The analysis of alpha parameter on Nakayasu Synthetic Unit Hydrograph in Timor Island watersheds

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Abstract. Benenain and Noelmina river are rivers on Timor Island which have large watershed area. With a large watershed area, it is necessary to observe and calculate the peak flood discharge deeply. One of the methods used for calculate the peak flood discharge Nakayasu Synthetic Unit. In calculating the peak flood discharge with Nakayasu Synthetic Unit Hydrographic Parameters difficulties often encountered in determining the accuracy of the α (alpha) value coefficient. To calculate the α (alpha) value coefficient required data in the form of area and length of river. The results of analysis using software IBM SPSS version 23 the (alpha) value coefficient on Timor Island can be obtained using equation α = 2,461. (L⁻⁰.⁴¹⁷. (A)⁰.²¹⁴ so that the α (alpha) value for each watershed varies depending on the size of the watershed and the length of the river. Thus, with the confidence level of the results of the analysis is 95% and the coefficient of determination (R²) is 0.826 then the watershed area and river length give an influence of 82.60% on the value of α (alpha) obtained.

1. Introduction
In East Nusa Tenggara Province, especially in Timor Island, there are various methods that have been used in calculating peak flood discharge. Calculation of peak flood discharge can be done empirically, statistically, or by using a Hydrograph. Hydrograph is a graphical representation of a flow element relationship such as discharge (Q) to time (t). The next term called hydrograph is briefly the relationship between discharge and time. The hydrograph forming component comes from runoff or surface flow / direct flow and base flow (formed by intermediate flow and underground flow). The hydrograph consists of three parts, namely the concentration curve / upward curvature, the top part, and the recession arch [1-3].

One of the most commonly used hydrograph methods is the Nakayasu Synthetic Unit Hydrograph. The method formulated by a Japanese national named Nakayasu is a popular method used in many plans in the field of water resources especially in the analysis of immeasurable watershed floods (DAS). Calculation with the Nakayasu Synthetic Unit Hydrograph method requires data on watershed characteristics such as watershed area, river’s length and in some cases includes land characteristics. Based on these data, river forms can be described to find out the shape of the river channel, so that the tendency of fluctuations in flood flows that occur in the watershed can be described. Therefore, this method is also known as one of the methods used to simulate the flow of an unmeasured watershed which ranges from 30 km² to 30,000 km² [2-3]. But in its use are often encountered various difficulties, especially in determining the value of α (alpha) used. The value of α (alpha) itself ranges from 1.5 to 3. But often the value of α (alpha) used does not represent the actual area to be studied or calculated using
the Nakayasu Synthesis Unit Hydrograph, so the selection of $\alpha$ (alpha) in a certain area or location becomes inaccurate. The value of $\alpha$ (alpha) is one of the important parameters used in the calculation using the Nakayasu Synthesis Unit Hydrograph method, where the value of $\alpha$ (alpha) actually shows the characteristics of a watershed. To get the value of $\alpha$ (alpha) requires data such as river’s length, and watershed area. The accuracy of $\alpha$ (alpha) value will greatly influence the results obtained in calculating peak flood discharge [4-11].

The existence of large rivers in Timor Island, such as the Benenain River Region, and the Noelmina River Region, is often used as a source of life that can be used by humans, especially those living around the river. Within the territory of Timor Island, there are two River Areas, namely the Noelmina River Region which straddles six regencies / cities which are divided into 186 River Subdistricts with a total River Area of 9,360.52 km² and the Benenain River Area which spans four districts divided into 46 Sub The River Region with the total area of the River Region within Timor Island is 6,460.12 km² while the rest of 3,158.16 km² is within the territory of the State of Timor Leste (River Area Station of East Nusa Tenggara II, 2013). So, in an effort to optimize river functions, especially rivers on Timor Island, studies are often carried out regarding major rivers on Timor Island so that they can be used as references that can be used in hydrological planning [12-15].

