for an in-depth analysis of small reservoirs. The future lies in aerial scanning bathymetry systems that employ the “Light Detection and Ranging” (LIDAR) method (Kerfoot et al. 2014; Collings et al. 2020). LIDAR is based on the time-dependent reflection of light beams and shows great promise in providing data on depths below the surface, as described in the case studies (Klemas 2011), (Janowski et al. 2022), (Wu et al. 2024). Presently, sonar is most commonly used for bathymetry measurements (Novák et al. 2017). Traditionally, bathymetry maps are created on a boat using echo-sounding equipment, as used in (Odhiambo and Boss 2007) and (Morlighem et al. 2017). These systems employ the transmission and reflection of acoustic waves to detect submerged objects and measure depths. While they are primarily used in the navigation of naval vessels, they are also utilized in various industries and in target-specific searches. PARASOUND is an example of such a system that utilizes simultaneous transmissions on two frequencies (known as the parametric effect) that can penetrate shallow geological layers and directly distinguish between upper sediment layers. The echo-sounding method can produce accurate depth profiles along transects, but it is inefficient and expensive (Gao 2009). It is also not feasible to measure shallow and episodical lakes, particularly in dry periods (Abdallah et al. 2013; Armon et al. 2020). In addition, the ADCP is a tool that measures water velocity throughout a water column. By moving the measuring device laterally in the water flow, the ADCP can be used to determine the bottom profile and flow velocity. The ADCP method relies on sound waves to measure the velocity of water based on the Doppler effect (Marval et al. 2018).

Where it is possible to safely move the gauge over the bottom or within shallow reservoirs (up to a maximum depth of 10 m), measurements can be performed from a boat using a total station or global navigation satellite system (GNSS)-real-time kinematic (RTK) technology (Novák et al. 2017). The accuracy of such measurements varies depending on the method used but typically is within a few centimetres.

In recent years, Basin Enterprises have been using modern and expensive instruments that cost between 350,000 and 400,000 euros to update bathymetric curves and assess levels of sediment in large reservoirs throughout the Czech Republic. These advanced instruments can distinguish between soft and hard bottoms, making them highly suitable for measuring deposited bottom sediments. This equipment is available in the Czech Republic and is offered by companies such as VARS Brno or the aforementioned Basin Enterprises.

Research in the field of reservoir sedimentation is continuously evolving, as evidenced by the large collection of relevant articles. One such study (Schumer et al. 2013) focused on experiments to measure bed elevation using a fine-scale LIDAR or sonar transducer for precise bed tracking. Another paper (Chih-Chung and Yen-Kai 2022) undertook a practical assessment of real-time suspended sediment load monitoring, employing time domain reflectometry (TDR). Addressing sediment storage in Alpine sedimentary systems, a separate study (Otto, Goetz, and Schrott 2008) delved into quantification and scaling issues. Furthermore, there are several articles centered around sediment modeling and simulations. Toniolo (2009) presents the results of experiments and numerical simulations related to sedimentation in reservoirs and lakes. Hilgert et al. (2016) investigated the echo sounder parameters for the characterization of spatially extensive sediment volumes of a subtropical reservoir. Hilgert, Sotiri, and Fuchs (2024) evaluated the advantages and disadvantages of four different techniques and discussed each method's applicability, depending on the reservoir type, sediment characteristics, and sediment thickness. In an effort to address the uncertainties in existing models, a new stochastic model for shallow water hydro-sediment-morphodynamics was introduced and explored in the paper (Ji, Zhixian, and Borthwick 2021). Additionally, Rodríguez González et al. (2023) conducted a sensitivity analysis of mean annual sediment yield modeling with respect to rainfall distribution probability functions. These articles contribute to the advancement of sediment measurement and modeling, emphasizing their relevance and significance to current research.

3 | Methodology

3.1 | Measurements Using a GNSS RTK Trimble R8s Geodetic Device

The measurement of sediment in water reservoirs utilizing the GNSS RTK Trimble R8s geodetic device is based on the GNSS, which enables precise geolocation on the surface of the Earth. This cutting-edge RTK technology allows immediate measurements to be made that are characterized by exceptional accuracy. An illustration of the working principles of RTK is provided in Figure 1.

The measurement precision that is achieved using a GNSS RTK Trimble R8s geodetic instrument is contingent upon a myriad of factors, meticulously listed by the manufacturer. Foremost among these determinants are the quality of the GPS signal, the fine-tuning of device configurations, the operator's proficiency, and the prevailing meteorological conditions. Generally, one can anticipate that the measurement accuracy will fall within a range of 1–3 cm, in both horizontal and vertical dimensions. However, it becomes patently evident that within more intricate terrain, such as densely vegetated shorelines or narrow valleys, the precision of measurement may experience a commensurate reduction.

