International Research Journal of Advanced Engineering and Science
ISSN (Online): 2455-9024

Analysis of Wanggu River Flood Inundation Kendari City Southeast Sulawesi Province Using HEC RAS 5.0.6

Rachmat Deby[1], Very Dermawan[2], Dian Sisinggih[2]
[1]Graduate School of Water Resources Engineering Department, Brawijaya University, Malang City, 65145, Indonesia
[2]Lecturer of Water Resources Engineering Department, Brawijaya University, Malang City, 65145, Indonesia

Abstract— *The decline in the quality of watersheds causes drought in the dry season and flooding in the rainy season. As one of the main rivers that passes through Kendari City, Wanggu River experiences flooding problems caused by the inability of the river to accommodate water discharge during the rainy season. This study aims to determine the return period of flooding that ever occurred as well as alternative flood control structures that can be done to overcome flood inundation. The results of the study showed that flooding that occurred in the Wanggu River was 330,21* m^3*/second equal to flood discharge of 25 years return period. The recommended alternative for the Wanggu River flood control system based on the results of the analysis of HEC-RAS 5.0.6 is to combine river normalization activities with the construction of flood dikes. This combination can reduce flood inundation 100% and has a value of B/C Ratio 1,74.*

Keywords— *River, Flood control, HEC-RAS 5.0.6, Reduction, B/C Ratio.*

I. PRELIMINARY

The activities of the community around the watershed have caused a decline in the quality of the watershed resulting in the occurrence of things that cause losses, namely drought in the dry season and flooding in the rainy season. Kendari City is located in the central region - downstream of the Wanggu Watershed. As one of the main rivers that flows in Kendari City, the Wanggu River experiences flooding problems caused by the inability of the river to accommodate water discharge during the rainy season. This condition results in obstruction of community activities, disruption of the wheels of the economy, and material losses.

Refers to the flood event data sourced from National Search and Rescue Agency/Badan Nasional Pencarian dan Pertolongan (BNPP), Regional Disaster Management Agency /Badan Penanggulangan Bencana Daerah (BPBD) as well as local and national news, in 2013 there was a flood in Kendari with 70% of Kendari city inundated by flood. Floods cause damage to facilities and infrastructure of public facilities, gardens, rice fields, and residential areas, especially in the area around the flow and estuary of the Wanggu River. The height of the flood that occurred 30 cm to 2 meters, caused hundreds of homes, shops, schools, and offices to be submerged by floods.

Inundation modeling is a fundamental tool for managing and reducing the risk of flooding. By using flood modeling, will be able to consistently simulate large-scale flooding and will provide benefits for flood risk management (Pena and Nardi, 2018). According to Papaioannou (2018) the use of models in the HEC RAS application helps in the modeling of flood inundation and mapping. Therefore, by modeling the flood inundation of the Wanggu River flood, it is expected to be able to provide information on the impact of the floods so that flood management plans can be made to reduce the area affected by flood inundation.

This study will discuss about:

1. Analysis of the amount of flood discharge on the Wanggu River.
2. The modeling of existing conditions flood inundation and flood inundation modeling after flood control using flood control structures.
3. Determination of alternative recommendations for flood control structures reviewed from technical aspects and economic aspects.

II. RESEARCH METHODOLOGY

The location of the research area was carried out in Kendari City, Southeast Sulawesi Province, Indonesia. Wanggu watershed area ± 327.41 Km², with geographical boundaries namely 3° 56' 54" SL – 4° 10' 24" South Latitude and 122° 22' 30" EL – 122° 35' 12" East Longitude.


Fig. 1. Location of the Wanggu watershed

As for the steps for working on this study are as follows:

a. Data collection
   The data used in this study are
   - DEM Map of the Wanggu Watershed

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- River cross section data.
- Daily rainfall data (in 2008 - 2017).
- Map of land use of Wanggu Watershed.
- Highest sea level elevation data.
- Data on flood inundation history and height of inundation.
- Price of wages and materials in Kendari City.

b. Rainfall Data Testing

Before the rainfall data used in the hydrological analysis, first performed statistical analysis on rainfall data. Statistical analysis used to ensure that the rainfall data is suitable for use includes consistency test, test of no trend, stationary test, persistence test, outlier-inlier test.

c. Calculation of the design flood discharge by the method of Nakayasu Synthetic Unit Hydrograph/Hidrograf Satuan Sintetis (HSS) Nakayasu.
d. Modeling of flood inundation using HEC RAS 5.0.6
e. Economic feasibility analysis using the B/C Ratio parameter.

