COMPARATIVE ANALYSIS FOR VOLUME ESTIMATION IN SMALL DAMS USING CONVENTIONAL BATHYMETRY AND REMOTE SENSING

ANÁLISE COMPARATIVA PARA ESTIMATIVA DE VOLUME EM PEQUENAS BARRAGENS POR BATIMETRIA CONVENCIONAL E SENSORIAMENTO REMOTO

ANÁLISIS COMPARATIVO PARA LA ESTIMACIÓN DE VOLUMEN EN PEQUEÑAS PRESAS UTILIZANDO BATIMETRÍA CONVENCIONAL Y TELEDETECCIÓN

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Abstract: The efficient management of water resources is a fundamental prerogative to guarantee water sustainability, especially in regions dependent on small dams to retain and dispose of water. These structures, important to water security, perform an essential role in diverse activities, from providing drinking water to supporting agriculture. Within the scope of water management, the precise determination of the volume of water retained in dams is a critical aspect, directly influencing decisions related to the sustainable use of these resources. This study aimed to carry out a comparative analysis between conventional bathymetry and remote sensing, aiming to evaluate their accuracy in determining the accumulated volume of water in small dams, with the aim of improving water management and allocating water resources efficiently for other activities. It was observed that both remote sensing methods II and III presented an overestimation of the volume accumulated in dams compared to conventional bathymetry. Method II demonstrated superior precision, with an error varying between 3.22% and 30.22%, which decreased as the area increased. On the other hand, method III presented an error ranging between 20.68% and 43.12%, following a similar pattern to that of method II in relation to the increase in area. It is concluded that remote sensing presents itself as a valid approach for estimating the water surface and accumulated volume, especially in small dams, being useful for preliminary and environmental studies in areas with low sediment deposition and no vegetation invasion, since conventional bathymetry often proves to be costly and logistical, especially in situations where access and size are challenging.
Keywords: Geoprocessing; Landsat; Google Earth Pro; Water management; QGIS.

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Resumo: A gestão eficiente de recursos hídricos é uma prerrogativa fundamental para garantir a sustentabilidade hídrica, especialmente em regiões dependentes de pequenas barragens para a retenção e destinação da água. Estas estruturas desempenham um papel essencial em diversas atividades, desde o fornecimento de água potável até o suporte à agricultura. No âmbito da gestão hídrica, a determinação precisa do volume de água retida em barragens é um aspecto crítico, influenciando diretamente nas decisões relacionadas ao uso racional desses recursos. Objetivou-se realizar uma análise comparativa entre a batimetria convencional e o sensoriamento remoto, visando avaliar sua precisão na determinação do volume acumulado de água em pequenas barragens, com o intuito de aprimorar a gestão hídrica e alocar os recursos hídricos de forma eficiente para outras atividades. Foi observado que tanto o método de sensoriamento remoto II quanto o III apresentaram uma superestimação do volume acumulado nas barragens em comparação com a batimetria convencional. O método II demonstrou uma precisão superior, com erro variando entre 3,22% e 30,22%, a qual diminuiu à medida que a área aumentou. Por outro lado, o método III apresentou erro variando entre 20,68% e 43,12%, seguindo um padrão semelhante ao do método II em relação ao aumento da área. Conclui-se que o sensoriamento remoto se apresenta como uma abordagem válida para a estimativa do espelho d'água e do volume acumulado, especialmente em pequenas barragens, sendo útil para estudos preliminares e ambientais em áreas com baixa deposição de sedimentos e sem invasão de vegetação, uma vez que a batimetria convencional frequentemente se mostra onerosa e logística, especialmente em situações em que o acesso e o tamanho são desafiadores.
Palavras-chave: Geoprocessamento; Landsat; Google Earth Pro; Gestão da água; QGIS.

Resumen: La gestión eficiente de los recursos hídricos es una prerrogativa fundamental para garantizar la sostenibilidad del agua, especialmente en regiones que dependen de pequeñas represas para retener y eliminar el agua. Estas estructuras desempeñan un papel esencial en diversas actividades, desde el suministro de agua potable hasta el apoyo a la agricultura. En el contexto de la gestión del agua, la determinación precisa del volumen de agua retenida en las presas es un aspecto crítico, que influye directamente en las decisiones relacionadas con el uso racional de estos recursos. El objetivo fue realizar un análisis comparativo entre batimetría convencional y teledetección, con el objetivo de evaluar su precisión en la determinación del volumen de agua acumulado en pequeñas presas, con el objetivo de mejorar la gestión del agua y asignar eficientemente los recursos hídricos para otras actividades. Se observó que ambos métodos de teledetección II y III presentaron una sobreestimación del volumen acumulado en las presas en comparación con la batimetría convencional. El método II demostró una precisión superior, con un error que varió entre 3,22% y 30,22%, que disminuyó a medida que aumentó el área. Por otro lado, el método III presentó un error que oscila entre 20,68% y 43,12%, siguiendo un patrón similar al del método II en relación al aumento de área. Se concluye que la teledetección se presenta como un enfoque válido para estimar la superficie del agua y el volumen acumulado, especialmente en presas pequeñas, siendo útil para estudios preliminares y ambientales en áreas con baja deposición de sedimentos y sin invasión de vegetación, como muchas veces lo demuestra la batimetría convencional. costoso y logístico, especialmente en situaciones donde el acceso y el tamaño son difíciles.
Palabras clave: Geoprocesamiento; Landsat; Google Earth Pro; Administracion del Agua; QGIS.

