The comparative study of peak discharge at Ngotok watershed by using the method of SCS, Snyder and Nakayasu for flood control needs

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Abstract. Flood problems often hit the Ngotok River watershed every year. The problem of flooding is generally caused by changes in land use and a decrease in river functions in the Ngotok River watershed area as well as frequent back water from rivers which empties into Brantas River when experiencing maximum discharge. For that reason, a comparative study of peak flood discharge needs to be done because there is no research on flood control. So that research is conducted on the analysis of synthetic unit hydrograph models. The synthetic unit hydrograph method used is SCS, Snyder, and Nakayasu. Rainfall data used is data from 1998-2016 from 14 rain stations in the Ngotok River watershed. The Thiessen polygon method is used to determine the amount of rain scattered in the Ngotok River watershed. The average rainfall in the Ngotok River watershed in the period 1998-2016 was 97.05 mm. In the modeling phase, the sub-catchment division of the watershed is carried out by dividing it into 5 sub-catchments. The modeling results using the SCS, Snyder, and Nakayasu methods show the amount of discharge for the return period of 2 years, 5 years, 10 years, 20 years, 50 years, 100 years, and 200 years which varies. AWLR data approaching the modeling results are 2014 data. The hydrograph calibration results for the SCS method with a 25 year return period are 0.88, for the Snyder method with a 25 year return period of 0.74, and the Nakayasu method with a 25 year return period of 0.43. Thus the SCS hydrograph approaches the existing hydrograph model based on the AWLR data that exists and is following the observations during the population survey.

1. Introduction
Floods in the Ngotok watershed occur almost every year during the rainy season [7]. The change in land use and the decline in river functions in the Ngotok watershed causes frequent flooding. From the impact and the absence of research on flood control, it is necessary to research the analysis of synthetic unit hydrograph models [21]. The synthetic unit hydrograph method used is SCS, Snyder, and Nakayasu [1]. By using these three synthetic unit hydrograph methods, we can see the comparison of the peak flood discharge values that occur in the Ngotok watershed by reading the graph of the hydrograph of each method [16]. The use of SCS, Snyder, and Nakayasu methods aims to determine which method is close to or following the characteristics of the Ngotok watershed [20].

Idfi defines Ngotok River watershed is administratively located in Mojokerto Regency, Mojokerto City, and Jombang Regency. Ngotok River is one of the rivers that functions as a collector of several...
rivers such as Tembelang River, Sambong River, Jombang Kulon River, Jombang Wetan River, Bening River, Sewedang River, Gunting River, Balong River and Brangkal River [7]. The length of Ngotok River is approximately 26.50 km with watershed coverage covering an area of ± 722 km².

The aim of this research is expected to help the government in efforts to control flooding. With this study, it can be seen the peak flood discharge in the Ngotok River watershed. While for researches, the results of the research are expected to add a contribution to researchers and can be a reference for further research [17].

2. Research method

2.1 Research location
The study was conducted in the location of the Ngotok River watershed (Figure 1) that passes through Mojokerto Regency, Mojokerto City, and Jombang Regency [7].

![Figure 1. Research location.](image)

2.2 Rainfall data analysis
The rainfall data obtained is point rain data, so that it can be used for further calculations, the point rain must be changed to regional rainfall by making Thiesen Polygon [2]. The equation of Thiessen Polygon is:

\[ P = \frac{P_1 + P_2 + P_3 + ... + P_n}{n} \]  

(1)
Where:

\( P \) : Daily Maximum Rainfall (mm)

\( P_1, P_2, ... P_n \) : Daily Maximum Rainfall at Rainfall point gauge (mm)

\( n \) : point gauge

In order to obtain the best frequency distribution, the existing data were analyzed first with 4 kinds of probability distribution methods, Gumbel, Normal, Log-Normal, and Pearson Log Type III [18][5]. Test probability distribution by using two methods, namely, Chi-square and Smirnov-Kolmogorof methods [16][4]. The distribution of sub-catchment watersheds into 5 sub-catchments is carried out before the modeling phase. Then perform data modeling rain with SCS, Snyder, and Nakayasu methods using software HEC-HMS 4.0 and Microsoft Excel 2007 [19].

