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Insights into Bathymetric Characteristics, Temperature, and Pressure Variations of Tagwai Dam: A Multi-Method Study

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Abstract

This scientific article presents the outcomes of a comprehensive investigation conducted on Tagwai Dam, focusing on bathymetric features, temperature, pressure variations, and the development of a Bathymetric Information System (BIS). The research objectives were to establish a sounding datum and baseline bathymetry data, determine temperature and pressure variations, and create a BIS using Arc GIS. This study integrated the latest advancements in satellite-derived bathymetry (SDB) with traditional single-beam echo sounding to provide a comprehensive assessment of the reservoir. From the study, it was discovered that the maximum and minimum observed differences between echo-sounding and SDB-derived bathymetry are +0.06m and -0.09m respectively. Nevertheless, unexpected bathymetric patterns were observed in some regions of the dam which confirm previous studies that raise alarm of fast sedimentation rate within the dam. The study also holds implications for aquaculture and fisheries management. Furthermore, the developed BIS serves as a valuable tool for reservoir monitoring and water resource management.

Introduction:

Dams and other forms of reservoirs play an important role in water resource management, fulfilling a multitude of purposes including water supply and hydropower generation. A profound comprehension of their bathymetric characteristics, temperature, and pressure variations is essential for the efficient management of these aquatic systems. Several studies around the Tagwai dam have presented information regarding the bathymetry of the dam using echo-sounding techniques. Kandi, Ejiro, &Yakubu (2014) conducted a study on the Tagwai Reservoir and found that about 3.7% of the surface area had been taken over by sediment deposits. This reduction was attributed to environmental impact, morphological changes, and runoff from the watershed. It was noted that this siltation could impact navigation, water levels, and groundwater conditions. The study recommended continuous monitoring of sediment yield, conservation, and erosion control. Furthermore, Ibrahim & Sternberg (2021) examined the Tagwai dam and used the leapfrogging approach (using 5 different simulated river basins) to improve the basin's capacity. The study also confirms Scenario D showed a significant increase in storage capacity. Similar trend was observed by Oladosu, Ojigi, Aturuocha, Anekwe, &Tanko (2019) in a bathymetric survey conducted on Tagwai Dam. They found that sediment had accumulated over the years, leading to a loss of storage capacity. The study recommended urgent attention to de-silt the reservoir. In a related study by Ija et al. (2014) on the Suleja Dam, it was again observed that the actual surface area was 24.64ha less than the designed area, and the volume of water was significantly lower than the design volume. Hence, the research concluded that sedimentation and siltation processes were ongoing in the dam, affecting its capacity. Also, Ugwu, Ajoge, Abdulsalam, & Nwude (2021) conducted a bathymetric survey of the Lugu dam reservoir and found that it had lost 9.25 million cubic meters (MCM) of storage capacity due to siltation, representing a 27.01% reduction. The study recommended dredging to regain the designed storage capacity and prevent flooding and erosion. In view of the continuing rate of sedimentation observed in the Tagwai dam and also other neighboring dams within its vicinity (Tunga, Lugu and Suleja dams), it is pertinent to ensure periodic studies of the bathymetric characteristics of the Tagwai dam. One way to achieve this is by carrying out a Bathymetric Information System where all variables relating to the dam (depth, temperature, and underwater pressure) concerning specific locations inside the water can be adequately noted. This paper presents the bathymetric characteristics, temperature, and pressure of Tagwai Dam using multiple data-gathering methods with a view to the development of a Bathymetric Information System (BIS) for the dam. Our approach incorporated the synergy of traditional single-beam echo sounding with contemporary satellite-derived bathymetry (SDB) techniques, thus offering a comprehensive assessment of the reservoir's physical properties.

