BULLETIN OF CIVIL ENGINEERING

Vol. 2 No. 2, August 2022

Artikel Riset

Dambreak Risk Analysis of Jenelata Dam and its Mitigation Plan

Calvin Sandi[a*], Eka Oktariyanto Nugroho[a], M. Cahyono[a]

[a] *Graduate School of Water Resource Management, Bandung Institute of Technology*

DOI: https://doi.org/10.18196/bce.v2i2.15533

Abstrak

Bendungan Jenelata direncanakan akan dibangun di Sulawesi Selatan dengan luas DAS 221,22 km^2 untuk mengatasi bencana kekurangan air dan banjir di Kota Makassar. Setiap bendungan memiliki potensi keruntuhan bendungan salah satunya diakibatkan oleh gempa bumi. Oleh karena itu, analisis resiko perlu dilakukan untuk mempelajari rencana mitigasi yang paling efektif. Penelitian ini bertujuan untuk melakukan analisis resiko kegagalan bendungan. Pemodelan hidrograf banjir akibat jebolnya bendungan dilakukan dengan menggunakan HEC-HMS dengan skenario jebolnya bendungan yang paling ekstrim akibat limpasan dengan puncak debit 48726,47 m^3/s. Pemodelan genangan banjir dilakukan menggunakan HEC-RAS dengan luas genangan akibat limpasan adalah 20.842,48 Ha. Hasil peta genangan dan data kependudukan kemudian dijadikan dasar penentuan indeks resiko per kecamatan. Rencana mitigasi tersebut berupa struktur dan non struktur. Solusi struktural ditentukan berdasarkan efektivitas dalam mengurangi luas genangan banjir. Dari hasil kajian, diperoleh solusi pemasangan tanggul setinggi 150 cm pada cabang utama dan cabang sungai memberikan hasil yang terbaik. Implementasi rencana mitigasi didasarkan pada nilai indeks resiko kecamatan dan komponennya. Hasil akhir berupa indeks resiko dengan implementasi rencana mitigasi sebagai pembanding indeks resiko tanpa rencana mitigasi. Dari hasil penerapan solusi, terjadi penurunan indeks resiko di beberapa kecamatan.

Kata kunci: bendungan, jebolnya bendungan, analisis resiko, rencana mitigasi

Abstract

The Jenelata Dam is planned to be built in South Sulawesi to overcome drought and flood hazard. It has 221.22 km^2 of catchment areas. Every dam may break due to external factors such as earthquakes. Therefore, risk analysis needs to be carried out to investigate the most effective mitigation plan. This study aims to analyze the risk of dam failure. Flood hydrograph modeling due to dam break was done using HEC-HMS with 48726.47 m^3/s of designed peak discharge. The flood inundation modeling was conducted using HEC-RAS. The flood model simulation resulted 20842.48 Ha of inundated area that caused dam overtopping. The results of the inundation map and demographic data are then used as the basis for determining the risk index per sub-district. The mitigation plan is in the form of structural and non-structural. The effectiveness of structural solution to mitigate flood was investigated. The result showed the existence of embankments with 150 cm high give the best result. Implementation of the mitigation plan is based on the risk index value of the sub-district and its components. The final result is a risk index with implementation of the mitigation plan as a comparison to the risk index without the mitigation plan. The result obtained is a decrease in the risk index on several sub-districts.

Keywords: dam, dam break, risk analysis, mitigation plan

Article History
Recieved
17 July 2022

Revised
29 August 2022

Accepted
31 August 2022

*Corresponding author
calvinsandi458@gmail.com

1 INTRODUCTION

In the 1970s, Makassar City and the surrounding area always suffered from floods every year, this was due to the inadequate capacity of the Jeneberang River and the poor drainage conditions. On the other hand, during the dry season, there is not enough water for drinking, industry, and irrigation, based on the Final Report on the Detailed Design of the Jenelata Dam, Gowa Regency

(2014). The extreme weather that occurred on January 22-24, 2019 (Rustan et al., 2019) in the Makassar City area caused 61 sub-districts spread across 13 districts/cities to be flooded (Musa et al., 2020). It caused the Jenelata River flow rate reached 1200 m^3/s (exceeding the river storage capacity) and contributes to a fairly large flood discharge in the Jeneberang River based on the Bili-Bili Dam Extraordinary Inspection Report by the Dam Office (2019).

Because of these problems, the Jenelata Dam is planned to be built on the Jenelata River. As one of the dams that have the potential for Dam Break to occur, it is necessary to study the risk analysis due to the destructive power of the water to determine an effective solution in reducing the risk index. Flood modeling due to dam collapse is needed to reduce losses from each potential dam break (Yakti et al., 2017).