Introduction

The efficient management of water resources is a fundamental prerogative to guarantee sustainable development, especially in regions dependent on small dams to retain and dispose of water. These structures, important to water security, perform an essential role in diverse activities, from providing drinking water to supporting agriculture and energy generation. Within the scope of water management, the precise determination of the volume of water retained in dams is a critical aspect, directly influencing decisions related to the responsible use of these resources since, in regions where water availability is very variable during the year, these small dams are essential structures to make irrigation viable and, consequently, maintain the quality of life of people in rural areas (Rodrigues et al., 2012; Andrade et al., 2020; Marques et al., 2021).

Precision in measuring the volume retained in small dams not only informs responsible authorities about the current state of water resources but also guides conservation and distribution policies, helping to mitigate the impacts of droughts and floods, as well as promoting equitable allocation and efficient use of water between different sectors and users. In this context, advanced monitoring and remote sensing technologies play a crucial role, allowing a continuous and accurate assessment of water levels in dams, as well as the early detection of any anomalies or potential risks (Rodrigues et al., 2012; Andrade et al., 2020).

Furthermore, integrating Geographic Information Systems (GIS) and hydrological modeling enables more integrated and data-based management, facilitating informed decision-making and the implementation of climate change adaptation strategies. Ultimately, effective water resources management requires a holistic and collaborative approach, involving multiple stakeholders and adopting proactive measures to ensure the long-term sustainability of freshwater systems (Andrade et al., 2020; Marques et al., 2021; Andrade et al., 2022).

Conventional bathymetry, a well-established method for measuring water depth, is a valuable tool in this context. This technique, based on underwater topographic survey methods, offers high-precision results, essential for understanding the geometry of the dam bed and, consequently, the stored volume. This approach's rigorous application provides reliable data crucial for strategic decisions in water resources management (International Hydrographic Organization – IHO, 2005; Andrade et al., 2020).

On the other hand, remote sensing emerges as an innovative and promising tool for obtaining volumetric data in dams. Using satellite images and remote sensors enables a quick and comprehensive assessment, overcoming some logistical limitations of conventional bathymetry. The spatial and temporal resolution of these technologies provides a holistic view of water behavior, expanding monitoring possibilities at different temporal and spatial scales (Rodrigues et al., 2012; Ferreira et al., 2016; Ferreira et al., 2019; Andrade et al., 2020; Caballero et al., 2020; Mateo- Perez et al., 2020; Marques et al., 2021; Andrade et al., 2022).

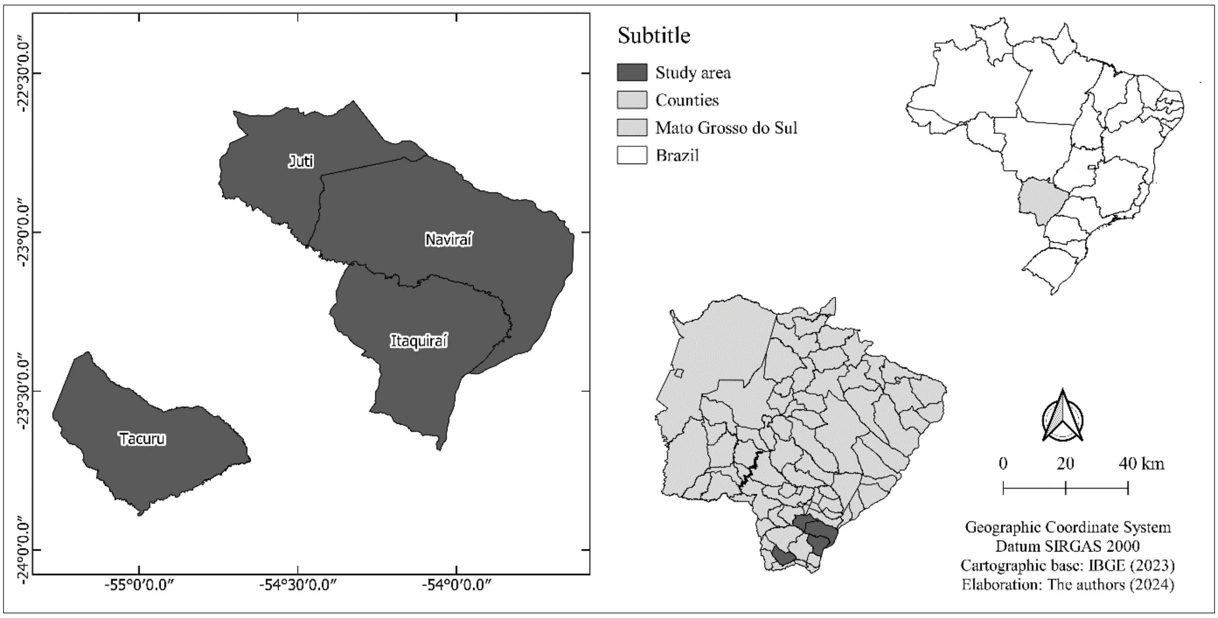
With the aim of providing valuable insights to water resource managers, hydrologists, environmental engineers, and policymakers, this report undertakes a comparative analysis between conventional bathymetry and remote sensing. The study evaluates the accuracy of these methods in determining the accumulated volume of water in small dams, a crucial factor in effective water resources management.

