METHODOLOGICAL APPROACH TO MODEL VOLUME VARIATION IN HYDROELECTRIC RESERVOIRS USING REMOTE SENSING AND HYDROLOGICAL VARIABLES

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INTRODUCTION

The variability of water levels in hydroelectric reservoirs is a critical characteristic that directly influences energy management, water-resource planning, and the mitigation of risks associated with extreme events. In this context, the use of remote sensing techniques, combined with in situ hydrological records, has become a key tool for the continuous and accurate monitoring of water bodies. Detection based on satellite imagery and remote sensing enables highly sensitive identification of water-covered surfaces. The ability to precisely characterize the dynamics of reservoir levels and discharges by integrating satellite observations is essential for identifying seasonal patterns, anticipating potential extreme events, and adjusting reservoir operations. This approach improves our understanding of hydrological processes and supports the development of robust predictive models that can be replicated in other regions with similar conditions.

In recent research, authors such as (Pimenta et al., 2025)developed a remote-sensing tool that combines Sentinel-2 imagery with machine-learning algorithms, achieving a mean absolute error of 5.35% and an R^2 of 0.90, thereby demonstrating its usefulness for volumetric monitoring in reservoirs. Similarly, (Mustafa & Noori, 2013) applied the NDWI to Landsat imagery to monitor changes in the surface area of the Duhok reservoir, obtaining a relative error below 2.15% when compared with ground-truth data. (Karaman & Özelkan, 2022)proposed a comparative model that integrates satellite-image processing with elevation models to evaluate temporal dynamics of volume in dammed lakes, showing that the TIN model offered higher accuracy relative to official data. For their part, (Han et al., 2024) demonstrated that the combined use of satellite sensors improves the accuracy of water-level estimation in small and complex reservoirs, thanks to the application of altimetric correction algorithms and adaptive dynamic filters. (Chang et al., 2025) designed a high-resolution drought index based on multispectral sensors and historical records, enabling the detection of hydrological droughts with an average observation frequency of 4.3 days, which substantially improves near-real-time detection for small and complex water bodies. Finally, (Han et al., 2024) implemented a dynamic filter in the MoRLa technique, significantly improving satellite altimetry measurements in reservoirs that are difficult to monitor using CryoSat-2, ICESat-2, and Sentinel-3.

The objective of this research is to find a model that computes reservoir volume variation from discharge and water-level data together with information extracted from satellite imagery via inundated-area detection. The expectation is that the model will accurately predict reservoir volume, providing a practical tool for water-resource monitoring and management. The study is limited to a single reservoir and a daily time series, using, for each month, two biweekly periods with a single maximum value of discharge, water level, and detected area. Although digital elevation models, internal operational variables of the reservoir, and sedimentation effects are not considered, the proposed approach offers a replicable, accurate, and low-cost framework for regions where in situ data availability is limited or discontinuous.

MATERIALS AND METHODS

For this study, we will use historical records of biweekly average water levels and discharge for the Urrá reservoir, Colombia, covering the period from June 2017 to July 2025. These records will be integrated and correlated with Sentinel-1 SAR satellite imagery, which has a spatial resolution of 10 meters and will be selected with the same temporal periodicity. Image processing will be carried out on the Google Earth Engine platform, where backscatter values will be reclassified through a binarization process to precisely delineate the areal extent of the reservoir's water surface.

The methodology entails a multivariate statistical analysis aimed at exploring the relationship between hydrological variables and the extent of the water body, with the objective of constructing an operational predictive model that estimates this extent from the available data. From this model, we will derive an estimate of storage-volume variation, and the results will be validated against official historical records to assess performance and validity. As the primary technique, we propose a multivariate analysis due to its effectiveness in modeling relationships among quantitative variables; however, validation through performance metrics is also considered to enhance predictive capability in the event that the observed relationships exhibit non-linear behavior or greater complexity.

RESULTADOS

As a result of processing the satellite imagery, biweekly mosaics were generated that enabled precise delineation of the Urrá Reservoir's water-surface area for each period analyzed. **"Figure 1"**.

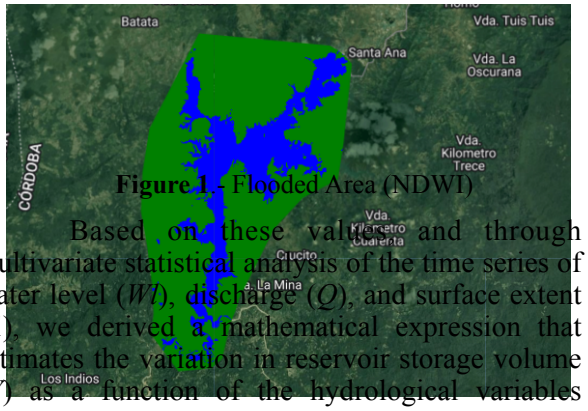

Figure 1.- Flooded Area (NDWI)

Based on these values and through multivariate statistical analysis of the time series of water level (*Wl*), discharge (*Q*), and surface extent (*A*), we derived a mathematical expression that estimates the variation in reservoir storage volume (*V*) as a function of the hydrological variables **"Equation 1 and Equation 2"**. This equation validated by comparison with historical records of stored volumes provides a rapid, practical tool for operational monitoring and management of the water resource.

$$V = \frac{\left(A_j + A_i\right)}{2} \Delta_H \quad Equation\ 1$$

$$A = aWl + bQ + c \quad Equation\ 2$$

$$\Delta_H = Wl_j - Wl_i$$

CONCLUSIONS

The results show that integrating Sentinel-1 SAR imagery through threshold-based binarization with historical hydrological data is an effective strategy for estimating water-surface extent and modeling variations in reservoir storage volume. The resulting statistical expression provides reliable estimates of the Urrá Reservoir's storage dynamics from readily available variables such as biweekly mean water level and discharge.

This methodology offers a robust, low-cost alternative for continuous reservoir monitoring and opens the door to incorporating machine-learning models to improve predictive accuracy and adapt to more complex water-resource management scenarios.

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