Rainfall-Runoff Modeling of Citarum Hulu River Basin by Using GR4J

Dhemi Harlan, Muljana Wangsadipura., and Cecep Muhtaj Munajat

Abstract— **This research is to study the rainfall-runoff modeling using GR4J (Ge´nie Rural a` 4 parame`tres Journalier) on Citarum Hulu River Basin. In this study, the data input of daily rainfall and potential evapotranspiration are used, and the result will calibrated with the observed data of daily discharge. In this study, the optimum value of GR4J model parameters will be observed to get the smallest error deviation. There are two stages in this modeling. Firstly is model calibration and secondly is model validation. Model calibration uses the first of five years of data input and model validation uses the following five years. The Nash-Sucliffe Coefficient (NS) and The Relative Volume Error (RVE) methods are used to obtain the error deviation. This study is intended to optimize four free parameters of the model, there is the maximum capacity of production store (X_1), the groundwater exchange coefficient (X_2), the maximum capacity of routing store (X_3), and the time base of unit hydrograph (X_4). The last parameter (X_4) is used to study flood discharge in the form of unit hydrograph analysis that uses linear reservoir cascade. In this study the result of GR4J method will be compared to another rainfall-runoff model, NRECA. This study uses gaged river basin, Citarum River Basin. Calibration uses the observed discharge data of Nanjung Station and based on the observed data of several rainfall stations inside the river basin. The result of this study shows that the first five years data has parameters quite similar with the second five years data. This shows rainfall and discharge patterns which are not changed significantly.**

Index Terms— **Rainfall-runoff, GR4J method, flood study, unit hydrograph, NRECA.**

I. Introduction

Most Hydrologists try to find better model simulation of stream flow by using rainfall-runoff modeling. One of the most outstanding achievements of the last three decades is the development of rainfall- runoff model that hydrologists are possible to use rainfall data comprehensively to predict the discharge of river. Rainfall-runoff modeling is often used because the discharge data of river is limited. Generally in a region, there is no AWLR (*Automatic Water Level Recording*). From available rainfall data, there are many modeling developed to predict inflow data for irrigation design or flood analysis.

Rainfall-runoff modeling usually involves statistic analysis to lengthen or predict data in the future. But there are many problems to build a structure model because rainfall-runoff model depends on the characteristic of river basin, and the theory of river basin characteristic generally is not yet accepted at hydrology science. Beside that, a model structure is related to many parameters. Too few parameters considered will give un accurate result and too many parameters will give some difficulties in the definition of parameters and model computation.

Several approaches can be used to build rainfall model into the discharge of river. These approaches are influenced by the main objective of a modeler in obtaining parameters. In a modeling, many parameters influence each other, for example: data input, the determination of model parameter values, modeling structure, etc. A possible way to improve flow simulation is to use the existing model structures as a starting point and then try to modify them. Today, most models are the result of a continuous development process, for example *Tank model* [10], *IHACRES* [12], *HBV* [7], *SMAR* [11], *TOPMODEL* [2], *Xinanjiang* [6] etc.

One of daily rainfall-runoff model is *GR4J* (*Genie Rural a 4 parametres Journalier*) which was developed by Perrin [9] and was proven having strong basic and efficient in a modeling. GR4J is developed from earlier model that is GR3J which is originally proposed by Edijatno and Mitchel [3] and then successfully improved by Nascimento [8] and Edijatno [4].

In this study, Citarum Hulu area is used. Citarum Hulu river basin is located in four kabupaten and cities at West Java Province. In Citarum river basin, there flows main river, called Citarum. It is a source for three reservoir, they are Saguling, Cirata and Jatiluhur. Water from those reservoirs is used for drinking water, agriculture, fishery, irrigation, power plant for the islands of Java and Bali. This study is to explain the investigation result to get optimum values from independent parameters of GR4J rainfall-runoff modeling at Citarum Hulu river basin.

II. Description of Citarum Hulu River Basin

Area of Citarum River Basin is 6,000 km^2 and area of Citarum Hulu River Basin is 1,771 km^2 (29.5%). It is located at lowland of Bandung. Most areas of Bandung are surrounded by volcanic quaternary mountain. Elevation between 656 m in west (near Curug Jompong) and 725 m at

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three other side (Cicalengka at east and Majalaya – Ciparay – Banjaran – Soreang at south) with slope between 0.5% and 1.5 %. Horizontal distance about 40 km at north – south and wide 15 km at west – east. The elevations of volcanic mountain at surrounding area are between 2000 m and 2600 m. In the west, Bandung is separated with Batujajar hill series.