2.3 Modeling input parameter

Before doing modeling with HEC-HMS 4.0 software, there are several parameters that must be calculated first [3]. The calculated parameters affect the output results from the modeling of the SCS and Snyder methods [11][12]. The parameters calculated are curve number (CN), impervious area, initial abstraction, watershed slope, river slope, and time lag for each sub-watershed [10][6]. The following are the formulas used for calculating the modeling input parameters. The equation of CN is

\[
CN(I) = \frac{4.2CN(II)}{10 - 0.058CN(II)}
\]

2.4 Calibration model

Model calibration can be done by comparing the hydrograph of the model with the observed hydrograph. According to Nash [13], as for the method for determining the model calibration criteria for the results of observations in the field as follows:

\[
EI = 1 - \frac{\sum_{i=1}^{n}(Q_o - Q_s)^2}{\sum_{i=1}^{n}(Q_o - Q_a)^2}
\]

Where:

\( EI \) = efficiency index

\( Q_o \) = measurement discharge (observation)

\( Q_s \) = Discharge simulation

\( Q_a \) = average discharge measurement

The value of EI according to the Nash method is divided into three categories: low accuracy level if \( EI \leq 0.50 \), moderate accuracy level if \( 0.50 < EI < 0.70 \), and high accuracy level if \( EI \geq 0 \) [9].

3. Result and discussion

3.1 Rainfall data analysis and sub catchment area

The rainfall data used is rainfall data from 1998-2016. From the calculation results, the average rainfall is 97.05 mm. The amount for each year is presented in the table 1.

Rainfall frequency analysis was carried out using the Log Pearson Type III method. From the results of the calculation of rainfall design with the Pearson Type III Log method obtained the value of the amount of rain based on the return period of rain [14][8]. The sub-catchment of the watershed is divided into 5 parts based on the topography and its constituent rivers. The value of the amount of rain based on the return period of rain and subcatchment area is presented in the table below.
Table 1. Average rainfall of the ngotok river watershed.

| Year | Rainfall (mm) | Year | Rainfall (mm) |
|------|---------------|------|---------------|
| 1998 | 84.34         | 2008 | 76.33         |
| 1999 | 85.52         | 2009 | 85.34         |
| 2000 | 119.82        | 2010 | 100.15        |
| 2001 | 98.58         | 2011 | 101.82        |
| 2002 | 90.16         | 2012 | 109.26        |
| 2003 | 105.31        | 2013 | 115.43        |
| 2004 | 120.39        | 2014 | 85.26         |
| 2005 | 80.73         | 2015 | 87.61         |
| 2006 | 82.02         | 2016 | 119.94        |
| 2007 | 95.94         |      |               |

Table 2. Rainfall plan calculation.

| Return Period (year) | Xt (mm) |
|----------------------|---------|
| 2                    | 95.440  |
| 5                    | 108.518 |
| 10                   | 116.476 |
| 20                   | 124.330 |
| 25                   | 125.964 |
| 50                   | 132.706 |
| 100                  | 139.220 |
| 200                  | 145.593 |

Table 3. Division of watershed sub catchment.

| Sub Catchment | Name of River     | Area (km²) |
|---------------|-------------------|------------|
| 1             | Tembelang         | 127.854    |
|               | Sambong           |            |
|               | Jombang Kulon     |            |
|               | Jombang Wetan     |            |
|               | Bening            |            |
| 2             | Trawasan          | 112.954    |
|               | Sebani Drainage System |  |
| 3             | Gunting           | 241.159    |
|               | Balong            |            |
|               | Panemon           |            |
| 4             | Prajurit Kulon Drainage System | 44.850    |
| 5             | System            | 195.182    |

3.2 Calculation of model input parameter

The result of model input parameter is presented in the table below.
Table 4. Curve number (CN).

| Sub | CN  |
|-----|-----|
| 1   | 80.75 |
| 2   | 79.67 |
| 3   | 79.44 |
| 4   | 80.49 |
| 5   | 79.04 |

Table 5. Impervious area and initial abstraction.

| Sub | Impervious (%) | Initial Abstraction |
|-----|----------------|--------------------|
| 1   | 10.10          | 0.477              |
| 2   | 8.83           | 0.511              |
| 3   | 8.55           | 0.518              |
| 4   | 14.45          | 0.485              |
| 5   | 6.77           | 0.530              |

Table 6. River and watershed slope.

| Sub | River Slope (%) | Watershed Slope (%) |
|-----|-----------------|---------------------|
| 1   | 6.59            | 4.50                |
| 2   | 5.83            | 3.96                |
| 3   | 5.08            | 3.82                |
| 4   | 6.26            | 4.30                |
| 5   | 5.33            | 4.64                |

Table 7. Time lag.