Regional Average Rain

The method used in this study is an algebraic average method/arithmetic method. This method is the simplest method in calculating regional rainfall because it is based on the assumption that all rain gauges have an equivalent effect. This method is suitable for areas with flat topography, the measuring device is spread evenly, and the individual value of rainfall is not too far from the average value. Average regional rainfall is obtained from the equation (Suripin, 2004, p. 27):

$$P = \frac{P_1 + P_2 + P_3 + \cdots + P_n}{n} = \frac{\sum_{i=1}^{n} P_1}{n} \quad (1)$$

With P_1, P_2,…,P_n is rainfall recorded in the rain gauge station/post 1, 2,3,…, n and n is the number of rain gauge posts.

Design Rainfall

Design rainfall calculations in this study used the Log Pearson Type III method, with the following equation (Soewarno, 1995, p. 143):

$$Log\ X = \overline{Log\ X} + k\ \overline{(SLogX)} \quad (2)$$

with:

Log X = design rainfall logarithmic value
$\overline{\text{Log X}}$ = the average value of logarithm of annual maximum rainfall
$\overline{SLog\ X}$ = standard deviation value from Log X
k = characteristics of the Log Pearson Type III distribution

Runoff coefficient

Runoff coefficient is a number that shows the ratio between the amount of water that overflows towards the amount of rainfall. If the land use of a region includes a mixture, then the C constant value must be weighted to obtain a weighted average value (Asdak, 2001, p. 165):

$$C_{weighted} = \sum_{i=1}^{n} \frac{A_i \cdot C_i}{A_i} \quad (3)$$

Design Flood Discharge

The design flood discharge was calculated using the Nakayasu Synthesis Unit Hydrograph method. The magnitude of unit hydrograph peak discharge value is calculated by the formula (Soemarto, 1987, p. 168):

$$Qp = \frac{A.Ro}{3{,}6\ .(0{,}3\ T_p + T_{0,3})} \quad (4)$$

with:

Qp = flood peak discharge (m^3/sec)
A = watershed area (to the outlet) (km^2)
Ro = unit rainfall (mm)
Tp = grace period from the beginning of the rain until the peak of the unit hydrograph (hour)
$T_{0,3}$ = the time required by the decrease in discharge, from peak discharge until discharge become 30% from unit hydrograph peak discharge (hour)

To obtained Tp and $T_{0,3}$ with a river length of more than 15 Km used the formula:

$$t_g = 0{,}4 + 0{,}058\ L \quad (5)$$

$$T_{o.3} = \alpha . t_g \quad (6)$$

with:

t_g = time of concentration (hour)
L = river length
α = coefficients that depend on the characteristics of the watershed.

Flow Profile Analysis

Flow profile analysis in this study uses the program of HEC RAS version 5.0.6 with *unsteady flow* conditions.

Flood Control Alternative

The flood control scenario in this study was carried out as shown in Table 1 below.

TABLE 1. Flood Control Alternative

No.	Flood Control Alternative
1.	River Normalization
2.	Construction of the Flood Dike
3.	Construction of the Retarding Basin
4.	Combination of River Normalization and Flood Dike
5.	Combination of River Normalization and Retarding Basin
6.	Combination of Flood Dike and Retarding Basin
7.	Combination of River Normalization, Flood Dike, and Retarding Basin

Economic Analysis

- *Capital Cost*

Capital costs are the sum of all expenses needed starting from pre-study until the project is built.

