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Satellite-based Framework for River Discharge Estimation: A Hybrid Approach Integrating Sentinel-1, Sentinel-2 and Altimetry Data

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Rivers are a critical component of the global water cycle, serving as dynamic pathways for freshwater flow and storage. However, global discharge data is limited, particularly in regions with sparse in-situ measurements. This study introduces a hybrid modeling framework that leverages advanced satellite observations combined with machine learning and deep learning algorithms to estimate river discharge.The framework combines Sentinel-2 optical imagery, Sentinel-1 Synthetic Aperture Radar (SAR) data, and satellite altimetry data from Sentinel-3 and Sentinel-6 leveraging their complementary strengths. The input variables for the model include total water surface area and water indices derived from Sentinel-1 and Sentinel-2, while satellite altimetry provides water level time series. Sentinel-1 effectively compensates for the limitations of optical sensors under cloudy conditions. Moreover, satellite altimetry data are particularly evaluable in areas where lateral water expansion is constrained by topography and SAR or optical are unable to detect variations. The hybrid model, combining Long Short-Term Memory (LSTM) networks and Random Forest Regression (RFR), estimates river discharge with satellite-derived measurements. In effort to account for varying river morphologies, reach boundaries and river centerlines from the SWOT River Database (SWORD) are incorporated, ensuring robust adaptability to diverse conditions.The model is calibrated and validated against in-situ measurements on corresponding dates, using in-situ discharge data from the Mississippi River (USA), Kizilirmak River (Türkiye), and Po River (Italy). Designed to achieve high accuracy across diverse climatic and topographical settings, the proposed framework offers a scalable solution for estimating river discharge. By integrating satellite observations with a hybrid methodology, this approach has significant potential for enhancing global hydrological assessments.