Throughout the course of the measurements, precise geographical coordinates must be diligently ascertained for the specific point locations where the measurements are conducted. To serve this purpose, the Joint Triangulation of Czechoslovakia (S-JTSK) coordinate system is conventionally employed within the territorial boundaries of the Czech Republic. This system assures seamless alignment with local cartographic representations and geodetic datasets (Technical Description of the Trimble System n.d.).

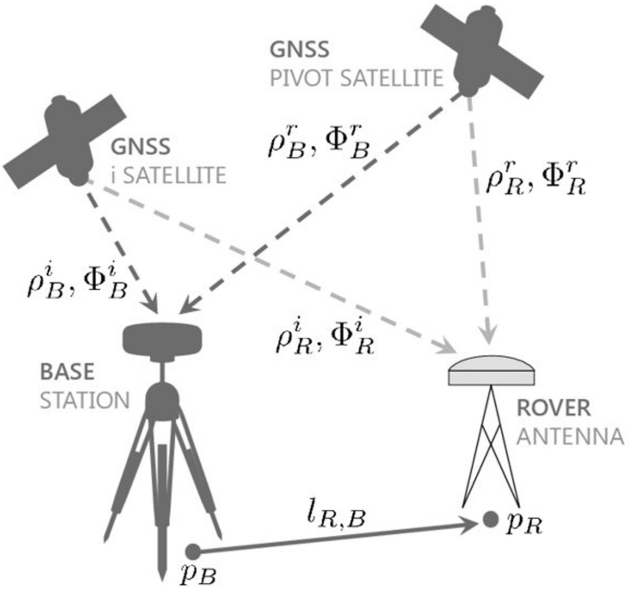

FIGURE 1 | An illustration of the working principles of RTK (Medina et al. 2018).

3.2 | Measurements Using a Echolot HDS LIVE 7 With Active Imaging 3-In-1

The Lowrance Echolot HDS LIVE 7 is an advanced high-resolution echo sounder equipped with powerful imaging features. When paired with the Active Imaging 3-in-1 transducer, it becomes a versatile tool that allows the acquisition of detailed information about the underwater topography of reservoirs, lakes, and rivers. The Active Imaging 3-in-1 transducer combines traditional CHIRP sonar technology with SideScan and DownScan Imaging, providing a comprehensive view of the underwater environment (Figure 2). Under optimal conditions, the system can achieve a measurement accuracy of several centimetres (with a maximum measuring distance of 1–2 m) in both the horizontal and vertical axes. However, measurement accuracy is contingent upon several key factors, such as the placement of the transducer, the type of sediment, the presence of vegetation and obstacles on the bottom, weather conditions, the selection of an appropriate sonar mode, transducer calibration, and operator experience. (Product Manual and Operator Manual HDS LIVE n.d.).

3.3 | Measurements Using a Mivardi Carp Scout Bait Boat

The Mivardi Carp Scout XL 6.0 bait boat is primarily designed for fishing purposes. Today, these vessels come equipped with advanced technology that allows precise positional tracking via the global positioning system (GPS) and water depth measurement using sonar (Figure 3). The GPS accuracy hinges on various factors, encompassing both signal quality and satellite

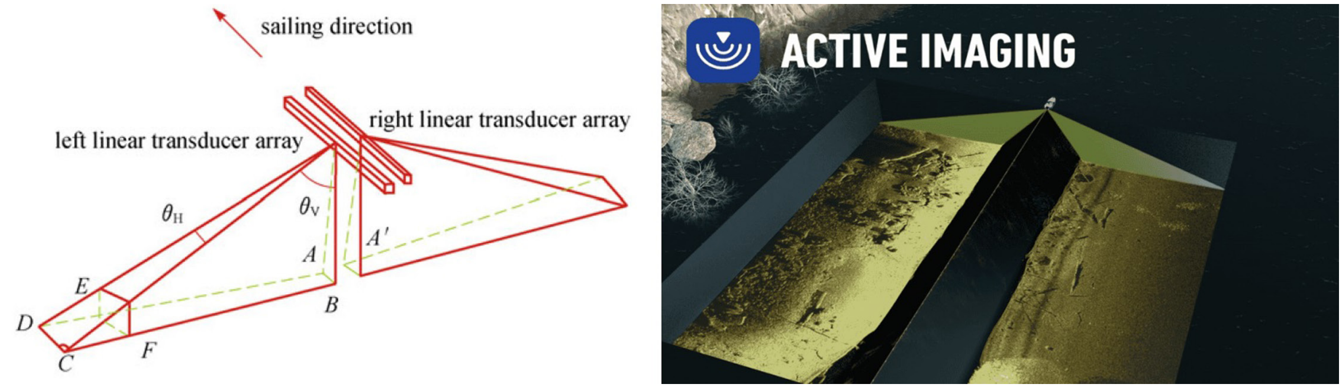

FIGURE 2 | The working principles of SideScan sonar and sonar imaging (Ding et al. 2021). [Colour figure can be viewed at wileyonlinelibrary.com]