2. Literature review

2.1. Nakayasu synthetic unit hydrograph

Nakayasu has investigated unit hydrograph in Japan and provided a set of equations to calculate the peak discharge of a unit hydrograph which is formulated as follows:

$$Q_p = \frac{CA.R_0}{3.6(t_{0.3}.T_p + T_{0.3})}$$  \hspace{1cm} (1)

$$T_p = T_g + 0.8 T_r$$  \hspace{1cm} (2)

$$T_r = (0.5 . T_g) \text{ s/d } (1 . T_g)$$  \hspace{1cm} (3)

$$T_{0.3} = \alpha . T_g$$  \hspace{1cm} (4)

with:

- $Q_p$: peak flood discharge (m³/s)
- $C$: runoff coefficient
- $A$: catchment area (km²)
- $R_0$: rainfall unit = 1 mm
- $T_p$: peak hour (hour)
- $T_g$: the time taken from the center of rain to get to the peak / delay time (hour)
- $T_r$: time of rainfall
- $T_{0.3}$: time when debit equals 0.3 times peak discharge (hour)
- $\alpha$: alpha coefficient, ranging from 1.5 - 3.0

Nakayasu also gives several equations to calculate the ordinates forming a hydrograph. The equation can be written as follows [16]:

- For rising limb (Qa) $0 < t < T_p$

$$Q_a = \frac{t^{2.4}}{T_p}$$  \hspace{1cm} (5)

- For decreasing limb part I (Qd₁) $T_p < t < (T_p + T_{0.3})$

$$Q_d_1 = Q_p . 0.3^{\frac{t-T_p}{T_{0.3}}}$$  \hspace{1cm} (6)

- For decreasing limb part II (Qd₂)
\[(T_p + T_{0.3}) \leq t \leq (T_p + T_{0.3} + 1.5T_{0.3})\]

\[Q_{d_2} = Q_p 0.3^{\frac{(t-T_p+0.5T_{0.3})}{1.5T_{0.3}}}\]  

- Decreasing limb part III \((Q_{d_3})\)
  \[t > T_p + T_{0.3} + 1.5T_{0.3}\]

\[Q_{d_3} = Q_p 0.3^{\frac{t-T_p+1.5T_{0.3}}{2T_{0.3}}}\]

2.2. The alpha parameter on Nakayasu synthetic unit hydrograph method

One important parameter in calculating the peak flood discharge with the Nakayasu Synthetic Unit Hydrograph method is to find in and find out the magnitude of the value coefficient \(\alpha\) (alpha) which is a description of the characteristics of a watershed [1-4].

\[\alpha = \frac{(0.47 \times (A \times L)^{0.25})}{T_g}\]

\[T_g = 0.21 \times L^{0.7} \text{ for } L \leq 15 \text{ km}\]

\[T_g = 0.4 + 0.058 \times L \text{ for } L \geq 15 \text{ km}\]

With:
- \(L\) : length of the main river (km)
- \(T_g\) : The time taken from the weight of rainfall to peak discharge / time lag (hour)

With notes:
- \(\alpha\) : 2.0= The rising part of the hydrograph shows time which tends to be the same as the decreasing part of the hydrograph
- \(\alpha\) : 1.5= The portion of the hydrograph rises slowly and the part decreases rapidly
- \(\alpha\) : 3.0= The part of the hydrograph rises fast and the part decreases slowly

3. Methodology of research

3.1. Research location

This research was conducted on the watersheds in Timor Island, East Nusa Tenggara with the distribution of sub-watersheds (Watersheds) taken in the districts/ cities in Timor Island. These sub-watersheds are sub-watersheds that are included in the Noelmina and Benenain Watersheds.

3.2. Data analysis

Data analysis carried out included the following:
- Determine and calculate the watershed area.
- Measuring the length of the river.
- Calculate the value of temporary \(\alpha\) (alpha).
- Calculate peak flood discharge using the Nakayasu HSS method.
- Analyse the value of \(\alpha\) (alpha).
- Calculating the flood peak discharge based on the \(\alpha\) (alpha) value that has been obtained.
4. Results and discussion

4.1. Watersheds area and river length
To analyse the value of $\alpha$ (alpha) the parameters used are the watershed area and the length of the river.