The purpose of the preparation of this paper is to analyze the collapse of the Jenelata Dam and assess the potential hazard to the downstream area of the Jenelata Dam as a result of water damage. The purpose of this paper is to create a risk map due to the collapse of the dam and to design a solution to control the destructive power of water at the downstream part of the Jenelata Dam. The contribution of this paper is to provide an analysis of the risk of dam collapse for the dam to be built, namely the Jenelata Dam, as well as to provide recommendations for effective and efficient countermeasures.

2 RESEARCH METHODOLOGY

2.1 Research Location

Jenelata Dam is planned to be built at coordinates 5°17'21.70"S and 119°36'3.59"E with a catchment area of 221.22 km^2. Data of Jenelata Dam is presented in Table 1.

Table 1 Technical Data of Jenelata Dam

Nama Sungai	:	Sungai Jenelata
Luas Genangan	:	1.128,15 Ha
Tipe Bendungan	:	Urugan Batu dengan Inti Kedap Air Tegak
El. Dasar Sungai	:	+43,00 m
El. Puncak Bendungan	:	+106,00 m
Tinggi Bendungan dari Dasar Sungai	:	63 m
Tinggi Bendungan dari Galian Terdalam	:	67 m
Panjang Bendungan	:	1433,88 m
Lebar Puncak	:	10 m
El. Tampungan Mati	:	+73,49 m
El. NWL	:	+99,50 m
Tampungan Mati	:	22 juta m³
Volume Tampungan Efektif	:	201,58 juta m³
Volume Tampungan Total	:	223,58 juta m³
Tipe Bangunan Pelimpah	:	Pelimpah Samping
Tipe Mercu Pelimpah	:	Ogee
Lebar Ambang	:	60 m

2.2 Data Collection

The data used for this study are data obtained from relevant agencies, namely BBWS Pompengan-Jeneberang, Badan Pusat Statistik (BPS), and Badan Informasi Geospasial (BIG). The data needed are rainfall data, topographic and land cover maps, dam technical data, and population data at related locations.

Figure 1 Location and Delineation Watershed of Jenelata Dam

2.3 Hydrology Analysis

The rain data used comes from the Kampili and Senre rain stations which can be seen in Table 2. The hydrology analysis is done by referring to the SNI 2415-2016 guidelines. The data is processed to obtain the maximum annual rainfall, which is then tested and calculated using the Thiessen Polygon method to get the regional rainfall. Meanwhile, based on SNI 7746-2012, the rain data used at each post is the largest daily rainfall data in one year or the maximum annual daily rain, regardless of the date of the rain.

Table 2 Annual Maximum Rainfall Data

Year	Annual Maximum Rainfall (mm)	
	Kampili Station	Senre Station
1999	125	108
2000	150	193
2001	49	123
2002	150	183
2003	300	138
2004	135	125
2005	150	110
2006	250	303
2007	125	225
2008	120	190
2009	189	180
2010	117	123
2011	91	90
2012	150	118
2013	142	203
2014	100	115
2015	140	169
2016	155	114
2017	160	160
2018	159	193
2019	163	237

Frequency analysis and data suitability tests were carried out to determine the rainfall design. The flood discharge design is then calculated using 4 Synthetic Unit Hydrograph methods, namely Nakayasu, SCS, ITB-1, and ITB-2. The synthetic unit hydrograph method is a popular method used and plays an important role in many planning in the field of water resources, especially in the analysis of unmeasured watershed flood discharges (Natakusumah et al., 2011). The selection of the HSS method uses the Creager curve method.

The same thing was then carried out for the PMP (Probable Maximum Precipitation) rainfall design, where the determination refers to the SNI 7746-2012 guidelines. Determination of PMP rainfall is done using methods, namely the Hersfield method and the PMP Isohyet Map.

2.4 Dam Break Analysis

Dam failure can occur due to overtopping or piping. Overtopping is where the elevation of the water level upstream of the dam exceeding the elevation of the crest so that the water flows over the crest of the dam, while piping is the condition of river water that is dammed by the dam and can flow into the ground along the base and walls of the natural dam (Brunner, 2014). Dam break begins with a breach (Purwanto et al., 2017), where the breach is an opening formed during the collapse of the dam body (Wijayanti et al., 2013). Therefore, the analysis of dam break begins with calculating the breach dimensions in the form of depth, width, side slope, and time of breach formation to occur using the following Froehlich (2008) equation.

$$B_{avg} = 8{,}239 K_o V_w^{\,0{,}32} h_b^{\,0{,}04} \quad (1)$$

$$t_f = 3{,}664 \sqrt{\frac{V_w}{g h_b^{\,2}}} \quad (2)$$

Where:
B_{avg} = average breach width (ft);
K_o = constanta (1,3 for overtopping, 1,0 for piping);
V_w = reservoir volume (ac-ft);
h_b = breach height (ft);
t_f = time of breach formation to occur (s).

