# TEMPORAL MODEL OF HYDROMETEOROLOGY IN THE CITARUM RIVER BASIN INDONESIA

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## Abstract:

*Water resources availability for meeting reservoir storage, water supply diversion and environmental in stream flow requirements must be assessed on various premises regarding future water used as well as climatic and hydrometeorological conditions. This study, therefore, investigates temporal dynamical model and detects persistence and plausible long-term trends of the hydrometeorology in the Upper Citarum River Basin, West Java, Indonesia. The investigations based on monthly observations data of the rainfall, evapotranspiration, humidity, and runoff from January 1968 to December 2000 and monthly global phenomena data from National Centers for Environmental Prediction (NCEP). Identification of the temporal dynamical model of the hydrometeorology based on adaptive neuro-fuzzy inference system (ANFIS). The conclusion obtained in this study shows that temporal dynamical model of the hydrometeorology based on ANFIS can simulate the observations accurately. The model is capable to minimize the bias and root mean squared error (RMSE). The rainfall, evapotranspiration, and humidity had two firm persistence i.e. wet and dry periods, while the runoff has no firm persistence. The rainfall and runoff had been decreased by about -3.64% and -1.11% respectively. On the other hand, the evapotranspiration and air humidity had been increased by about 3.88% and 4.21% respectively. The results of this studies can give an information for improvement of an integrated water management in the Citarum river basin.*

***Key words :*** *rainfall, evapotranspiration, humidity, runoff, wet and dry periods, long-term trends*

## Introduction:

The design, planning, and operating of river system depend largely on relevant information derived from extreme event forecasting and estimation. Reliable runoff and rainfall forecasts are particularly important for warning against dangerous flood or inundation and drought as well as in the case of multi-purpose reservoirs. Variability of hydrometeorology in Indonesian had been changed as consequences of global climate changes and ENSO (Peel, et al., 2001, Hendon, 2002). The rainfall in South East Asian had been changed significantly (Burn and Hag, 2002, Leon, 2002; Xua et al., 2003; Cheng et al., 2004).

The Citarum river basin is a complex basin containing most of the feature of water system: storage, uncontrolled sources, multi purposes, and potential for all forms of operational management. Information of temporal models, predictions, persistence (wet and dry periods), and long-term trends of the hydrometeorological components have the

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potential to drastically improve the effective use of available water resources in this basin.

The application of ANFIS to various aspects of hydrometeorological modeling has undergone much investigation in recent years (Franc and Panigrahi, 1997; Mashudi, 2001; Ozelkan and Duckstein. 2001). ANFIS is mostly suited to the modeling of nonlinear system. Zhu (2000) and Shapiro (2002) have indicated that ANFIS is the best modeling to analysis numerical data, because in training process based on minimize value of root mean square error (RMSE). The others investigation show that ANFIS can predict better than back propagation multilayer preceptron (BPMP) or autoregression. This computational methods offers real advantages over conventional modeling, especially when the underlying physical relationship are not fully understood ( Nayak et al., 2004; Cigizoglu, 2003; Tokar and Markus, 2000 ). This study aims at applying ANFIS as a modeling tool to predict and estimate the runoff and rainfall data of the Citarum river basin in West Java. Several ANFIS applications comprise of predictions of runoff and rainfall 1-month to 12-months and 1-year to 6 years in advance model.

The purposes of this study are investigates temporal dynamical model and detects persistence and plausible long-term trends of the hydrometeorology in the Upper Citarum River Basin, West Java. The results of this studies can give an information for improvement of an integrated water management in the Citarum river basin.

## Study Area and Data:

The upper Citarum river basin is located in West Java Indonesia, with a geographical position of about *6°43’-7°04’* southern latitude and *107°15’-107°55’* eastern latitude. It covers an area of approximately 4.500 km2. The investigations based on monthly observations data of the rainfall, evapotranspiration, humidity, and runoff from January 1968 to December 2000 and monthly global temperature (GT) and central Indian precipitation (CIP) data from National Centers for Environmental Prediction (NCEP).