- *Benefit*

In this study, the value of benefits equals the value of the losses caused by flooding, calculated by the formula (Waluyo, 1996):

$$F_d = d_s . M_s . A . f_a \quad (7)$$

with:

Fd = flood damage to the building facilities (Rp./year)
Ds = building density of each house (house/hectar)
Ms = the value or price of the building and the influence of the household of each house (Rp./house)
fa = inundation area (hectar)

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TABLE 2. Coefficient of Building Damage

No.	Depth (m)	Building				
		Settlement	Office	School	Store	Factory
1	0,0 - 0, 5	0.22	0.24	0.19	0.15	0.11
2	0, 5 - 1,0	0.36	0.38	0.30	0.28	0.21
3	1,0 - 1,5	0.44	0.43	0.35	0.38	0.28
4	1,5 - 2,0	0.47	0.48	0.38	0.47	0.34
5	2,0 - 2,5	0.48	0.49	0.39	0.54	0.38
6	2,5 - 3,0	0.49	0.50	0.41	0.59	0.40
7	> 3,0	0.49	0.50	0.41	0.60	0.41

TABLE 3. Coefficient of Household Effects

No.	Depth (m)	Household Effect				
		Settlement	Office	School	Store	Factory
1	0,0 - 0, 5	0.20	0.12	0.20	0.22	0.00
2	0, 5 - 1,0	0.62	0.73	0.78	0.63	0.29
3	1,0 - 1,5	0.80	0.90	0.90	0.79	0.62
4	1,5 - 2,0	0.92	0.98	0.95	0.89	0.83
5	2,0 - 2,5	0.98	1.00	0.98	0.95	0.95
6	2,5 - 3,0	1.00	1.10	1.00	1.00	1.00
7	> 3,0	1.00	1.10	1.00	1.10	1.00

➢ Project Economic Feasibility Criteria

The parameters to be used are the comparison of benefits and costs or *Benefit Cost Ratio* (BCR). To find out whether an investment is feasible or not, a criterion is needed in the BCR method, the criteria are:

- If BCR ≥ 1 then investment is feasible (*feasible*)
- BCR < 1 then investment is not feasible (*unfeasible*)

III. Result and Disscussion

Hydrological Analysis

Rainfall data is one of the important elements in river planning. In the Wanggu watershed there are two rain gauge stations, the Moramo Rain Station and the Haluoleo Airport Meteorological Station. Based on the results of statistical analysis, rainfall data at the study location can be used.

Regional average rainfall calculations use algebraic averages/ arithmetic method. The Wanggu watershed has an area of ± 348.75 Km².

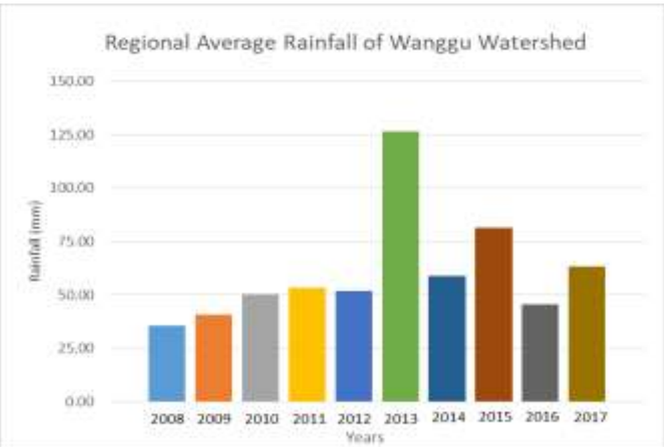

Fig. 2. Regional Average Rainfall of Wanggu Watershed

Design rainfall calculations will use the Log Pearson Type III method with the calculation results listed in Table 4 as follows:

TABLE 4. Design Rainfall

Return Period (year)	Design Rainfall (mm)
2	56.882
5	81.619
10	100.534
20	123.429
25	128.599
50	152.046
100	177.264
200	205.570

After obtained the design rainfall, will be conducted the test of goodness of fit of frequency distribution. There are two tests that can be done in this case, namely the Smirnov-Kolmogorov test or Chi Square Test (Limantara, 2010).