From the grouping data on the distribution of watershed areas that have been obtained from the Nusa Tenggara River Basin II Territory, 30 sub-basins and river lengths were taken randomly to represent the watershed and the length of the river in Timor Island territory. After the calculation to get the size of the watershed and the length of the river is obtained using Google Earth software, the data is then continued to calculate watershed area and river length. The following is a picture of grouping sub-watersheds obtained from the Nusa Tenggara River Basin II, image of the extensive sub-watershed calculation using Google Earth software, and a table of recapitulation of the area of sub-watersheds and the length of the river.
Figure 2. Noelmina and Benenain Sub-Watersheds Grouping

Figure 3. Watersheds Calculations Using Google Earth Software

Table 1. Recapitulation of Catchment Area and River Length in Noelmina and Benenain

| No | Name of Sub Watersheds | Name of The River Basin | City / District Administrative Region | Catchment Area (km²) | River length (km) |
|----|------------------------|-------------------------|---------------------------------------|----------------------|------------------|
| 1  | Biboko                 | Noelmina                | Kupang District                       | 91.7                 | 20.1             |
| 2  | Kapsali                | Noelmina                | Kupang District                       | 154                  | 47.9             |
| 3  | Kenino                 | Noelmina                | Kupang District                       | 170                  | 42.4             |
| 4  | Kuu Oepaha             | Noelmina                | Kupang District                       | 78                   | 9.36             |
| 5  | Manikin Baki           | Noelmina                | Kupang district and Kupang city       | 195                  | 25.2             |
| 6  | Meto batulesa          | Noelmina                | Kupang district and Kupang city       | 89.9                 | 17.5             |
| 7  | Meto                   | Noelmina                | Kupang District                       | 18                   | 9.92             |
| 8  | Muke                   | Noelmina                | TTS District                          | 531                  | 54.8             |
| 9  | Naitlopen              | Noelmina                | Kupang District                       | 177                  | 22.9             |
| 10 | Nita                   | Noelmina                | Kupang District                       | 78                   | 21.1             |
| 11 | Noelmina               | Noelmina                | Kupang district and TTS district      | 1981                 | 107              |
| 12 | Otnui Okuuh            | Noelmina                | Kupang District                       | 23.8                 | 7.71             |
| 13 | Patukolo               | Noelmina                | Kupang District                       | 5.37                 | 4.29             |
| 14 | Sahak Orman            | Noelmina                | Kupang District                       | 18.9                 | 4.12             |
| 15 | Sitoto                 | Noelmina                | Kupang District                       | 268                  | 37.4             |
| 16 | Siumate                | Noelmina                | Kupang District                       | 98.7                 | 15.5             |
| 17 | Termanu                | Noelmina                | Kupang District                       | 428                  | 50.3             |
| 18 | Kasmuti                | Noelmina                | Kupang District                       | 90.8                 | 25.9             |
| 19 | Bisnain                | Noelmina                | Kupang District                       | 43.8                 | 13.8             |
### Table 1. Recapitulation of Catchment Area and River Length in Noelmina and Benenain (cont.)

| No | Name of Sub Watersheds | Name of The River Basin | City / District Administrative Region | Catchment Area (km²) | River length (km) |
|----|------------------------|-------------------------|---------------------------------------|----------------------|------------------|
| 20 | Metan                  | Noelmina                | Kupang District                       | 224                  | 49.6             |
| 21 | Benenain               | Benenain                | Malaka, Belu, TTU and TTS district    | 3310                 | 107              |
| 22 | Boking                 | Benenain                | TTS District                          | 44.8                 | 9.96             |
| 23 | Bone                   | Benenain                | TTS District                          | 135                  | 25               |
| 24 | Halilammutu            | Benenain                | Belu and TTS district                 | 216                  | 33.2             |
| 25 | Nenoat                 | Benenain                | TTS District                          | 38.3                 | 7.41             |
| 26 | Oemanu                 | Benenain                | TTU District                          | 399                  | 33               |
| 27 | Punu                   | Benenain                | TTS District                          | 228                  | 25               |
| 28 | Rainawe                | Benenain                | Malaka and Belu District              | 171                  | 28.1             |
| 29 | Hasfuik Maubesi        | Benenain                | Belu and TTU District                 | 193                  | 33.2             |
| 30 | Umaklaran              | Benenain                | Malaka and TTU District               | 341                  | 39.4             |

