Hydrological modelling of Air Bengkulu river watershed in Indonesia using SUH and HEC-HMS models

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Abstract. The purpose of this research is to develop a synthetic unit hydrograph model to determine the most suitable model for predicting peak discharge in the Air Bengkulu Watershed. Rainfall data were obtained from the Bengkulu Province Meteorology, Climatology, Geophysics Agency, from 2000 to 2019 year. The Synthetic Unit Hydrograph (SUH) method used to estimate the discharge in the Air Bengkulu Watershed is the synthetic unit hydrograph, namely Snyder, ITB-1 and ITB-2, in addition to that also used HEC-HMS software. The estimation results of peak discharge and peak time for each type of hydrograph in the Air Bengkulu watershed are: Peak Discharge of Snyder 1,302.76 m$^3$/s with Peak Time 6,596 hours, Peak Discharge of ITB-1 2,395.50 m$^3$/s with Peak Time of 4,705 hours, Peak Discharge of ITB-2 2,165.857 m$^3$/s with Peak Time of 6,341 hours. It can be concluded that the synthetic unit hydrograph has been able to estimate the peak discharge based on the time sequence of a rain event, so there is a relationship between peak time and peak discharge. The peak and peak times obtained from the output of each method are different, so more in-depth research is needed if this model is to be used as a basis for decision making.

Keywords: synthetic unit hydrograph, Air Bengkulu, ITB-1, ITB-2, Snyder, HEC-HMS

1. Introduction
Decision making in water resources management requires information about the discharge value [1]. The required discharge is design discharge or peak discharge [2-4]. There are various methods to get the peak discharge value [5-8]. Each method requires different data. In general, the peak discharge value calculated using different methods will result in different values, although the difference is not too big.

In general, the choice of method is based on the availability of data on the location of the activity plan, so that adequate knowledge of the location of the planned activity, the process of rainfall-runoff relationship is very important to estimate the amount of discharge generated in a particular catchment area.

Traditional techniques for planning flood estimation include rational methods, empirical methods, flood frequency methods, unit hydrograph techniques, and watershed modelling [1]. Unit hydrograph techniques and watershed models can be used to estimate the planned flood hydrograph in addition to the magnitude of the planned flood peak. The hydrological response of a watershed to precipitation can be estimated using hydrological modelling. The choice of model depends on the characteristics of the watershed and the purpose of carrying out the hydrological prediction.
The first researcher to introduce the concept of synthetic unit hydrograph (SUH) was Sherman in 1932 [1-4]. The next researchers who developed HSS were Snyder (1938) [9], Nakayasu (1940), Gray (1961) and Soil Conservation Service (1972). The development of synthetic unit hydrographs in Indonesia was carried out by Harto (1985) [5], Natakusumah (1990) [6], Lasidi, et al. (2003) [7], and Limantara (2009) [8].

SUH can be used to estimate peak discharge (Qp), peak time (Tp) in a watershed that does not have an automatic rainfall gauge and an automatic water level meter. SUH has been widely used by hydrologists to estimate flood designs in data-poor watersheds, the output of this method is able to provide an estimated discharge value that is close to the measured discharge value. In Indonesia, synthetic unit hydrograph analysis methods commonly used include the Snyder-Alexeyev, Snyder-SCS, Nakayasu and GAMA-1, GAMA-2, ITB-1, ITB-2 methods and others [3].

The Air Bengkulu Watershed is one of the watersheds in Indonesia that often experiences flooding due to overflowing rivers, namely the Air Bengkulu River. In the Air Bengkulu Watershed, there is no complete automatic water level measurement tool so that the prediction of flood discharge can only be done using SUH.

However, each SUH provides unequal discharge forecast results, so that the dimensions of the planned flood control building design are also not the same. The SUH used in the discharge estimation must be in accordance with the flood discharge value that occurs at the project location. The purpose of this study is to develop a SUH model to determine the most suitable SUH model for predicting peak discharge in the Air Bengkulu Watershed.

2. Methods

2.1. Research site

Geographically, the location or position of the Air Bengkulu watershed is between 5 ° 40'2" south latitude to 100 ° 40'104" east longitude. This Air Bengkulu River flows through seven districts along the river flow. The research location is presented in Figure 1.

