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Design of Peak Discharge Model Based on the Watershed Shape Factor

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ABSTRACT

This paper intended to investigate the characteristic of observed hydrograph in each watershed and all of watersheds in South Sulawesi Province. However, the main aim of this study is to formulate parameter model of Synthetic Unit Hydrograph such as Peak Discharge (Qp) and Time to Peak (Tp) as the function of watershed shape (FD). Formulation of peak discharge and time to peak in this study are based on the two physical characteristics watershed such as watershed round (K) and area number of watershed (A). Analysis of modeling uses regression method with some alternatives. Result indicates that factor of watershed shape (FD) has strong linear relation to the parameter of synthetic unit hydrograph
KEYWORDS: peak discharge, time to peak, watershed shape factor

INTRODUCTION

Characteristic of watershed is as the most important scheme in watershed management system [1]. In a hydrological system of watershed, there will be seen the variety of components such as physical component of watershed, vegetation, type of soil, and flow that dynamically interaction among each other [2]. If there is carried out the system approach, however, it will give big opportunity to be carried out quantitatively rational approach. Model is as the simplicity of a system which only illustrates some aspects of a system and it has not to reflect the whole process being happened. Representative hydrological system always involves two different systems such as system of prototype and model. Prototype system is as really natural system, which is in hydrology is known as watershed. One of the efforts in system approach that is frequently used is practical hydrology which generally uses empirical approach such as by investigating the correlation among the parameters without finding the explanation of physical rule or the relation among the parameters, so it is known as black box [3]. The lack of availability of hydrograph data is as the constraint for water structure design. Unavailability of data can be caused by the recorder is damaged, the official is careless, the data is damaged, so it is not read or missing [4] or of course the recorder has not been installed. These constraints cause the synthetic unit hydrograph (SUH) can give the important information for the evaluation need, the safety of hydraulic structure, and the risk that based on planning [5][6].

Factor of watershed shape (FD) gives good hope to be used and developed synthetic unit hydrograph (SUH) modelling in further.[7]. Factor of watershed shape is as the physical characteristic of watershed and is defined as the ratio value between watershed round (km) towards the area number of watershed (km^2). Therefore, it can be built the parameter model of synthetic unit hydrograph (HSS) such as peak discharge (Qp) and time to peak (Tp) which is as the function of watershed shape. For ideal cases, there is necessary to be carried out the calibration of model parameters based on the characteristic of watershed [8][9]. One of the techniques for developing synthetic unit hydrograph (SUH) is based on regression analysis [10]. Statistic of regression is one of the manners to analyse hydrological model [11]. This manner is used because watershed has the such complexity and heterogeneity, so it is very difficult (even it is almost impossible) to know the parameters detailed (in the meaning of the effect of a parameter to the one of components processing). In further, result of accurate discharge estimation may be difficult to be hoped because the transformation of rainfall into flow in watershed is as the related natural process.

The objective of this study is to formulate peak discharge (Qp) and time to peak (Tp) of synthetic unit hydrograph (SUH) in South Sulawesi Province as the function of waterhed shape factor. It is hoped to produce the relatively simple mathematical model and without calibration of some parameters.

MATERIALS AND METHODS

Research location

This research is conducted in river area of Walanae-Cenranae which includes 39 watersheds. Map of location is as in Figure 1 below.

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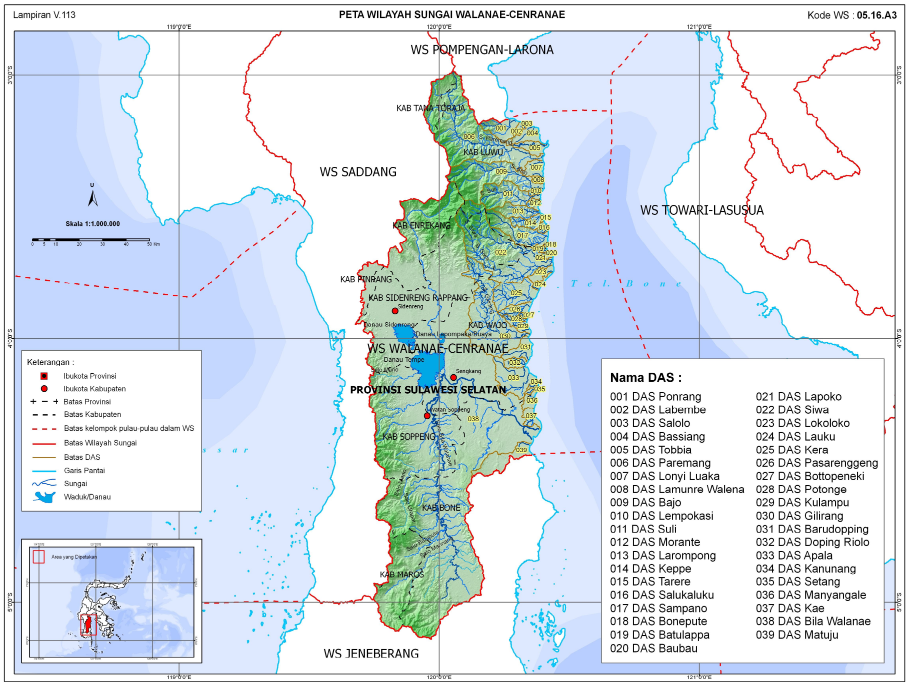