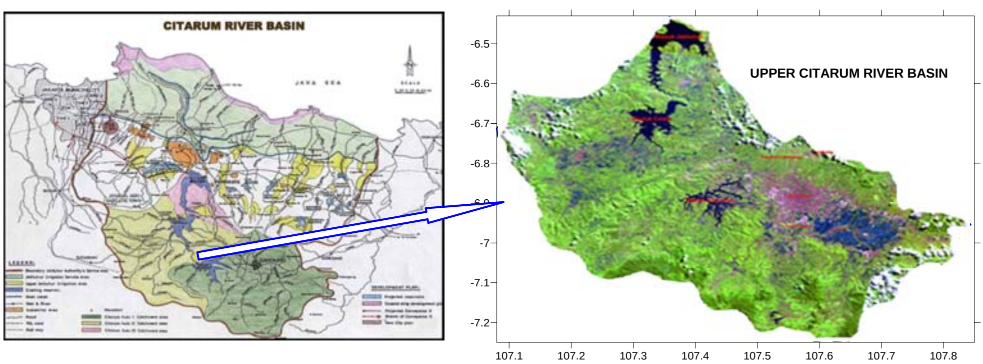


Figure 1: **Map of the Upper Citarum River Basin**

## Statistical Methods:

Identification of the temporal dynamical model of the hydrometeorology based on adaptive neuro-fuzzy inference system (ANFIS). The cumulative sum chart analysis and logistic linear regression are used in this study for estimating wet and dry periods and long-term trends in hydrometeorological components, respectively.

ANFIS is a type biologically inspired computational model. The functioning of ANFIS is based on learning process (Jang, 1993). A network of this model is made up of a member interconnected nodes arranged into three basic layers: input, hidden, and output. The input nodes perform no computation but are used to distribute input to network. In this network an information passed one way through the network from the input layers, through the hidden layers and finally to the output layer. In this study, ANFIS trained with the standard back propagation algorithm which uses a set of input and output pattern was applied. An input pattern is used by the system to produce an output, which then is compared with the actual output. If these no difference, then no learning takes place.

The application of the ANFIS to the time series data consisted of two steps. The first step was the training of the ANFIS, which comprised the time series data describing the input and output to the network and obtaining the inter-connection weight. Once the training stage was complete the ANFIS were applied to the testing data. The best training of the ANFIS is the lowest root mean square error (RMSE) and the lowest mean absolute percentage error (MAPE) and is defined as:

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where $Y'_t$ is the model's output; $Y_t$ is the observed data; and N is the number of data points.

The degree of the model precision (also was used to evaluate general quality of the model) is defined as E :

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Where **Error! Objects cannot be created from editing field codes.** is the variation of the observation data and **Error! Objects cannot be created from editing field codes.**is the variation of the difference between the observation data and model results.

The cumulative sum (CUSUM) chart analysis is a standard technique used to show changes in the underlying mean of a system (Simmonds and Hope, 1997; Kadolu et al., 1999; Whiting et al., 2003). The CUSUM were calculated from :

$$S_t = \sum_{k=1}^{t} (x_k - \overline{x}) \qquad \text{……………..(4)}$$

where $S_t$ : CUSUM, $x_k$ : time series, ***Error! Objects cannot be created from editing field codes.*** : average of the time series data, and n : number of data points.

Logistic regression is a special case of formal generalization of linear regression concepts commonly summarized under the term generalized linear models. These statistical models apply for trend modeling of rare events (Frei and Schar, 2000, Sveinsson et al.,2002). The logistic trend model expresses a transformed form of the expected value of counts ($\pi$) as a linear function of time:

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here t is time; $\alpha$, $\beta$ are the regression intercept and coefficient, respectively, to be estimated from the data, ; $\pi$ is a events probability; and $\eta$ is a prescribed monotonic link function.

The magnitude of the trend, as given by model parameter $\beta$ is conveniently expressed as the odds ratio defined as :

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The odds ratio represents the relative change in the ratio of the events against nonevents during the period ($t_1$, $t_2$) and is an exponential function of the period length.

# Results and Discussion:

## Temporal Dynamical Model of the Hydrometeorology:

The first application of the ANFIS was carried out for identification and prediction the annually temporal dynamical model of the runoff. The simulation during training and testing stages showed that ANFIS provides the lowest RMSE or MAPE and the highest values E (precision) to forecasts the unique value in the output. The prediction and scatter plot for the training period are compared with the observed data of the runoff showed in Figure 2. Relationship between input and output of the annually runoff (RO) and rainfall models showed in Figure 3. The statistical measures exhibit satisfactory agreements between observed and forecasted data, i.e. RMSE= 18.87 mm and 17.41 mm, for training and testing stages respectively. This model has values precision (E) =66.6% (Table 1).