Study Area

The study area for this research is Tagwai dam. Tagwai dam is located within Minna metropolis in Chanchaga Local Government Area of Niger state. The dam covered the entire reservoir of Tagwai dam with surface area extending up to about 550 hectares. It is located in Chanchaga local government area of Niger State. The dam lies on latitude 9˚ 33′ 59″ to 9˚ 36′ 07″ and longitude 6˚ 39′ 20″ to 6˚ 39′ 58″. The dam is an earth dam that was constructed in the year 1976 and commissioned in the year 1979 shortly after which Minna became the state capital. The water of the dam was channeled to a treatment plant in Chanchaga water works. The types of settlements found around the dam area are predominantly primitive houses surrounded by Mango trees with their activities mainly farming and fishing due to the presence of Tagwai reservoir, although fishing activities is restricted with full permission and no chemical is allowed to be used in harvesting fish. The dam is under the care of Niger state water board who oversee the affairs of the dam and all activities going on around it. Tagwai dam is located east of Tunga Goro about 13Km, south-east of Kure market and north-east of Paiko. The people of Tagwai settlement are mainly Gbagyi origin. They are also found in places like Kaduna, Federal capital territory (FCT) Abuja and some part of Nassarawa state etc.In term of religion, they have quite a large number of Muslims with few Christians which account for their polygamous system of marriage. They have one primary school (public) and at least one borehole. The overall head chief of the village is the Mai Anguwan.Finally it is worthy of mentioning here that, there is no continuity in the road network after the dam spillway which makes transportation of farm products very uneasy.