### 4.2. Form of the watersheds

The water flows from the upstream which is located at the top of the hill to the downstream which is located close to the sea. The upstream part of this watershed has a denser density of river flow compared to the downstream. The form of rounded sub-watersheds is caused by having a long river and branching tributaries which are quite large cause this sub-watershed has sufficient fast concentration time, so that flood fluctuations that occur are also high. The flood trend that occurs is located at downstream. Thus, it can be concluded that the shape of the Noelmina sub-watershed is in the form of a radial where the shape of the water flow seems to centre on a point with a fan-like shape or circle with the coming flow time from all corners tends to be almost the same.

Figure 5 shows the shape of the Benenain Watershed located in the Benenain River Region. In the watershed it is seen that water flows from upstream at the top of the hill to the downstream near the sea. In the upstream part there are two quite wide river grooves where the two river channels are bordered by ridges. The two river channels gradually flow at one point to form a main river channel. The Benenain sub-watershed has high flood fluctuations where the tendency for flooding to occur at the meeting point of two river channels. In line with the high flood fluctuations, the shape of the Benenain sub-watershed is far from oval, so the tendency for the watershed to form is like a fan. Based on the characteristics described, it can be concluded that the Benenain sub-watershed with an area of ± 3,310 km² sub-watersheds has a parallel form in which sub-watersheds are formed by two united paths downstream, causing flooding to occur at the meeting point.

![Figure 4. Form of Noelmina sub-watersheds](image-url)
4.3. Calculation of temporary $\alpha$ (Alpha) parameter

- Calculate the amount of time taken from the Heavy Rain Point to the Peak of Debit. In Table 1, the results of the calculation of the river length of the Biboko watershed are shown, the Noelmina River Area is 20.1 km, so $T_g$ can be calculated as follows:

$$T_g = 0.4 + 0.058 (20.1)$$

$$T_g = 1,566 \text{ hours}$$

- Calculating temporary $\alpha$ (alpha) value

$$\alpha = \frac{(91.720.1)^{0.25}}{1.566}$$

$$\alpha = 1,967$$

4.4. Peak flood calculation

- Calculating the Time Required to Reach 30% of Flood Peak ($T_{0.3}$)

$$T_{0.3} = \alpha \cdot T_g$$

$$T_{0.3} = 1,967 \cdot 1,566$$

$$T_{0.3} = 3,080$$

- Calculating Rainfall Time ($T_r$)

$$T_r = 0.8 \cdot T_g$$

$$T_r = 0.8 \cdot 1,566$$

$$T_r = 1,253 \text{ hours}$$

- Calculating the time needed from the start of the rain to the peak of the flood ($T_P$)

$$T_P = T_g + (0.8 \cdot T_r)$$

$$T_P = 1,566 + (0.8 \cdot 1,253)$$

$$T_P = 2,568 \text{ hours}$$

- Calculating Peak Flood Discharge ($Q_p$)

$$Q_p = \frac{C.A.R_0}{3.6(0.3T_P + T_{0.3})}$$

$$Q_p = \frac{1.917.1}{3.6(0.3 \cdot 2,568 + 3,080)}$$

$$Q_p = 6,616 \text{ m}^3/\text{second}$$
4.5. Analysis of Alpha Parameters Using the IBM SPSS Version 23 Program

In analyzing this program the temporary $\alpha$ (alpha) value that has been obtained is used as the dependent variable (bound) while the river length and watershed area are used as independent variables (explanatory) so that the assumption that can be built is to find out how much influence given / contribution given river length and watershed area to predict variations in the value of $\alpha$ (alpha) to be searched. Thus input the temporary $\alpha$ (alpha) value, river length and watershed area that has been obtained into the IBM SPSS version 23.