Material and methods

Characterization of the study área

The study was conducted on four rural properties in the municipalities of Itaquiraí, Juti, Naviraí, and Tacuru in the southern region of Mato Grosso do Sul. This region is characterized by its importance in Brazilian agribusiness, including agriculture and livestock. It is also recognized for its extensive hydrographic network, which houses a diversity of ecosystems associated with water resources (Figure 1).

Figure 1: Location of the study area



Source: The authors, 2024.

According to the Köppen classification, the climate is classified as Cfa, a humid subtropical climate with hot summers and mild winters, with rainfall well distributed throughout the year. Annual precipitation varies between 1,200 and 1,500 mm, with a rainy season between September and March and a dry period between April and August. The average temperature ranges from 15 to 35 °C, with evapotranspiration varying between 1,000 and 1,400 mm/year (Alvares et al., 2013; Beck et al., 2018).

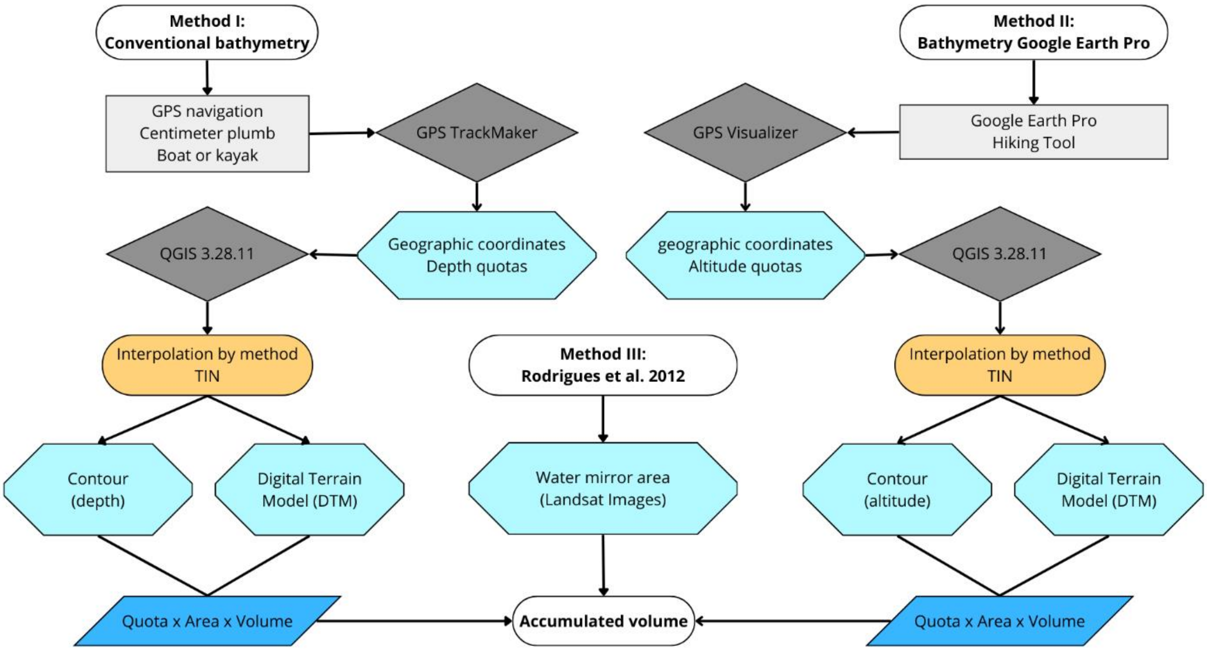
The region's relief is characterized by flood plains and lowlands, with highlands, test hills, steep walls, colluvial strips, wavy strips, hills, and floodplains. The presence of the Paraguay and Paraná rivers and their tributaries significantly influence the configuration of the relief, creating alluvial plains suitable for agriculture. About pedology, the soils of the southern region of Mato Grosso do Sul exhibit considerable diversity. Floodplains along rivers often have fertile soils rich in organic matter, suitable for agriculture. On the other hand, highland areas may have less fertile and more sandy soils, requiring specific management practices for sustainable agriculture (Lima et al., 2020; Pirajá et al., 2020; Lima & Silva, 2022; Capoane, 2023).

About the vegetation, the region is marked by a transition between the Cerrado and the Pantanal region. The Cerrado predominates in areas of highlands and gentle undulations, with its characteristic vegetation of low trees, shrubs, and grasses adapted to local conditions. As we approach the alluvial plains and areas close to rivers, we observe greater plant diversity influenced by the Pantanal biome, characterized by floodable areas, gallery vegetation, and rich biodiversity (Alves et al., 2018; Bueno et al., 2018).

