Rainfall Runoff Modeling by Using Adaptive-Network-Based Fuzzy Inference System (ANFIS) *- Case Study Ciliwung River -*

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MEE09210

ABSTRACT

In this study, Adaptive-Network-Based Fuzzy Inference System (ANFIS) approach, introduced by Jang (1993) was employed to investigate its applicability in predicting water level in the Ciliwung River, more specifically in the MT Haryono gauging station as selected target. And for the purpose, specific objectives were set, which were to predict the water level by introducing some models and to identify the most fitted model among those given models. The ANFIS combines the explicit knowledge representation of Fuzzy Inference System with the learning power of Artificial Neural Networks, therefore it is a very powerful approach to build complex relationship between a set of input and output data. For modeling implementation, average of rainfall from three stations and water level measured in the MT Haryono gauging station were provided as input. And for the output, water level with certain lead time in the MT Haryono gauging station was predicted. Two years hourly data of rainfall and water level from January 2005 to December 2006 were used for modeling process. Models were varied with 5 differences lead time of predicted water level, 4 types of membership function for each of different lead time and 3 differences number of membership functions for each type of membership function. The results of the modeling were reasonable in terms of statistical performances. Several indices of performance such as root mean squared error, coefficient of correlation, efficiency and coefficient of determination showed good performance. The results were compared in three differences categories, including lead time, type of membership function and number of membership function. The model with 5 hours lead time and 3 gaussian membership functions gave the best performance among all given models. The capability ANFIS system in producing such reasonable result indicated that this approach has potentially to be used as predictor of water level in the Ciliwung River, particularly at the MT Haryono gauging station.

Key words: *ANFIS, Neuro-fuzzy, Ciliwung River, Water Level*

INTRODUCTION

In order to avoid the lost of human lives and reduced the lost of properties caused by floods, river forecasting activities as one of component of flood management is required. Year 1996, 2002 and 2007 were recorded in which Jakarta city most severely hit by floods in the last 15 years. There were enormous lost and casualties due to unpreparedness of the citizen in expecting the flood. Therefore citizen's preparedness is one of priorities of the government's agenda in flood management which can be raised by reliable of flood forecasting. Modern artificial intelligence methods such as neuro-fuzzy systems can be used for forecasting. These methods provide fast, reliable and low-cost solutions. Another advantage of these methods is that they can handle dynamic, non-linear and noisy data, especially when the underlying physical relations are very complex and not fully understood. The purposes of this study are to investigate the applicability of ANFIS in predicting water level in the Ciliwung River and to identify the most fitted model to the study area.

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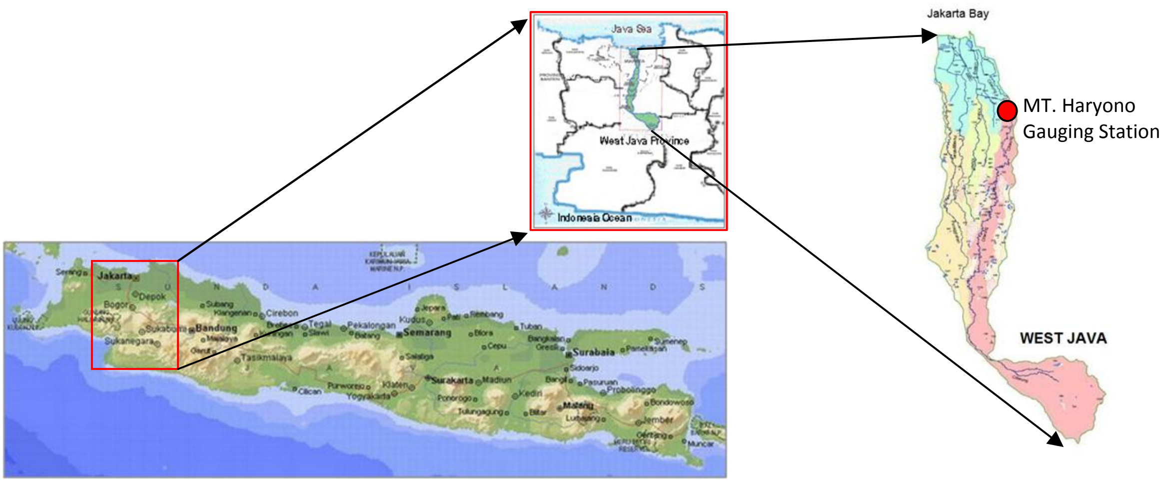


