ABSTRACT

PREDICTING 1-DIMENSIONAL LAKE BATUR TEMPRATURE USING DEEP LEARNING AND PHYSICS INFORMED NEURAL NETWORK COMBINED APPROACH

By

Naufal Hafizd Prayoga

Lake Batur in Bali, Indonesia, experiences periodic mass fish mortality events caused by lake turnover, where rapid mixing brings sulfur-rich bottom water to the surface. This research develops a predictive model for Lake Batur's one-dimensional water temperature profile using a hybrid approach combining Deep Learning and Physics-Informed Neural Networks (PINN). Five models were evaluated: Random Forest (RF), Long Short-Term Memory (LSTM), Convolutional Neural Network (CNN), PINN, and PINN-LSTM. The PINN-LSTM model, which integrates LSTM's temporal pattern recognition with physics-based constraints from the heat diffusion equation, achieved the best overall performance with an RMSE of 0.203°C, NSE of 0.819, and physical inconsistency of only 3.42%. This research confirms a trade-off between data-driven accuracy and physical consistency, where pure data-driven models (LSTM, CNN) achieve high accuracy but exhibit 12-14% physical inconsistency, while the pure PINN model maintains physical consistency but performs poorly (negative NSE). The optimal configuration uses 72 hours of historical data ($n_p = 72$) as input and predicts 12 hours ahead ($n_f = 12$), providing sufficient lead time for early warning systems. Only the PINN-LSTM model was capable of reproducing the critical transition from stratification to mixing events. These findings demonstrate that hybrid physics-informed deep learning approaches offer an effective solution for lake temperature prediction and early warning system development.

Keywords: PINN-LSTM, Lake Temperature Prediction, Physics-Informed Neural Network, Deep Learning, Early Warning System

ABSTRAK

PREDIKSI SATU DIMENSI SUHU DANAU BATUR DENGAN MENGGUNAKAN PENGGABUNGAN METODE DEEP LEARNING DAN PHYSICS INFORMED NEURAL NETWORK

Oleh

Naufal Hafizd Prayoga

Danau Batur di Bali, Indonesia, mengalami peristiwa kematian ikan massal secara periodik yang disebabkan oleh fenomena pencampuran danau, di mana pencampuran cepat membawa air dasar yang kaya belerang ke permukaan. Penelitian ini mengembangkan model prediksi profil suhu air satu dimensi Danau Batur menggunakan pendekatan *hybrid* yang menggabungkan *Deep Learning* dan *Physics-Informed Neural Networks* (PINN). Lima model dievaluasi: *Random Forest* (RF), *Long Short-Term Memory* (LSTM), *Convolutional Neural Network* (CNN), PINN, dan PINN-LSTM. Model PINN-LSTM, yang mengintegrasikan kemampuan pengenalan pola temporal LSTM dengan batasan berbasis fisika dari persamaan difusi panas, mencapai performa terbaik secara keseluruhan dengan RMSE sebesar 0.203°C, NSE sebesar 0.819, dan ketidakkonsistenan fisika hanya 3.42%. Penelitian ini mengkonfirmasi adanya *trade-off* antara akurasi berbasis data dan konsistensi fisika, di mana model berbasis data murni (LSTM, CNN) mencapai akurasi tinggi tetapi menunjukkan ketidakkonsistenan fisika 12-14%, sedangkan model PINN murni mempertahankan konsistensi fisika tetapi memiliki performa buruk (NSE negatif). Konfigurasi optimal menggunakan 72 jam data historis ($n_p = 72$) sebagai *input* dan memprediksi 12 jam ke depan ($n_f = 12$), memberikan waktu tunggu yang cukup untuk sistem peringatan dini. Hanya model PINN-LSTM yang mampu mereproduksi transisi kritis dari stratifikasi ke peristiwa pencampuran. Temuan ini menunjukkan bahwa pendekatan *hybrid physics-informed deep learning* menawarkan solusi yang efektif untuk prediksi suhu danau dan pengembangan sistem peringatan dini.

Kata-kata kunci: PINN-LSTM, Prediksi Suhu Danau, *Physics-Informed Neural Network*, *Deep Learning*, Sistem Peringatan Dini