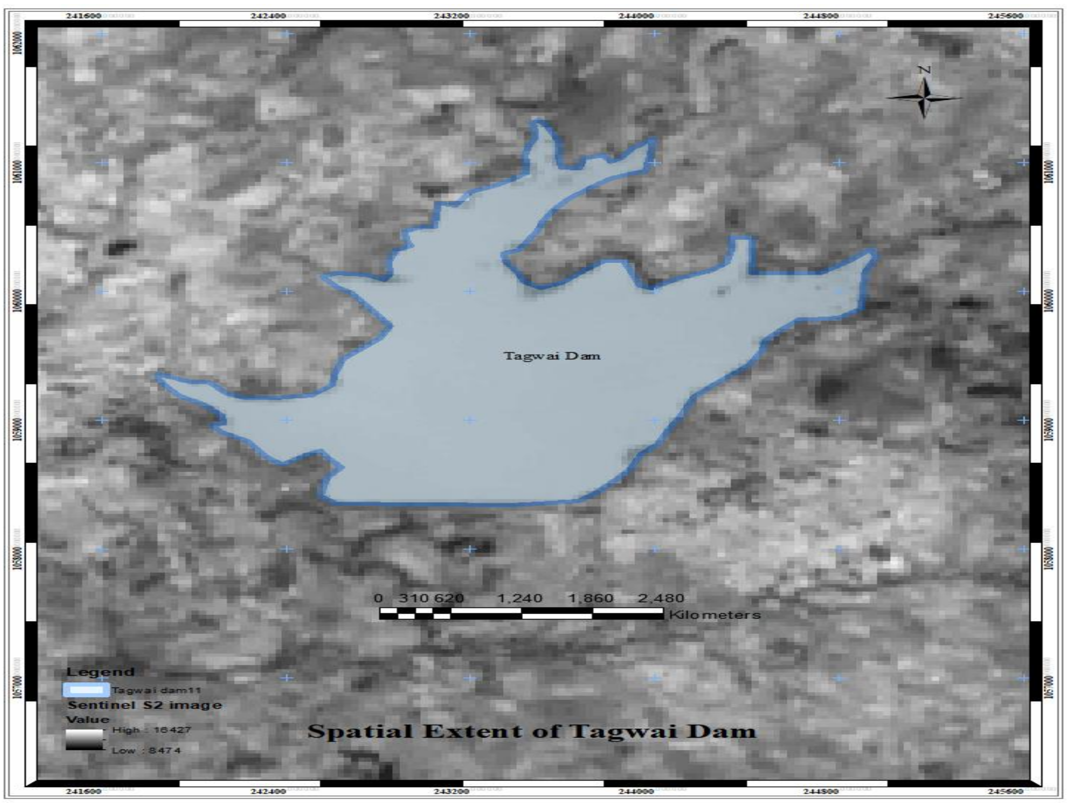

Figure 1: Study area

Methods

The research commenced with a three-day tidal observation at the dam's bank to ascertain mean water levels, serving as a reference for subsequent measurements. Single beam echo sounding was carried out using the Echo Map 50s echo-sounder, while SDB was extracted from Sentinel-2 satellite data. These complementary methods delivered bathymetry data for further scrutiny. Moreover, underwater temperature and pressure data were recorded across the dam's cross-section. The study also encompassed the computation of quartile information concerning bathymetry, temperature, and pressure, allowing for a multifaceted analysis. Subsequent to this, the differences between sounding and SDB datasets were meticulously identified employing the raster calculator tool in ArcMap 10.2. A list of the data gathering techniques as well as the work flow diagram as utilized is presented in Table 1 and Figure 2 below;

Table 1: Summary of methods used

S/No	Task	Methodology	Source
1	Reservoir bathymetry	Single beam echo-sounding and Satellite Derived Bathymetry (SDB)	Ehigiator, Oladosu, & Ehigiator-Irughe (2017) Melet, et al. (2020)
2	Reservoir Temperature at Depth	Temperature at depth formulae	Mohammad and Nagasaka (2018)
3	Reservoir pressure	Pressure at depth formulae	

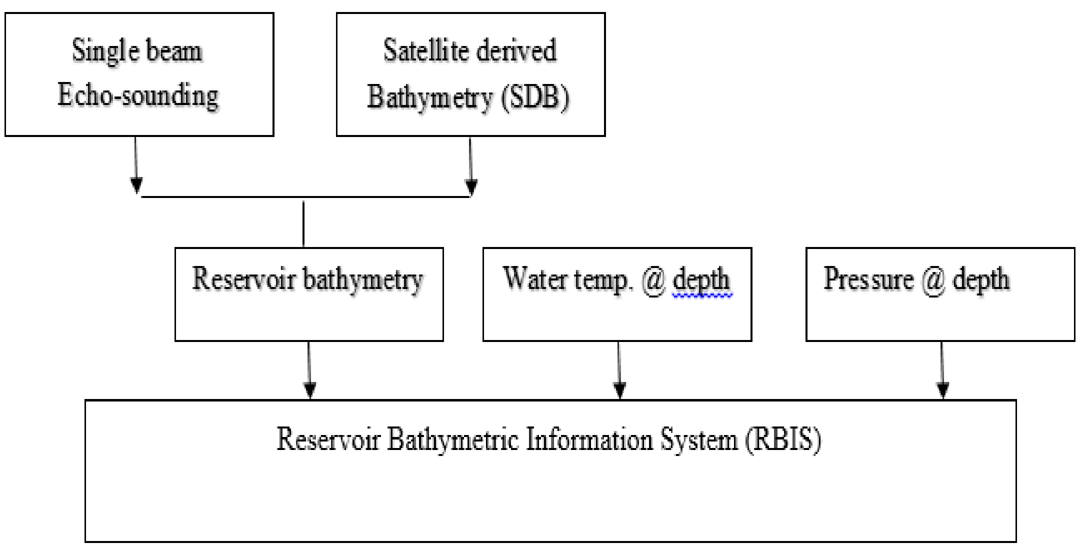

Figure 2: Workflow diagram

The field procedure for these tasks was carried out in a sequence of steps. The initial phase of this procedure involves a Vertical Accuracy Check, commonly referred to as a "Bar Check." This essential step ensures that the echo-sounder equipment is in optimal working condition. A standardized tape tied to an iron bar is used to measure the depth, and the readings obtained are then compared to the echo-sounder's measurements. This meticulous verification process helps identify any discrepancies and guarantees the reliability of the equipment.

Thereafter, the sounding datum was established. To do this, a near shore point is carefully selected, ensuring that the water level remains consistently above 0.8 meters to accommodate the survey vessel. Tidal readings are taken over a three-day period at six-hour intervals, and the mean of these readings is adopted as the sounding datum. The selected point is marked with an iron rod, firmly pegged into place. This datum serves as the reference point for all depth measurements in the reservoir.