Figure 1 River area of Walanae-Cenranae

There is found observed unit hydrograph in each watershed and the observed unit hydrograph for all of the watersheds is obtained by averaging the ordinates of observed unit hydrograph in each watershed in the same time, peak discharge, and time to peak by following the steps as follow:

1. To analyse the mean of time to peak and peak discharge.
2. To analyse the dimensionless observed unit hydrograph (t/Tp and Q/Qp) for each watershed.
3. To analyse the mean of dimensionless observed unit hydrograph.
4. To analyse the mean of observed uniy hydrograph.

Modelling of peak discharge and time to peak

Modelling of peak discharge and time to peak in this research is based on the two physical characteristic of watershed such as watershed round (K) and area number of watershed (A). Analysis of modelling uses regression method with some alternatives based on independence variables being used. In this analysis, peak discharge (Qp) and time to peak (Tp) are as in independent variables, however, the physical characteristic of watershed such as watershed round (K) and area number of watershed (A) as the independent variables. Therefore, it will be produced much alternatives. The selection of model is based on the rational model with the criteria as follow [12]:

1. Dependent and independent variables have strong enough correlation by the correlation coefficient (r) between 0.60 and 1.00 and has the maximum determination coefficient (R^2).
2. The value of standard error estimation (SEY) is minimum
3. There is the significant effect between dependent and independent in regression model and it is used F-test
4. Deviation test on selected hydrograph model that is baed on the observed unit hydrograph by attending the low enough of deviation level.

Data collection

The criteria of sample selecting or data for each watershed are as follow;

1. There is available hydrometric station (Automatic Water Level Recorder) and in or surrounded watershed there is automatic rainfall recorder (ARR)
2. Physical factor of watershed has relatively homogeny of soil type. Therefore the shape of hydrograph is relatively similar.
3. Hydrograph has to be selected of a single peak one, which is caused by hourly rainfall. Rainfall and hydrograph period have to be the same. If there are some hydrographs which are fitted to the condition, so it will be carried out the averaging of hydrograph with the note that the hydrograph is remain to represent the maximum peak for the watershed

The secondary data that are needed are as follow:

1. Watershed map with minimum scale of 1: 500,000.
2. State hydrograph from AWLR station is included the rating curve.
3. Hourly rainfall from rainfall manual station for watershed that is not available ARR
4. Data of river slope and forest area number is fitted with period of observed hydrograph and rainfall data.

The same factor of watershed has the strong relation, in the meaning of that every factor can be seen as a sub system and each of them has the specific response characteristic for a certain input, and the change to sub system response characteristic is effected to the related characteristic with the other sub system. Therefore, the hydrological system is as a complex system [11]. There are some characteristics of watershed as follow [11]:

a. Watershed with bird feathers shape:
   This watershed is marked by the route in left and right side of main river where the affluent flow to the main river. This watershed has small peak discharge because time to flood peak from the affluent are different and the flood will happen in rather long time.
b. Watershed with radial shape
   Radial watershed is formed as fan or circle where the affluent radially concentrate to a point with the shape like that. Watershed with this shape has small flood in near meeting point of the affluent.
c. Watershed with parallel shape:
   Parallel watershed has the shape where two routes of catchment area unite in the downstream. Flood will happen in the downstream as the meeting point of rivers.
d. Watershed with complex shape:
   Complex watershed is as the union of two or more bird feathers, radial, and paralel watersheds. In Indonesia, this shape is very seldom to be met.

Observed unit hydrograph

Observed hydrograph is as flood hydrograph that is as discharge hydrograph such as the relation curve between discharge and time which is obtained from the conversion of water level hydrograph with the general equation as follow [12]:

$$Q = c\,H^{m} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

Note

Q = discharge (m^3/s}
H = water level depth (m)
c, m = constant of direct calibration in water level recorder

Unit hydrograph has the basic principals and based on the idea of [11]

1. Unit hydrograph is caused by the rainfall which as averagely distribution in the whole watershed (evenly spatial distribution)
2. Unit hydrograph is caused by the rainfall which is averagely during the certain time (constant intensity)
3. Ordinates of unit hydrograph is balanced with rainfall volume (linear system)'
4. Response of watershed is not depended on happened time of rainfall input (time invariant)'
5. Time to rise of unit hydrograph peak discharge until the ending of direct run-off hydrograph is always remained (it does not depended on the level capacity of rainfall intensity)

