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

Alternative Flood Control in Kening River Downstream Sub-watershed of Bengawan Solo

Heddy Bramantya[1], Mohammad Sholichin[2], Andre Primantyo Hendrawan[2]
[1]Water Resources Engineering Student Magister Program, Brawijaya University, Malang, East Java, Indonesia- 65145
[2]Lecturer of Water Resources Engineering Magister Program, Brawijaya University, Malang, East Java, Indonesia- 65145

***Abstract* — *Kening River has a flood problem every rainy season, floods in the Kening River are caused by land use changes and the absence of flood control infrastructure. The analysis is done by calculating the flood discharge design of the Nakayasu based on existing rainfall data and then calculating the design flood discharge at each return period. The results of these calculations are used in hydraulic analysis using the HEC-RAS software through the RAS Mapper extension, so that a simulation of inundation is obtained at each return period. From the results of hydraulic analysis, it was found that in the 2 year return period, there was an inundation area of 1,0218 Km^2 and in the 1000 year return period there was inundation of 1,8445 Km^2. From this result it can be concluded that in carrying out flood control it is divided into 3 (three) periods, that is short term, medium term, and long term where the controlling is a combination of structural and non structural flood control.*

***Keyword*— *HEC RAS, RAS Mapping, Flood, GIS.*

I. INTRODUCTION

Flooding is a problem that is always encountered in the management of a Water Resources (SDA). There are five factors that cause flooding in Indonesia, namely the rain factor, the watershed factor, the river channel development error factor, the silting factor and the zoning factor. – Construction of facilities dan infrastructure (Aji 2009).

Kening River is a tributary of Bengawan Solo in the downstream of Bengawan Solo Watershed which experiences flooding every year. This is due to the high intensity of rainfall during the rainy season, land use that has been transformed into a settlement and the absence of irrigation facilities and infrastructure for flood control.

In its development to date, studies that specifically discuss flood control in the Kening River are very limited. Therefore, this study is needed to analyze the effective flood control in the Kening River.

II. STUDY OBJECTIVES

The objectives of this study are as follows:

1. To find out the peak discharge in the Kening River in 2003 and 2017.
2. To find out the return period of the flood discharge that occurred in the Kening River.
3. To find out the existing capacity of Kening River to accommodate flood discharge.
4. To find out the optimal alternative in flood in the Kening River.

III. LITERATURE REVIEW

In achieving the objectives of this study, several analyzes are used, namely hydrological analysis and hydraulic analysis which will then be used as a basis for determining optimal flood control.

IV. HIDROLOGICAL ANALYSIS

According to Sri Harto, 1993, there are four types of problems in managing a river basin, namely:

1. Discharge fluctuation during the dry season.
2. Damage to land in the catchment area.
3. Damage to land in the catchment area.
4. Increased waste in rivers.

These 4 problems, which are relevant to this study, are related to river discharge and land degradation. In this study, the hydrological analysis was carried out by calculating the flood discharge of the Nakayasu synthetic hydrograph design.

A. Regional Average Rainfall

There are 3 (three) kinds of ways to determine the regional average rainfall, namely the Algebraic Average method, the Thiessen Polygon method and the Isohyet method. In this study the Thiessen Polygon method was used. This method is based on a weighing average. Each measure has an area ofinfluence which is formed by drawing axes perpendicular to the connecting line between two measuring posts. Polygon thiessen can be calculated by the following equation:

$$d = \frac{A_1 d_1 + A_2 d_2 + \cdots + A_n d_n}{A_1 + A_2 + \cdots + A_n} = \sum_{i=1}^{n} \frac{A_i d_i}{A}$$

Explanation :
A = area
d = high average area rainfall
$d_1, d_2, .., dn$ = high rainfall in post 1,2,...,n
$A_1, A_2, A_3, .., A_n$ = the area of influence of posts 1,2,3,...,n