In identification and prediction the annually temporal dynamical model of the rainfall show that for the simulation during training and testing stages have the lowest RMSE and the highest values E (precision) to forecasts the rainfall. The prediction and scatter plot for the training period are compared with the observed data of the rainfall showed in Figure 2. The statistical measures exhibit satisfactory agreements between observed and forecasted data, i.e. RMSE= 1.16 mm and 1.16 mm, for training and testing stages respectively. The annually temporal model of the rainfall has values E =69.3%.

The others application of the ANFIS was carried out for identification and prediction the monthly temporal dynamical model of the runoff and rainfall. The simulation during training and testing stages showed that ANFIS can not provide the RMSE and values E as well as that of the annually temporal dynamical models. The prediction and scatter plot for the training period are compared with the observed data of the runoff and rainfall showed in Figure 4. Relationship between input and output of the monthly runoff and rainfall models showed in Figure 5. The statistical measures and forecasts of the models showed in Table 1 and 2.

Table 1: **Statistics of the temporal dynamical model of the rainfall and runoff.**

| Model | Training | | Testing | Precision (E) (%) | $\chi 2$ test | Note |
|---|---|---|---|---|---|---|
| | RMSE | MAPE | RMSE | | | |
| Monthly Runoff | 19.087 | 0.145 | 22.041 | 77.6 | 3.91 | Acceptable |
| Monthly Rainfall | 21.471 | 2.039 | 21.713 | 49.9 | 18.20 | Acceptable |
| Annually Runoff | 18.872 | 0.151 | 17.410 | 66.6 | 4.80 | Acceptable |
| Annually Rainfall | 1.159 | 0.013 | 1.156 | 69.3 | 6.41 | Acceptable |

RMSE=(Root Mean Square Error),
MAPE=(Mean Absolute Percentage Error)

Table 2: **Statistics of the rainfall and runoff forecasted**

| Model | Forecasted Data | | Observed Data | |
|---|---|---|---|---|
| | Minimum | Maximum | Minimum | Maximum |
| Monthly Runoff | 381 M m3 | 576 M m3 | 392 M m3 | 587 M m3 |
| Monthly Rainfall | 85 mm | 181 mm | 90 mm | 197 mm |
| Annually Runoff | 3641 M m3 | 7565 M m3 | 3691 M m3 | 8170 M m3 |
| Annually Rainfall | 2905 mm | 4539 mm | 2832 mm | 4642 mm |

M = million

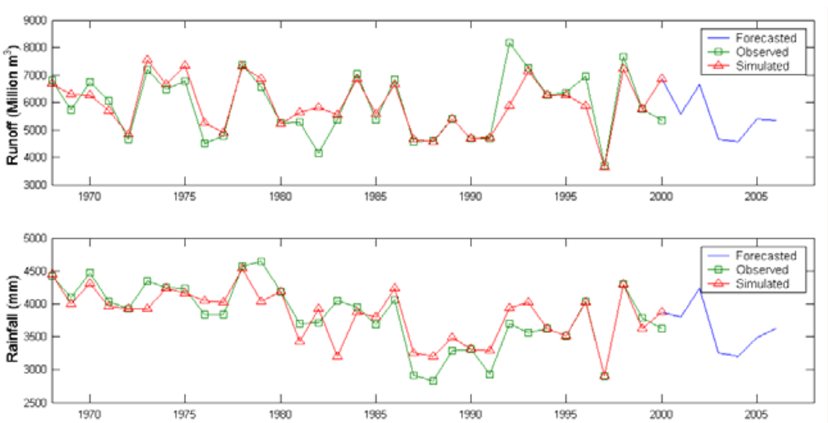


Figure 2: **Annually temporal dynamical models of the runoff and rainfall**

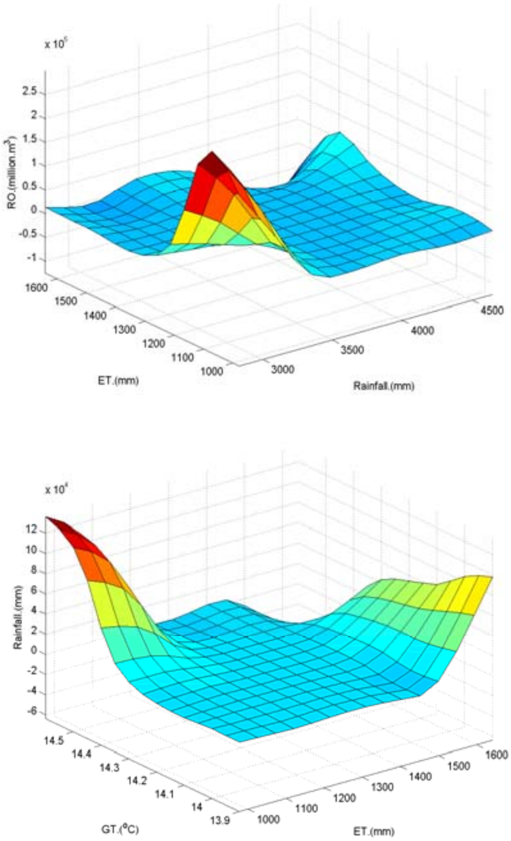


Figure 3: **Relationship between input and output of the annually runoff (RO) and rainfall models**

