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An Artificial Neural Network Model for River Flow Forecasting

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ABSTRACT

An artificial neural network model developed to forecast river flow/discharge is presented. The model is based on the feed-forward, back-propagation network architecture optimized through a conjugated training algorithm. The observations of daily mean river discharge and daily mean rainfall data during the period 2002 to 2005 were used to train the model and verify the model predictions. The Hanwella station downstream of the Kelani river basin was chosen as the target station where the discharge was to be predicted. The river discharge at the Glencourse, Deraniyagala, Holombuwa and Kithulgala stations upstream of the target station were selected as the main inputs to the model. The contribution of inputs to the model output was determined by studying the correlation between the predicted and the actual discharge values. The best correlation coefficients between the forecasted and observed discharge for the Hanwella station are 0.95, 0.86 and 0.68 for the same day, one day ahead and two days ahead forecasting respectively.

1. INTRODUCTION

A successful flood management system needs accurate forecasting of river flow/discharge [1]. The purpose of forecasting is to reduce the risk in a decision taken at any given point of interest. Accurate models of river flow/discharge are yet to be developed perhaps due to the lack of physical information related to the river basins/catchments.

Sri Lanka has 103 river basins scattered all over the island. Kalu ganga, Kelani ganga, Gin ganga, Nilwala ganga and Mahaweli ganga basins are identified as the areas which are most vulnerable to floods [2]. The Kelani River is located in the wet zone where heavy and prolonged rainfall is observed. Much of the rain in the wet zone is received from mid May to September, when the south-west monsoon sweeps across the Arabian Sea. In addition, the second inter monsoon too causes heavy rain in the wet zone from October to November.

The Kelani River is the second largest river in Sri Lanka by volume of discharge, although it is only the sixth largest in watershed size [3]. Downstream of Glencourse gorge in the Kelani river is a lowland area which is frequently subjected to flooding [3]. Flood occurrences are mainly due to the excessive rainfall during the monsoon periods. Occasionally, depressions over the Bay of Bengal too bring in heavy rains causing floods [4]. Abrupt changes in river slope, blockage of drainage paths, rapid urban development, and reclamation of low lying flood plains are the main causes of the overflowing of the Kelani river [2].

The development and the implementation of successful water resource management tools often require the analysis of river flow/discharge data. The predictions of river

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flow/discharge are also important when measurements are unavailable or insufficient [5]. In this work, results are presented for forecasting river discharge at Hanwella which is situated about 20 km downstream of Glencourse and 35 km from the river mouth.

2. MODEL DEVELOPMENT

To develop the neural network model, both river discharge data and rainfall data have been used. Daily mean river discharge data of five stations (Hanwella, Glencourse, Deraniyagala, Holombuwa and Kitulgala) and daily rainfall data from six stations (Hanwella, Maliboda, Dunedin, Watawala, Maussakale and Castlereigh) in the Kelani river basin (Fig. 1) during the period 2002 October to 2005 September were used in this study. The percentage of missing values in the daily mean rainfall data within the selected study period varied from approximately 3% to 8%. The missing values were excluded in pair-wise in order to get a better performance from the neural network.

Fig. 1: Map of Kelani river basin

Data were divided into two separate subsets for training and testing. The subsets were selected by dividing the 3 years data evenly such that 2/3 of data include training subset and 1/3 of data include test subset. Data relevant to higher volume of river discharge are chosen based on the monsoon periods to study the accuracy when the low land areas are most vulnerable for floods.

The feed-forward multi-layer perception model [1, 5] with the error back-propagation algorithm was used for optimizing the neural network architecture. Levenberg-Marquardt algorithm (*trainlm*) is chosen for optimizing the training. Activation functions used in this network are *tansig* and *purelin*.

To minimize the possibility of getting poorly trained values due to local minima in the error surface, the network was trained 5 times and the best one was chosen according to its training performance. To evaluate the outcome of neural network training and prediction, correlation coefficient between the actual and the estimated discharge values were used.

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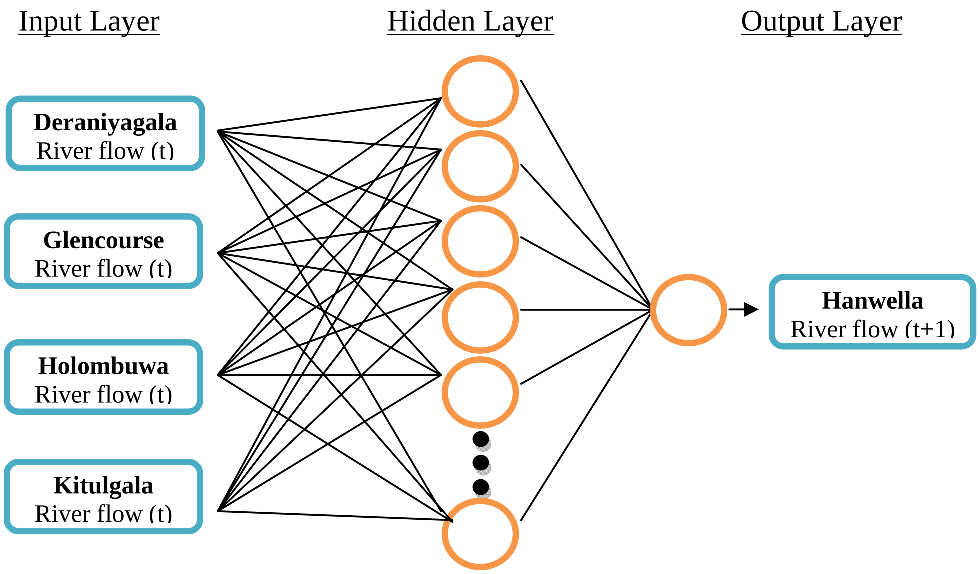