Data acquisition and processing

The comparative analysis to estimate the accumulated volume in different hydraulic structures for the study area was carried out using data obtained in situ on the properties through conventional bathymetry (method I), by remote sensing with the extraction of altitude and geographic coordinates using the source of the altimetric base of the Shuttle Radar Topography Mission – SRTM (Nasa, 2024), from the National Aeronautics and Space Administration present in Google Earth Pro (method II) and by the equation proposed by Rodrigues et al. (2012) via remote sensing as a function of the dam's water surface (method III) according to the flowchart illustrated in Figure 2.

Figure 2: Methodological flowchart used to develop the study



Source: The authors, 2024.

For the data obtained by remote sensing, images from the Landsat8 satellite were used for the southern region of Mato Grosso do Sul, made available by the *United States Geological Survey* (USGS) in its Earth Explorer database and by the Google Earth Pro software. They were initially selected as satellite images in which it was possible to identify hydraulic structures without interference from clouds or with as little interference as possible. For this work, eight (8) images were considered to delimit the reservoir area on the computer visually and compared with data obtained in the field using GPS. With these data, using QGIS software version 3.28.11, the digital terrain model was generated through *Triangulated Irregular Network* (TIN) interpolation, the level curves (altitude and depth), and finally, each bus's areas and accumulated volume (CARMO et al., 2015).

The estimated volume of water accumulated depending on the area formed by the dam's water surface, calculated via remote sensing, was measured using Equation 1 proposed by Rodrigues et al. (2012). This equation was generated based on information from 42 small dams in the Rio Preto River basin, and its adjustment presented $R^2 = 0.83$.

$$V = 12{,}802 \cdot A^{1.1144} \quad (1)$$

Where,

V is the accumulated volume of water in the dam, cubic meters;
A is the area of the water surface in hectares.

Finally, for statistical treatment, a descriptive analysis of the data was carried out in Python using the Google Colab IDE, and to evaluate the conformity of the samples with a statistical probability distribution, the Shapiro-Wilk non-parametric hypothesis tests were applied. (1965), Anderson-Darling (1954), and Jarque-Bera (1987).

Results and discussion

Table 1 shows the estimated storage capacity for each hydraulic structure following the three methods proposed in the methodology. For each property studied, the water mirror areas of the dams vary between 0.26 and 9.85 hectares, values obtained through visual delimitation using Landsat8 images and field surveys with GPS. In general, the variation in area between both methods presented very close values (±0.5 to 1%) and did not indicate significant statistical variation.

Comparison of the estimated water volumes for properties X, Y, W, and Z, obtained through different assessment methods, reveals significant discrepancies between the results. When analyzing the data, it is observed that the volumes estimated in situ, using Google Earth Pro and as described by Rodrigues et al. (2012), present considerable variations for each property. This divergence in results can be attributed to different measurement and modeling methods used in each approach, as well as variations in the accuracy and representativeness of the data. Furthermore, the magnitude of the discrepancies increases proportionally to the area of the property, as evidenced by property Z, which has a significantly larger area and presents the largest differences between the volumes estimated by the different methods.

Table 1: Water storage capacity of the hydraulic structures studied

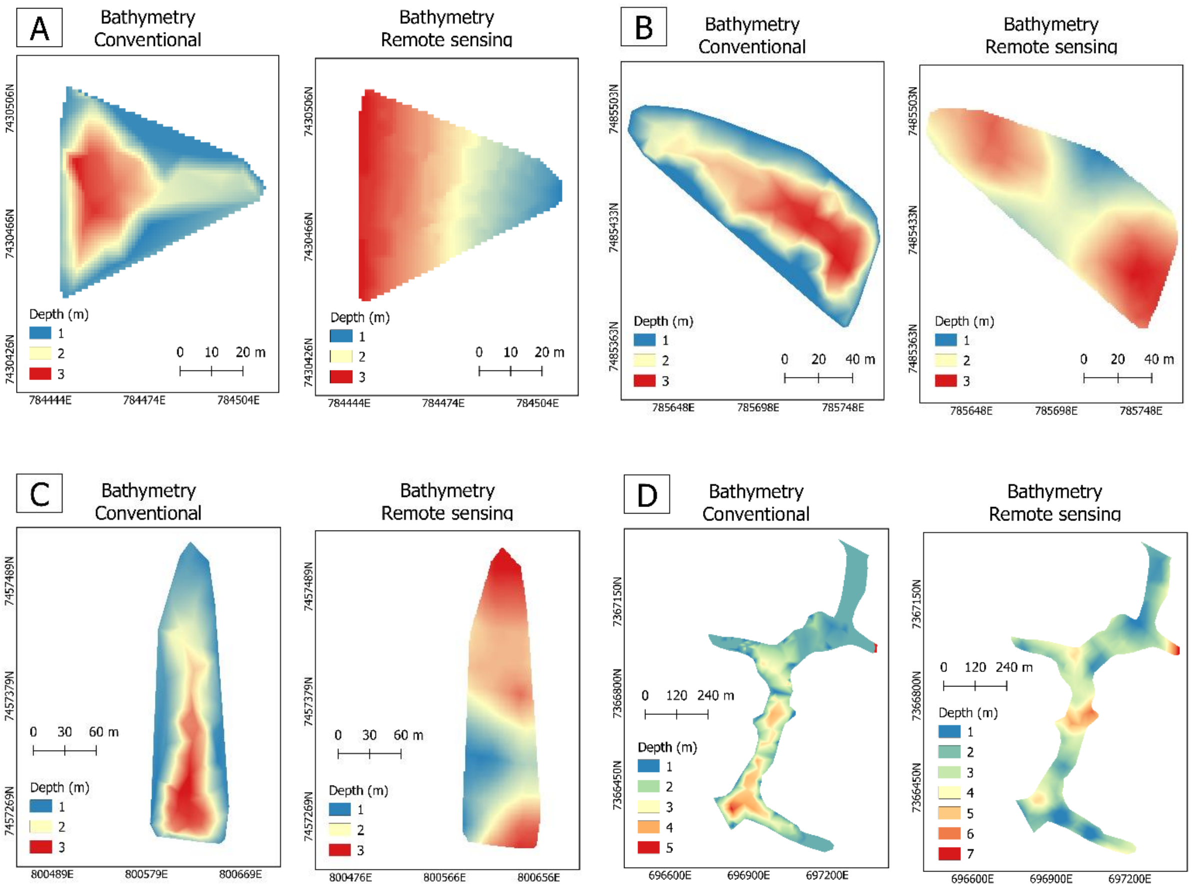
Property	Area (ha)	Volume (m^3) In loco	Volume (m^3) Google Earth Pro	Volume (m^3) Rodrigues et al. 2012
X	0.26	1,623.01	2,325.93	2,853.15
Y	0.73	5,833.97	6,160.54	9,014.98
W	1.09	9,895.86	10,235.09	14,092.43
Z	9.85	129,945.26	134,269.14	163,818.58