| Sub | Watershed Time Lag | River Time Lag |
|-----|--------------------|----------------|
|     | Hour   | Minute | Hour   | Minute |
| 1   | 8.872  | 532.338| 15.811 | 948.679|
| 2   | 8.532  | 511.892| 17.457 | 1047.390|
| 3   | 11.198 | 671.894| 26.794 | 1607.615|
| 4   | 4.667  | 280.009| 13.758 | 825.508|
| 5   | 9.477  | 568.602| 24.002 | 1440.141|

3.3 Rainfall run off modelling result

3.3.1 SCS method. From the computational results, the final results are in the form of a graph of the hydrograph model and peak flood discharge data that occur based on certain returns in each sub watershed.

Figure 2. SCS Hydrograph chart return period 25 years of sub watershed 3.
Table 8. Recapitulation of SCS method modeling results.

| Return Period (year) | Flood Duration (hour) | Sub 1 Peak Discharge (m$^3$/sec) | Flood Duration (hour) | Sub 2 Peak Discharge (m$^3$/sec) | Flood Duration (hour) | Sub 3 Peak Discharge (m$^3$/sec) | Flood Duration (hour) | Sub 4 Peak Discharge (m$^3$/sec) | Flood Duration (hour) | Sub 5 Peak Discharge (m$^3$/sec) |
|----------------------|-----------------------|----------------------------------|-----------------------|----------------------------------|-----------------------|----------------------------------|-----------------------|----------------------------------|-----------------------|----------------------------------|
| 2                    | 64                    | 124.2                            | 62                    | 108.1                            | 68                    | 196.4                            | 44                    | 63.9                             | 67                    | 172.1                            |
| 5                    | 64                    | 147.6                            | 62                    | 129.9                            | 68                    | 233.9                            | 44                    | 75.9                             | 68                    | 205.6                            |
| 10                   | 64                    | 162.1                            | 63                    | 142.8                            | 68                    | 257.2                            | 44                    | 83.3                             | 68                    | 226.5                            |
| 20                   | 64                    | 176.6                            | 63                    | 155.8                            | 68                    | 280.4                            | 45                    | 90.7                             | 68                    | 247.3                            |
| 25                   | 64                    | 179.7                            | 63                    | 158.5                            | 68                    | 285.3                            | 45                    | 92.3                             | 68                    | 251.7                            |
| 50                   | 65                    | 192.2                            | 63                    | 169.7                            | 68                    | 305.5                            | 45                    | 98.7                             | 68                    | 269.8                            |
| 100                  | 66                    | 204.5                            | 63                    | 180.7                            | 69                    | 325.2                            | 45                    | 105.0                            | 68                    | 287.4                            |
| 200                  | 66                    | 216.5                            | 63                    | 191.5                            | 69                    | 344.5                            | 45                    | 111.1                            | 68                    | 304.8                            |

3.3.2 Snyder method. From the computational results, the final results are in the form of a graph of the hydrograph model and peak flood discharge data that occur based on certain returns in each sub watershed.

Table 9. Recapitulation of Snyder method modeling results.

| Return Period (year) | Flood Duration (hour) | Sub 1 Peak Discharge (m$^3$/sec) | Flood Duration (hour) | Sub 2 Peak Discharge (m$^3$/sec) | Flood Duration (hour) | Sub 3 Peak Discharge (m$^3$/sec) | Flood Duration (hour) | Sub 4 Peak Discharge (m$^3$/sec) | Flood Duration (hour) | Sub 5 Peak Discharge (m$^3$/sec) |
|----------------------|-----------------------|----------------------------------|-----------------------|----------------------------------|-----------------------|----------------------------------|-----------------------|----------------------------------|-----------------------|----------------------------------|
| 2                    | 40                    | 141.9                            | 40                    | 123.3                            | 44                    | 223.4                            | 32                    | 74.8                             | 42                    | 194.3                            |
| 5                    | 40                    | 168.5                            | 40                    | 146.7                            | 44                    | 266.0                            | 32                    | 88.7                             | 42                    | 231.9                            |
| 10                   | 40                    | 185.0                            | 40                    | 161.3                            | 44                    | 292.5                            | 32                    | 97.3                             | 42                    | 255.2                            |
| 20                   | 40                    | 201.5                            | 40                    | 176.0                            | 44                    | 318.9                            | 32                    | 105.9                            | 42                    | 278.5                            |
| 25                   | 40                    | 205.0                            | 40                    | 179.1                            | 44                    | 324.4                            | 32                    | 107.7                            | 42                    | 283.3                            |
| 50                   | 40                    | 219.4                            | 40                    | 191.8                            | 44                    | 347.3                            | 32                    | 115.1                            | 42                    | 303.6                            |
| 100                  | 40                    | 233.3                            | 40                    | 204.2                            | 44                    | 369.7                            | 32                    | 122.4                            | 42                    | 323.3                            |
| 200                  | 40                    | 247.1                            | 40                    | 216.3                            | 44                    | 391.7                            | 32                    | 129.5                            | 42                    | 342.7                            |