Figure 1. Location of study area

DATA

For this study, rainfall data and water level data are required. It is about 16,700 hourly data which are extracted from two years data (January 1, 2005 to December 31, 2006). Rainfall data from three stations and water level from one gauging station were utilized in the calculation. Rainfall data were retrieved from Citeko, Ciledug and Jakarta Obs station while water level obtained from the MT Haryono gauging station.

THEORY AND METHODOLOGY

Adaptive Network-Based-Fuzzy Inferences System (ANFIS) approach was employed in this study. The ANFIS architecture consists of fuzzification layer, inferences process, defuzzification layer, and summation as final output layer. Typical architecture of ANFIS is shown by Figure 2. The process flows from layer 1 to layer 5. It is started by giving a number of sets of crisp values as input to be *fuzzyfied* in layer 1, passing through inference process in layer 2 and 3 where rules applied, calculating output for each corresponding rules in layer 4 and then in layer 5 all outputs from layer 4 are summed up to get one final output. The main objective of the ANFIS is to determine the optimum values of the equivalent fuzzy inference system parameters by applying a learning algorithm using input-output data sets. The parameter optimization is done in such a way during training session that the error between the target and the actual output is minimized. Parameters are optimized by hybrid algorithm which combination of least square estimate and gradient descent method. The parameters to be optimized in ANFIS are the premise parameters which describe the shape of the membership functions, and the consequent parameters which describe the overall output of the system. The optimum parameters obtained are then used in testing session to calculate the prediction. A number of 8,760 data were utilized during training session and 7,900 data were used during testing session.

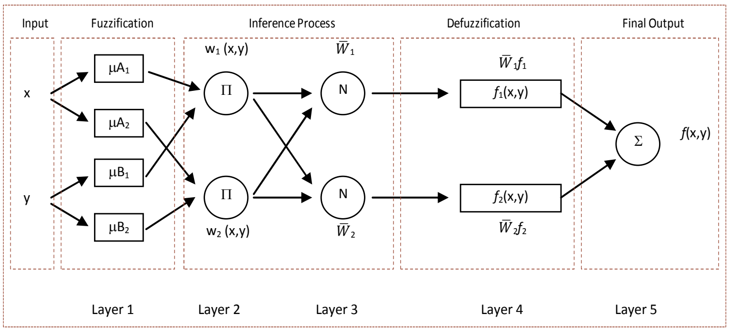


Figure 2: Typical Architecture of ANFIS

In this study, basic model is constructed by 2 inputs and 1 output. The inputs are rainfall data and water level data while for the output is predicted water level at certain of lead time. The basic model then varied in 3 components, which are 5 different lead times, 4 different type of membership functions and 3 different number of membership functions. The combination of this variation formed 60 models which applied to the ANFIS system

For computational purposes, some Matlab programming codes have been developed, to compute bell shaped membership function with 2 numbers of membership function, but most of the times, fuzzy toolbox is used.

RESULTS AND DISCUSSION

Depend upon the model and combinations, the ANFIS system produced different results. To find the most fitted model, the results are compared and discussed as follows.

Result with Differences in Lead Time

Figure 3 below shows sample plotting of observed and predicted value of the results with differences in lead time. In this sample, lead time of 5 hours, 7 hours, 9 hours and 12 hours were compared. Other component i.e. type of membership function and number of membership function were remain fixed. Gaussian function and 3 number of membership function were selected in this plotting sample. Dotted line in this graphic represents predicted value and solid one is observed value. It can be seen that results are acceptable for all differences lead time, but the performance is decreasing with the increasing of lead time, as shown in Figure 4.