Source: The authors, 2024.

It is observed that the stored volume values for each dam show a direct behavior about the area of the water surface, a result already expected due to the traditional behavior of the area x volume relationship. Regarding the estimation of the accumulated volume, all methods showed similar behavior; however, there was an overestimation of the volume by method II, and especially by method III, compared to method I. On the other hand, the estimation of the accumulated volume by methods I and II, based on the area x elevation x volume calculation, presented values closer to those than method III, which depends exclusively on the area of the water surface.

Figure 3 shows the spatial distribution of each reservoir's depths obtained by methods I and II. The dams on properties estimated a maximum depth of 7 meters, indicating possible errors in the estimate in deep reservoirs.

Figure 3: Comparison between Digital Depth Models obtained by methods I and II (a) dam X, (b) dam Y, (c) dam W and (d) dam Z



Source: The authors, 2024.

Figure 3 reveals significant differences in the behavior of depth curves between method I and method II. Based on real conditions, Method I exhibits a tendency for greater accumulation near the dam slope, indicating a more concentrated distribution. In contrast, method II estimates the curves with a more dispersed behavior, suggesting a less cohesive data distribution, possibly due to the altimetry data's average altitude error of five to ten meters. These disparities underscore the crucial need for meticulous evaluation, particularly in studies of small dam structures' hydraulic and geotechnical behavior.

Several authors have lauded remote sensing as a low-cost and time-efficient procedure for its applicability in bathymetry. Andrade et al. (2020) exemplify this with their bathymetry methodology, which utilizes RPA (Unmanned Aerial Vehicles, or drones) and NDWI (Modified Normalized Water Index) data. Their study demonstrates the validity of this approach for shallow regions, comparing the data with depth values obtained by a single-beam echo sounder equipped with a dual-frequency transducer.

Khomsin et al. (2021) compared single-beam and multi-beam echo sounders, revealing a vertical difference of 0.018m between the two types. The single-beam echo sounder sampled lower depths and volumes than the multi-beam, with a lower point density. However, the results were deemed satisfactory, underscoring the suitability of the survey method depending on the objective.

In turn, Julian and Nunes (2020) used tools available in QGIS to analyze bathymetry. Their results suggest that using single-beam equipment with free software such as QGIS can be a adequate alternative for obtaining reliable data without requiring the executor to be susceptible to risk, as in conventional onboard bathymetry.

Marques et al. (2021) compared a single-beam echo sounder and geometric measurements of a swimming pool. They found that the difference between the volume obtained by interpolating single beam echo sounder data in QGIS and the calculation using geometric values was 1.30%. They concluded that granting water resources and preliminary assessments of projects can be considered appropriate.

According to the International Hydrographic Organization – IHO (2005), the conventional bathymetric survey is the most suitable Method for estimating accumulation capacity as it considers real field conditions. From Table 2, it is possible to observe that Method II presented the lowest percentage error in estimation and greater precision compared to Method III. This behavior can be attributed to the estimation process adopted by Method II, which is similar to conventional bathymetry, and Method III, which was paired with edaphoclimatic conditions in the Rio Preto River basin region.

Furthermore, it was found that, as the water surface area of the dams increased, the percentage of errors decreased. This pattern suggests an inverse relationship between the percentage error and the size of the water area, indicating that estimates tend to become more precise as the sampling area increases. It may also be associated with water structures' more significant siltation process in smaller dams, resulting from the absence of sediment removal devices, structural simplicity, and dilution of errors about the accumulated volume.