3.3.3 Nakayasu method. From the computational results, the final results are in the form of a graph of the hydrograph model and peak flood discharge data that occur based on certain returns in each sub watershed.
Table 10. Recapitulation of Nakayasu method modeling results.

| Return Period (year) | Flood Duration (hour) | Sub 1 Peak Discharge (m³/sec) | Flood Duration (hour) | Sub 2 Peak Discharge (m³/sec) | Flood Duration (hour) | Sub 3 Peak Discharge (m³/sec) | Flood Duration (hour) | Sub 4 Peak Discharge (m³/sec) | Flood Duration (hour) | Sub 5 Peak Discharge (m³/sec) |
|----------------------|-----------------------|------------------------------|-----------------------|-------------------------------|-----------------------|-------------------------------|-----------------------|-------------------------------|-----------------------|-------------------------------|
| 2                    | 86                    | 194.9                        | 88                    | 168.6                         | 96                    | 255.1                         | 68                    | 74.9                          | 96                    | 226.9                          |
| 5                    | 88                    | 239.1                        | 90                    | 206.8                         | 96                    | 313.2                         | 69                    | 92.0                          | 96                    | 278.4                          |
| 10                   | 89                    | 266.6                        | 91                    | 230.5                         | 96                    | 349.1                         | 70                    | 102.5                         | 96                    | 310.4                          |
| 20                   | 90                    | 293.9                        | 92                    | 254.2                         | 96                    | 385.1                         | 71                    | 113.0                         | 96                    | 342.3                          |
| 25                   | 90                    | 299.7                        | 92                    | 259.1                         | 96                    | 392.6                         | 71                    | 115.3                         | 96                    | 348.9                          |
| 50                   | 91                    | 323.5                        | 93                    | 279.7                         | 96                    | 423.9                         | 71                    | 124.4                         | 96                    | 376.7                          |
| 100                  | 91                    | 346.6                        | 93                    | 299.7                         | 96                    | 454.3                         | 72                    | 133.3                         | 96                    | 403.7                          |
| 200                  | 92                    | 369.5                        | 94                    | 319.5                         | 96                    | 484.3                         | 72                    | 142.1                         | 97                    | 430.3                          |

Figure 4. Nakayasu hydrograph chart return period 25 years of sub watershed 3.

3.3.4 Calibration model. The calibration process relies on AWLR (Automatic Water Level Recorder) data located in the Gunting River (Sub Watershed 3). The results of the hydrograph graph of the AWLR data are compared with the results of the modeling hydrograph. In addition to using AWLR data, calibration also considers the survey results of residents living in the Ngotok River watershed area. The model used is a model hydrograph in the sub basins Gunting River with a return period of 25 years and data AWLR used was 2014. From the calculation using the formula Nash shows a model with a 25 year SCS method, the calibration value is 0.88. The Snyder method gives the calibration value is 0.74 and the Nakayasu method gives the calibration value is 0.43. The result of the comparison hydrograph is presented in figure below.

Figure 5. The comparison of hydrograph chart return period 25 years of sub watershed 3.
4. Conclusion
Based on the formulation of the problem, the results, and discussion that the hydrograph model on Ngotok watershed has been described previously, it can be simulated using the SCS, Snyder, and Nakayasu method. The hydrograph model that occurs when compared or calibrated with the field hydrograph model is quite significant. For the SCS method with a 25 year return period, the suitability of the calibration has a high level of accuracy of 0.88. For the Snyder method with a 25 year return period, the suitability of the calibration has a high level of accuracy of 0.74. Whereas for the Nakayasu method with a 25 year return period, the suitability of the calibration has a low level of accuracy of 0.43. Models that approach existing or existing conditions based on existing calibration data are models with the SCS method with a 25 year return period. The SCS method for 25 years return produces a peak discharge of 285.30 m$^3$/s and a peak existing discharge of 255.99 m$^3$/s.

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