FIGURE 3 | The Mivardi Carp Scout XL 6.0 bait boat—remote control measurement. [Colour figure can be viewed at wileyonlinelibrary.com]

accessibility. Under optimal conditions, the GPS can achieve an accuracy of around the meter level, with the manufacturer specifying an accuracy of better than 3 m. In terms of recording water depth, the sonar technology leverages sound waves to gauge the distance between the boat and the river/lake/reservoir bed, which allows for the determination of water depth. The accuracy of the depth measurement achieved by the sonar in these types of boat is in the range of centimetres to tens of centimetres (Product Manual Mivardi Carp Scout n.d.).

3.3.1 | The Creation of a Digital Terrain Model

A digital terrain model was created from the individual measurements using the Atlas DMT software. This software is used to model and visualize three-dimensional spatial surfaces, particularly terrain, based on topographical and elevation data. Additionally, it provides computational capabilities. The algorithm constructs a triangular mesh between data points according to predefined rules, and the mesh can also be collectively or individually modified through the addition of mandatory boundaries. Furthermore, the software offers functionality that allows volume calculations, including the direct utilization of a differential model (Atlas DMT programme n.d.).

4 | Case Study

The measurements were conducted in Žebětínský Pond located in Brno, in the Czech Republic. This nature reserve covers an area of 4.4 ha, including wetland meadows. The pond was constructed in the 1950s and has not been cleaned for approximately 20 years. Currently, the pond is heavily silted and overgrown with reeds. The pond is positioned as a flow-through relative to the stream. The water level is controlled by an open sluice with wooden gates, which are used to drain the pond. There is no sediment flushing during the operation of the pond. The height of the reservoir dam is approximately 3 m, along which a road runs. Additionally, there is a safety spillway in the form of a combined functional block together with a sluice gate, from where the water is discharged into a sinkhole and a drainage gallery under the road.

The average annual precipitation for the period 1991–2020 is 511 mm for the closest station Brno Tuřany under the administration of the Czech Hydrometeorological Institute. The catchment area upstream of the pond is 3.5 km^2. Of this, the forest is dominant, accounting for almost 90% of the area. The source of sediment at the bottom of the pond is therefore overwhelmingly forest. This location was chosen due to its significance, as there is an obvious issue with siltation and it is anticipated that the pond will be dredged in the future.

The measurements were carried out in May 2023, when the underwater plant growth was expected to be less pronounced than in the summer months. This facilitated the use of measuring equipment on the small water reservoir, such as an inflatable boat or bait boat. Initially, the survey focused on the shoreline, embankment, and surrounding objects. Subsequently, the "hard" (original) and "soft" (silted—current state) bottoms were surveyed in shallow areas using the GNSS RTK, Measurement A, allowing movement without the need for a boat. Further, the "hard" and "soft" bottoms were measured from a boat using the GNSS RTK, Measurement A. The measurement rod was 2.5 m long, which proved to be sufficient for the comprehensive survey of this small water reservoir. Additional measurements of the "soft" bottom were performed using the Echolot HDS LIVE 7 with Active Imaging 3-in-1 mounted on a boat, Measurement B. The final measurements of the "soft" bottom were conducted using the Mivardi Carp Scout bait boat, Measurement C. All measurements were conducted over a 5-day period to maintain consistent conditions.

All the collected data was converted into uniform S-JTSK coordinates. Depth measurements, relative to the water surface for Measurements B and C and relative to the current water level for Measurement A, were precisely recorded to calculate the height above sea level of the "soft" bottom in meters. A digital terrain model was then generated from all the measurements using the Atlas DMR software.

5 | Results and Discussion

A digital terrain model was constructed from the measured point height and topographic data (Figure 4). Specifically, 306 data points for the "soft" bottom and shoreline edges, including