In the Smirnov-Kolmogorov test with α = 5%, obtained Δ max = 0.169 dan Δ Critical = 0.410. Becaue of Δ max < Δ Critical, then distribution can be accepted.

While in the Chi Square test with α = 5%, obtained the value of (c²) arithmetic = 0,000 and (c²) critical = 5,99. Becaue of (c²) arithmetic < (c²) critical, then distribution can be accepted.

After conducting the test of goodness of fit, performed the calculation of runoff coefficient. Runoff coefficient is obtained from calculating the land cover area. The value of C Mixture of the Wanggu watershed is 0,514.

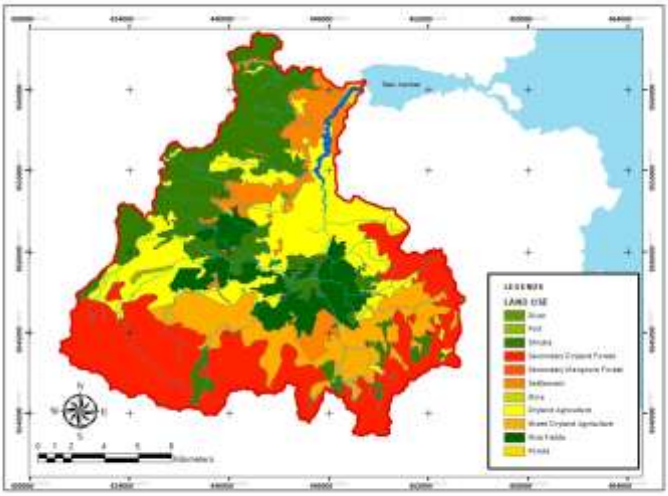

Fig. 3. Map of Wanggu Watershed Land Use

Design Flood Discharge

In this study, the Wanggu Watershed will be divided into several Sub-Watersheds, namely:

TABLE 5. Wanggu Watershed Division

No.	Division of Sub-Watersheds	Q design (m³/s)
1.	Upstream Wanggu Sub-Watershed	330.21
2.	Lepo-Lepo Sub-Watershed	53.15
3.	Ea Sub-Watershed	21.62
4.	Wua-Wua Sub-Watershed	22.21

The purpose of this division is to facilitate the inputting of flood discharge in inundation modeling.

Fig. 4. The Division of Wanggu Sub-Watershed

Calibration of Design Flood Discharge

The results of the calculation of the design flood discharge in the Upstream Wanggu Sub-Watershed will be calibrated with the flood discharge design of the Wanggu *Automatic Water Level Recorder* (AWLR) in order to find out the return period of flooding that ever occurred. The calibration results will be displayed in the following TABLE 6:

TABLE 6. Calibration of Upstream Wanggu Sub Watershed Discharge

No.	Return Period (Year)	Q design (m³/sec)	
		Calculation Results	AWLR of Wanggu
1.	2	155.71	102.69
2.	5	223.53	182.95
3.	10	275.02	240.04
4.	20	311.00	289.39
5.	25	330.21	317.24
6.	50	415.28	375.73
7.	100	483.94	438.06
8.	200	561.01	502.19

Based on data sourced from the Office of River Basin/Balai Wilayah Sungai (BWS) of Sulawesi IV Kendari, the maximum discharge recorded at AWLR of Wanggu is 302.19 m³/sec. This value is between the return period of 20 years and 25 years. By interpolating, the value is close to the 22-years return period. Therefore, this study will use flood discharge of 25-years return period.