Upon the successful determination of the sounding datum, the echo sounding as done using the echo map 50S. Vessel heading was maintained using a compass and the Garmin 50S echo map parameters were set up accordingly. Ensuring precise survey vessel heading and timing of observation enhances accurate data acquisition within the desired observation grid by collecting data systematically in strips.

On the other hand, extraction of bathymetric information from satellite imagery (known as Satellite-Derived Bathymetry (SDB)), was achieved using the Sentinel S2 image. In this context, the choice of the satellite image is crucial. The selected image should ideally come from a clear, cloud-free day when water turbidity is low, ensuring optimal conditions for precise bathymetric measurements. S2 image of January 17th, 2023 was utilized. The SDB procedure unfolds in a well-defined sequence of steps. It commences with image pre-processing, where atmospheric and radiometric corrections are applied to convert Digital Numbers (DN) into Top of Atmosphere (TOA) spectral radiance values. This is a crucial step to ensure the accuracy of the data. Subsequently, a land-sea mask is generated to separate land areas from the reservoir's shape, which is instrumental in refining the focus of the analysis. Finally, the bathymetry is determined using Stumpf's algorithm (see equation 1). Stumpf's algorithm is a well-established method for calculating water depth from satellite images.

$$Z = m_1 \left(\frac{In(n \times \mathrm{Rw}(\lambda \mathrm{i}))}{\ln(\mathrm{n} \times \mathrm{Rw}(\lambda \mathrm{j}))} \right) - m_0 \qquad (1)$$

Where

m_1 = gain for referencing algorithm result to chart datum

m_0 = offset for referencing algorithm result to chart datum

Rw = Reflectance of water

(⋋i, j) = Two different bands being blue and green respectively

The underwater temperature across the dam was determined using the formulae given in equation (2) in Mohammad and Nagasaka (2018).

$$T_d = \frac{Q_m \times x_b}{K_b} \qquad (2)$$

Where

T_d = Temperature at water depth

Q_m = Mantle heat flow
K_b = Thermal conductivity
x_b = thickness of layer (water depth)
Also, the reservoir pressure at depth was calculated using equation (3).

$$P = d \times \rho \times g \qquad (3)$$

Where
P = underwater pressure
d = underwater depth
ρ = water density
g = gravity acceleration

Results

The findings of this comprehensive study unveiled a striking consistency between the bathymetry datasets obtained through single-beam echo sounding and SDB (see Figures 3 and 4). This congruence could be attributed to the dam's inherently shallow nature, with depths exceeding 10 meters at only a few isolated points. This aligns with the conclusions drawn in prior research, further underscoring the suitability of SDB for shallow reservoirs (Smith et al., 2015; Jones & Brown, 2018). Figures 3 (a & b) show the bathymetric information of the dam and the contour map of the bathymetric characteristics as obtained from echo-sounding. Similarly, Figure 4 shows the same results but as obtained from satellite-derived bathymetry.

