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Harnessing Quantum Variational Circuits for Enhanced Streamflow Forecasting in the Greater Pamba River Basin, India

Arathy Nair G R[1,2] , Adarsh S[1,2]

[1] *TKM College of Engineering, Kollam, 691005, India*

[2]*APJ Abdul Kalam Technological University, Thiruvananthapuram, Kerala-695016, India*

Email: 212027@tkmce.ac.in

Abstract: Accurate streamflow forecasting is vital for managing water resources and mitigating flood risks, particularly in climate-sensitive regions such as the Greater Pamba River Basin (GPRB) in Kerala, India. While classical machine learning methods like Long Short-Term Memory (LSTM) networks have shown considerable success in hydrological modeling, Quantum Machine Learning (QML) offers a new computational paradigm capable of capturing the intricate, non-linear dependencies inherent in hydro-climatic systems. This study introduces a QML framework utilizing a Variational Quantum Circuit (VQC) architecture for daily streamflow prediction across three gauging stations in the GPRB, leveraging historical data spanning from 1985 to 2015. The model incorporates four hydro-meteorological predictors: daily rainfall, maximum temperature, minimum temperature, and soil moisture. Trained on 70% of the dataset and tested on the remaining 30%, the QML-VQC model achieved an R^2 of 0.91, RMSE of 9.1 m^3/s, and NSE of 0.88. Compared to its classical LSTM counterpart, QML-VQC demonstrated enhanced capability in simulating seasonal shifts and extreme flow events, with a 13% improvement in high-flow detection and a 28% reduction in training time per epoch (11 seconds for QML vs. 15 seconds for LSTM). Furthermore, QML required 22% fewer epochs to converge and exhibited a 17% lower validation loss gap, reflecting better generalization performance. Post-training evaluation on the 2016–2026 period further confirmed its superiority, with an NSE improvement of 10% during high-variability scenarios. These findings underscore the transformative potential of QML—specifically VQC architectures—in hydrological forecasting. The approach offers not only enhanced predictive performance but also computational efficiency, making it a viable tool for real-time, data-driven flood preparedness in complex river systems.

Keywords: *Long Short-Term Memory, Quantum Machine Learning, Variational Quantum Circuit, Seasonal shifts, Extreme flow events.*