Mathematical modelling

In hydrological process, there are some related parameters, so in practice there is frequently carried out the effort to obtain the functional relation between an independent parameter (y) and some dependent (process) parameters (x) as the physical factors of watershed. For this case, it is used multiple regressions [11] as follow:

$$y = a_0 + a_1 * x_1 + a_2 * x_2 + \ldots\ldots + a_i * x_i + error \ \ldots\ldots\ldots (2)$$

Note

y = dependent variable
a_0, a_1 … etc. = coefficient
x = independent variable
error = error

To anticipate the residual variables are not the same for the whole observation, so it is needed to be carried out the logarithmic transformation. Mulyantari [14] presented that y has to be zero if the physical parameter of watershed is the same as zero. Therefore, it is needed the logarithmic transformation (Y – ln y and X = ln x) so:

$$Y = e^{a0} . X_1^{a1} . X_2^{a2} . X_3^{a3} . \ldots\ldots X_i^{ai} \quad \ldots\ldots\ldots\ldots \quad (3)$$

RESULTS AND DISCUSSION

Observed unit hydrograph

Based on the observed flood hydrograph, there is analysed observed unit hydrograph for each watershed by using Collins Method. Data of flood hydrograph (from AWLR analysis) which is used for differentiating observed unit hydrograph for each watershed is selected for the highest one and single peak. Time period of the AWLR data (flood hydrograph data) have to be the same with ARR data (hourly rainfall data) for each watershed. However, there is not necessary in homogenous time among watersheds because the objective of unit hydrograph analysis is for high flow. Therefore, data for analysis must have the extreme as optimal as possible such as by taking the food hydrograph with the highest peak in each watershed.

Physical parameters watershed which is affected the model

By the peak discharge (Qp) and time to peak as the dependent variables and watershed shape factors such as watershed around (K) and area number of watershed (A) as the independent variables, it will be produced some alternatives regression equation. The selection of model is based on the rational model and the criteria rule as above.

Asdak [15] said that the longer length of river, the distance between rainfall drop location and outlet bocame bigger, so rainfall time to reach outlet was longer and it would reduce peak discharge. It is caused by the longer length of river, it will give more chance for rainfall to flow as run-off so the quantity of water losses is bigger. Based on the expression as above, it is meant that the longer length of river will produce flood peak discharge is smaller. Of course it is true as being said by Asdak [15] that the longer length of river would produce more water losses, but the percentage of water losses is very small if it is compared with flood peak discharge (high flow session). In addition, the longer length of river will give the chance of rainfall is remained in river body, in the meaning of the possibility to overflow is very small. Therefore, for the length of river that is relatively long, it is very possible that almost the whole rainfall will reach the outlet which will rise the flood peak discharge.

The bigger watershed will cause the longer time of run-off to reach outlet, so time base of hydrograph (time of run-off) becomes longer and peak discharge will be reducing [11]. This problem is related with the wider watershed will cause rainfall distribution is not in averaged. This characteristic is opposite with the concept that was presented by Sherman (1932) [11]. He presented that unit hydrograph is as direct run-off hydrograph which is produced by effective rainfall that was averaged distributed in watershed. Watershed size determines tha maximum base of unit hydrograph using. The certain size has not really been remained, but according to Soemarto [16], it was remained the maximum size of watershed was 5,000 km^2 while it has been carried out in this research. Therefore, if there is happened averaged rainfall in a watershed, so the bigger watershed will cause run-off fast reach the outlet and it will rise flood peak discharge.

Modelling of peak discharge (Qp) and time to peak (Tp)

Factor of watershed shape (FD) is defined as the ratio between watershed round (K) and area number of watershed (A) (km/km^2), Factor of watershed shape is used as single variable in modelling of synthetic unit hydrograph parameters. Modelling of peak discharge parameter (Qp) with independent variable such as factor of watershed shape (FD) use statistical technique of multiple regression. If the initial result of modelling has not satisfied, then it is carried out the data transformation into natural logarithmic and invers data, and if there is not obtained the good result too, then it is continued with homogeneity test or abnormality test of data that may be has the maximum deviation.

Modelling process of time to peak parameters is the same as the steps of peak discharge modelling. The best parameter modelling of selected synthetic unit hydrograph (HSS) is due to the criteria of the highest determination coefficient that is calibrated to observed hydrograph data. The calibration test is intended to know the =reliability level of model to predict the parameter values of synthetic unit hydrograph (HSS).

CONCLUSION

Based on the analysis as above, it is concluded as follow:

1. Modelling of synthetic unit hydrograph (HSS) parameter with selected single variable and due to the criteria of determination coefficient has high enough of sensitivity.
2. Factor of watershed shape (FD) has strong linier relation with the parameter of synthetic unit hydrograph (SUH)

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