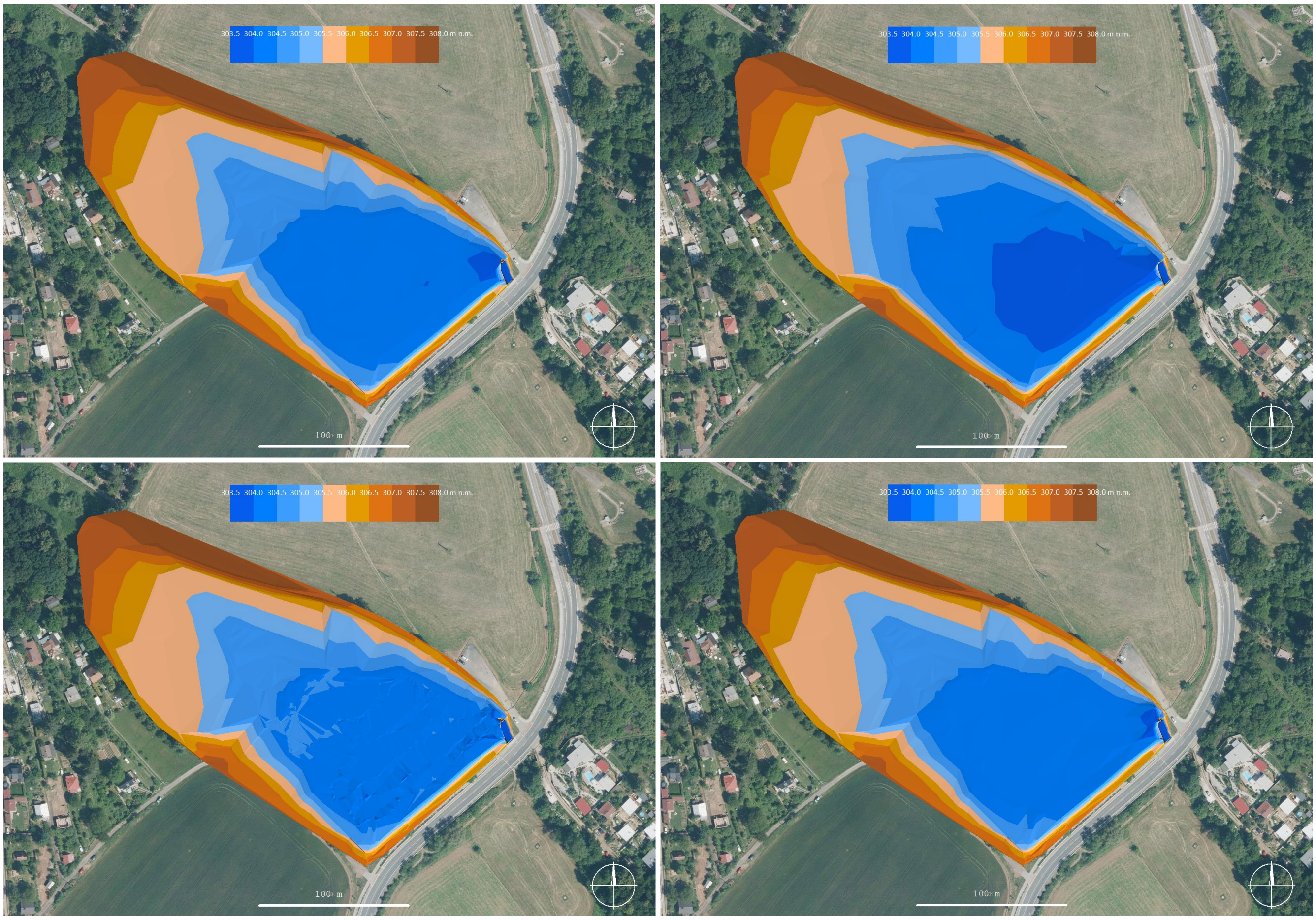

FIGURE 4 | The terrain model generated from the triangulated mesh (Measurement A, hard bottom (top right); Measurement A, soft bottom (top left); Measurement B, soft bottom (bottom left); Measurement C, soft bottom (bottom right)). [Colour figure can be viewed at wileyonlinelibrary.com]

