APPLICABILITY OF NEURAL NETWORK MODELS FOR REAL-TIME FLOOD FORECASTING IN DRY ZONE AND WET ZONE RIVER BASINS, SRI LANKA

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Degree of Master of Science Engineering

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Thesis submitted in partial fulfilment of the requirements for the degree
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Name of the supervisor: Prof. R. L. H. L. Rajapakse

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ABSTRACT

Flood forecasting is a powerful tool for flood management and early warning, where the anticipated flow values are determined by incorporating basin attributes and climatic factors. In the field, data-driven models offer beneficial solutions compared to comprehensive physical and statistical tools; neural networks have evolved to perform flood forecasting without understanding the physical mechanism. However, forecasting efficiency and reliability are insufficient due to the augmentation of predictive span and improper data handling strategies. In addition, the poor interconnectivity of spatial-temporal resolution influences the accuracy of flood forecasting in a dry zone. Thus, the present study aimed to enhance the flood forecasting ability of neural network models for a 30-day horizon by learning the daily input series of climatic and physiographic factors of the catchment region. Further, the data manipulation strategies were adapted to enhance the learning capabilities. In addition, pre-trained models were developed based on the model performance in the wet zone basin to enhance the predictive quality in the dry zone basin.

The NN models were developed for the Kelani River flood forecasting, where significant flood events have frequently destroyed the socio-economic features of the basin. Besides, pre-trained models were tested on the Maduru Basin flood events, which have encountered inundation due to prolonged flood peaks. Thus, climatic and physiographic data were gathered for both basins and improved with hydrological and data science-based data manipulation strategies. On the other hand, the Box-Cox transformation was employed to redistribute the input series into a Gaussian state to enhance the learning ability of NN models.

Consecutive windows were proposed to consider 30-day daily input to forecast the next 30-day streamflow values while sampling. Thirteen (13) NN models were compiled, fitted, and tested on the Kelani Basin. In addition, grid analysis was adapted to rank the performance of models based on statistical tools, where bidirectional models explicated excellent quality in flood forecasting. Besides, uncertainty analysis was proposed to investigate the impacts of data handling and input combination on flood forecasting. Two hybrid models significantly expounded underperformance without box-cox transformation; none of the models illustrated excellent performance without box-cox transformation. Moreover, scaling/normalization severely influenced the model performance considerably for hybrid models. Besides, sensitivity analysis was applied to verify the applicability of model architecture on model performance. Unlike the types of optimizers, other sensitivity parameters revealed inconclusive results for model performance. None of the modified models delivered more excellent performance than the core models. Further, Bidirectional Gated Recurrent Unit (Bi-GRU), Bidirectional Long- and Short-Term Model (Bi-LSTM), and Attention Based Bi-LSTM (Att-BiLSTM) expressed 0.98, 0.95, and 0.97 for the wet zone flood forecasting, respectively, which were chosen as pre-trained models delivered a similar performance for the dry basin.

In future studies, the consecutive data batches must be determined according to the guiding parameters, such as global warming and climate change. Besides, the loss function should be replaced with other statistical terms to incorporate an optimizer, and autocorrelation must be adapted to control the error propagation. In addition, the core model must be trained for extended periods to effectively perform transfer learning on other basins.

Key Words: Box-Cox; Data science; Sensitivity analysis; Sliding window; Uncertainty analysis

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List of Abbreviations

AHP	Analytic Hierarchy Process
AI	Artificial Intelligence
ALSM	Attention Based CNN – LSTM
AMC	Antecedent Moisture Condition
ANN	Dense Artificial Neural Network
AMC	Antecedent Moisture Condition
ARIMA	Autoregressive Integrated Moving Average
Att Bi-LSTM	Attention -Based Bidirectional LSTM
BDLSTM	Bidirectional LSTM
Bi-GRU	Bidirectional GRU
Bi-LSTM	Bidirectional LSTM
BL	Baseline Model
BR	Bayesian Regularization
CEEMDAN	Complete Ensemble Empirical Mode Decomposition with Adaptive Noise
CHIRPS	Climatic Hazards Group InfraRed Precipitation
CNN	Convolution Neural Network
CNTK	Cognitive Toolkit
CPU	Central Processing Unit
CTS-LSTM	Correlated Time Series - LSTM
DCNN	Dilated Casual CNN
DEM	Digital Elevation Model
DL	Deep Learning
DWT	Discrete WT
DWT-iNARX	Hybrid Model of Discrete Wavelet Transformation - Improved Nonlinear Autoregressive with Exogeneous Input Network
FCN	Fully Connected Neural Network
FDC	Flow Duration Curve
FDC-Q	FDC Behavioral Error
FNN	Feedforward Neural Network
GC-LSTM	Graph Convolution Embedded LSTM
GCN	Graph Convolution Neural Network
GEE	Google Earth Engine
GPU	Graphics Processing Unit
GRU	Gated Recurrent Unit (RNN)
IDE	Integrated Development Environment
IGBP	International Geosphere-Biosphere Program
IoT	Internet of Things
LeM	Levenberg-Marquart
LS-SVM	Least Squares Support Vector Machine Regression
LSTM	Long Short Term Memory (RNN)
LSTM-I	LSTM – Imputation
LULC	Land Use and Land Cover
MAE	Mean Absolute Error
MANN	Memory Augmented Neural Network
MCS	Monte Carlo Simulation
MLP	Multi-Layer Perceptron
MLR	Multi Linear Regression
MNDWI	Modified Normalized Difference Water Index
MRTPP	Multiple Relevant and Target variables Prediction Patterns

N A	Not Available
NARX	Nonlinear Autoregressive Network with Exogenous Input
NDBI	Normalized Difference Built-up Index
NDVI	Normalized Difference Vegetation Index
NIR	Near Infrared
NN	Neural Network
NOAA	National Oceanic and Atmospheric Administration
PCA	Principal Component Analysis
R^2	Coefficient of Determination
ReLU	Rectified Linear Unit
R_{FDC}	FDC Behavioral Error
RM	Residual Max Error
RMSE	Root Mean Square Error
RNN	Recurrent Neural Network
S	Potential Maximum Retention
SAR	Synthetic Aperture Radar
SBU-LSTM	Stacked Bidirectional and Unidirectional LSTM
SCS CN	Soil Conservation Service Curve Number
SGD	Stochastic Gradient Descent
SRTM	Shuttle Radar Topography Mission
ST	Spatial – Temporal
SWIR	Shortwave Infrared
TCN	Temporal Convolutional Network
TCN-ED	TCN-Encoder Decoder
TOA	Top of Atmosphere
USDA	United States Department of Agriculture
WT	Wavelet Transformation