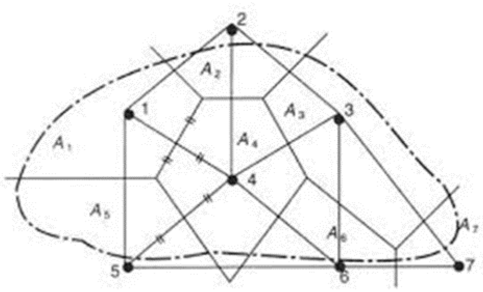

Fig. 1. Polygon Thiessen Method

Heddy Bramantya, Mohammad Sholichin, and Andre Primantyo Hendrawan, "Alternative Flood Control in Kening River Downstream Sub-watershed of Bengawan Solo," *International Research Journal of Advanced Engineering and Science*, Volume 6, Issue 1, pp. 55-60, 2021.

B. *Rain Data Consistency Test*

Consistency test is testing the correctness of data taken from the field which is not affected by errors during data transmission or at the time of measurement. if there is data inconsistency due to changes in the way data is collected and recorded, moving tools and so on, then it is possible to deviate from the original trend.

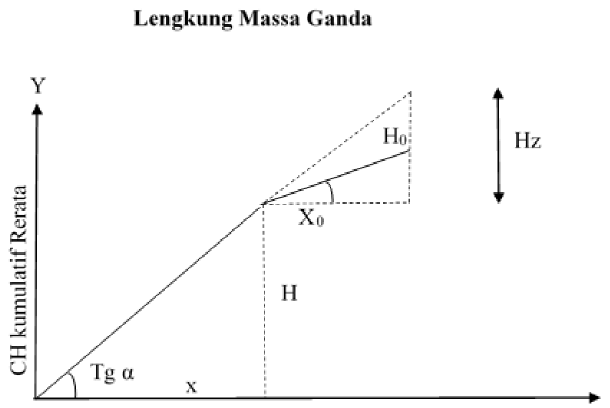

Fig. 2. Rain Data Consistency Test

C. *Design Flood Discharge Analysis*

In this study, the flood discharge was calculated using the Nakayasu synthetic unit hydrograph method. Nakayasu derived the synthetic unit hydrograph formula based on observations and research on several rivers. The amount of the unit hydrograph peak discharge value is calculated by the formula:

$$Qp = \frac{C.AR_0}{3,6(0,3T_p + T_{o,3})}$$

Explanation :

Q_p = peak flood discharge (m^3/sec)
A = watershed area (km^2)
R_0 = rainfall unit (mm)
Tp = grace period from the onset of rain to the peak of the flood (hour) :
= tg + 0,8 tr
tg = concentration time, the time span from the center of gravity of the rain to the point of gravity of the hydrograph in this case if :
L < 15 km tg = 0,21 . $L^{0,7}$
L > 15 km tg = 0,4 + 0,058 . L
Tr = *time base of hidrograf*
= 0,5 to 1 tg (hour)
$T_{0,3}$ = α . Tg
α = $\frac{0,47(A.L)^{0,25}}{tg}$

For :

- Regular drainage area α = 2
- Slow rising hydrograph and fast descending sections α = 1,5
- Fast rising hydrograph and slow descending sections α = 3

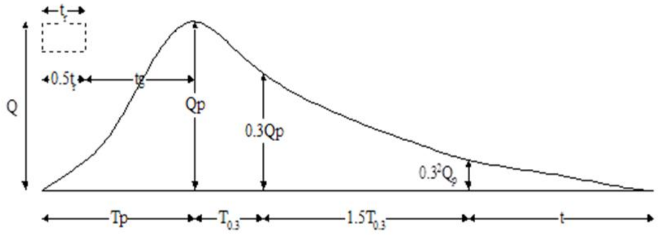

Fig. 3. Hydrograph Unit of the Nakayasu Cynical Unit

D. *Hydraulic Analysis*

Calculation or analysis of hydraulics can be done with a variety of assistive software, one of which is the HEC-RAS. HEC-RAS can assist in analyzing the capacity of a river or channel against a certain design discharge.