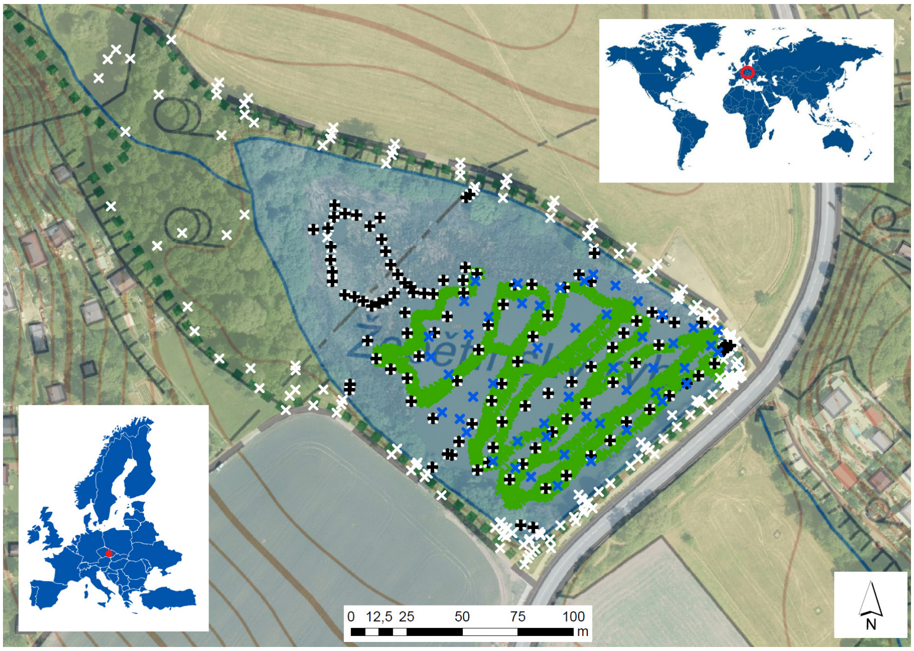

FIGURE 5 | Measured points using methods A, B, and C (Measurement A: white cross for hard bottom and shoreline edges, black cross: Soft bottom; Measurement B: green cross for soft bottom; Measurement C: blue cross for soft bottom). [Colour figure can be viewed at wileyonlinelibrary.com]

objects, were measured, along with 110 data points for the "hard" bottom using GNSS RTK. In total, 416 data points were measured, Measurement A. The water surface was traversed by a boat-mounted echosounder, and after data filtration (high point density), 1410 data points were used, Measurement B. Using a bait boat, 50 data points evenly distributed across the entire surface of the water were measured, Measurement C (Figure 5).

Four triangulated networks were created from the measured data using the Atlas DMT program (Figure 5). Points measured without the need for a boat (freely accessible), such as shoreline edges, shallows, and objects, were measured using method A and used in all networks (model edges). The triangular network of the original hard bottom was drawn using Measurement A data points (white crosses), as the other measurement techniques are not able to measure sediment thickness. The remaining three networks of soft bottom or current sedimentation were drawn using the data from each of the measurement methods, i.e., Measurements A (black), B (green), and C (blue) Figure 6.

From the Measurement A hard bottom model, the potential storage volume of the reservoir, at an operational level of 305.5 m above sea level (m a.s.l.), was determined to be 24,877 m^3. This result was incorporated into the soft-bottom models for Measurements A, B, and C. From the Measurement A soft bottom model, the reservoir volume was calculated to be 19,374 m^3, and the sediment volume was 5503 m^3 (22.1%). From the Measurement B soft bottom model, the reservoir volume was calculated as 17,428 m^3, and the sediment volume wa 7449 m^3 (29.9%). From the Measurement C soft bottom model, the reservoir volume was calculated to be 17,341 m^3, and the sediment volume was 7536 m^3 (30.3%). The average value of reservoir sedimentation from the three different soft bottom measurement techniques (A, B, and C) was 6829 m^3. This corresponds to 27.5% of the original reservoir volume. However, the measured values ranged from 22.1% to 30.3%.

For a detailed assessment in terms of sediment distribution in the reservoir, the pond area was divided into three parts: the shallowest part at the inflow, the medium-deep part, and the deepest part at the outflow. The hard bottom from measurement model A was considered constant. On the other hand, the soft bottom was variable according to the measurement method A, B, and C. The results of the average sediment accumulation (height) including the standard deviation are presented in the following table for the three parts of the reservoir (Table 1).

According to the basic distribution of typical sediment deposits in a reservoir based on bedload from inflows to the reservoir (Morris and Fan 1998), four variations can occur. Specifically, (i) delta deposition, where the bed sediments settle at the beginning of the reservoir, (ii) tapering deposition, where the sediments settle gradually at the inflow and the deposition tapers toward the reservoir, (iii) uniform deposition, where the sediment settles gradually and evenly along the length of the tank bottom, and (iv) wedge deposit, where the sediment will settle only at the deepest point of the reservoir, i.e. in the dead space of the reservoir. It is clear from the evaluated results in Table 1 that the tested reservoir is close to uniform deposition, i.e. variant (iii). The sediments in the reservoir are uniformly deposited, with an average height of 35.5 cm.