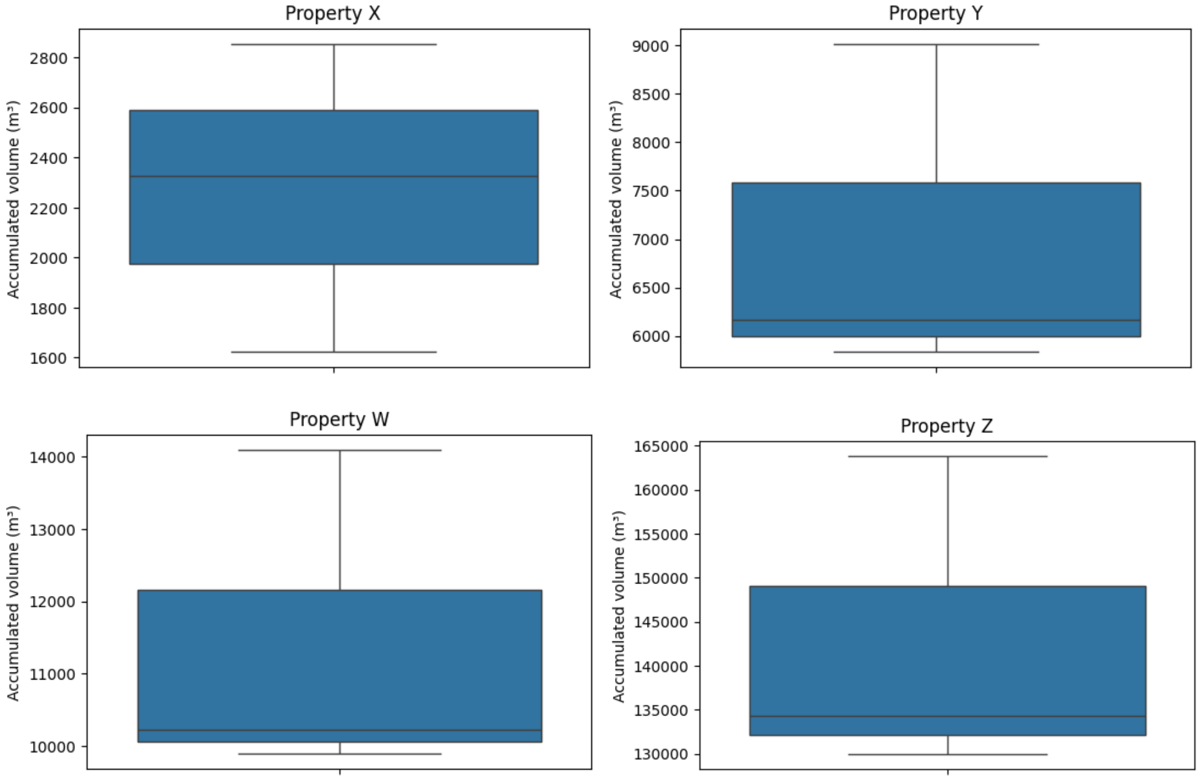
Table 2: Descriptive analysis of accumulated volumes in dams

Property	Standard deviation	Percent error (I/II)	Percent error (I/III)
X	617.16	30.22%	43.12%
Y	1,749.92	5.30%	35.29%
W	2,331.14	3.31%	29.78%
Z	18,435.78	3.22%	20.68%

Source: The authors, 2024.

On the other hand, Table 2 and Figure 4 show that, concomitantly, with the decrease in the percentage error, the standard deviations increased, suggesting a greater dispersion of the data around the estimates as the water mirror area increases. This is represented by increases in the lengths of the boxplots. Although estimates become more accurate in percentage terms, data variability also increases, which can be crucial when considering measurement accuracy in different application contexts.

Figure 4: Boxplot graphs of the accumulated volume of dams



Source: The authors, 2024.

Table 3 presents the results of the parametric normality tests applied to the data evaluated in this study. For property X, the Shapiro-Wilk and Jarque-Bera tests produced p-values of 0.8429 and 0.8624, respectively, suggesting possible conformity with a normal distribution. However, the Anderson-Darling test, with a test statistic of 0.1970, did not reveal significant evidence against the normality of the data. In contrast, for property Y, the Shapiro-Wilk test indicated a p-value of 0.1178, suggesting a possible violation of normality. However, the Anderson-Darling test displayed a test statistic of 0.3924, still indicating possible conformity with normality. Likewise, the Jarque-Bera test did not provide substantial evidence against normality (p-value of 0.7741).

Table 3 – Normality tests for the different volumes stored in each structure

Property	Shapiro-Wilk	Anderson-Darling	Jarque-Bera
X	0.8429	0.1970	0.8624
Y	0.1178	0.3924	0.7741
W	0.1391	0.4119	0.7712
Z	0.2245	0.3706	0.7782

Source: The authors, 2024.