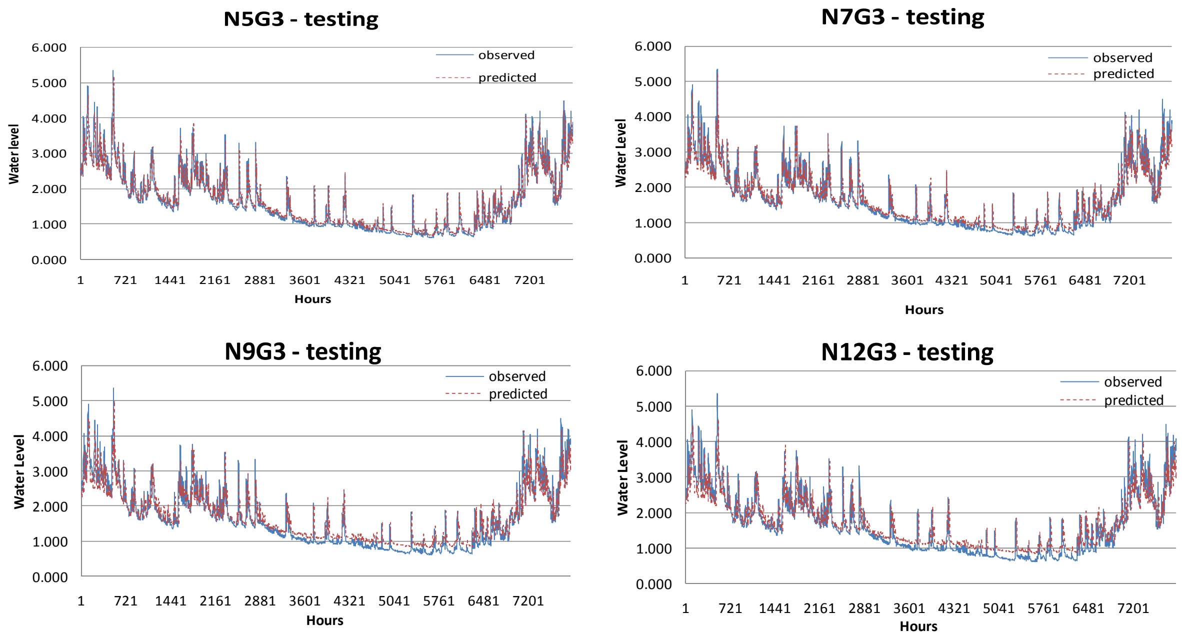


Figure 3. Plotting of some result (observed-predicted) with differences in lead time

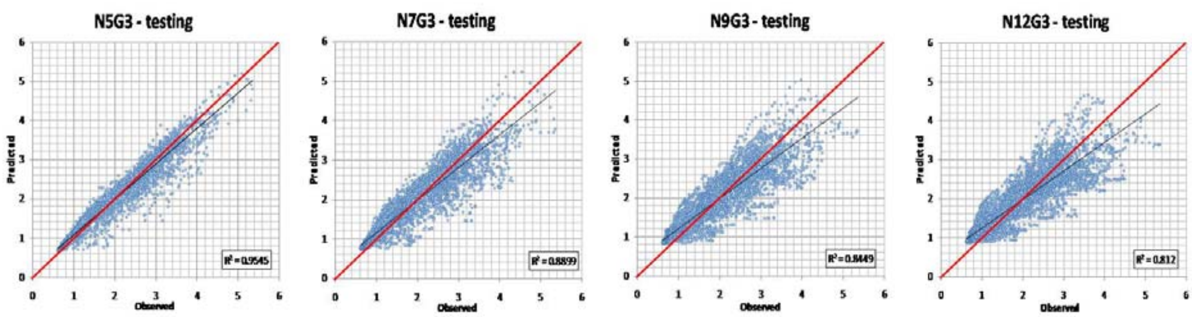


Figure 4. Performance of model with differences in lead time

Result with differences in Type of Membership Function

Figure 5 and 6 show the results of differences in type of membership function. The other two components, i.e. lead time and number of membership were fixed. For plotting sample, 5 hours lead time and number of membership function equal to 2 was selected and four differences membership function were compared, namely gaussian, triangular, trapezoidal and bell shape function.