Parameters obtained from the calculation above are then used in routing the dam break with the help of the HEC-HMS software and modeling the inundation area with the help of the HEC-RAS software (Murdiani et al., 2020).

2.5 Risk Analysis

The risk analysis is done by referring to the Perka BNPB No. 2 of 2012, where the parameters used are the hazard threat index, vulnerability index, and adaptive capacity index which are determined based on Table 3, Table 4, and Table 5.

Table 3 Hazard Threat Index Component

Depth (m)	Class	Value	Percentage (%)	Score
< 0.76	Low	1		0,333
0.76 - 1.5	Medium	2	100	0,667
> 1.5	High	3		1,000

Table 4 Vulnerability Index Component

No	Parameter	Percentage (%)
1	Social Vulnerability	40
2	Economic Vulnerability	25
3	Physical Vulnerability	25
4	Environment Vulnerability	10

Table 5 Adaptive Capacity Index Component

No	Parameter	Percentage (%)
1	Regulations and Disaster Management Institutions	15
2	Early Warning and Disaster Risk Assessment	15
3	Disaster Education	20
4	Reduction of Basic Risk Factors	25
5	Establishment of Preparedness at All Lines	25

The risk index is then calculated using the equation below.

$$R \approx H \times \frac{V}{C} \quad (3)$$

Where:
R = Disaster Risk
H = Hazard Threat
V = Vulnerability
C = Adaptive Capacity

3 RESULT AND DISCUSSION

3.1 Hydrology Analysis

In the hydrology analysis, delineation watershed of the dam is done to obtain the dam's catchment area. The delineation was done using ArcGIS 10.5 software with topographic data sourced from DEMNAS. The results of the delineation of Jenelata Dam catchment area are shown in **Error! Reference source not found.**.

The data from the 2 rain stations were then tested using the RAPS (Rescaled Adjusted Partial Sums) and outlier method, and the regional rainfall was then calculated using the Thiessen Polygon method. After that, a frequency analysis was done to determine the rainfall design with a certain return period. The results were then tested using the Chi Square test and the Smirnov Kolmogorov test. The recapitulation of the calculation results is shown in

Table 6.

From the table, it can be concluded that the Normal Distribution Method was chosen to be used in further analysis because the method produces the smallest Chi-Square Calculated value, which used as a parameter to determine the best method. The PMP design rainfall was also calculated, where the calculation results gave a PMP rain value of 787.41 mm for the Hersfield method and 943 mm for the Isohyet PMP Map method, so the PMP value from the Isohyet PMP Map method was used as the PMP design rain value.

Table 6 Recapitulation of Rainfall Design Calculation Results of The Jenelata Dam Watershed

No.	Return Period (Year)	Rainfall Design (mm)				
		Gumbel Method	Normal Method	Log Normal Method	Pearson Type III Method	Log Pearson Type III Method
1	2	153,81	161,53	154,18	153,59	152,10
2	5	208,99	205,28	200,02	201,42	199,16
3	10	245,52	228,19	229,23	231,27	231,09
4	25	291,68	250,49	261,76	266,98	272,47
5	50	325,93	268,28	290,99	292,25	304,10
6	100	359,92	282,86	317,36	316,46	336,39
7	200	393,79	295,88	342,92	339,92	369,66
8	1000	472,24	322,44	401,63	392,18	451,71
SMIRNOV KOLMOGOROF TEST						
D Maximum, D Max		0,121	0,165	0,157	0,165	0,157
Degree of Significance		5,000	5,000	5,000	5,000	5,000
D Critis		0,286	0,286	0,286	0,286	0,286
HYPOTHESIS		ACCEPTED	ACCEPTED	ACCEPTED	ACCEPTED	ACCEPTED
CHI SQUARE TEST						
Chi - Square Calculated		11,857	4,357	6,143	6,143	9,000
Chi - Square Critis		7,815	7,815	7,815	7,815	7,815
Degree of Freedom		3,000	3,000	3,000	3,000	3,000
Degree of Significance		5,000	5,000	5,000	5,000	5,000
HYPOTHESIS		NOT ACCEPTED	ACCEPTED	ACCEPTED	ACCEPTED	NOT ACCEPTED

The results is then used in calculating the PMF (Probable Maximum Flood) flood discharge design, which is the discharge design of the Jenelata Dam using various Synthetic Unit Hydrograph methods used with the results as shown in Figure 2.