In HEC-RAS, several model simulations can be performed, such as steady flow, unsteady flow, sediment transport and water quality.

The basic equation for hydraulic calculation in HEC-RAS is:

$$Y_2 + Z_2 + \frac{\alpha_2.V_2^2}{2g} = Y_1 + Z_1 + \frac{\alpha_2.V_1^2}{2g} + h_e$$

Where is :

Y_1, Y_2 = depth in the *cross section* 1 and 2
Z_1, Z_2 = the basic elevation of the channel in the *cross section* 1 and 2
α_1, α_2 = coefficient of velocity
g = gravity
h_e = lost energy

Meanwhile, in the discharge calculation, the HEC-RAS uses the equation:

$$Q = K.S_f^{1/2}$$

$$K = \frac{1,486}{n}.A.R^{2/3}$$

Where is :

K = flow coefficient
n = manning roughness coefficient
A = wet cross sectional area
R = hydraulic radius

In dividing the flow to determine the coefficient of roughness, Manning can use the following figure:

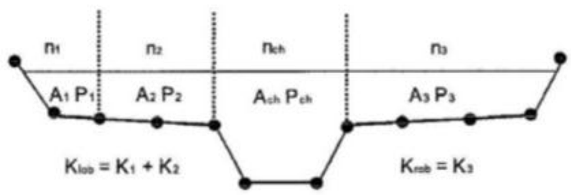

Fig. 4. Flow Distribution Method on HEC-RAS

The equation in determining the flow velocity is:

$$V = \frac{1,49}{n} R^{\frac{2}{3}} S^{\frac{1}{2}}$$

Where is :

V = average velocity (m/sec)
R = hydraulic spoke (m)
S = slope of energy
n = coeffiecient of roughness

Heddy Bramantya, Mohammad Sholichin, and Andre Primantyo Hendrawan, "Alternative Flood Control in Kening River Downstream Sub-watershed of Bengawan Solo," *International Research Journal of Advanced Engineering and Science*, Volume 6, Issue 1, pp. 55-60, 2021.

E. Geographical Information System (GIS)

The Geographic Information System (GIS) became known in the early 1980s. In line with the development of computer equipment, both software and hardware, GIS developed very rapidly in the 1990s. in line with the development of computer equipment, both software and hardware, GIS developed very rapidly in the 1990s. GIS can be defined as "a component consisting of hardware, software, geographic data and human resources that work together effectively to capture, store, repair, update, manage, manipulate, integrate, analyze, and display data in an information-based basis. geographical".

F. Digital Elevation Model (DEM)

There are several methods for presenting the shape of the earth's surface using a DEM, including the grid model, the TIN (Triangulated Irregular Network) model, and the Cellular Automata (CA). The grid / raster data model presents the earth's surface in a matrix or small square pixels representing the actual area on the earth's surface. Each pixel in this model has its own elevation (elevation) attribute. TIN presents a surface model as a set of triangular facets that are interconnected from points having the attributes of horizontal coordinates (x, y) and vertical coordinates (elevation). Meanwhile, Cellular Automata (CA) presents in the form of triangles, rectangles, or regular hexagons.

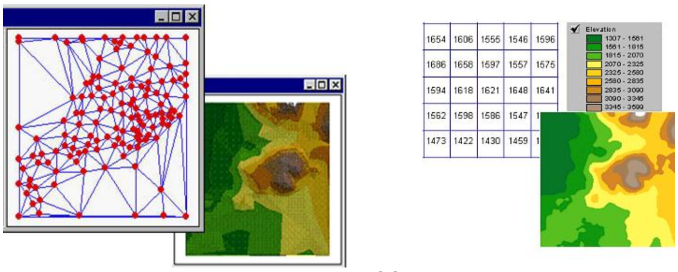

Fig. 5. DEM Model Type

G. Flood Control

Flood control is one of the inseparable aspects of an integrated watershed (DAS) management of water resources from upstream to downstream. In an effort to control floods, there are 2 (two) efforts, namely structural and non-structural measures. Optimal flood control is a combination of these two efforts.

