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Runoff Analysis in The Telomoyo River Basin

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Abstract— Surface runoff occurs due to rain falling and flowing over the ground surface. This is due to the intensity of the rain exceeding the infiltration capacity. This surface runoff will combine and flow into the river. This causes an increase in the amount of flow in the river. A large increase in flow that exceeds the capacity of the river can cause water overflows. This can cause flooding. The Telomoyo River Watershed is a watershed located in Kebumen Regency, Central Java Province. In this watershed, the Telomoyo River flows. When there is heavy rainfall, the amount of runoff flowing into the Telomoyo River is large. This condition can cause a large increase in river flow. Surface runoff calculations are carried out by determining the Nakayasu synthetic unit hydrograph and calculating effective rainfall. Based on the analysis results, the maximum runoff that occurs can be approximated by the equation 141.16 Ln (x) + 917.22. Meanwhile, runoff depth increases with increasing effective rainfall. The runoff depth can be approximated by the equation y = 0.1253x – 0.0679.

Keywords: Nakayasu, Surface runoff, Telomoyo.

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1. Introduction

Surface runoff occured because of rainfall in a river basin area. The effected of rainfall intensity on surface runoff depends on the infiltration capacity [1]. Surface runoff occured when the rainfall was greater than the soil infiltration capacity [2]. If the infiltration capacity has been achieved, rainwater will flow over the land surface as surface runoff [3]. The formation of runoff begins with rain falling to the earth. Some of the rainwater will be collected in depressions on the surface of the ground and some will seep into the ground. Rainwater that is not collected will flow or overflow over the surface of the ground [4].

Surface runoff will flow into ditches and gutters, which then join and flow into tributaries. The flow from these tributaries will then enter the river and become river flow. This condition caused the flow in the river to increase. Runoff that is not handled properly will cause various problems for the community, especially flooding [5]. This happens when the river's capacity to flow a discharge has been exceeded. Floods, which are essentially a natural process, can be a disaster for humans if the process affects humans and causes loss of life and material [6]. Floods can damage agricultural land, plantations, forests or other infrastructure such as roads, bridges, buildings or residential buildings of local residents.

Telomoyo River Basin is a watershed located in Kebumen Regency, Central Java Province. Land use is a manifestation in nature of how land use is organized, both naturally and planned [7]. Land use in the Telomoyo watershed includes plantations, fields, rice fields, buildings, weeds, dry forests, bushes, reservoirs or ponds. The existence of various land uses will provide different runoff coefficient values. The

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runoff coefficient is the ratio between flow and rainfall at a certain time interval and physical condition of the watershed [8]. This will affect the amount of runoff that occurs.

When there is high intensity rain, the runoff that flows into the Telomoyo River is large. This condition can cause a large increase in river flow. Therefore, it is necessary to analyze the runoff that will occur in the Telomoyo Watershed. By knowing the runoff value, an action can be taken to reduce the runoff that will occur. The hope is that the runoff can be controlled so that it does not cause a significant increase in river flow. Surface runoff assessment is a very important component in integrated watershed planning [9].

Research on Surface Runoff Estimation using the Modified CN Method in the Mamasa Sub-DAS has been conducted previously. The modified Curve Number (CN) method was carried out to improve the accuracy in calculating surface runoff based on hydrological and topographic characteristics. The modified CN method involves a detailed analysis of soil type, land cover, and topography, rainfall data in the Mamasa Sub-watershed in 2020. Sensitivity analysis was carried out to determine the effect of these variables on the calculation of surface runoff and groundwater retention capacity. The results of this study provide an overview of the relationship between surface runoff and CN values in the Mamasa Sub-watershed ranging from CN 49 to CN 100 and have shown that the higher the CN value, the lower the infiltration potential value, conversely the lower the CN value, the higher the infiltration potential value. The highest Q contribution in the Mamasa Sub-watershed is at a CN value of 67 with an area of 66% and Q of 884,186 m^3/s/year while the highest S is at a CN value of 79 with an area of 15% and S of 128,496 m^3/s/year [10].

The hydrological model is defined as a set of mathematical statements that express the relationship between the phases of the hydrological cycle with the aim of simulating the transformation of rainfall into runoff [11]. Precipitation is one of the most important components of water balance in the water cycle and has high spatial and temporal variability [12]. Surface runoff is a flow component whose magnitude is the amount of rainfall minus the amount of infiltration [13].

2. Method

The research location is in the Telomoyo Watershed which is included in the Serayu Opak-Bogowonto River Basin, which is located in the administrative area of Kebumen Regency, Central Java Province. The Telomoyo Watershed has an area of 471.44 km^2. The research design is made in a flowchart, which is shown in Figure 1.