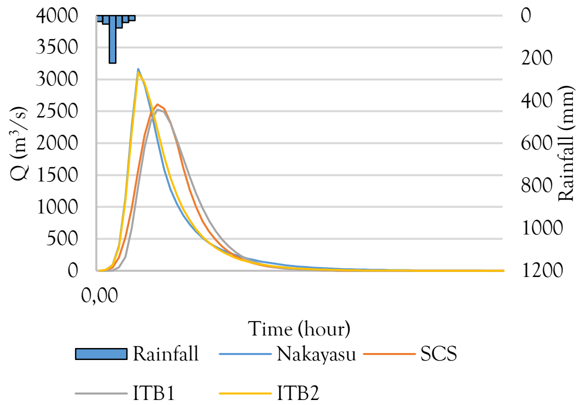

Figure 2 Recapitulation of Jenelata Dam PMF Flood Discharge

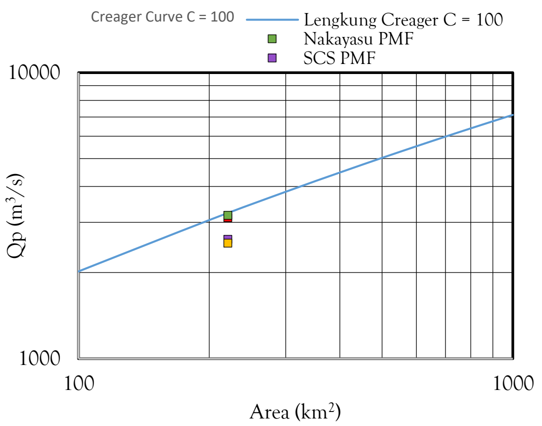

Figure 3 Jenelata Dam Creager Curve Graph

The selection of the Synthetic Unit Hydrograph method was done using the Creager curve with a coefficient C is 100, which is the maximum flood blanket that has ever occurred worldwide. From the Creager curve, the Nakayasu method was chosen as the PMF flood discharge design for the Jenelata Dam.

3.2 Dam Break Analysis

Characteristics of flood that occur due to dam break have a very high flood peak and the time of the occurrence of flooding is very short between the beginning and the peak of the flood, causing large amounts of water from the dam to be released suddenly to downstream of the dam (Kusuma et al., 2008).

The results of the calculation of dam break parameters with the Froehlich equation (2008) are as follows:

- Water height (H_b) = 63 m
- Reservoir volume (V_w) = 303.44 million m^3
- Breach slope:
  - Overtopping, H : V = 1 : 1
  - Piping, H : V = 0.7 : 1
- Breach width (B_{avg}):
  - Overtopping, B_{avg} = 214.59 m
  - Piping, B_{avg} = 165.07 m
- Time of breach formation to occur (T_f) = 1.55 hours

The results of the calculations above are used as parameters in routing the dam break using the HEC-HMS software. The peak discharge values as a result of dam break routing are shown in Table 7.

From Table 7, it is found that the peak discharge value is a dam break scenario due to overtopping, so the overtopping scenario is used in flood inundation modeling using HEC-RAS. Flood inundation modeling is in 2D with Unsteady Flow parameters and topographic data sourced from DEMNAS. The result of the flood inundation modeling due to overtopping is shown in Figure 4.

Table 7 Dambreak Routing of Jenelata Dam

Dambreak Scenario	Discharge Peak Outflow (m3/s)
Overtopping	48726,466
Bottom Piping	43779,949
Middle Piping	36724,008
Top Piping	24973,879

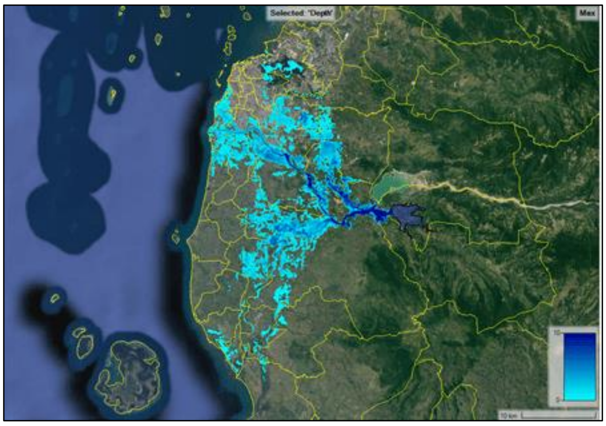

Figure 4 Flood Inundation Modeling Result of Jenelata Dam

3.3 Risk Analysis

The analysis is done using demographic data obtained from BPS, previous analyzes, and other supporting data. The hazard score was calculated using the modelling result, vulnerability score was calculated using the data from BPS, meanwhile the capacity score was a subjective assessment as also mentioned in Perka BNPB. It is a result of interviews with several related instances. However, due to the author's limitations, it became a limitation of this study. Therefore, the capacity score was based on the author's subjective assessment. The results of the risk index analysis along with the risk map for the sub-districts that are estimated to be affected by inundation due to the dam break of Jenelata Dam are shown in Table 8 and Figure 5.