Some example of structural measures include:

1. Embankment loading.
   Embankments can withstand river overflows when there is high discharge.
2. Sediment dredging.
   To increase the capacity of the river so that water does not overflow from the river.
3. Flood evasion channel.
   It is a creation of an artificial river in the form of a floodway that can reduce the amount of flood discharge.
4. Construction of a reservoir/dam.

The dam and its reservoir can accommodate large discharge due to flooding so that there is no overflow downstream.

1. Use of land use appropriately
   Land use designed as forestry and water catchment areas are not allowed to be used as settlements.
2. Preservation of the function of the catchment area in the catchment area so that the surface water flow is minimal.
3. Development and management of flood hazard early warning systems.
4. Environmental adaptation to flood conditions.
5. Cleaning garbage along the river to prevent the occurrence of obstruction to the river flow.

V. STUDY METHOD

A. Research Location

The study site used in this research is the Kening river or the Kening river watershed. The total area of the Kening sub-watershed is 810,44 Km^2 with a total length is 80,43 km.

B. Study Progression Steps

1. Collecting data;
2. Delineate watershed boundaries with ArcSWAT;
3. Create a Thiessen Polygon to determine the area's average maximum daily rainfall;
4. Hydrology analyze with rain consistency test;
5. Discharged flood period of analysis with HSS Nakayasu method;
6. Analysis of river geometry and cross section with HecGeoRAS in ArcGIS 10.3;
7. Analysis of existing capacities;
8. Flood control selection.

VI. RESULT AND DISCUSSION

A. Flood Event Data

In the period 2003 to 2017, there are some of the flood events that occurred:

TABLE 1. Flood Event Data

No	Date	Water Surface Height (m)	Water Discharge (m3/sec)
1.	01 Juni 2003	12,05	70,54
2.	12 December 2004	13,89	129,23
3.	14 May 2005	12,66	90,89
4.	16 October 2006	14,00	128,63
5.	13 December 2007	15,89	635,32
6.	11 February 2008	14,65	153,01
7.	13 November 2009	12,98	92,39
8.	27 December 2010	15,81	295,47
9.	25 December 2011	13,55	153,33
10.	30 May 2012	14,14	139,08
11.	13 December 2013	16,08	315,81
12.	01 June 2014	15,78	287,73
13.	13 May 2015	13,80	119,43
14.	28 June 2016	15,28	255,15
15.	05 July 2017	13,55	105,18

From the data above, it is found that the maximum flood discharge that has ever occurred is 635,32 m^3/sec which occurred on 13 December 2007.

B. Watershed Delineation

Delineation is the process of delineating watershed boundaries using elevation or topography data. Altitude or topographic data can be obtained through the Rupa 'bumi Indonesia Digital Map (RBI) or the Digital Elevation Model (DEM) data.

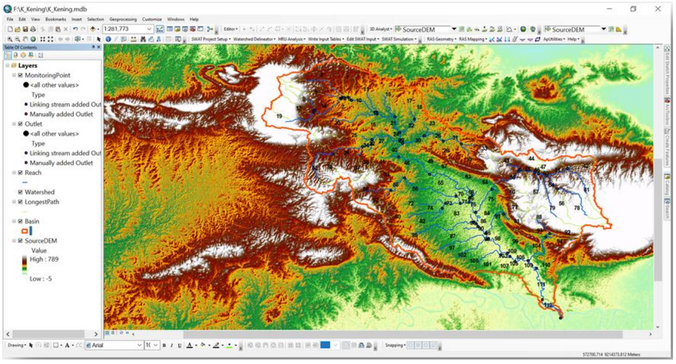

Fig. 6. Result of Delineation Kening Watershed

C. Polygon Thiessen

The rain station used in this calculation is Station Kebonharjo, Station Laju and Station Mundri. The result of making polygon is:

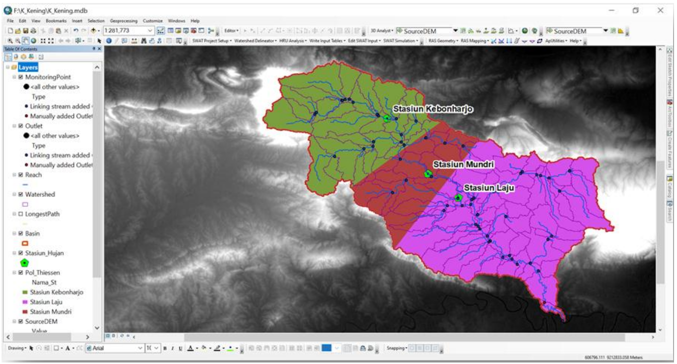

Fig. 7. Polygon Thissen the Kening Watershed

D. Rainfall Data

Rainfall data in this study were taken from Kebonharjo, Laju, and Mundri Station, in the observation period from 1981 to 2017.

E. Rain Data Consistency Test

The consistency test is a test of the truth or validity of data, taken from the field which is a picture of the real situation. This test is performed using a multiple mass curve. From the result of the consistency test of the three rain stations above, it can be concluded that there is no need for rainfall correction or consistent rain data because there is no deviation in the rainfall data.

F. The Goodness of Fit Test

F.1 Chi Square Test

The result of the Chi Square test are as follows :

TABLE 2. Chi Square Test

No	α	X^2table	X^2hit	Information	
1	1%	11,345	1,4	X^2 hit < X^2 tabel	Distribution is acceptable
2	5%	7,815	1,4	X^2 hit < X^2 tabel	Distribution is acceptable

Source : the calculation results

F.2 Smirnov-Kolomogorov Test

TABLE 3. Smirnov-Kolmogorov Test

α	Δ critical	Δ max	Information
0,2	0,18	0,07	Accepted
0,1	0,20	0,07	Accepted
0,05	0,22	0,07	Accepted
0,01	0,26	0,07	Accepted

G. Flood Debit Analysis Nakayasu (HSS) Design

The calculation of Tp or the grace period from the beginning of rain to the peak of the hydrograph (hour):

Tp = *Timelag* + 0,8 x Tr

= 7,09 hour

From the Tp value, the peak flood discharge is 33,67 m3/second. The graphic of Nakayasu HSS unit can be seen in the following picture:

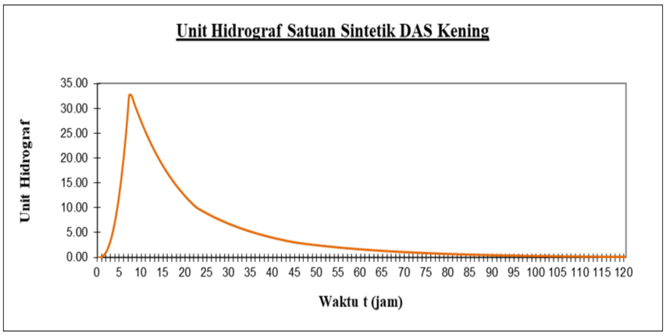

Fig. 8. Nakayasu Synthetic Unit Hidrograph Method

H. Flood Discharge Analysis Design Each Return Period

From the analysis of the hourly net rain distribution at each return period, the maximum Q value for each return period is obtained as follows:

TABLE 4. Recapitulation of Maximum Q value for Each Return Period

Q maksimum (m^3/dt)						
$Q_{2\ th}$ (m^3/dt)	$Q_{5\ th}$ (m^3/dt)	$Q_{10\ th}$ (m^3/dt)	$Q_{25\ th}$ (m^3/dt)	$Q_{50\ th}$ (m^3/dt)	$Q_{100\ th}$ (m^3/dt)	$Q_{1000\ th}$ (m^3/dt)
481.05	**542.79**	**577.47**	**616.43**	**642.65**	**666.88**	**739.05**

I. Hydraulic Analysis

The analysis was carried out using HEC-RAS 5.0.7, ArcGis and HecGeo-RAS Software. In this analysis, a simulation of inundation is produced at each return period for per village or location in the Kening Sub Watershed and based on the using of in order to their land. The classification of the area of inundation that occurs is based on the 2012 PERKA BNPB, namely Low (<0,76 m), Medium (0,76-1,5 m) and High (>1,5 m).