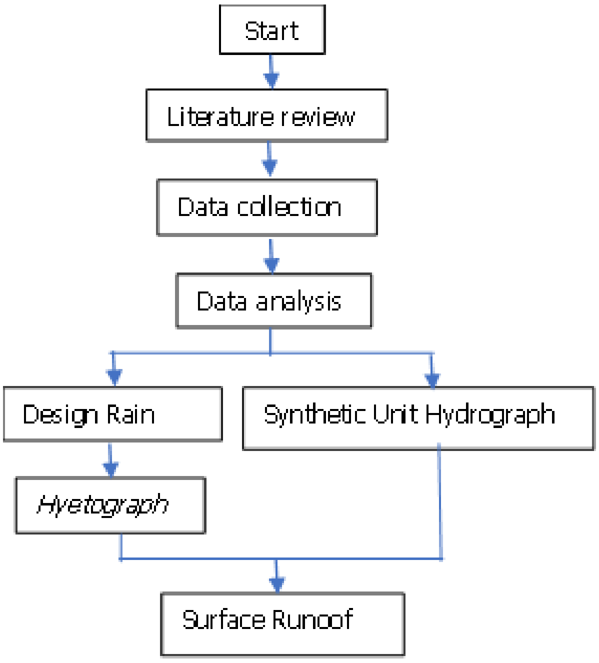

Figure 1. Research Design

The data used in this study are daily rainfall data, land use) and watershed characteristics. These data were obtained from the Serayu Opak River Basin Center, Probolo Water Resources Management Center in Central Java Province. Other data comes from the website : tanahair.indonesia.go.id, 2023 [14].

Data analysis includes:

1) Design Rain Analysis.
   The design rainfall analysis is carried out by analyzing daily rainfall data. Before the rainfall data is analyzed further, a data consistency test is carried out. The consistency test is carried out using the Double Mass Curve method. The calculation of the average rainfall area uses the Thiessen method. For the distribution type test, the Chi Square and Smirnov Kolmogorov methods are used. The determination of the planned rainfall amount follows the selected distribution type.
2) Hyetograph.
   Hyetograph was analyzed using the Alternating Block Method (ABM).
3) Synthetic Unit Hydrograph (HSS).
   In this study, the Synthetic Unit Hydrograph used is the Nakayasu HSS.
4) Surface Runoff Analysis
   Surface runoff, calculated based on the hyetograph and Nakayasu Synthetic Unit Hydrograph.

Determination of average watershed rainfall is done using Thiessen Polygons [1].

$$R = \frac{R_1.A_1+R_2A_2+\ldots+R_nA_n}{A\ total} \quad (1)$$

With:
R : Average rainfall of watershed (mm).
$A_1, A_2, \ldots, A_n$: The area of the part of the region that represents each point (km^2).
$R_1, R_2, \ldots, R_n$: Rainfall at each rain station (mm).
A_{total} : Total area of watershed (km^2).

Frequency analysis of rainfall data is carried out to obtain the design rainfall value. Determination of the type of distribution is carried out by matching the data parameters with the requirements of each type of distribution. The conditions for each type of distribution are shown in Table 1. [15].

Table 1. Statistical parameter requirements of a distribution.

No.	Distribution	Parameter requirements
1	Gumbel	Cs = 1,14 C_k = 5,4
2	Normal	Cs = 0 C_k = 3
3	Log Normal	Cs = $C_v^3 + 3\ C_v$ $C_k = C_v^8 + 6C_v^6 + 15\ C_v^4 + 16\ C_v^2 + 3$
4	Log Pearson III	Apart from the above values

Distribution type testing is carried out to determine whether the selected probability distribution type can represent the statistical distribution of the analyzed data sample. Distribution type testing is carried out using the Chi Square Test and the Smirnov Kolmogorov Test. In the Chi Square test, the calculated Chi Square value is sought from the specified rainfall data. The selected distribution type can be accepted if the calculated Chi Square value (λ^2) is smaller than ($\lambda_{critical}$).

$$\lambda^2 = \sum_{i=1}^{n} \frac{(O_f \times E_f)^2}{E_f} \quad (2)$$

With:

λ^2 : Chi-Square calculated
E_f : The expected frequency is according to the class division
O_f : Observed frequencies in the same class

The Smirnov Kolmogorov goodness-of-fit test is carried out by observing the curve and depicting the data on probability paper. The Δmax value is obtained by finding the distance of the largest deviation of each data point from the theoretical curve. The selected distribution type can be used if the Δmax value is smaller than Δcritic.