3.4 Mitigation Plan

In order to reduce the risk and the impact that can be caused by a dam break disaster, several solutions are offered so that the losses can be minimized. The solutions offered are divided into Non-Structural and Structural solutions.

1. Non-Structural
   a. Disaster education
   b. Destana (Desa Tangguh Bencana)
   c. Arrangement of residential and industrial area
   d. IoT-based early warning system

Table 8 Risk Index Analysis Result

No	Sub-District	Hazard Threat Score	Vulnerability Score	Adaptive Capacity Score	Total Risk Score	Risk Class
Makassar City						
1	Biring Kanaya	0.67	0.78	0.92	0.57	Medium
2	Mamajang	0.67	0.76	0.83	0.61	Medium
3	Manggala	1.00	0.78	0.83	0.94	High
4	Mariso	0.67	0.80	0.83	0.64	Medium
5	Panakkukang	0.67	0.77	0.92	0.56	Medium
6	Rappocini	0.67	0.75	0.83	0.60	Medium
7	Tallo	0.33	0.75	0.92	0.27	Low
8	Tamalanrea	0.33	0.76	0.92	0.28	Low
9	Tamalate	0.67	0.77	0.83	0.61	Medium
Gowa District						
10	Bajeng	1.00	0.74	0.83	0.88	High
11	Bajeng Barat	0.67	0.67	0.77	0.59	Medium
12	Barombong	1.00	0.71	0.85	0.83	High
13	Bontomarannu	1.00	0.58	0.83	0.69	High
14	Bontonompo	1.00	0.74	0.92	0.80	High
15	Bontonompo Selatan	0.67	0.75	0.75	0.67	Medium
16	Bungaya	1.00	0.58	0.75	0.78	High
17	Manuju	1.00	0.58	0.85	0.68	High
18	Pallangga	1.00	0.72	0.70	1.03	High
19	Pattallassang	1.00	0.49	0.78	0.62	Medium
20	Somba Opu	1.00	0.71	0.92	0.78	High
Takalar District						
21	Galesong Utara	0.67	0.71	0.53	0.89	High
22	Mangara Bombang	0.33	0.57	0.45	0.42	Medium
23	Mappakasunggu	0.33	0.61	0.62	0.33	Low
24	Pattallassang	0.67	0.77	0.65	0.79	High
25	Polombangkeng Selatan	0.33	0.58	0.47	0.41	Medium
26	Polombangkeng Utara	1.00	0.62	0.58	1.06	High
27	Sanrobone	0.33	0.59	0.52	0.38	Medium
Maros District						
28	Moncongloe	0.67	0.60	0.53	0.74	High