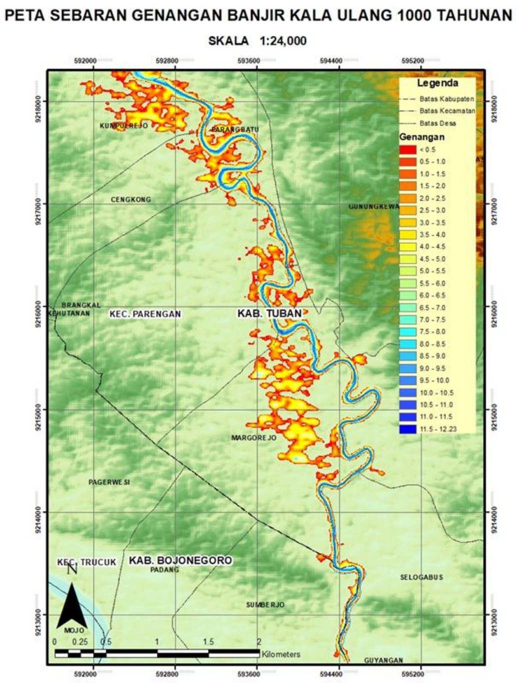

Fig. 9. Inundation Flood Discharge 1000 Years Return Period

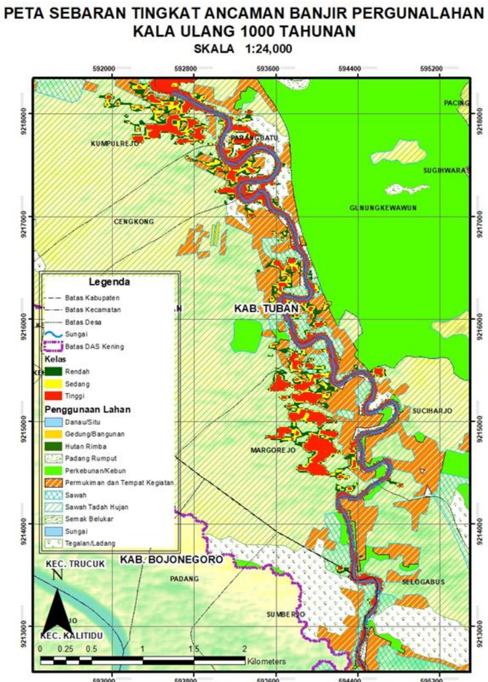

Fig. 10. Inundation Flood Discharge Period Return 1000 Years per Land Use

The results of flood inundation that occur in the Kening watershed per return based on the class of flood threat according to the 2012 PERKA BNPB that at low criteria (<0,76 m) the maximum flood inundation area that occurred was 0,4180 km^2 during the 1000 year return period, at medium criteria (0,76-1,50 m), the maximum total area of flood inundation is 0,3341 Km^2 at the 1000 year return period. At the height criteria (>1,5 m), the maximum total area of flood inundation is 1.0924 Km^2.