The Synthetic Unit Hydrograph is calculated using the Nakayasu Synthetic Unit Hydrograph.

$$Qp = \frac{1}{3,6} \times \left(\frac{A \times R_0}{0,3Tp + T_{0,3}}\right) \quad (3)$$

$$tg = 0,21 \times L^{0,7} \quad \rightarrow L < 15 \text{ km}$$

$$tg = 0,4 \times 0,058\, L \quad \rightarrow L > 15 \text{ km}$$

$$T_{0,3} = \alpha \times tg$$

$$Tr = 0,5\, tg - tg$$

Nakayasu divides the unit hydrograph into 2 parts, namely the rising curve and the falling curve.

1. For up and down curves, $0 < t < Tp$

$$Qt = Q \left(\frac{t}{Tp}\right)^{2,4} \quad (4)$$

2. For stage I descending curve, $Tp < t < Tp + T_{0,3}$

$$Qt = Qp \times 0,3 \left(\frac{t - Tp}{T0,3}\right) \quad (5)$$

3. For stage II descending curve, $Tp + T_{0,3} < t < Tp + T_{0,3} + 1,5T_{0,3}$

$$Qt = Qp \times 0,3 \left(\frac{(t - Tp) + (0,5T_{0,3})}{1,5T_{0,3}}\right) \quad (6)$$

4. For stage III descending curve, $t > Tp + T0,3 + 2T0,3$

$$Qt = Qp \times 0,3 \left(\frac{(t - Tp) + (0,5T_{0,3})}{2T_{0,3}}\right) \quad (7)$$

Where,
Qp = Peak flood discharge (m^3/s/mm)
A = River basin area (km^2)
R0 = Unit rain (mm)
Tp = Time from the start of the flood to the peak of the hydrograph (hours)
T0,3 = Time from peak flood to 0.3 times peak discharge (hours)
Tg = Concentration time (hours)
Tr = Unit of time of rainfall (hour)
ɑ = Watershed characteristic coefficient
L =Length of main river (km)

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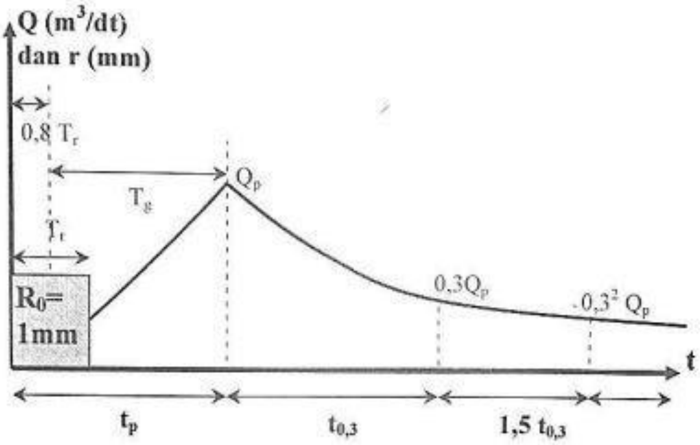

Figure 2. Nakayasu Synthetic Unit Hydrograph

3. Result and Discussion

The rainfall data used is daily rainfall data from 2013 to 2022 from four rainfall stations: Sampang, Kedung Wringin, Somagede, and Pohkumbang. Based on the results of the data consistency test, corrections were made to the rainfall data to ensure consistency. Next, an analysis of the average rainfall area was performed. The results of the calculation of the average rainfall for the area using the Thiessen Polygon method are shown in Table 2.

Table 2. Average rainfall of river basin

No	Average rainfall of river basin (mm)
1	173,68
2	141,81
3	119,16
4	153,78
5	150,88
6	144,48
7	196,54
8	153,35
9	106,43
10	202,40

From this data, frequency analysis and distribution type testing were performed. Based on these test results, design rainfall for various return periods was determined. The design rainfall for various return periods is shown in Table 3.

Table 3. Design Rainfall

No	Return Period (T)	Design Rainfall (mm)
1	2	152,54
2	5	179,61
3	10	194,87
4	20	206,15
5	50	223,56

The hyetograph was conducted using the ABM method. The time of concentration was calculated using the Hathway method based on data obtained from the Serayu Opak Watershed Management Agency

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(BBWS) in 2023. Meanwhile, rainfall intensity was calculated using Mononobe. Effective rainfall was calculated using a flow coefficient analysis. The flow coefficient in the Telomoyo Watershed is based on land use within the watershed. Land use for the Telomoyo Watershed is shown in Table 4. The results of the effective rainfall calculations are shown in Table 5.