Fig. 2: Structure of neural network model

The input layer includes river flow data of upstream stations (see Fig. 2). The input layer performs no computations on the data but merely distributes the values it receives to the first hidden layer. One hidden layer with 20 nodes was used for the final model. The output was the river flow of the downstream target station. The network training was stopped after 200 epochs. The mean square error (MSE) obtained under the training phase was 1000.

3. RESULTS AND DISCUSSION

Initially, the model predictions when using only upstream river discharge data as inputs are presented for Hanwella river gauge station.

Table 1: Results for forecasting river discharge at Hanwella using upstream river discharge data

Hanwella	Glencourse	Deraniyagala	Holombuwa	Kitulgala
Same day	0.9225	0.7517	0.6215	0.6870
One day before	0.7976	0.7672	0.6661	0.6554
Two days before	0.6162	0.5642	0.4611	0.5064

Table 1 shows the correlations between the measured discharge at Hanwella and discharge from upstream measurements. It can be concluded that there is a high correlation between Hanwella station and Glencourse station even though there is an unaccounted tributary joining Kelani river. The upstream three river gauge stations also show a considerable correlation. However, due to the increase in number of tributaries joining the river when moving upstream has affected the accuracy in predictions. The amount of correlation decreases as the time lag increases.

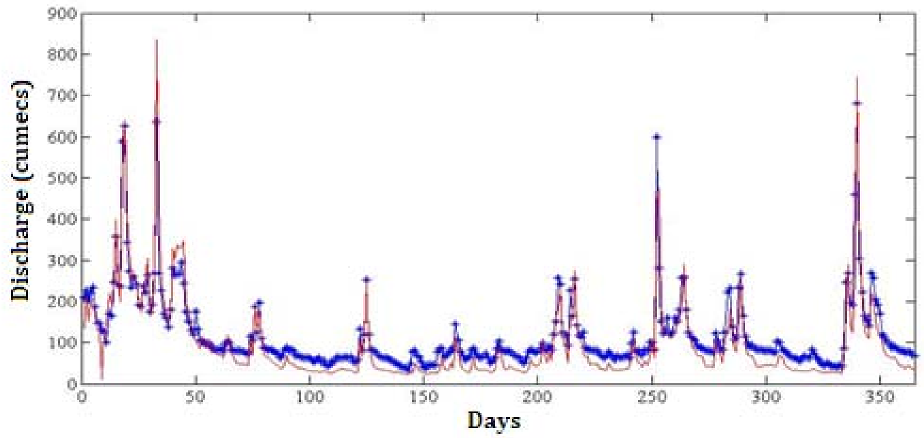

Fig. 3: Actual and predicted river discharge in Hanwella station using Glencourse data on the same day

Fig. 3 show the results for observed and predicted output at Hanwella using the Glencourse discharge data. The regression between the predicted and actual discharge gives a correlation of 0.95. The standard deviation between the actual and predicted discharge difference is ±31.5 (cumecs).

The correlation coefficient between predicted and actual discharge differ when different input combinations are used. A slightly higher correlation is observed when the river discharge of Glencourse, Deraniyagala, Kitulgala and Holombuwa are used as inputs. However, this approach did not produce a significantly higher performance compared to using Glencourse alone as the input.

The combination of Glencourse, Deraniyagala, Kitulgala and Holombuwa not producing a significant improvement compared to using Glencourse alone reveals that river discharge at Glencourse is crucial in estimating the river discharge at Hanwella. Without Glencourse, a reasonable correlation (0.8) can be obtained by using all three upstream stations. The above results can be explained based on the physical layout of the tributaries at the Kelani river basin.

When the combination of inputs of Glencourse, Deraniyagala, Kitulgala and Holombuwa are used to predict one day ahead in Hanwella station, correlation coefficient around 0.85 is obtained. The same combination produced a correlation coefficient around 0.65 for two days ahead forecasting. As expected, performance reduced as the number of days ahead forecast is increased.

