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Characterizing transboundary dam operations using only remote sensing data: insights from the Korea border

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Abstract: Two major transformations are reshaping water management: climate change, which intensifies floods and droughts, and a global shift from infrastructure-oriented approaches (e.g., dams, weirs) to software-based strategies emphasizing efficient operation and planning. Under these changing conditions, engineers must manage water resources amid severe climatic constraints and limited infrastructure, circumstances that have frequently led to water conflicts among stakeholders, particularly where rivers cross borders. While some countries successfully manage shared rivers through cooperative treaties, North and South Korea exchange no hydrological information due to political tensions. This lack of communication resulted in a severe incident in 2019, when an unannounced water release from North Korea's Hwanggang Dam caused 6 casualties downstream. In such politically restricted regions, installing conventional hydrological monitoring stations is challenging, making remote sensing an essential tool for hydrological analysis and for preventing artificial water-related disasters.

This study presents a satellite-only framework to infer dam operation characteristics, focusing on the Hwanggang Dam at the North–South Korea border. A rainfall–runoff model was developed to estimate reservoir inflow using Multi-Source Weighted-Ensemble Precipitation (MSWEP), which provides global precipitation fields at 0.1° spatial resolution. Reservoir water levels were extracted from multiple altimetry satellites (CryoSat, ICESat, Sentinel-3A/B) using Measurement of Reservoir Level from Altimetry (MoRLa) software (Han et al., 2024). Although altimetry offers accurate level estimates, its revisit frequency is relatively low; therefore, to densify the water-level time series and reduce temporal gaps, we integrated Harmonized Landsat–Sentinel (optical) and Sentinel-1 SAR datasets using a newly developed dynamic-threshold method (Han et al., 2025). To characterize downstream flow conditions in the absence of gauging stations, surrogate streamflow was derived by counting water pixels from Sentinel-1 imagery. These upstream and downstream signals were then linked within a dam operation model. Parameters for constant-release (normal operations) and proportional-release rules linked to reservoir level (flood operations) were systematically explored. Model calibration relied on a multi-objective criterion that combined R^2 and correlation metrics between model outputs and satellite observations. This optimization process allowed us to identify operational patterns while reducing uncertainties inherent in satellite data.

The optimized model identified key operational characteristics of the Hwanggang Dam, including hydropower-related discharge patterns on a monthly scale, the volume of water secured from water-balance analysis, and the operational range of reservoir water levels. Overall, the results demonstrate the feasibility of characterizing dam operation solely from remote sensing in data-sparse and politically inaccessible basins. By integrating complementary datasets at multiple temporal and spatial scales, the framework reduces uncertainties and offers a practical tool for disaster risk reduction and transboundary water management.

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