Table 4. Telomoyo watershed drainage coefficient

Land Use	**Area (km^2)**	**C**
Agri Garden	161,99	0,5
Agri Farm	21,94327	0,5
Agri Field	187,707793	0,5
Building	0,090631	0,7
Non-Agricultural Weeds	8,545095	0,45
Reservoir	2,844337	0,3
Non-Agricultural Dry Forest	8,545095	0,4
Non-Agricultural Bushes	7,192114	0,45
pond	0,173796	0,3
C average		**0,49**

Table 5. Effective Rainfall

T (hour)	**Return Period (years)**				
	2	**5**	**10**	**20**	**50**
1	5,04	5,94	6,44	6,81	7,39
2	7,50	8,83	9,58	10,14	10,99
3	41,13	48,43	52,55	55,59	60,28
4	10,69	12,59	13,66	14,45	15,67
5	5,97	7,03	7,63	8,07	8,75
6	4,41	5,19	5,63	5,96	6,46

Unit hydrograph analysis was performed using the Nakayasu method. The results of the corrected Nakayasu Synthetic Unit Hydrograph analysis are shown in Figure 3. Based on the results of hourly rainfall distribution calculations using the Alternating Block Method and the Nakayasu Synthetic Unit Hydrograph, a runoff hydrograph was calculated. The runoff hydrographs for various return periods are shown in Figure 4. The maximum runoff hydrographs for various periods are shown in Figure 5. Runoff depth is calculated based on the volume of runoff that occurs. The relationship between effective rainfall and runoff depth is shown in Figure 6. Based on the figure, it can be seen that increased effective rainfall causes an increase in runoff depth. Increased effective rainfall causes an increase in runoff volume. With the increased runoff volume and a constant watershed area, the runoff depth increases. This increase in runoff depth causes a large amount of runoff entering the Telomoyo River. This increases the potential for flooding.