![Figure 1. Research site.](image-url)
2.2. Data collection
Rainfall data were obtained from the Meteorology, Climatology, Geophysics Agency of Bengkulu Province. Rainfall data is presented in Table 1.

| No | Year | Rainfall Station (mm) | Rtheissen (mm) |
|----|------|----------------------|---------------|
|    |      | Tanjung jaya | Bajak | Taba Mutung |
| 1  | 2000 | 105.40 | 122.20 | 98.70 | 107.531 |
| 2  | 2001 | 200.10 | 115.00 | 69.00 | 119.367 |
| 3  | 2002 | 136.20 | 122.20 | 98.70 | 116.167 |
| 4  | 2003 | 180.70 | 94.00 | 79.30 | 112.080 |
| 5  | 2004 | 166.00 | 110.30 | 105.80 | 124.011 |
| 6  | 2005 | 218.50 | 105.50 | 94.50 | 132.523 |
| 7  | 2006 | 137.60 | 450.00 | 112.80 | 219.507 |
| 8  | 2007 | 107.00 | 109.20 | 114.10 | 110.660 |
| 9  | 2008 | 117.50 | 153.70 | 77.70 | 111.343 |
| 10 | 2009 | 151.20 | 94.60 | 163.70 | 139.753 |
| 11 | 2010 | 122.20 | 95.20 | 98.20 | 104.042 |
| 12 | 2011 | 95.00 | 100.00 | 90.80 | 94.699 |
| 13 | 2012 | 223.50 | 53.50 | 71.70 | 108.667 |
| 14 | 2013 | 80.20 | 28.00 | 103.50 | 74.632 |
| 15 | 2014 | 131.00 | 120.00 | 87.70 | 109.396 |
| 16 | 2015 | 113.00 | 200.00 | 161.60 | 159.333 |
| 17 | 2016 | 198.00 | 240.40 | 129.90 | 181.684 |
| 18 | 2017 | 175.00 | 100.00 | 126.70 | 132.344 |
| 19 | 2018 | 186.00 | 126.00 | 61.90 | 115.659 |
| 20 | 2019 | 130.80 | 177.00 | 131.10 | 144.594 |
| Mean | 148.745 | 135.84 | 103.85 | 125.900 |

Source: BMKG Agency, Bengkulu Province, 2020

2.3. Synthetic Unit Hydrograph (SUH)
The SUH method has been widely used by hydrologists to estimate flood plans in watersheds that do not have automatic water level recording devices. The SUH method is able to provide an adequate estimate of the peak discharge value and peak time. In Indonesia, the commonly used SUH methods include the Snyder-Alexeyev, Snyder-SCS, Nakayasu and GAMA-1, GAMA-2, ITB-1, and ITB-2 methods. The choice of this method is based on the consideration that the amount of data required is simpler than other methods.

In this study, the synthetic unit hydrograph tested to estimate the discharge in the Bengkulu watershed is Snyder, ITB-1 and ITB-2. The equations used for each synthetic unit hydrograph are presented in Table 2.
Table 2. Synthetic Unit Hydrograph (SUH) Equation