Main Rivers flow intensively from south to north they are Citarum and Cipunegara. There are three multi purposes Dams at Citarum River, they are Saguling, Cirata, and Jatiluhur. They have a function to regulate river flow. Water from Citarum River intensively is used for drinking, power plant, industry, and irrigation.

III. Description of Model

GR4J model is rainfall runoff modeling which was based on four free parameters from daily rainfall data. The GR4J model is the last modified version of the GR3J model originally proposed by Edijatno and Michel [3] and then successively improved by Nascimento [8] and Edijatno [4]. GR4J optimize four free parameters, they are:

X_1 Maximum capacity of *production store* (mm)
X_2 *groundwater* exchange coefficient (mm)
X_3 maximum capacity of *routing store* (mm)
X_4 time peak ordinate of hydrograph unit *UH1* (day)

From earlier study which developed by Perrin et al [9], GR4J give better result than other rainfall runoff modeling such as *Tank model*, *IHACRES*, *HBV*, *SMAR*, *TOPMODEL*, *Xinanjiang* etc. From that study, Perrin et al [9] used 429 river basins in which have different climates included tropic climate (Brazil). So this modeling can be used for Indonesia that has tropic climate. The description of physical GR4J modeling from rainfall process to runoff at river is gives as following below.

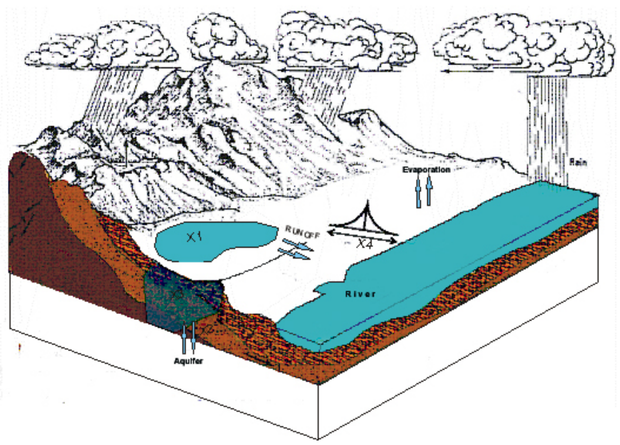

Fig. 1 – Physic Description of *Rainfall-Runoff* GR4J Model

Production Store (X_1) is storage in the surface of soil which can store rainfall. There are evapotranspiration and percolation in this storage. The capacity of this storage depends on the types of soil in that river basin. Few porosity of soil can make production store bigger. *Groundwater exchange coefficient* (X_2) is a function of groundwater exchange which influence routing store. When it has a negative value, then water enter to depth aquifer, when it has a positive value, then water exit from aquifer to storage (routing storage). *Routing storage* (X_3) is a mount of water which that can be storaged in soil porous. The value of this routing store depends to the type and the humidity of soil. *Time Peak (X_4)* is the time when the ordinate peak of flood hydrograph is created on GR4J modeling. The ordinate of this hydrograph is created from runoff, where 90 % of flow is slow flow that infiltrates into the ground and 10 % of flow is fast flow that flows on the soil surface.

In **Fig. 2**, the diagram of model calculation is shown and the steps of calculation are explained in Perrin [9] clearly.

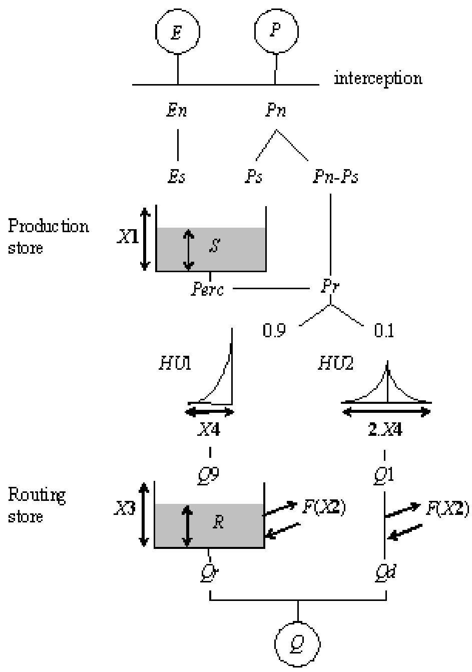

Fig. 2 – Model Diagram of *Rainfall-Runoff* GR4J [9]

