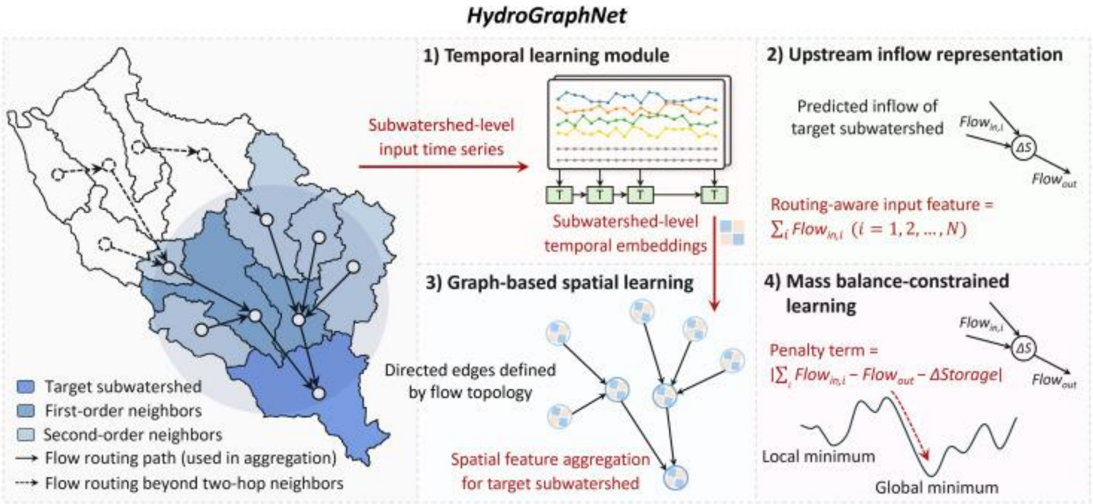
Knowledge-Guided Graph Machine Learning for Spatially Distributed Prediction of Daily Discharge and Nitrogen Export Dynamics

Background/Objective

Spatially distributed prediction of streamflow and nitrogen (N) export dynamics is essential for precision management of agricultural watersheds. While temporal deep learning models have shown strong basin-scale performance, their ability to generalize spatially is limited, particularly under data-scarce conditions. To address this gap, researchers propose HydroGraphNet, a knowledge-guided graph machine learning framework integrating process-based knowledge and explicit spatial learning into temporal modeling.

Approach

The HydroGraphNet framework incorporates directed graph topology to encode watershed connectivity and upstream inflows, using mass balance constraints to improve physical consistency. It was pretrained on synthetic data to enhance generalization in sparsely monitored regions. HydroGraphNet was evaluated in the upper Sangamon River Basin against two baselines.



Overview of the HydroGraphNet framework for spatially distributed prediction of daily discharge and NO_3-N load.

Results

After fine-tuning the model with USGS monitoring data, the model substantially outperformed baseline for both discharge and NO_3-N load. Attribution analysis further highlighted the importance of upstream inflow representation and graph-based spatial learning in capturing cross-subwatershed dependencies. The model reproduced seasonal hydrological and biogeochemical patterns consistent with known processes, demonstrating its robustness and process fidelity for spatially distributed predictions.

Significance/Impacts

HydroGraphNet offers a generalizable framework for distributed modeling to support spatially targeted water quality management in data-scarce watersheds.

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