Table 2: Results for predicting river discharge at Hanwella using upstream rainfall

	Hanwella	Maliboda	Dunedin	Watawala	Maussakale	Castlereigh
Same day	0.2096	0.2855	0.2711	0.2522	0.2376	0.2607
One day before	0.4554	0.5461	0.5764	0.5079	0.5023	0.4955
Two days before	0.3992	0.4457	0.4270	0.4221	0.3405	0.3460

Table 2 shows correlation coefficients between the measured rainfall data and the measured Hanwella discharge data. The lowest correlation is seen on the same day discharge. A highest correlation is seen in the next day discharge for all six stations. Again, the correlation is low for two days ahead discharge. The highest correlation was seen for Dunedin followed by Maliboda rainfall stations. Results indicate that the influence of rain for river discharge at Hanwella is not significant except for the day after the rain.

Using river discharge at Glencourse station as input was found to be the best in predicting river discharge at Hanwella on the same day. Since marginal improvements are seen in adding the three remaining upstream stations (Deraniyagala, Holombuwa and Kitulgala), to reduce the complexity, these stations were not considered when developing the model to include rainfall. From rainfall inputs, stations producing correlation values higher than 0.25 are chosen. i.e., Maliboda, Dunedin, Watawala, Castlereigh stations are chosen to enhance the predictions. Fig. 4 shows the model predictions.

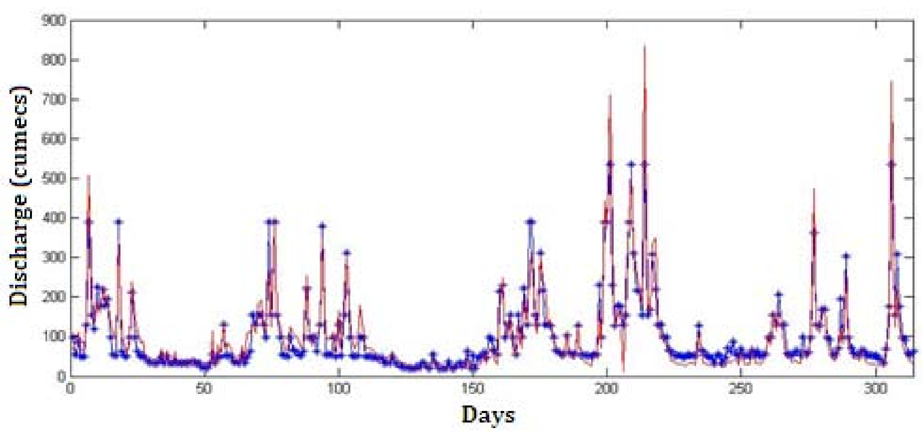

Fig. 4: Actual and predicted river discharge in Hanwella using upstream river discharge and rainfall

For the prediction of one day ahead river discharge at Hanwella, the rain guage stations having correlation values above 0.5 were chosen. i.e., Maliboda and Dunedin stations are chosen for further investigations. There was no significant improved performance by adding rainfall to the model input. However, the model performance slightly improved when upstream river discharge of Deraniyagala, Holombuwa and Kitulgala were added.

For the prediction of two days ahead discharge at Hanwella the rain guage stations having correlation values greater than 0.42 were chosen. i.e., Maliboda, Dunedin and

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Watawala stations are chosen for further investigations. The results obtained from this study did not show a significant improvement in forecasting discharge by using rainfall data. To study the model performance during rainfall seasons, the river discharge rate of 100 cumecs was chosen as the threshold level to identify high flow rates. Higher flows are generally found in the period from June to November which is the southwest monsoon period followed by the second inter monsoon period.

The best performed models were retrained to capture the seasonal effects and tested for the new set of data to evaluate the performance of the model during southwest monsoon period and second inter monsoon period where the discharge rates are generally high. Results show that using upstream discharge data as input, correlations above 0.9 between predicted and actual discharge can be achieved during the monsoon periods on the same day.

4. CONCLUSION

Utilizing the information available at stations upstream of the Kelani river, the developed back-propagation neural network model was able to forecast river flow/discharge at stations downstream of the river with reasonable accuracy (especially if the time lag is limited to one day). In this study, two parameters were considered for the input layer. They are the river discharge and rainfall. Both parameters were studied separately to analyze the contribution of these parameters to forecasting performance.

The performance of the neural network models have been evaluated using the correlation coefficient and the standard deviation. The best correlation coefficients between the forecasted discharge and the observations obtained from the Hanwella station are around 0.95, 0.86 and 0.68 for the same day, one day ahead and two days ahead forecasting respectively.

All the models provided reasonable accuracy for same day analysis which decreased when the number of days ahead to be forecasted increased. This shows us that the water from upstream tributaries takes only a day to flow/discharge through downstream stations and finally reach the sea. Thus, it can be concluded that measurements made in short time intervals (3-6 hourly) are essential to develop flow/discharge forecasting models for catchments such as the Kelani river basin.

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