IV. Model Calibration

In order to calibrate a model, the daily discharge data from Citarum River for 5 years is necessary to get four parameters of GR4J model where rainfall data processed by using MATLAB 7,0 program. By this program, the optimal parameter values will be obtained, hence deviation or error happens will be small.

Rainfall data used here is a regional rainfall produced using Thiessen Polygon from rainfall station in Citarum Hulu river basin. The Regional Rainfall of Citarum Hulu river basin is given below.

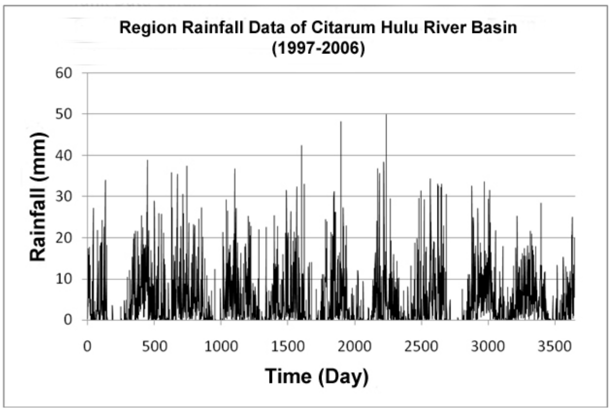

Fig. 3 – Rainfall Data of Citarum Hulu River Basin Region

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In the calculation of deviation, the method of Nash-Sutcliffe Coefficient (NS) is used for computing the change between square summation of observation data to modeling result data and the method of Relative Volume Error (RVE) for computing the volume of observation data with modeling result data [1].

General Equation of Nash-Sutcliffe Coefficient is given as

$$R^2 = 1 - \frac{MSE(Q)}{VAR(Q_{obs})} \quad (1)$$

and general equation of Relative Volume Error as

$$VE = \frac{\Sigma(Q_{sim} - Q_{obs})}{\Sigma(Q_{obs})} \quad (2)$$

V. Result

GR4J model is implemented on daily rainfall data for upstream Citarum river basin from 1997 until 2001. Then after obtaining the parameter values that give the smallest deviation values, model is validated using rainfall data from 2002 until 2006. Computation in modeling uses Matlab 7.0 program. Observed discharged data are 1825 (5 years). They are used as calibration data to get parameter values that produce the smallest deviation values. In this model, calibration value from Nash-Sutcliffe coefficient (NS) should be one and calibration value from Relative Volume Error (RVE) should be zero.

In order to get very optimum result, every parameter value needs to be evaluated by the selection of parameter that gives very optimum value. If new parameters from iteration produce better value, then the previous parameter will be replaced by the new one. Hence, if there is no better parameter, then the value is not changed.

Figure 4 and Figure 5 show the comparation of observed discharge data to discharge of modeling result computed using parameters values that give the smallest deviation.