From the results of the iteration, a constant value of $A = 2.461$, $X_1 = -0.417$ and $X_2 = 0.214$ where the level of confidence in the results of the analysis obtained is 95%. Based on the results of parameter estimation, the error predicts the data for $A$ constant value of 0.105, for the $X_1$ variable of 0.039 and for the $X_2$ variable of 0.025. It can also be seen that the value of $R^2$ obtained is 0.826. The value of 0.826 shows a high level of satisfaction because it is above 0.5 and almost close to 1, so that the contribution given parameters given in this case the independent variables along with the equation model entered has reached 82.60%. From the value of $R^2$ it is also known that the value obtained does not reach 1 and the remaining value is 0.174, so that it can be interpreted to have other factors that influence the value of $\alpha$ (alpha) with a percentage of 17.40%. Thus it can be concluded that the river length and watershed area influence the variation of $\alpha$ (alpha) value of 82.60% with a constant value = 2.461, rank value for river length variable = -0.417 and rank value for watershed area variable = 0.214 analyzed by using equation $\alpha = A \cdot \text{River Length}^{X_1} \cdot \text{Area of watershed}^{X_2}$.

4.6. Nakayasu synthetic unit hydrograph

Based on the calculation of the peak flood discharge and hydrograph image in the Biboko Sub-watershed, the Noelmina River Region obtained an $\alpha$ (alpha) value of 1.852 different from the previously calculated $\alpha$ (alpha) value of 1.967. This $\alpha$ (alpha) value affects the results of the calculation of peak flood discharge where the results of the calculation of peak flood discharge are 6.940 m$^3$/sec different from the results of previous calculations obtained by the value of smaller peak flood discharge which is 6.616 m$^3$/second.

It can be compared also, based on calculations to obtain peak flood discharge and hydrograph produced, in the previous calculation for the same watershed, namely in the Biboko watershed of the Noelmina River Region, the coefficient $\alpha$ (alpha) value was 1.967 and the second coefficient $\alpha$ (alpha) was obtained to 1.852. As for the decreasing part of the hydrograph shown by the amount of time needed to reach 30% of peak flooding ($T_{0.3}$), where the coefficient value of $\alpha$ (alpha) of 1,852 gets a time that tends to be faster that is 2.9 hours so the hydrograph down time faster than the coefficient value of $\alpha$ (alpha) of 1,967 parts decreases to slower that is equal to 3,080 hours.

\[ Q_p = 6.940 \text{ m}^3/\text{detik} \]
\[ \alpha = 1.852 \]
\[ T_{0.3} = 2.568 \text{ jam} \]
\[ T_{0.5} = 2.900 \text{ jam} \]
\[ 1.8. T_{0.3} = 4.350 \text{ jam} \]
5. Conclusion

- Curve of the Watershed Sub-Region on Timor Island which is a representation of the Noelmina River Region and the Benenain River Region in the form of radial and parallel.
- The value of $\alpha$ (alfa) for the River Region on the Island of Timor can be obtained based on equation $\alpha = 2,461 \cdot (L)^{0,417} \cdot (A)^{0,214}$ so that the value of $\alpha$ (alpha) varies depending on the size of the watershed and the length of the river. Where the largest $\alpha$ (alpha) value is found in the Sahak Orman River Sub-Region, the Noelmina River Region with a value of $\alpha$ (alpha) of 2.558. While the smallest $\alpha$ (alpha) value is found in the Kapsali River Sub-Region, the Noelmina River Region with a value of $\alpha$ (alpha) of 1.441.
- The confidence level of the results of analysis using IBM SPSS Version 23 software is 95%, with the $R^2$ value (Determination Coefficient) obtained at 0.826 so that it can be concluded that the watershed area and river length have an effect of 82.60% on the value of $\alpha$ (alpha) obtained

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