It is observed that for the W property, the Shapiro-Wilk test revealed a p-value of 0.1391, indicating a possible non-normality; however, both the Anderson-Darling test (0.4119) and the Jarque-Bera test (0.7712) did not provide concrete evidence against normality. Similarly, for the Z property, the Shapiro-Wilk test resulted in a p-value of 0.2245, indicating a possible lack of normality, but the Anderson-Darling (0.3706) and Jarque-Bera (0. 7782) did not provide conclusive evidence against normality. These results suggest that the variables X, Y, W, and Z have signs of conformity with a normal distribution, therefore justifying the application of parametric methods in subsequent studies.

Therefore, when considering the practical application of volume estimates in small dams, it becomes essential to evaluate the accuracy of the estimated values and the variability of the data obtained. This variability can have significant implications for planning, management, and decision-making across various sectors, particularly in the sustainable management of water resources. Such evaluation is fundamental for agricultural irrigation planning, monitoring the availability of potable water, and preventing natural disasters such as floods and droughts.

In the agricultural context, bathymetry enables optimized management of essential water resources for irrigation by providing precise data on the volume of water available in reservoirs. This precision allows for the adequate planning of crops and the implementation of more efficient irrigation systems, resulting in the maximization of agricultural productivity by adjusting the planting and harvesting schedule according to the available water capacity.

Regarding water supply, bathymetry plays a fundamental role in monitoring and maintaining reservoirs by identifying sediment accumulations and ensuring maximum storage capacity. This aspect is essential for planning the expansion of supply infrastructure, ensuring that future demands are effectively met. Additionally, bathymetric data allows for the correlation of volume and depth with water quality, enabling the implementation of preventive measures against contamination and promoting public health.

In water management, bathymetry substantially contributes to flood prevention by modeling and predicting flood behaviors, and to efficient management during drought periods by providing detailed information that allows for informed decisions on water rationing and distribution. Moreover, this method facilitates the planning of multiple uses of reservoirs, sustainably balancing recreational activities, fishing, and environmental conservation.

In this context, the more accurate estimates provided by the remote sensing method II can be especially valuable as they allow for a more reliable assessment of the monitoring and maintenance needs of dams. This improved accuracy translates into more efficient and sustainable water resource management, meeting sectoral demands effectively and mitigating risks associated with hydrological variability and extreme events.

Final Considerations

Conventional bathymetric surveying represents the most accurate and comprehensive approach for the detailed characterization of submerged relief, as it represents real field conditions. Studies that require high precision, accompanied by detailed data, must be conducted with rigorous field control using this described methodology.

The application of remote sensing techniques emerges as an economically advantageous procedure, characterized by a reduced execution time, for determining the water mirror area and accumulated water volume, highlighting the improved precision of method II, which is similar to the conventional bathymetry process and because it was estimated using the same interpolation method. On the other hand, caution is required when using this tool since, for greater precision and reliability, more studies are needed in different areas or reservoirs with different characteristics to validate its applicability.

However, it is concluded that remote sensing presents itself as a valid approach for estimating the water surface and accumulated volume, especially in small reservoirs that have accumulated volumes and shallower depths, being useful for preliminary and environmental studies in areas with low sediment deposition and no vegetation invasion, since conventional bathymetry often proves to be costly and logistical, especially in situations where access and size are challenging.

References

ALVARES, C. A., STAPE, J. L., SENTELHAS, P. C., GONÇALVES, J. D. M., SPAROVEK, G. Köppen's climate classification map for Brazil. **Meteorologische zeitschrift**, v. 22, n. 6, p. 711-728, 2013.

ALVES, F. M., LEHNI, C. R., DAMASCENO-JÚNIOR, G. A., SARTORI, A. L. B., POTT, A., POTTI, V. J., BORTOLOTTO, I. M., ISHII, I. H., SALIS, S. M., URBANETZ, C., BUENO, M. L., SCIAMARELLI, A. Coleções Botânicas do estado de Mato Grosso do Sul: situação atual e perspectivas. **Iheringia, Série Botânica**., [S. l.], v. 73, p. 93–100, 2018. DOI: 10.21826/2446-8231201873s93.

ANDERSON, T. W., DARLING, D. A. A test of goodness of fit. **Journal of the American Statistical Association**, 49, 765–769, 1954.

ANDRADE, L. C. D., FERREIRA, I. O., GIBRIM, V. T., SANTOS, F. C. M. On the use of artificial neural networks in remotely piloted aircraft acquired images for estimating reservoir's bathymetry. **Boletim de Ciências Geodésicas**, *28*, e2022006, 2022.

ANDRADE, L. C., FERREIRA, I. O., MEDEIROS, N. G., FONSECA, I. G. R. Viabilidade de uso de imagens de RPA's para extração da batimetria em reservatórios de água rasos. **Editora Unesc.** DOI http://dx.doi.org/10.18616/geop06. p. 165-175, 2020.

BECK, H. E., ZIMMERMANN, N. E., MCVICAR, T. R., VERGOPOLAN, N., BERG, A., WOOD, E. F. Present and future Köppen-Geiger climate classification maps at 1-km resolution. **Scientific data**, v. 5, n. 1, p. 1-12, 2018.

BUENO, M. L., DE OLIVEIRA-FILHO, A. T., PANTARA, V., POTT, A., DAMASCENO-JUNIOR, G. A. Flora arbórea do Cerrado de Mato Grosso do Sul. **Iheringia, Série Botânica**., [S. l.], v. 73, p. 53–64, 2018. DOI: 10.21826/2446-8231201873s53.