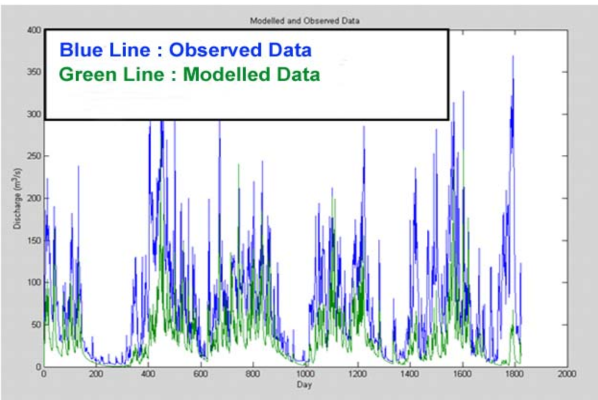

Fig. 4 Calibration Result

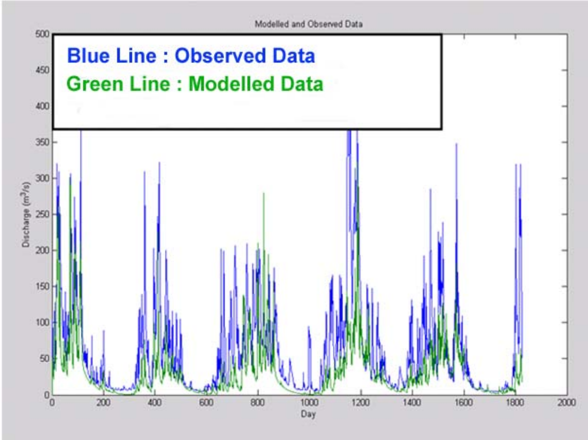

Fig. 5 Validation Result

Sensitivity analysis is investigated to obtain very optimum parameters by changing the parameters of X_1, X_2, X_3, and X_4 including the various of boundary value combination. The very optimum combination value will be as an input in the model. **Fig 6-9** show the sensitivity effect of parameters X_1, X_2, X_3, and X_4 to *NS* dan *RVE*.

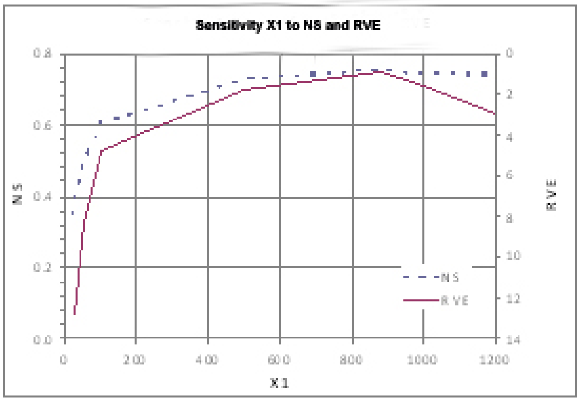

Fig 6 Sensitivity of X_1 to *NS* and *RVE*

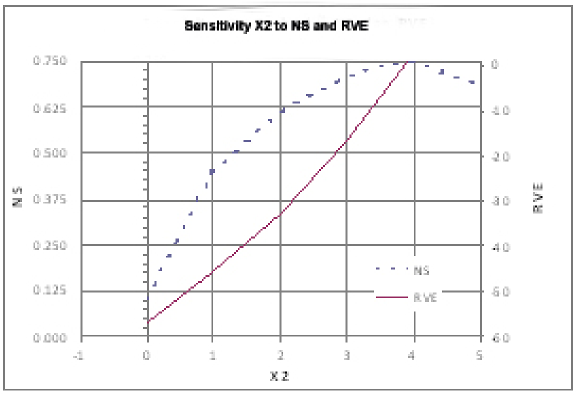

Fig 7 Sensitivity of X_2 to*NS* and *RVE*

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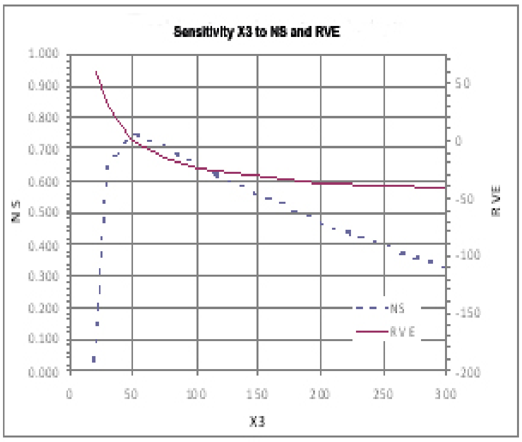

Fig 8 Sensitivity of X_3 to *NS* and *RVE*

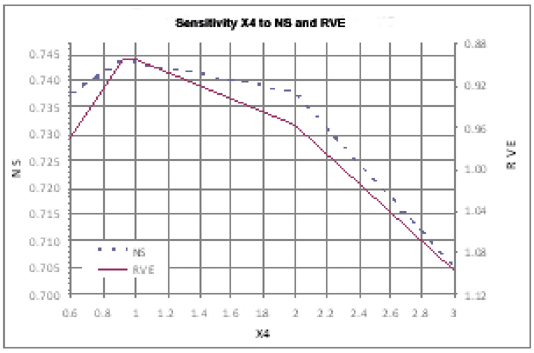

Fig 9 Sensitivity of X_3 to *NS* and *RVE*

Fig 6 - 9 show the optimum value of X_1 is 880.68, X_2 is 3.92, X_3 is 48.53, and X_4 is 0.93.