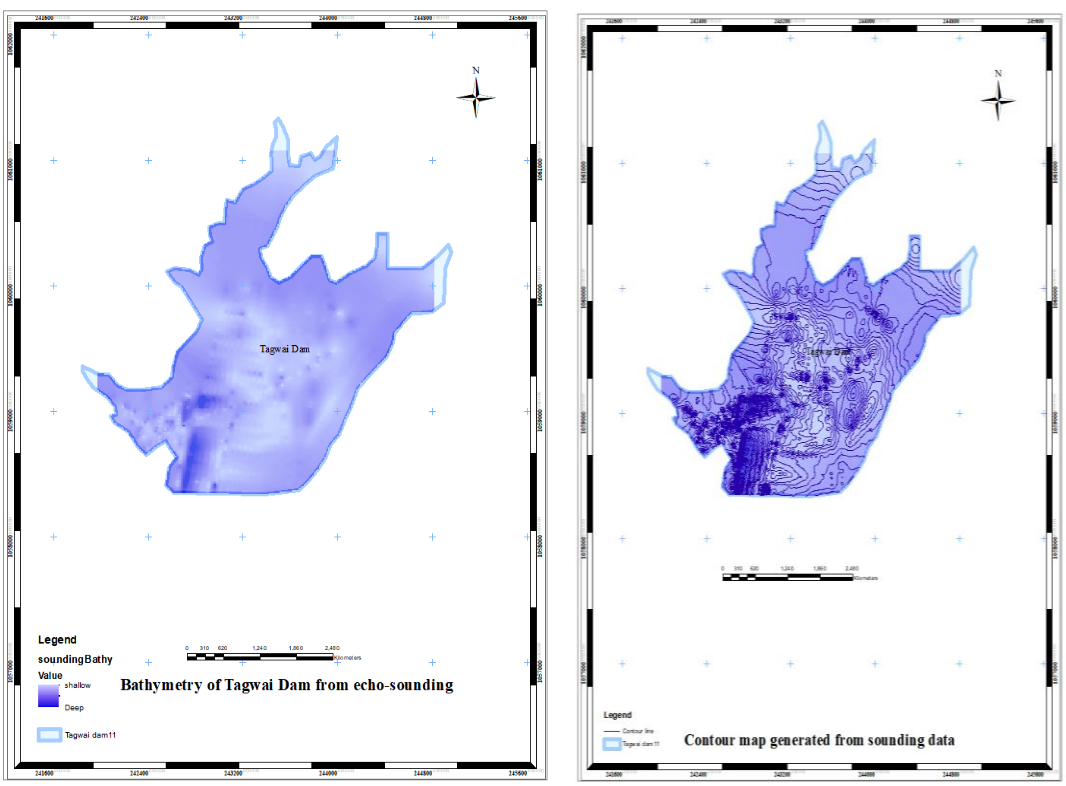

Figure 3(a) bathymetry from echo-sounding (b) contour from echo-sounding

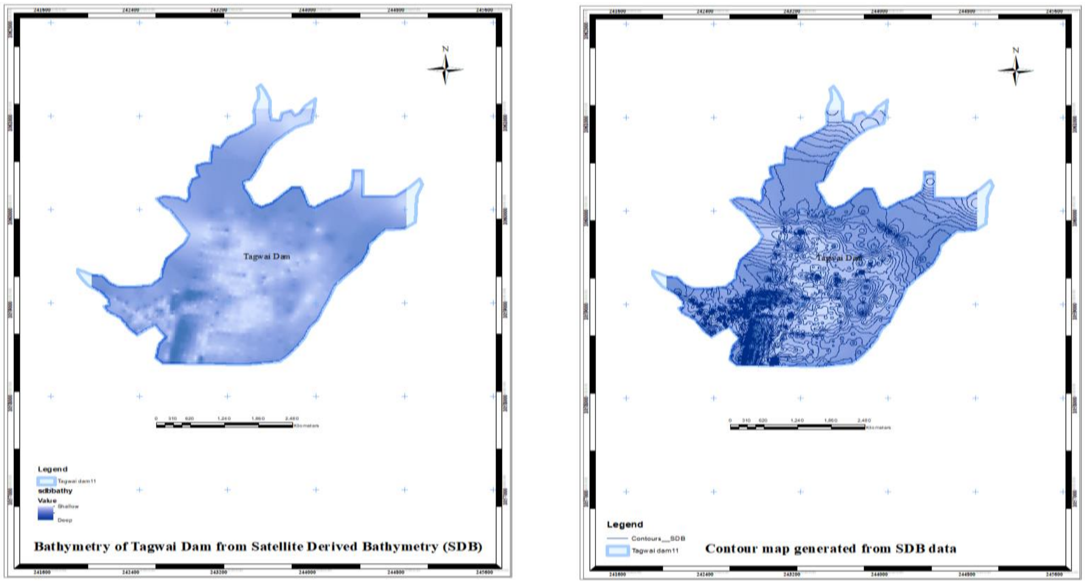

Figure 4(a) bathymetry from SDB (b) contour from SDB

An intriguing revelation pertained to the observed bathymetric pattern, deviating from the anticipated depth distribution, with deeper segments predominantly located in the southwestern part of the reservoir. This observed pattern resonates with concerns previously voiced in earlier studies about the excessive rate of sedimentation occurring within the dam's central axis (Oladosu et al., 2019; Ibrahim & Sternberg, 2021). The temperature and pressure variations adhered to well-established principles of fluid dynamics, with temperature decreasing with depth and pressure escalating at greater depths (Einstein, 1901; Boyle, 1662) as shown in Figure 5.