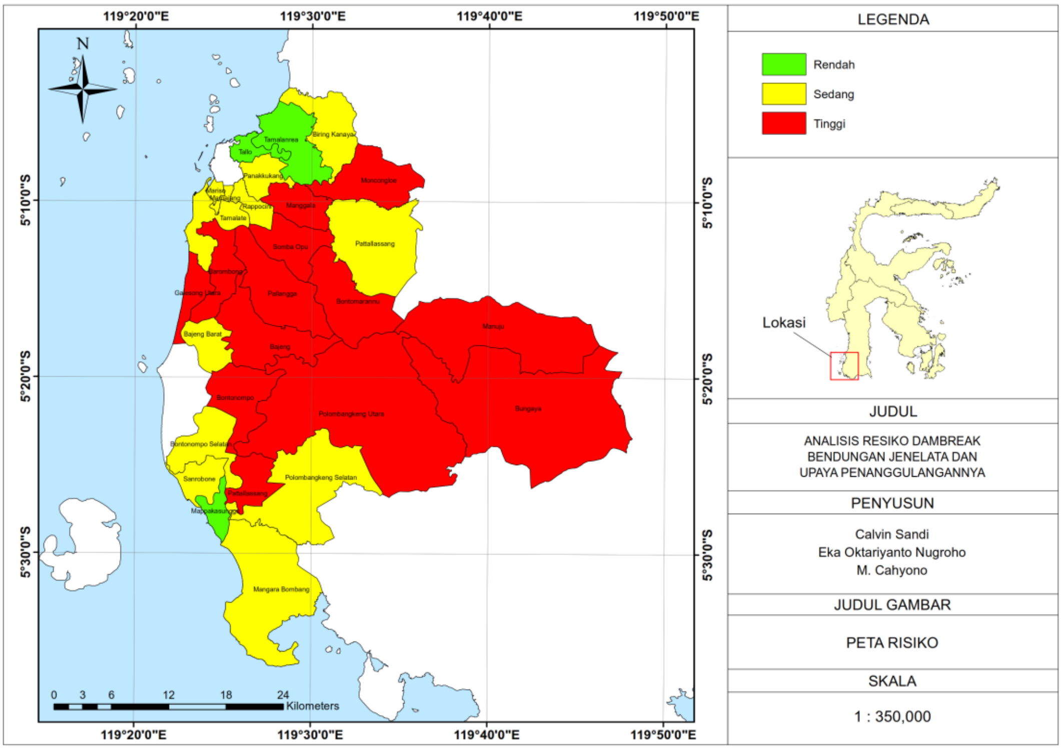

Figure 5 Dam Break Risk Map of Jenelata Dam

2. Structural

Structural solutions are determined through testing the effectiveness of river embankment installation in the following scenarios:

a. Scenario 1: Embankment installation with height 50 cm on the main river
b. Scenario 2: Embankment installation with height 100 cm on the main river
c. Scenario 3: Embankment installation with height 150 cm on the main river
d. Scenario 4: Embankment installation with height 50 cm on the main and river branch
e. Scenario 5: Embankment installation with height 100 cm on the main and river branch
f. Scenario 6: Embankment installation with height 150 cm on the main and river branch

The scheme of embankment installation scenarios is shown in Figure 6. The height of embankment is limited to 1.5 m because above 1.5 m height could cause a very high cost to build and make the solution become less effective.

The implementation of the offered solutions is to reduce the risk index value in sub-districts affected by the inundation, where the non-structural solution is to reduce the vulnerability index value and increase the adaptive capacity index value, while the structural solution is to reduce the hazard threat index value.

The recapitulation of the modeling results for dam break with embankment installation is presented in Table 9. The best results are shown by scenario 6 with the smallest inundation area, so it is recommended to apply scenario 6 for structural solution. The flood inundation area of scenario 6 is shown in Figure 7.

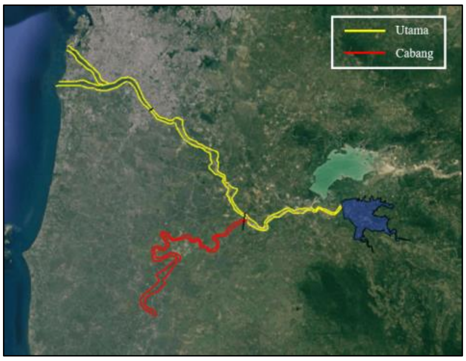

Figure 6 Embankment Installation Scheme

Table 9 Flood Inundation Modeling Results with Structural Solution

Skenario	Luas Genangan (Ha)
Tanpa Tanggul	21063,644
Skenario 1	20435,145
Skenario 2	19703,094
Skenario 3	19398,516
Skenario 4	19693,834
Skenario 5	18487,824
Skenario 6	17984,331

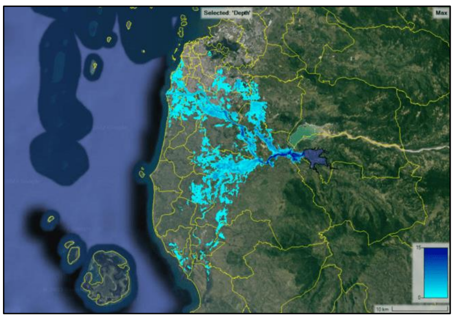
Figure 7 Flood Inundation Modeling Result of Scenario 6

The results of the risk analysis with the implementation of the solutions that have been offered, as well as the implementation of the structural solution scenario 6 to the risk index of each analyzed sub-district along with the risk map are shown in Table 10 and Figure 7**Error! Reference source not found.**.