It is evident from the results obtained that both of the cheaper and faster variants (Measurements B and C) yielded near identical results (a difference of only 87 m^3 in the calculated volume of sediment). It is likely that these two methods took their measurements from the very soft upper layer of mud (sediment). Conversely, the manual measurement with a staff may have only encountered resistance when it came into contact with greater thicknesses of mud (harder sediment). It would be advisable to verify this, for example, by adding a pad (plate) to the staff, which would produce resistance upon contact with the soft upper layer of mud (fine sediment). In the future, these measurement techniques could be verified at

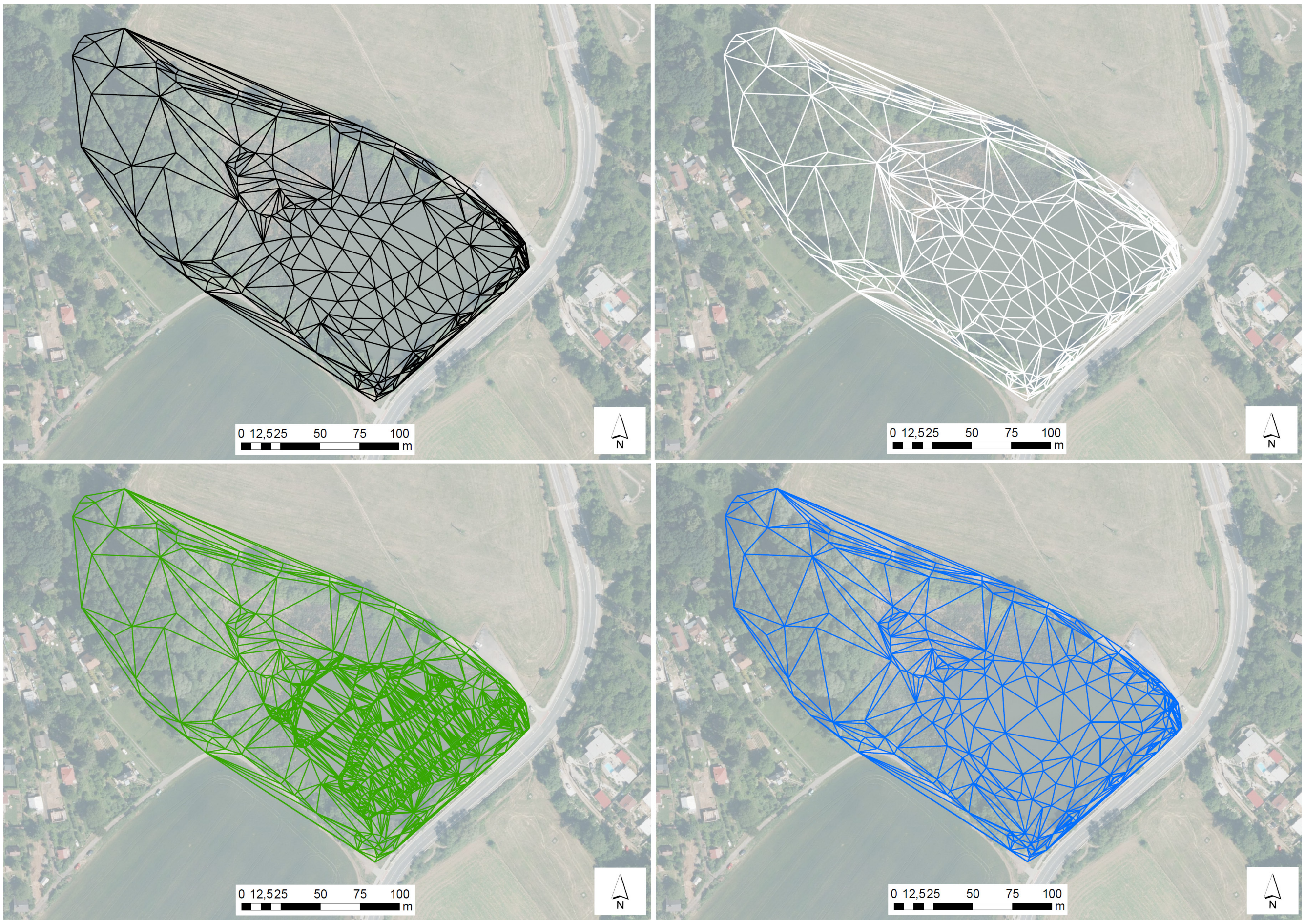

FIGURE 6 | An example of a triangulated mesh (white mesh for hard bottom, Measurement A; black mesh for soft bottom, Measurement A; green mesh for soft bottom, Measurement B; blue mesh for soft bottom, Measurement C). [Colour figure can be viewed at wileyonlinelibrary.com]

TABLE 1 | The average sediment accumulation (height in cm).