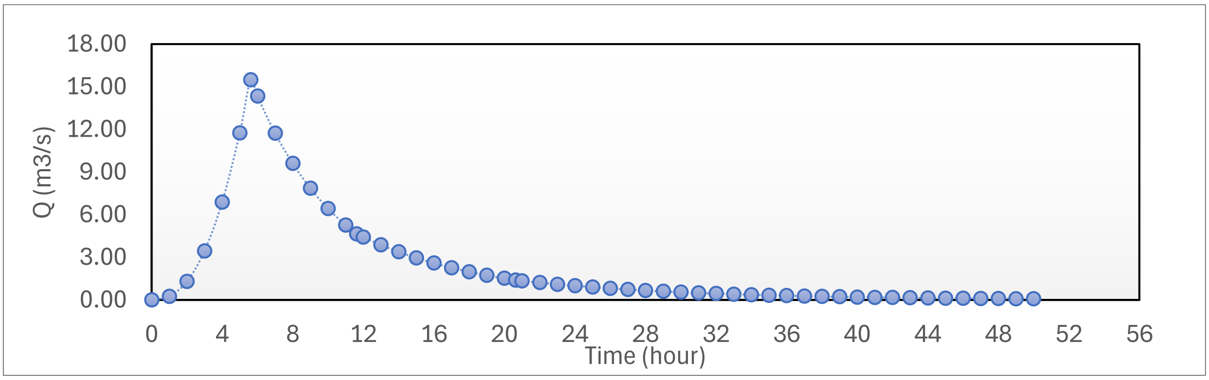

Figure 3. Corrected Nakayasu Synthetic Unit Hydrograph

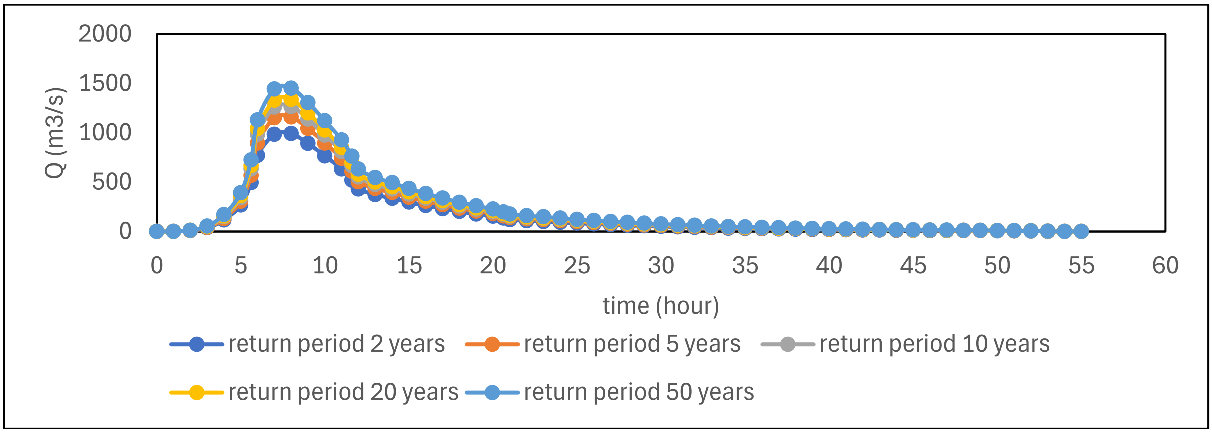

Figure 4. The runoff hydrographs for various return periods

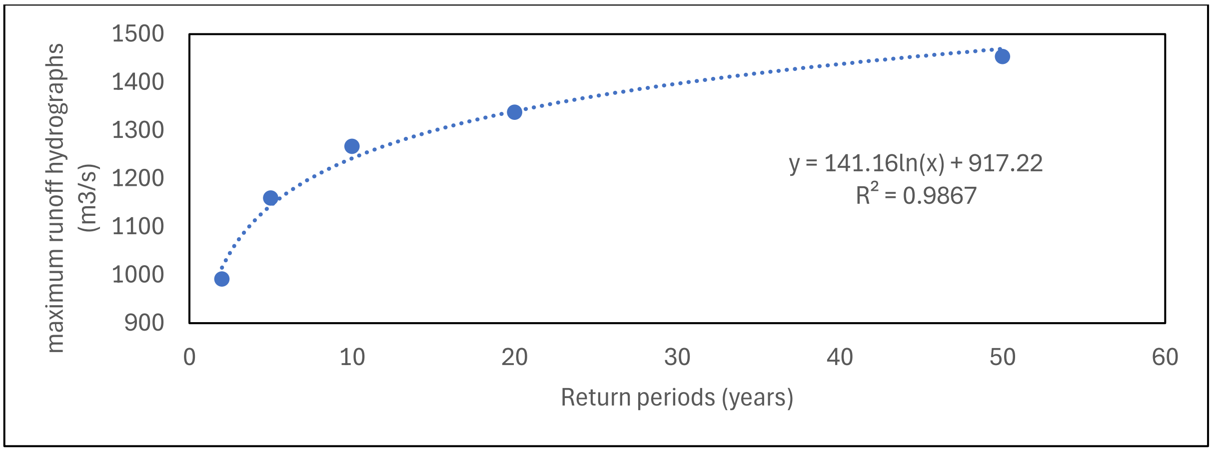

Figure 5. The maximum runoff hydrographs for various periods

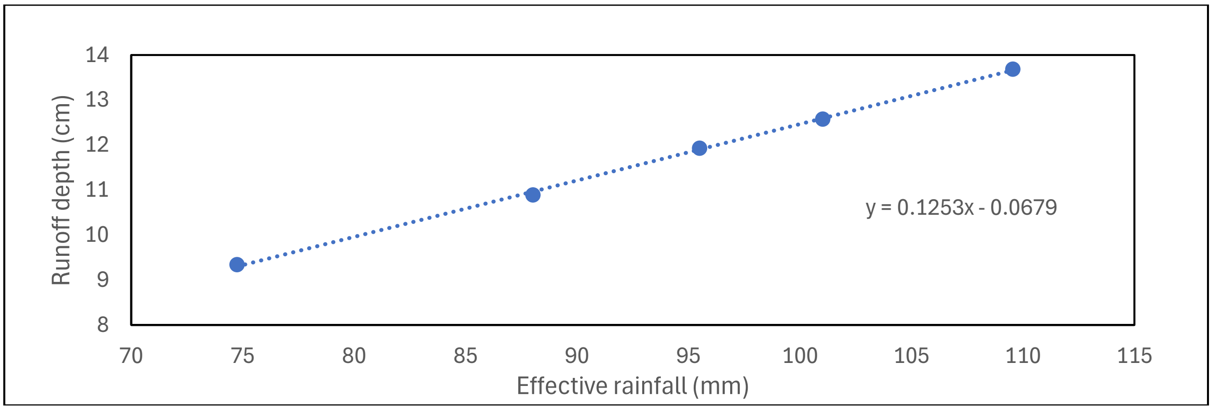

Figure 6. The relationship between effective rainfall and runoff depth

4. Conclusion

Based on the analysis results, the maximum runoff that occurs can be approximated by the equation 141.16 Ln (x) + 917.22. Meanwhile, runoff depth increases with increasing effective rainfall. The runoff depth can be approximated by the equation $y = 0.1253x – 0.0679$.

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