From this scheme, we can conclude the relation between parameter values and deviation values are obtained as shown in **Table 1**.

Tabel 1 Optimum Value of GR4J Parameters and Deviation

Coefficient		(1997-2001)		(2002-2006)	
		NS	RVE	NS	RVE
X1	880.68	0.75	0.96	0.73	11.08
X2	3.92				
X3	48.53				
X4	0.93				

Source : Analysis result

Table 1 shows that deviation using Nash-Sutcliffe coefficient gives the value of 0.75 and model validation gives the value of 0.73. This shows that calibration and validation data have the same patterns. Nash-Sutcliffe describes the similar value of discharge from modeling result compared to observed discharge. If the value is close to one, then the discharge of the modeling result has a similar pattern with the observed discharge. Beside the deviation value has a similar pattern, the deviation value has to satisfy a limitation value. For that reason, the deviation computation method to compute error volume is used. In this research, RVE (Relative Volume Error) method is used. By the limitation of two types method, Nash-Sutcliffe coefficient and Relative Volume Error (RVE), GR4J parameters can be obtained that produce very optimum deviation values. **Table 1** shows that RVE value is 0.96 % for calibration and 11.08 % for validation.

Linear Reservoir Cascade [5] is used in this study to analyze hydrograph unit. From modeling result, the parameter of X_4 (peak time of flood) is about 0.925 day or 22.2 hour. In this hydrograph unit, hourly rainfall data from previous investigation [5] is used. **Fig 10** shows computation result compared to observed hydrograph unit and the computation using *linear cascade reservoir method* with *Nakayasu, Snyder, and SCS* methods.

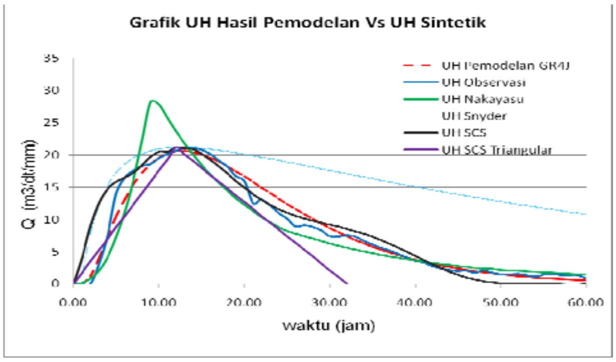

Fig 10 Hydrograf Unit of Modeling vs Others Hydrograf Unit

Fig. 10 shows the hydrograph unit of modeling gives good result compared to the observed hydrograph unit. It has the same base time and peak time as the observed hydrograph unit.

In next investigation, GR4J modeling result is compared to NRECA model. The optimum values that give the smallest deviation values are given in **Table 2** following below.

Table 2 Optimum Values of NRECA Parameters and Deviation

Coefficient		(1997-2001)		(2002-2006)	
		NS	RVE	NS	RVE
PSUB	1.08	0.78	25.61	0.74	15.08
GWF	0.16				
SM STOR	3224.22				
GW STOR	37.22				

Source : Analysis result

Table 2 shows NRECA model gives the deviation value of RVE greater than 15 percent. This happens because NRECA model developed for monthly rainfall data. So, for daily rainfall data, GR4J will give better result compared to NRECA.

VI. Conclusion

From the investigation above, we can conclude as following below:

- In a modeling using GR4J, sensitivity analysis is needed to know the effect of parameters to modeling result, hence giving modeling result close to real condition.
- From investigation result, the value of NS on validation of model is the same as NS on the calibration of model, hence it can be concluded that the first five years data has the same parameters as the second five years. This is caused the rainfall and discharge data recording are done consistently enough.
- From the investigation, the parameter of Production Capacity Store (X_1) is 880.68 mm, Groundwater Coefficient (X_2) is 3.92, Routing Store Capacity (X_3) is

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48.53 mm, and Peak Time of Hydrograph Unit Ordinate (X_4) is 0.93 day.

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