| Parameters | Snyder-Alexeyev | ITB-1 | ITB-2 |
|------------|-----------------|-------|-------|
| Physical Input | A = Area of the watershed | A = Area of the watershed | A = Area of the watershed |
|             | L = Length of the longest river | L = Length of river | L = Length of river |
|             | Lc = Length of river to watershed center |                      |                   |
| Non Physical Input | R = Rainfall Unit | R = Rainfall Unit | R = Rainfall Unit |
|             | Tr = Standard rain duration | Tr = Standard rain duration | Tr = Standard rain duration |
|             | Cp = Peak Discharge Coef (0.59-0.66) | Cp = Coef Discharge (For calibration) | A_DAS / A_SUH |
|             | Ct = Coef Time (1-1.2) n = 0.2-0.3 |                      | ASUH = 1.69 |
| Peak Discharge | Qp = (0.275 Cp A) / Tp | Qp = R / (3,6 Tp) A_DAS / A_SUH | Qp = R / (3,6 Tp) |
|             | Cp = Coef Discharge (For calibration) |                      | A_DAS / A_SUH |
| Time Lag tp | tp = Ct (Lc / Tp) n = 0.8122 L0.6 Cp = Coef Time (For calibration) | tp = Ct 0.8122 L0.6 Cp = Coef Time | tp = Ct 0.8122 |
| Effective rain | te = t_p / 5,5 | t_e = t_p / 5,5 | t_e = t_p / 5,5 |
| Peak time (t_p) | te > Tr Tp = tp + 0.25 (Tr - te) | te > Tr Tp = tp + 0.25 (Tr - te) | te > Tr Tp = tp + 0.25 (Tr - te) |
|             | te < Tr Tp = tp + 0.50 Tr | te < Tr Tp = tp + 0.50 Tr | te < Tr Tp = tp + 0.50 Tr |
| Time Base | Tb = 5.0 (Tp + Tr/2) | Tb = 10 Tp | Tb = 10 Tp |
| Recession Coefficient | Not stated explicitly but follows the shape of the SUH curve | Not stated explicitly but follows the shape of the SUH curve | Not stated explicitly but follows the shape of the SUH curve |
| Curve Properties | A single curve changes and turns into a watershed | A single curve cannot represent a watershed | Double curve can't imagine watershed |

2.4. Hydrologic Engineering Centre-Hydrologic Modeling System (HEC-HMS)

The procedures used in developing the HEC-HMS model are as follows: first, identifying the characteristics of the Air Bengkulu watershed.

The method used in the calculation is the SCS method with the criteria used for modeling are presented in the Table 3
Table 3. The parameters used in HEC-HMS Model

| Sub-Code  | Area (km²) | SCS Curve Number | Baseflow (m³/s) |
|-----------|------------|------------------|-----------------|
| Rindu Hati | 192.08     | Initial Abraction (mm) | 20.75 | Initial Discharge 1.61 |
|           |            | Curve Number      | 71              |
| Susup     | 98.9       | Initial Abraction (mm) | 20.27 | Initial Discharge 1.61 |
|           |            | Curve Number      | 71              |
| Bengkulu  | 224.02     | Initial Abraction (mm) | 20.27 | Initial Discharge 1.92 |
| Hilir     |            | Curve Number      | 71              |

Simulation of rainfall to surface runoff using HEC HMS in each sub-watershed requires several model components, namely: Rain models, Loss models, Transform models, and Baseflow models [10], [11].

3. Results and Discussions
The SUH used to estimate the discharge in the Air Bengkulu Watershed are Snyder, ITB-1 and ITB-2. The parameters used as input to estimate each SUH models are presented in Table 4.