Table 10 Risk Index Analysis Result with Solutions

No	Sub-District	Hazard Threat Score	Vulnerability Score	Adaptive Capacity Score	Total Risk Score	Risk Class
Makassar City						
1	Biring Kanaya	0.33	0.61	0.92	0.22	Low
2	Mamajang	0.33	0.67	0.83	0.27	Low
3	Manggala	1.00	0.63	0.83	0.75	High
4	Mariso	0.33	0.78	0.83	0.31	Low
5	Panakkukang	0.67	0.67	0.92	0.49	Medium
6	Rappocini	0.67	0.71	0.83	0.57	Medium
7	Tallo	0.33	0.71	0.92	0.26	Low
8	Tamalanrea	0.33	0.64	0.92	0.23	Low
9	Tamalate	0.67	0.62	0.83	0.50	Medium
Gowa District						
10	Bajeng	1.00	0.52	0.92	0.57	Medium
11	Bajeng Barat	0.67	0.50	0.77	0.44	Medium
12	Barombong	0.67	0.59	0.93	0.42	Medium
13	Bontomarannu	1.00	0.44	0.92	0.48	Medium
14	Bontonompo	1.00	0.57	0.92	0.62	Medium
15	Bontonompo Selatan	0.67	0.54	0.75	0.48	Medium
16	Bungaya	1.00	0.45	0.83	0.54	Medium
17	Manuju	1.00	0.45	0.93	0.48	Medium
18	Pallangga	1.00	0.55	0.83	0.66	Medium
19	Pattallassang	1.00	0.35	0.83	0.43	Medium
20	Somba Opu	1.00	0.67	0.92	0.73	High
Takalar District						
21	Galesong Utara	0.67	0.59	0.72	0.55	Medium
22	Mangara Bombang	0.33	0.48	0.63	0.25	Low
23	Mappakasunggu	0.33	0.53	0.80	0.22	Low
24	Pattallassang	0.33	0.61	0.85	0.24	Low
25	Polombangkeng Selatan	0.33	0.44	0.63	0.23	Low
26	Polombangkeng Utara	1.00	0.53	0.72	0.74	High
27	Sanrobone	0.33	0.40	0.68	0.20	Low
Maros District						
28	Moncongloe	0.33	0.41	0.72	0.19	Low

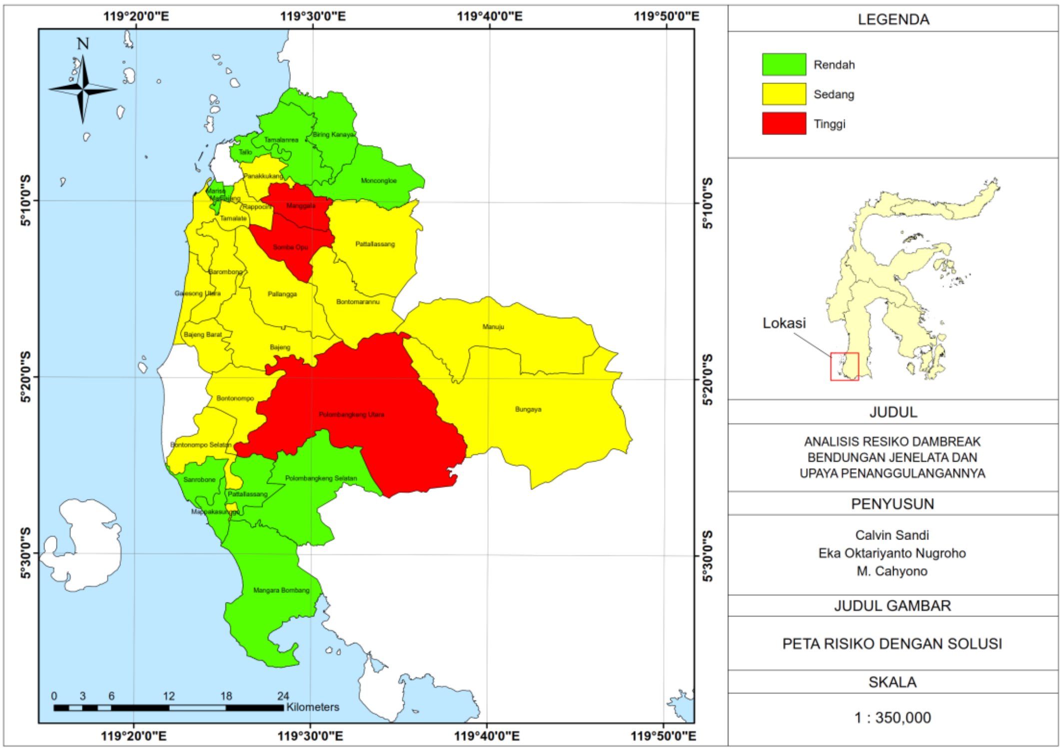

Figure 8 Dam Break Risk Map of Jenelata Dam with Solutions

4 CONCLUSION

From the results of the analysis, it can be concluded that several sub-districts have changes in the risk index from high to medium or from medium to low, as a result of the implementation of the offered solutions. The recommended structural solution is scenario 6, which is the installation of embankments on the main and river branch as high as 150 cm.