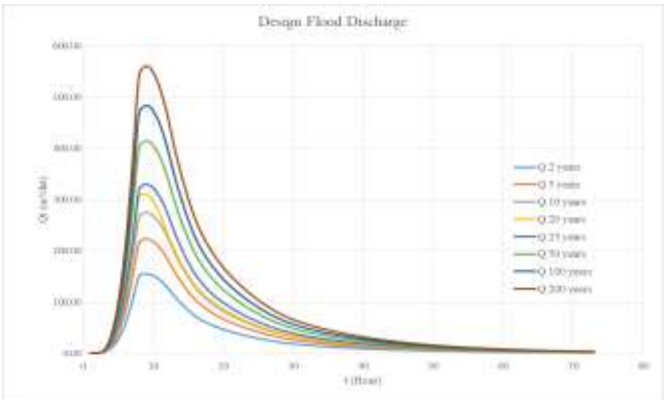

Fig. 6. Hydrograph of Design Flood Discharge of Upstream Wanggu Sub Watershed

Flood Inundation Modeling

a. Existing flood inundation modeling

Existing inundation modeling is done to get the distribution of flood inundation before flood control is carried out. After conducting the modeling at the HEC RAS application, it was found that the distribution of flood inundation in Kendari City was ± 499.70 Hectares.

Model verification is conducted to obtain a model that matches or approaches the actual condition. The method used to test the accuracy of the model is the *Root Mean Square Error* (RMSE) test. The results of the RMSE test will be shown in Table 7 below:

TABLE 7. RMSE Calculation of Flood History With the HEC RAS Model

No.	Flood History (m)	Model of HEC RAS (m)	Square of Error
1.	0.500	0.600	0.010
2.	0.500	0.600	0.010
3.	1.300	1.400	0.010
4.	2.500	2.600	0.010
		Totals	0.040

$$RMSE = \sqrt{\frac{\sum_{t=1}^{n}(A_t - F_t)^2}{n}}$$

$$RMSE = \sqrt{\frac{0.04}{4}} = 0.10$$

From the RMSE calculation above, using the number of manning 0.025, obtained the results of the RMSE test value equal to 0,10. Therefore, existing inundation modeling can be accepted because the inundation height in inundation modeling approaches the historical height of the flood event.

b. Flood Control

In this study several alternative of flood control will be used. This aims to get the most effective alternative.

The recapitulation of flood control alternatives will be shown in Table 8 below:

TABLE 8. Recapitulation of Flood Inundation Reduction

No.	Flood Control	Flood Inundation Reduction (%)
1.	River Normalization	15.84
2.	Construction of the Flood Dike	100.00
3.	Contruction of the Retarding Basin	11.22
4.	Combination of River Normalization and Flood Dike	100.00
5.	Combination of River Normalization and Retarding Basin	19.90
6.	Combination of Flood Dike and Retarding Basin	100.00
7.	Combination of River Normalization, Flood Dike, and Retarding Basin	100.00

Economic Analysis

Calculation of economic analysis includes calculation of the budget plan, calculation of the benefits of activities, and calculation of economic feasibility.

a. Budget Plan

In calculating this budget plan, there will be counted 4 (four) alternatives for the handling of flood inundations that are able to reduce inundation on land, namely the construction of flood dikes, River Normalization activities and the construction of the Flood Dike, construction of flood dikes and construction of retarding basins, and a combination of river normalization, construction of flood dikes and construction of a retarding basin.

As for the recapitulation of Budget Plan/RAB calculation from 4 (four) alternative of inundation handling will be presented in Table 9 below :

TABLE 9. Recapitulation of the Budget Plan

No.	Control	Cost (Rp.)*
1.	Construction of the Flood Dike	20,556.00
2.	Combination of River Normalization and Flood Dike	19,863.00
3.	Combination of Flood Dike and *Retarding Basin*	31,517.00
4.	Combination of River Normalization, Flood Dike, and *Retarding Basin*	31,659.00

(*In Million Rupiah)

b. Benefit Analysis

Benefit analysis is used to calculate the benefits caused due to flood control. n this study, the calculation of flood disaster losses is a direct benefit due to flood management activities.

Calculation of benefit analysis includes building losses and household losses. The calculation results will be shown in Table 10 below:

TABLE 10. Calculation of Losses Due to Flood Disasters

No	Description	Cost (Rp.)*
1.	Building Losses	12,715.50
2.	Household Losses	21,805.50
	Totals	34,521.00

(*In Million Rupiah)

c. Economic Feasibility Criteria

The parameter to be used is the Benefit Cost Ratio (B/C Ratio). The results of the B/C ratio calculation will be displayed in Table 11. Referring to Table 11, it was found that the most economical combination of flood control buildings/structures namely a combination of the river normalization with flood dikes with the B/C ratio of 1.74.