Table 4. The parameters used to estimate each synthetic unit hydrograph

| Parameters                       | Snyder-Alexeyev | ITB-1 | ITB-2 |
|----------------------------------|-----------------|-------|-------|
| Physical Input                   |                 |       |       |
| A = 194.64 km²                   | A = 184 km²     | A = 515 km² |
| L = 27.36 km                     | L = 34.2 km     | L = 40 km |
| Lc = 13.68 km                    |                 |       |       |
| Non Physical Input               |                 |       |       |
| R = 0.988                        | R = 1           | R = 1 |
| Tr = 1 hour                      | Tr = 1          | Tr = 1 |
| Cp = 1.2                         | Ct = 1          | Ct = 1 |
| n = 0.042                        |                 |       |       |
| Peak Discharge                   | Qp = 10.894 m³/s| Qp = 4.855 m³/s| Qp = 16.41 m³/s |
| Cp = 1.2                         |                 | A_{SUH} = 1.57| A_{SUH} = 1.45 |
| Time Lag (tp)                    | tp = 5.915 hours| tp = 6.705 hours | tp = 7.429 hours |
| Cp = 1.2                         |                 | Cp = 1.2 |        |
| Effective rain                   | tq = 1.075 hours| te = 1.23 hours | te = 1.35 hours |
| Peak time (T_p)                  | Tp = 5.896 hours| Tp = 6.705 hours | Tp = 7.341 hours |
| Time Base                        | Tb = 31.98 hours| Tb = 67.05 hours | Tb = 73.41 hours |
| Recession Coefficient            |                 |       |       |
| Not stated explicitly but follows the shape of the SUH curve | Not stated explicitly but follows the shape of the SUH curve | Not stated explicitly but follows the shape of the SUH curve |
| Curve Properties                 | A single curve changes and turns into a watershed | A single curve cannot represent a watershed | Double curve can’t imagine watershed |
| Curve Shape                      | Qt = 4.829 m³/s | Qt = 0.741 m³/s | Qt = 10.93 |
| Where:                           | λ = 0.330       |       |       |
| a = 0.530                        |                 |       |       |
3.1. The synthetic unit hydrograph in the Air Bengkulu Watershed.
The estimation results using the synthetic unit hydrograph Snyder, ITB-1 and ITB-2. After the hydrograph form is obtained, the flood discharge due to the planned rain is calculated with the superposition. In practice, the hydrograph superposition process can be calculated in tabular form as it is easy to find in various reference books. In this research is used the 6 hour rain distribution. As an indicator of the accuracy of the calculation results, the principle of mass conservation is used, namely the volume of rain the effective fall in the watershed must be equal to the volume of flood hydrograph produced. The total Runoff height calculated for the three hydrographs is very close to the total rainfall height given as input. The final superposition result in the form of SUH is shown in Figure 2.

![Figure 2. The synthetic unit hydrograph in the Air Bengkulu Watershed.](image)

The final superposition result estimation of the peak discharge of Air Bengkulu Watershed using 3 Synthetic Unit Hydrograph methods namely Snyder-Alexevey, ITB-1 and ITB-2 are shown in Table 5.

| Parameters      | Snyder-Alexevey | ITB-1       | ITB-2       |
|----------------|-----------------|-------------|-------------|
| Peak Discharge | Qp = 1.302,766 m³/s | Qp = 2395,5m³/s | Qp = 2.165,857 m³/s |
|                | Cp = 1.2        | A_{SUH} = 1.57 | A_{SUH} = 1.45 |
| Time Lag (tp)  | tp = 5.915 hours| tp = 6.705 hours | tp = 7.429 hours |
|                | Cp = 1.2        | Cp = 1.2     | Cp = 1.2     |
| Peak Time (T_p)| Tp = 6.596 hours| Tp = 4.705 hours | te > Tr Tp = 6.341 hours |
3.2. The hydrograph in the Air Bengkulu Watershed from HEC-HMS

The hydrograph form of the output of the HEC-HMS model developed in the Air Bengkulu Watershed is shown in Figure 3.

![Figure 3. Hydrograph in the Air Bengkulu River watershed using HEC-HMS.](image)

The flow obtained from the HEC-HMS output is 690 cms (cubic meters per second) with the time the peak occurred at 13.00, as presented on Fig. 4. This discharge value is much smaller when compared to the three synthetic unit hydrograph models (Nakayasu, ITB-1 and ITB-2) developed at the research location. The difference in peak discharge values that occurs between SUH and HEC-HMS is caused by various factors in the process of estimating the relationship between rain to flow.

One of the factors is the difference in rainfall data input. SUH uses maximum daily rainfall data, namely from rainfall data from 2000 to 2019 year. HEC-HMS uses maximum daily rainfall data during floods in the Air Bengkulu Watershed. In addition, the SUH method used in this study did not take into account the land cover and soil type factors, while the HEC-HMS took these two factors into account. Land cover and soil type affect the surface runoff value, if the land cover is predominantly forest and the soil type has a high permeability value, then the surface flow that occurs in the watershed will be smaller.

4. Conclusions

Based on the results of synthetic hydrograph modelling that has been carried out in the watershed using Snyder, ITB-1 and ITB-2 and HEC-HMS synthetic hydrographs, it can be concluded that the synthetic unit hydrograph has been able to estimate the peak discharge based on the time sequence of a rain event, so that the relationship between peak time and peak discharge. However, the value of the peak discharge and peak time obtained from the output of each method is different, so that more in-depth research is needed if this model is to be used as a basis for decision making.

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