Height in cm	Measurement A	Measurement B	Measurement C	Average value
Shallowest part	31.35 ± 23.45	31.87 ± 23.09	35.96 ± 21.06	33.06 ± 23.98
Medium-deep part	28.63 ± 15.65	42.70 ± 14.08	44.59 ± 14.66	38.64 ± 16.43
Deepest part	22.42 ± 8.66	43.34 ± 16.75	39.19 ± 20.70	34.99 ± 18.53

a small reservoir, which could be drained to allow measurement of the hard bottom, and measured using all three methods after it was refilled. However, it would be challenging to test these techniques after the reservoir was drained using Measurement A, as drying of the mud (sediment) would result in a change in volume. All the measurement techniques A, B, and C could be more appropriately tested with a new small reservoir or a reservoir after cleaning out the sediment, but again, only for hard bottom measurement.

The following table (Table 2) shows the approximate costs, requirements, and accuracy of the measurements used.

Looking at Table 2, it is evident that Measurement A provides the greatest accuracy but is also the most expensive; it requires a boat to take measurements from the surface of the water and ultimately for the measurement of depth. It is significantly limited in terms of the depth of the reservoir. The results of the cheaper measurement methodologies, Measurements B and C, provided almost identical results for the sediment volume in the small reservoir. Therefore, based on the results, it may be recommended that, when measuring the actual bottom after reservoir construction, or after cleaning a reservoir and under dry conditions, the cheaper methods are sufficient to allow a quick estimate of sediment thickness. Moreover, these cheaper methods, Measurements B and C, are much more efficient when measurement of the sedimentation levels of deeper small reservoirs is needed in comparison to the more expensive variant, Measurement A.

The results of this study are in close accordance with a Spanish study (Erena et al. 2019) comparing echosounder and RTK-GNSS

TABLE 2 | Evaluation of measurement methods.

	Measurement A	Measurement B	Measurement C
Approximate cost	€8 k	€1.7 k	€1.6 k
Boat required	YES	YES	NO
Manual measurement of banks	YES	YES	YES
Time required	Long	Medium	Short
Accuracy	Max 1–3 cm	A few cm (max 1–2 m)	1 m (max 3 m)
Staff required	2 persons	1 person (2 persons)	1 person
Equipment calibration	NO	YES	YES
Max. depth of measurement	A few meters	max 305 m (DownScan 91 m)	Max 30 m

methods for sediment measurement. The study, conducted at a reservoir in Spain, evaluated the effectiveness of echosounder and RTK-GNSS methods for sediment measurement. The findings revealed that the echosounder method, although less precise than RTK-GNSS, presents a cost-effective and reasonably accurate alternative for estimating sediment volumes. This conclusion echoes the observations made in this study, where the Echolot HDS LIVE 7 and Mivardi Carp Scout systems proved efficient and economically viable compared to the GNSS RTK Trimble R8s. In both the referenced study and this one, the RTK-GNSS method exhibited excellent accuracy in measuring hard substrate and providing detailed sediment profiles. This method is particularly valuable for projects demanding high precision in sediment volume calculations and distribution mapping. Conversely, the cheaper, faster, and simpler echosounder option, despite its lower precision, was found to be sufficiently accurate for general sediment assessment. Both studies concluded that echosounders are more practical for routine sediment monitoring, offering adequate accuracy at significantly lower costs and with simpler operation.

Studies dealing with field methods for suspended and bedload sediment measurement (Muhammad et al. 2019) review various sediment measurement techniques, highlighting their merits and limitations. Techniques such as bottle sampling and the Helley–Smith sampler are commonly used for suspended and bedload sediment due to their widespread applicability and time-tested reliability. The study emphasizes, as well as this study, that the choice of technique depends on factors like budget, equipment availability, manpower, and data requirements.

Sedimentation study in Brazilian reservoirs using acoustic techniques (Sotiri, Hilgert, and Fuchs 2019) utilized acoustic techniques to measure sedimentation in reservoirs. The study demonstrated that acoustic methods, similar to your use of echosounders, can efficiently map sediment distribution and volume, proving beneficial for large-scale sediment management at lower costs.

Next study presents various methodologies for assessing sediment accumulation in diverse reservoir types (Hilgert, Sotiri, and Fuchs 2024). Four distinct techniques were elucidated through detailed case studies, with topographic differencing being the most commonly utilized approach. The study aims to evaluate the advantages and drawbacks of each technique. Drawing from case studies and existing literature, an overview table summarizing available sediment detection techniques, along with qualitative assessments of their strengths and weaknesses, was provided.

Bathymetric and sedimentation surveys (Odhiambo and Boss 2007) were conducted using a dual-frequency echo sounder system. The results from echo sounder surveys and GIS analyses suggest a projected lifetime of Lakes. This study demonstrated the utility of merging geophysical survey (echo sounder) data within a GIS as an aid to understand patterns of reservoir sedimentation.

None of the studies compared the very cheap version of the Mivardi Carp Scout XL 6.0 bait boat, which is primarily designed for fishing purposes. Still, this economical and user-friendly variant (measurements C) showed the same sediment volume results in the reservoir as the better-quality boat-installed echolocator (measurement B).