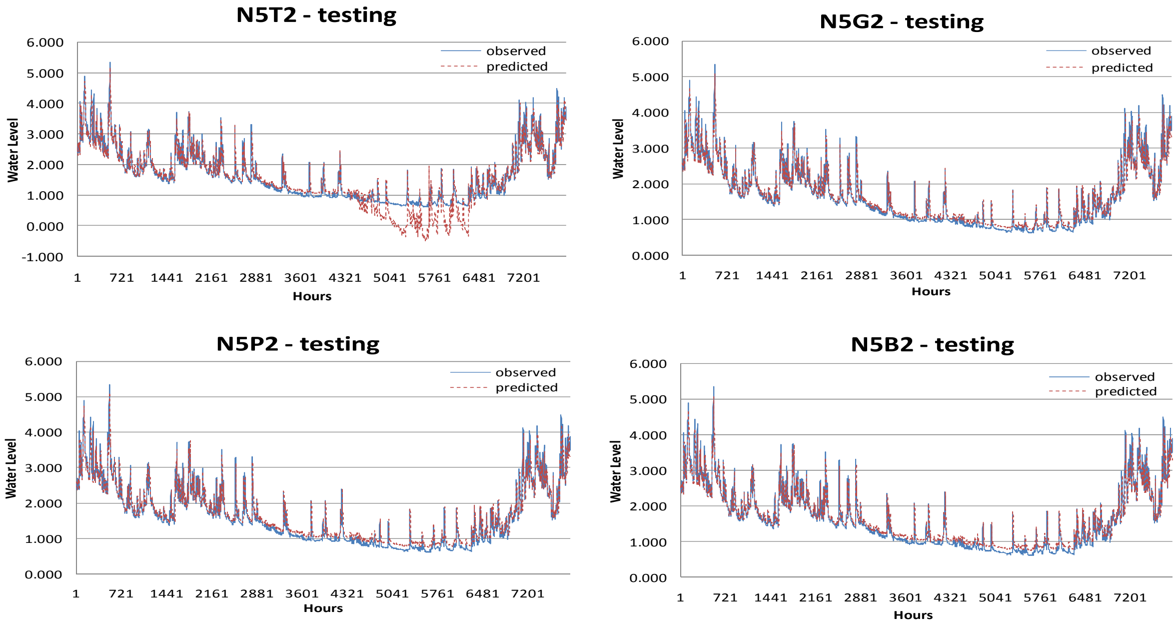


Figure 5 : Plotting of some result (observed-predicted) with differences in type of membership function