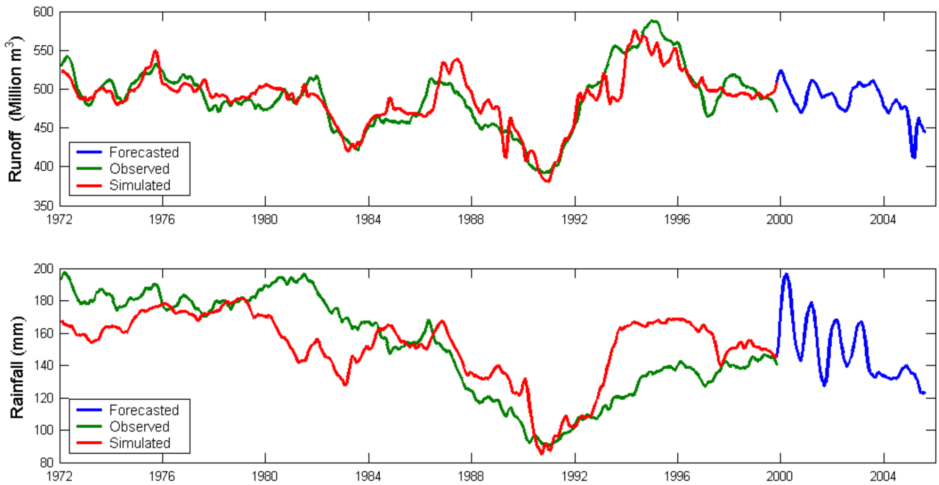


Figure 4: **Monthly temporal dynamical model of the runoff and rainfall**

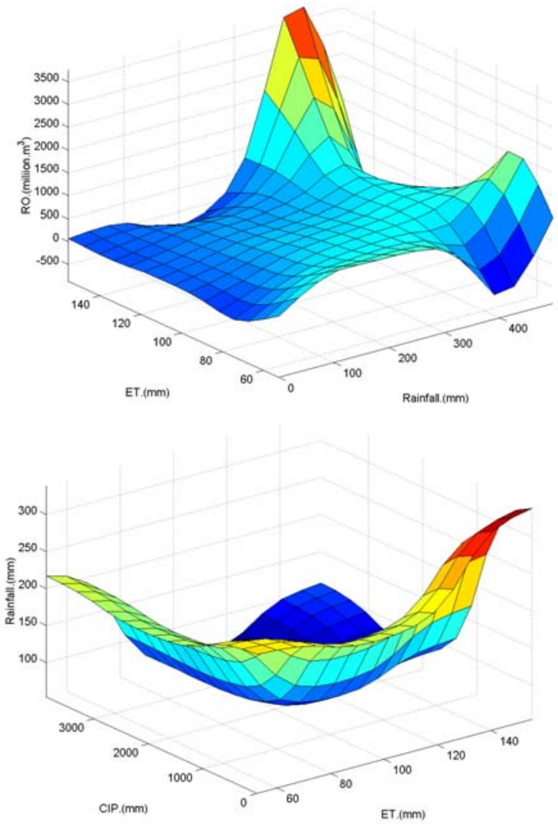


Figure 5: **Relationship between input and output of the monthly runoff (RO) and rainfall models.**

## Wet and Dry Periods in Citarum River Basin:

The cumulative sum chart of the hydrometeorological component in Citarum river basin clearly show periods during which the time series data is persistence below or above the long-term mean (Fig.6). Positive slope on these chart indicate a period of above average values (wet periods) and negative slope indicating a below average values (dry periods). The rainfall, evapotranspiration, and air relative humidity had two firm persistence i.e. wet and dry periods, while the runoff has no firm persistence. The rainfall has wet periods for 1968-1981 and dry periods for 1987-2000.

The absence of the firm persistence in the hydrometeorological components indicated that temporal dynamical of the hydrometeorology in Citarum river basin has relationship with land cover changes, deforestation, and land used changes as well as impacts of the global climate changes.