The level of reservoir sedimentation, based on the measurements, is clear, and steps should be taken to remove the sediment. Since it is a naturally preserved location, sediment removal will need to be dealt with the Nature Conservation Agency of the Czech Republic. Furthermore, according to the relevant legislation (Law No. 334/1992 Coll., the Act of the Czech National Council on the Protection of the Agricultural Soil Fund (1992)), it will lead to the analysis of the sediment quality to the limit values (Decree No. 257/2009 Coll., the Decree on the Use of Sediments on Agricultural Land (2009)) for the possible deposit of sediments on the adjacent municipal land of the City of Brno as the cheapest possible alternative. As part of the planned sediment removal and revitalization of the reservoir, it would be very beneficial to build a small sedimentation pond upstream of the reservoir to capture sediment from the forest land.

The range of sedimentation, or the difference in the quantity of sediment from the various methods of measurement (22.1%–30.3% of the total volume of the reservoir), is relatively high. From the perspective of water management in small reservoirs, sediment poses a significant challenge. When creating mathematical models, it is necessary to define or at least estimate the degree of sedimentation on the bathymetric curves of the reservoir. The input values used for water management analysis applied in articles (Marton and Paseka 2017) and (Paseka and Marton 2021) had a degree of uncertainty. They were constructed using the Monte Carlo method and applied to data used in the water management solution for the reservoir: average monthly water inflows, hydrographs, bathymetric curves, water losses due to evaporation, and dam seepage. In the analysis of these uncertainties, it was found that the water inflow into the reservoir is the most significant source of uncertainty. However, other input uncertainties, including the bathymetric curves of the reservoir, also had a considerable impact on the results. Therefore, from both a reservoir functionality and water management perspective, it is crucial to seek readily available and rapid solutions for the measurement of sediments on the bottom of small reservoirs.

6 | Conclusion

This study aimed to address the critical issue of sedimentation in small water reservoirs, emphasizing the importance of accurate and cost-effective methods of measurement. The research focused on three distinct techniques—GNSS RTK Trimble R8s, Echolot HDS LIVE 7 with Active Imaging 3-in-1, and the Mivardi Carp Scout bait boat—to measure sediment levels in Žebětínský Pond in Brno, in the Czech Republic.

The findings revealed that all three methods provided valuable information about the degree of sedimentation. Each method had its own unique advantages and limitations. The study confirmed clear soil degradation in the catchment of the small reservoir tested and thus served to quantify soil degradation over time in a relatively simple and quick way using modern measurements.

The GNSS RTK Trimble R8s was very accurate, especially in freely accessible areas, but faced challenges in densely vegetated regions. The Echolot HDS LIVE 7 with Active Imaging 3-in-1 provided high-resolution imaging capabilities, but its accuracy was influenced by various environmental factors. The Mivardi Carp Scout bait boat, designed for fishing, showcased the integration of GPS and sonar technologies for efficient positional tracking and water depth measurement.

Through meticulous measurements and triangulated networks, the study created digital terrain models, that enabled a determination of reservoir volumes and sediment quantities. The comparison of the three methods showed that the cost-effective alternatives, the Echolot HDS LIVE 7, and the Mivardi Carp Scout, produced different results when compared to the more expensive GNSS RTK Trimble R8s. However, considering just the two cost-effective alternative measurement techniques demonstrates that they produced very similar results.

The evaluation of the measurement methods indicated that while the GNSS RTK Trimble R8s provides the highest accuracy and is unique in its measurement of the shoreside edges of the reservoir and the hard bottom, it comes with increased costs and logistical challenges. On the other hand, the Echolot HDS LIVE 7 and Mivardi Carp Scout provide efficient and cost-effective solutions, making them suitable for a quick estimate of sediment thickness.

The significant range of sedimentation values underscored the importance of choosing appropriate measurement methods based on the specific project requirements. The results suggested that cheaper and faster methods could offer a practical and efficient means of estimating sediment thickness, especially when the hard bottom depths are known and for deeper reservoirs.

As impacts of land degradation and subsequent sedimentation pose substantial challenges to reservoir management and affects ecology and hydrology, these findings contribute to the development of reliable mathematical models and water management strategies. The study conducted confirmed that the simplicity and accuracy of cheaper measurement techniques can be used to determine soil loss quickly and accurately by water erosion in the catchment upstream the reservoir. The study advocates for a pragmatic approach in the selection of measurement methods based on the unique characteristics and objectives of each project, ensuring both accuracy and cost-effectiveness. Overall, the research provides valuable insights into sediment measurement techniques, guiding future endeavors in reservoir management and environmental conservation, which is key to future environmental management strategies.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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