CABALLERO, I., STUMPF, R. P. Towards Routine Mapping of Shallow Bathymetry in Environments with Variable Turbidity: Contribution of Sentinel-2A/B Satellites Mission. **Remote Sensing**. 1-5, 2020.

CAPOANE, V. Classificação automatizada do relevo da bacia hidrográfica do Córrego Lajeado, Campo Grande, Mato Grosso do Sul. **Boletim de Geografia**, v. 41, 2023.

CARMO, E. J.; RODRIGUES, D. D.; SANTOS, G. R. dos. Avaliação dos interpoladores Krigagem e Topo to Raster para geração de modelos digitais de elevação a partir de um "as built". **Boletim de Ciências Geodésicas**, Curitiba, v. 21, n. 4, p. 674-690, 2015.

FERREIRA, I. O.; EMILIANO, P. C.; SANTOS, A. de P. dos; MEDEIROS, N. das G.; OLIVEIRA, J. C. de. Proposição de um Estimador Pontual para Incerteza Vertical de Levantamentos Hidrográficos. **Revista Brasileira de Cartografia**, v. 71, n. 1, p. 1-30, 2019.

GEOFRONTER
https://periodicosonline.uems.br/index.php/GEOF

FERREIRA, I. O.; NETO, A. A.; MONTEIRO, C. S. O uso de embarcações não tripuladas em levantamentos batimétricos. **Revista Brasileira de Cartografia**, Rio de Janeiro, v. 68, n. 10, p. 1885-1903, 2016.

JARQUE, C. M., BERA, A. K. A Test for Normality of Observations and Regression Residuals. **International Statistical Review**, 55, 163-172, 1987.

JULIAN, C., NUNES, J. O. R. Uso de VANT e geoprocessamento para cálculo de solo erodido em voçoroca localizada no distrito de Amadeu Amaral, Marília/SP –Brasil. **Revista Brasileira de Geomorfologia** 21, 4, 1-11, 2020.

KHOMSIN, PRATOMO, D. G., SAPUTRO I. Comparative analysis of singlebeam and multibeam echosounder bathymetric data. In: **IOP Conference Series: Materials Science and Engineering**. IOP Publishing, 2021. p. 012015.

LANDSAT 8 OLI. U.S.G.S. **Department of the Interior U.S. Geological Survey**. Available in: <https://earthexplorer.usgs.gov/>. Access in: fevereiro de 2024.

LIMA, B. D. S., SILVA, C. A. D. As paisagens e as potencialidades de turismo de natureza da feição central da Serra Maracaju, Mato Grosso do Sul, Brasil. **Revista Geográfica de América Central**, n. 69, p. 313-334, 2022.

LIMA, B. D. S., SILVA, C. A. D., BOIN, M. N., MEDEIROS, R. B. As paisagens e as dinâmicas territoriais na Serra de Maracaju, Mato Grosso do Sul, Brasil. **Cuadernos de Geografía: Revista Colombiana de Geografía**, v. 29, n. 1, p. 224-241, 2020.

MARQUES, G. M., PESSI, D. D., HAUPENTHAL, M. R., RODRIGUES, M. G. Estimativa de volume de reservatório de água com software livre através de dados obtidos com embarcação remotamente pilotada. **Revista Brasileira de Geografia Física**, 14 (7), 3804-3813, 2021.

MATEO-PEREZ, V., CORREAL-BOBADILLA, M., ORTEGA-FERNÁNDEZ, F., VERGARA-GONZÁLEZ, E. P. Port Bathymetry Mapping Using Support Vector Machine Technique and Sentinel-2 Satellite Imagery. **Remote sensing**, 1-5, 2020.

MATO GROSSO DO SUL, SEMAC/IMASUL. Secretaria de Estado de Meio Ambiente, do Planejamento, da Ciência e Tecnologia/Instituto de Meio Ambiente de Mato Grosso do Sul. **Plano estadual de recursos hídricos de Mato Grosso do Sul -PERH-MS**. Campo Grande: Editora UEMS, 2010. 194p.

NASA - National Aeronautics and Space Administration - **Shuttle Radar Topographic Mission**. 2003. Available in: <http://www-radar.jpl.nasa.gov/srtm>. Access in: fevereiro de 2024.

PIRAJÁ, R. V., PARANHOS FILHO, A. C., SILVA, M. H. S. da. Taxonomia do relevo do estado de Mato Grosso do Sul e da bacia hidrográfica do rio Taboco. **Geofronter**, [S. l.], v. 6, n. 1, 2020.

QGIS Development Team. **QGIS versão 3.16.15 Hannover**, 2021. Available in: <https://www.qgis.org/en/site/forusers/download.html>. Access in: fevereiro de 2024.

RODRIGUES, L. N., SANO E. E., STEENHUIS, T. S., PASSO, D. P. Estimation of small reservoir storage capacities with remote sensing in the Brazilian Savannah Region. **Water resources management**, v. 26, p. 873-882, 2012.

SHAPIRO, S. S., WILK, M. B. An Analysis of Variance Test for Normality. **Biometrika**, 52, 591-611, 1965.

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