TABLE 5. Flood Innundation in Kening Watershed

No	Luas Genangan Banjir dengan Kala Ulang	Luas Total Genangan Banjir Pada Kelas Ancaman (Km^2)			Luas Total Genangan (Km^2)
		Rendah (< 0.76 m)	Sedang (0.76-1.5 m)	Tinggi (>1.5 m)	
1	2 Tahun	0.1863	0.1480	0.6874	1.0218
2	5 Tahun	0.2320	0.1777	0.7568	1.1665
3	10 Tahun	0.2553	0.1910	0.7907	1.2370
4	25 Tahun	0.2886	0.2244	0.8344	1.3475
5	50 Tahun	0.3061	0.2444	0.8746	1.4251
6	100 Tahun	0.3387	0.2612	0.9170	1.5168
7	1000 Tahun	0.4180	0.3341	1.0924	1.8445
	Total	2.0250	1.5807	5.9534	9.5591

J. Flood Control

This study is based on an analysis of recurrent inundation, per village and per land use in the Kening Watershed, it can be seen the areas that need to be controlled against flooding. In this study, there are 3 (three) recommendations for flood control, namely short term flood control, medium term flood control and long term flood control.

J.1 Short Term Flood Control

Short term flood control is carried out by constructing embankments where there are no embankments in the existing condition.

TABLE 6. Embankments Constructions

No	Kabupaten	Kecamatan	Desa	Total Panjang Tanggul (Kanan dan Kiri) (m)	Luas Total Genangan (Q1000 thn)(Km^2)
1	Tuban	Parengan	Brangkal	2369.21	0.1905
			Cengkong	1280.70	0.1364
			Gunungkewawun	0.00	0.0027
			Kumpulrejo	1175.61	0.2953
			Margorejo	3808.78	0.5730
			Parangbatu	3541.45	0.2835
			Selogabus	1085.34	0.0912
			Suciharjo	3964.79	0.2242
2	Bojonegoro	Trucuk	Sumberjo	852.32	0.0476
			Total	18078.21	1.8445

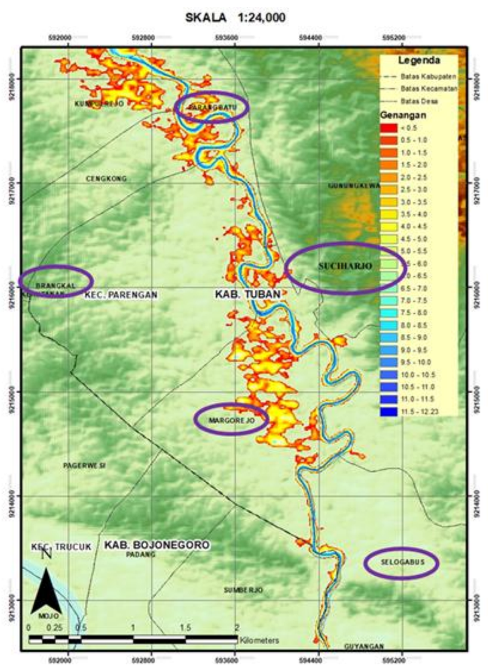

Fig. 11. Priority Village Location for Embankmen Construction

J.2 Medium Term Flood Control

The recommendation for medium term flood control in the Kening River is the construction of an artificial river in the form of a waterway diversion or a floodway. This is consistent with the character of the Kening River, which is a meandering river. Waterway diversion needed to straighten the river flow alignment so that the water can flow directly downstream into the Bengawan Solo River.

J.3 Long Term Flood Control

Long term flood control is a flood control that requires a long controliing time to get results. Based on the existing conditions in the Kening River, especially those in the upstream part, the recommended long term flood control is conservation or afforestation with community empowerment.