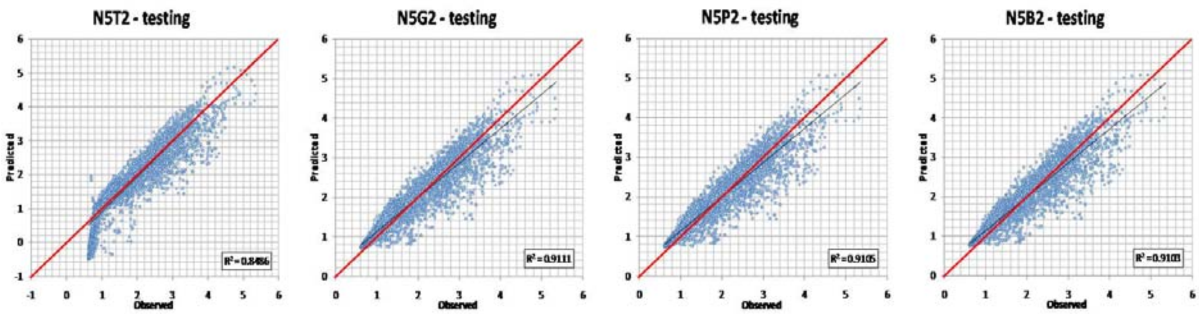
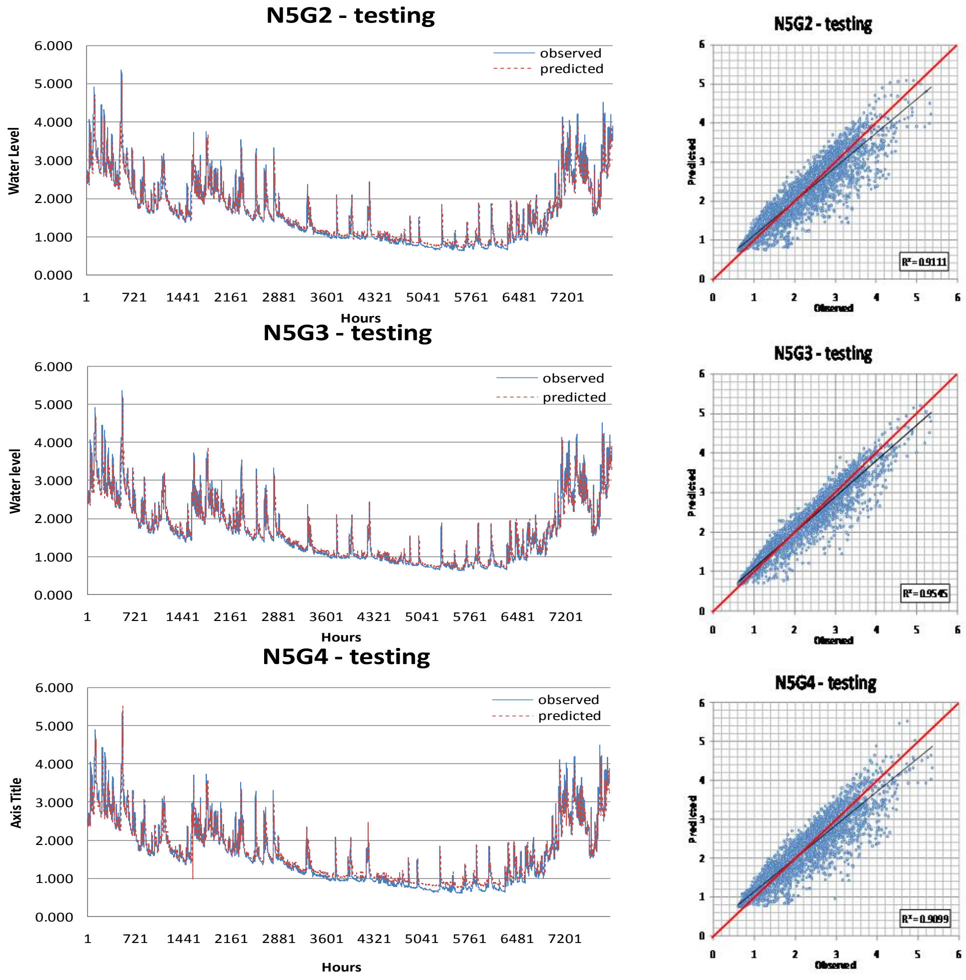


Figure 6 : Performance of models with differences in type of membership function

Applying different type of membership function obviously determined the results. Figures 5 and Figure 6 above are showing that the results also altered due to differences in type of membership function. Gaussian function gave the best result while triangular membership function gave poor performances compared to others function.

Result with differences in Number of Membership Function

The last comparison is the differences in number of membership function. In this study, three different number of membership functions were applied, which were 2, 3 and 4. By fixing the other two components, lead time and type of membership function, the results produced by different of number of membership function were compared. In this sample, 5 hours lead time and gaussian function were selected and fixed.



(a) (b)

Figure 7(a). Plotting of some result (observed-predicted) with differences in number of membership function. (b). Performance of models with differences in number of membership function

From the Figure 7(a) and Figure 7(b) above can be seen that ANFIS system is sensitive to number of membership function. Giving additional number of membership function to the system did not always improve the result. For those models, by increasing number of membership function from 2 to 3 the results are better. But by increasing number of membership function from 3 to 4, in most cases the performances are decreasing. Applying 3 number of membership function gave the best results.