TABLE 11. Calculation of Economic Feasibility

No.	Handling	Cost (Rp.)*	Benefit (Rp.)*	B/C Ratio	Explanation
1.	Construction of the Flood Dike	20,556.00	34,521.00	1.68	*feasible*
2.	Combination of River Normalization and Flood Dike	19,863.00	34,521.00	1.74	*feasible*
3.	Combination of Flood Dike and Retarding Basin	31,517.00	34,521.00	1.10	*feasible*
4.	Combination of River Normalization, Flood Dike, and Retarding Basin	31,659.00	34,521.00	1.09	*feasible*

(*In Million Rupiah)

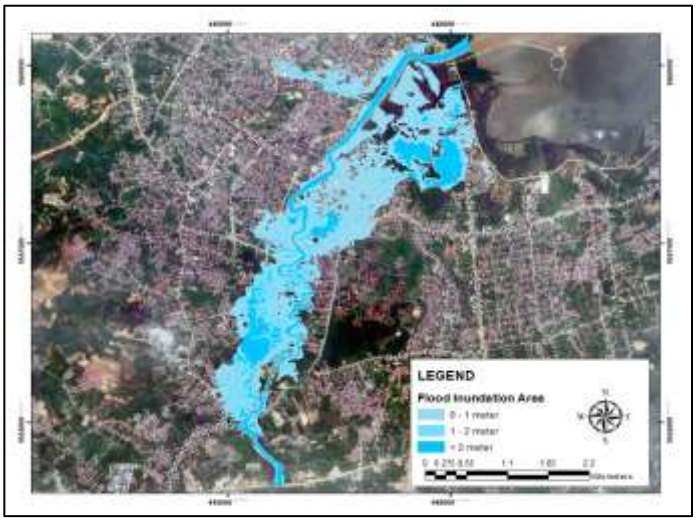

Fig. 7 (a). Flood Inundation of Existing Conditions

Fig.7 (b). Flood Inundation with The Handling of Combination of River Normalization and Flood Dike

Recommendation of Flood Control Building/Structure

In this study, recommendations for flood control buildings are based on technical and economic aspects. The recapitulation of both calculations will be shown in Table 12 below.

Based on Table 12, the combination of river normalization with flood dikes is the most effective and economical combination of handling in overcoming flood problems in the Wanggu River with 100% flood reduction capability and has a value of B/C Ratio of 1.74.

TABLE 12. Recapitulation of Technical Aspects and Economic Aspects

No.	Handling	Flood Reduction (%)	B/C *Ratio*
1.	Construction of the Flood Dike	100.00	1.68
2.	Combination of River Normalization and Flood Dike	100.00	1.74
3.	Combination of Flood Dike and Retarding Basin	100.00	1.10
4.	Combination of River Normalization, Flood Dike, and Retarding Basin	100.00	1.09

IV. CONCLUSION

Based on the study results of the Wanggu River flood inundation analysis it can be summarized as follows:

1. The design flood discharge used in this study is flood discharge of 25-years return period (Q25) equal to 330.21 m^3/second.
2. Wanggu River flood control is carried out to overcome runoff that occurs through the alternative of river normalization, construction of flood dikes, and construction of retarding basin. To get effective flood control, a combination method is used among the alternative of flood control. The combination used is a combination of river normalization with flood dikes, a combination of flood dikes with retarding basin, and a combination of river normalization, flood dikes and retarding basin. Based on analysis of inundation reduction, handling with flood dikes and combination methods is able to reduce inundation to 100%.
3. Based on the analysis of B/C ratio, the most economical flood controller is a combination of normalization of rivers and flood dikes with a B/C ratio of 1.74.
4. Selection of flood control recommendations based on technical and economic aspects. Based on these two aspects, the proposed flood controllers are a combination of normalization of rivers and flood dikes because it can reduce flood inundation 100% and had the highest B/C ratio with a value of 1.74.

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