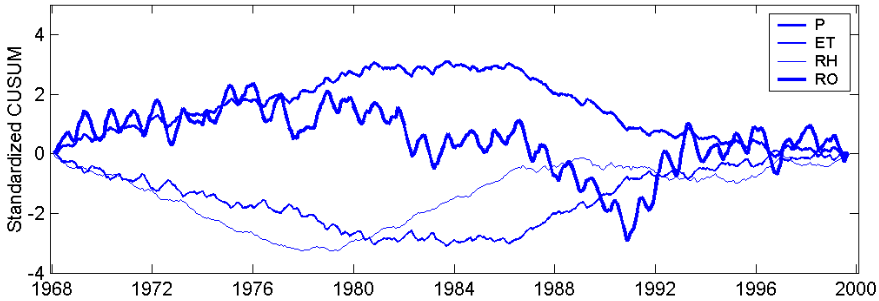


Figure 6: **Standardized CUSUM of rainfall (P), evapotranspiration (ET), relative humidity(RH), and runoff (RO).**

## Long-term Trends of the Hydrometeorology:

The rainfall and runoff had been decreased by about 3.64% and 1.11% respectively (Fig.7). The decreasing trend in the rainfall had controlled mainly by the decreasing of the clouds and rains formation as a consequence of the global climate change. The runoff also has decreased in Citarum river basin. The main factor determining the change in river runoff is rainfall. In 1968 to 2000, periods of rainfall decline have coincided with declining river runoff.

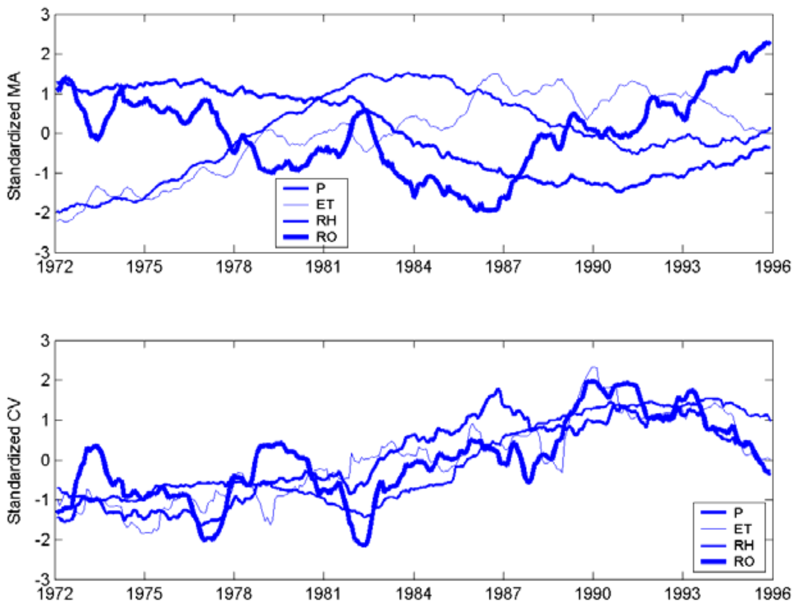


Figure 7: **Standardized moving averages (MA) and coefficient of variability (CV) for rainfall (P), evapotranspiration (ET), relative humidity(RH), and runoff (RO).**

The evapotranspiration and air humidity had been increased by about 3.88% and 4.21% respectively. The increasing trend in the evapotranspiration and air humidity had influenced by the increasing of the water vapour removal from vegetation lands surface to the atmosphere by both evaporation and transpiration.

Variability of rainfall, evapotranspiration, relative humidity, and runoff had been increased significantly by about 31.37 %, 24.38%, 105.48%, and 14.19% respectively (Fig.7). This result incicated so that the events of flood and drought in Citarum river basin are more extremes.

## Conclusions:

The conclusion obtained in this study shows that temporal dynamical model of the hydrometeorology based on ANFIS can simulate the observations accurately. The model is capable to minimize the bias and root mean squared error (RMSE). This model can use to predict the runoff or rainfall in the future. The rainfall, evapotranspiration, and humidity had too firm persistence i.e. wet and dry periods, while the runoff has no firm persistence. The rainfall and runoff had been decreased by about 3.64% and 1.11% respectively. On the other hand, the evapotranspiration and air humidity had been increased by about 3.88% and 4.21% respectively. Variability of rainfall, evapotranspiration, relative humidity, and runoff had been increased significantly so that the events of flood and drought are more extremes.

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