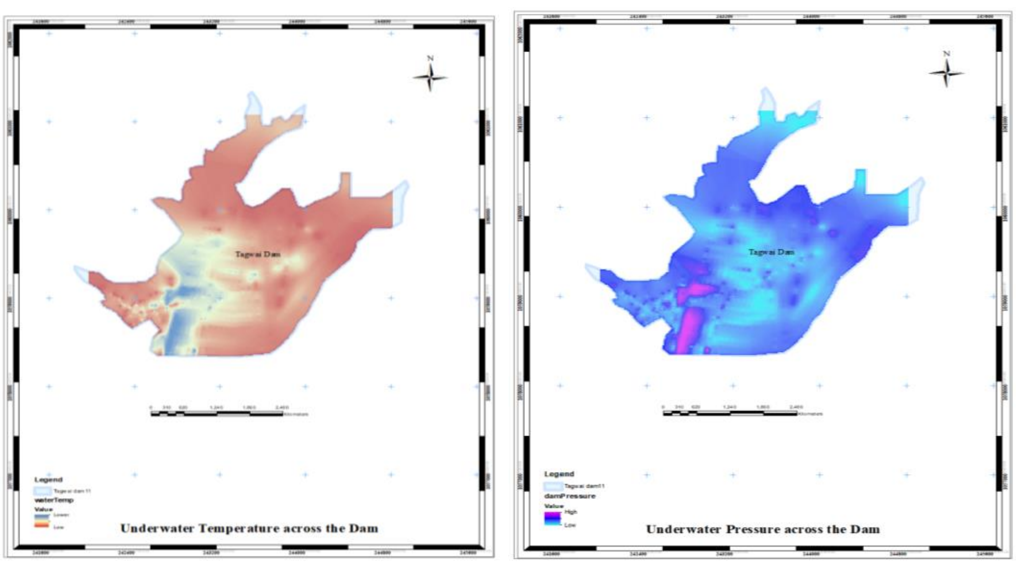

Figure 5(a): underwater temperature (b) Underwater pressure across Tagwai dam

Discussion of Results

The study's findings carry significant implications for the management of water resources, aquaculture, and fisheries. The conspicuous bathymetric patterns and their correlation with sedimentation rates warrant a deeper inquiry into the underlying causes and the far-reaching ramifications of sedimentation within the dam. Furthermore, the temperature and pressure data offer invaluable insights into the physical attributes of the reservoir, with direct relevance to the selection of suitable habitats for different fish species and fish farming.

Conclusion

This study has effectively realized its objectives, providing a substantial understanding of the bathymetry, temperature, and pressure characteristics of Tagwai Dam. The Bathymetric Information System (BIS) developed within the ArcGIS environment serves as a robust platform for the ongoing monitoring of the reservoir and its effective management. The research contributes substantially to the comprehension of reservoir morphology, positioning itself as a foundation for further inquiries into the dynamics of sedimentation and the suitability of habitats for aquatic life.

Recommendations

In light of the unexpected bathymetric patterns observed, we recommend that future research focuses on the execution of a comprehensive sedimentation study within the dam's central axis. This should encompass sediment sampling and rigorous analysis to quantify sedimentation rates, thus providing insight into the impact on the dam's functionality and water quality (Oladosu et al., 2019; Ibrahim & Sternberg, 2021).

Decision-makers and water resource managers should leverage the Bathymetric Information System (BIS) developed in this study as a cornerstone for the creation of advanced Decision Support Systems (DSS). These DSS should strive to enhance functionality, integrate real-time data, and provide user-friendly interfaces, thereby empowering water resource management and decision-making processes. This strategic recommendation not only addresses the sedimentation issue but also equips reservoir managers with sophisticated tools to enhance their conservation and management practices (Smith & Johnson, 2015; Jones & Brown, 2018).

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