In terms of statistical performances, four indices including root mean squared (RMSE), coefficient of correlation (CoC), efficiency (Eff) and coefficient of determination (CoD) are also used to find the most fitted model. Following figures show sample of performances of four indices of different models.

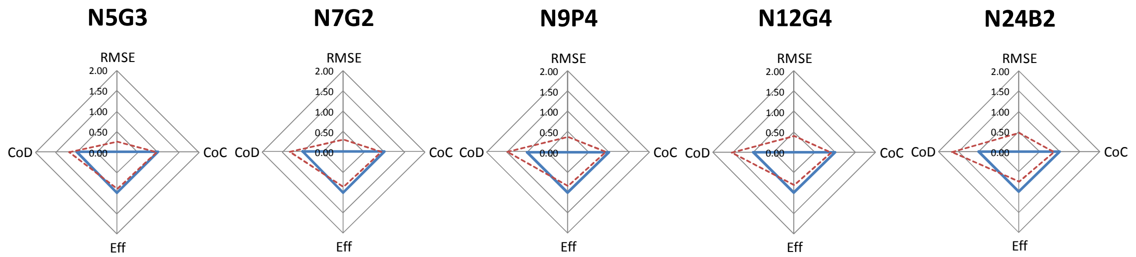


Figure 8. Plotting of statistical performances of some models

Solid line as shown in figure 8 above is the optimum value of indices and dotted line is the performance of the model. The closer the dotted line to the solid line the more fitted the model to the system. From all the given models, model with 5 hours lead time and 3 gaussian functions gave the best performance.

CONCLUSIONS

a. In this study water level in the MT Haryono gauging station was predicted by using ANFIS method and the results clearly illustrated that ANFIS has the potential for modeling in hydrologic time series to predict The Ciliwung River's water level with certain lead time by applying appropriate membership function and the number of membership function.
b. Predicting water level in The Ciliwung River, in particular the MT Haryono gauging station by using ANFIS method gave reasonable result. The system succeeded to predict for almost one year forecast ahead based on one year trained data.
c. Model with 5 hours lead time and 3 membership function of Gaussian function, namely model N5G3, has given the best performance. Referring to observed value, its prediction has value of 0.255, 0.954, 0.909 and 1.116 for RMSE, correlation, efficiency and coefficient of determination value respectively.

RECOMMENDATION

ANFIS has shown its potential to be used as alternative predictor of flood in The Ciliwung River. In order to improve the result it might be recommended several things as follows:

a. This current study selected four types of membership function and three different numbers of membership function in advance. Thus, the selected type of membership function and number of membership function were applied in a trial and error way into the ANFIS system to select the most fitted type membership function and the number of membership function. It might be interesting to study a method that can be used to choose the type of membership function or the number of membership function that is appropriate to particular river system not in trial and error way as it was done in this study.
b. Parameters obtained in this study can be used to compute the future water level of the MT Haryono gauging station. It can be done by using any spreadsheet application, such as excel application from Microsoft or Calc in OpenOffice.org. Water level can be calculated by following the computational procedure of ANFIS and applying those parameters directly. But since those parameters were obtained from outdated data, it is recommended to recalculate those parameters with the latest data.

ACKNOWLEDGEMENT

I would like to express my deep and sincere gratitude to my supervisor Dr. Takahiro Sayama for his encouragement and his extremely patience in guiding me to accomplish my study. His deeply understanding of research inspired me in conducting this study.

REFERENCES

Haykin, S. (2005). *Neural Networks : A Comprehensive Foundation.* Pearson, Prentice Hall.

Roger Jang, J. (May 1993). *ANFIS : Adaptive-Network-Bassed Fuzzy Inference System*. IEEE System, Man and Cybernetics , 665-685.

Takagi, T. S. (1985). Fuzzy Identification of systems and Its Application to Modelling and Control. *IEEE Transactions on System, Man and Cybernetics 15* , 116 - 132.

MathWorks. (2009). *MATLAB : Getting Started Guide.* The MathWorks, Inc.