VII. CONCLUSION

1. From the observation data of the maximum annual discharge that occurred in the period 2003 to 2017, it was found that the highest flood discharge was 635,32 m^3/sec which occurs on December 13, 2007.
2. Flood discharge plan based on Nakayasu Synthetic Unit Hydrograph is as follows:
   a. The 2 years return period is 481,05 m^3/second ;
   b. The 5 years return period is 542,79 m^3/second ;
   c. The 10 years return period is 577,47 m^3/second ;
   d. The 25 years return period is 616,43 m^3/second;
   e. The 50 years return period is 642,65 m^3/second ;
   f. The 100 years return period is 666,88 m^3/second ;
   g. The 1000 year return period is 739,05 m^3/second.
3. The ability of the existing capacity of the Kening river to accommodate the planned discharge can be seen in the analysis simulation results using HEC-RAS, where in the analysis of each return period there was a pool or overflow of river water with a varied area, where in the 2 year return discharge there was an inundation of 1,0218 Km^2 and at the 1000 year return discharge there was a pool of 1,8445 Km2.
4. Flood control in the Kening River is a combination of structural and non structural flood control which is divide into 3, namely short, medium and long term flood control. In short term flood control, it is recommended to build a retaining embankment for river water overflow with a total length of the planned dike requirement of 18.078,21 meters Medium term flood control recommend the construction of an artificial river in the form of a stream or floodway. This is adaptes to the typical meandering River Kening. Meanwhile, for long term flood control it is recommended to carry out conservation or afforestation especially in the upstream part of the Kening Watershed.

REFERENCES

[1] Asep Sulaeman. Ery Suhartanto. Sumiadi. 2017. Analisis Genangan Banjir Akibat Luapan Bengawan Solo untuk Mendukung Peta Risiko Bencana Banjir di Kabupaten Bojonegoro
[2] Limantara, L. M. 2010. *Hidrologi Praktis*. Bandung : CV. Lubuk Agung.
[3] Chow, V. T. 1997. *Hidrolika Saluran Terbuka*. Jakarta : Erlangga.
[4] ESRI (Environmental System Research Institute, Inc). 1996. ArcView GIS, The Geographic Information System for Everyone. ESRI, New York.
[5] Asdak, Chay. 2004. Hidrologi Dan Pengelolaan Daerah Aliran Sungai. Yogyakarta : Gajah Mada University Press.
[6] Fahmi Zamroni, Mohammad Sholichin, Andre Primantyo. 2015. Analisa Pengendalian Banjir Kali Ciliwung Ruas Jembatan MT. Haryono – Pintu Air Manggarai. “Jurnal Teknik Pengairan”, Vol 6 No.1.
[7] Wahyuddin Qadri S, Mohammad Sholichin, Dian Sisinggih. 2016. Studi Penanganan Banjir Sungai Bila Kabupaten Sidap. “Jurnal Teknik Pengairan”, Vol 7 No.2.
[8] Indra Nurdianyoto, Ery Suhartanto, Emma Yuliani, 2019. Analysis of Rain-Flood Discharge Using HEC-HMS in Sadar Sub catchment, Mojokerto. “International Research Journal of Advanced Engineering and Science”, Volume 5, Issue 1, pp. 41-47.
[9] Rachmat Deby, Very Dermawan, Dian Sisinggih, 2019. Analysis of Wanggu River Flood Inundation Kendari City Southeast Sulawesi Province Using HEC RAS 5.0.6. “International Research Journal of Advanced Engineering and Science”, Volume 4, Issue 2, pp. 270-275.
[10] Soemarto, C. D. 1989. *Hidrologi Teknik*. Malang : PPMTT.
[11] Soemarto, C. D. 1999. *Hidrologi Teknik (Edisi Ke-2)*. Jakarta : Erlangga.
[12] Soewarno. 1995. Hidrologi (Aplikasi Metode Statistik untuk Analisa Data) Jilid 1. Bandung : Nova.
[13] Soewarno. 2000. *Hidrologi Operasional Jilid Kesatu*. Bandung : Penerbit PT. Citra Aditya Bakti.
[14] Sosrodarsono, S. 1978. *Hidrologi Untuk Pengairan*. Jakarta : PT. Pradnya Paramita.

Heddy Bramantya, Mohammad Sholichin, and Andre Primantyo Hendrawan, “Alternative Flood Control in Kening River Downstream Sub-watershed of Bengawan Solo,” *International Research Journal of Advanced Engineering and Science*, Volume 6, Issue 1, pp. 55-60, 2021.