Based on the calculations and data processing that had been done, some data were obtained based on assumptions due to the limited data experienced by the authors. Some data that are assumed are the ratio of poverty data, the ratio of people with disabilities data, and the ratio of age groups data, which are used in determining the vulnerability index. These data are assumed to be evenly distributed in each sub-district based on the number of residents in the sub-district. This is because the data obtained is in the form of district data.

Therefore, the results obtained are less accurate. For further development, it is recommended to use more valid and more updated data, as well as field visit, so that the analysis can be more accurate and suggestions for mitigation plan can be more effective.

5 REFERENCES

Adityawan, M. B., Tanaka, H., 2012, Bed Stress Assessment under Solitary Wave Run-up, *Earth, Planets and Space Journal* 64(10), 945-954.

BNPB, 2012, *Peraturan Kepala Badan Nasional Penanggulangan Bencana Nomor 02 Tahun 2012: Pedoman Umum Pengkajian Resiko Bencana*, Jakarta: Badan Nasional Penanggulangan Bencana.

Brunner, G., 2014, *Using HEC-RAS for Dam Break Studies*, U.S. Army Corps of Engineers, Virginia: Institute for Water Resources.

BSN, 2012, *SNI 7746-2012: Tata Cara Penghitungan Hujan Maksimum Boleh Jadi dengan Metode Hersfield*, Jakarta: Badan Standarisasi Nasional.

BSN, 2016, *SNI 2415-2016: Tata Cara Perhitungan Debit Banjir Rencana*, Jakarta: Badan Standarisasi Nasional.

Farid, M., Yakti, B. P., Rizaldi, A., Adityawan, M. B., 2016, *Finite Difference Numerical Scheme for Simulating Dam Break Flow*, The 5th HATHI Int. Sem. Water Resil. In a Changing World, Bali, Indonesia.

Froehlich, D. C., 2008, Embankment Dam Breach Parameters and Their Uncertainties, *Journal of Hydraulic Engineering* 134(12), 1708-1721.

Kusuma, M. S. B., Farid, M., Adityawan, M. B., 2008, *Numerical Model Study of Two Dimension Flow Generated by a Dam Break*, International Conference on Earthquake Engineering and Disaster Mitigation, Jakarta, Indonesia.

Magdalena, I., Adityawan, M. B., Jonathan, C., 2020, Numerical Model for Dam Break over a Movable Bed using Finite Volume Method, *International Journal of GEOMATE* 19(71), 98-105.

Maitsa, T. R., Mardika, M. G. I., Adityawan, M. B., Harlan, D., Kusumastuti, D., Kuntoro, A. A., 2020, *2D Numerical Simulation of Urban Dam Break and Its Effect to Building using Lax Scheme with Numerical Filter*, 4th ICEEDM, Padang, Indonesia.

Mellivera, A., Zain, K., Adityawan, M. B., Harlan, D., Farid, M., Yakti, B. P., 2020, Development of FTCS Artificial Dissipation for Dam Break 2D Modelling, *Jurnal Teknik Sipil* 27(1), 1-8.

Murdiani, K. M., Sangkawati, S., Sadono, K. W., 2020, Pemodelan Keruntuhan Bendungan Menggunakan HEC-RAS 2D Studi Kasus Bendungan Gondang, Kabupaten Karanganyar, *Journal of Science and Technology* 13(2), 205-211.

Musa, R., Ashad, H., Fahrial, A. F., 2020, Pengaruh Kapasitas Geometri Sungai terhadap Debit Banjir Rencana (Studi Kasus S. Jeneberang Kab. Gowa), *Open Science Framework* 4(1), 139-146.

Natakusumah, D. K., Hatmoko, W., Harlan, D., 2012, Prosedur Umum Perhitungan Hidrograf Satuan Sintetis dengan Cara ITB dan Beberapa Contoh Penerapannya, *Jurnal Teknik Sipil* 18(3), 251-291.

Purwanto, P. I., Juwono, P. T., Asmaranto, R., 2017, Analisa Keruntuhan Bendungan Tugu Kabupaten Trenggalek, *Jurnal Teknik Pengairan: Journal of Water Resources Engineering* 8(2), 222-230.

Putri, P. I. D., Iskandar, R. F., Adityawan, M. B., Kardhana, H., Indrawati, D., 2020, 2D Shallow Water Model for Dam Break and Column Interactions, *Journal of the Civil Engineering Forum* 6(3), 237-246.

Rustan, Chumaedi, I., Handayani, L., 2019, Simulasi Keruntuhan Bendungan Bili-Bili Kabupaten Gowa Provinsi Sulawesi Selatan, *Journal Online of Physics* 5(1), 24-28.

Sari, P., 2018, Performance of Retarding Basin in Flood Disaster Risk Mitigation in Welang River, East Java Province, Indonesia, *Journal of the Civil Engineering Forum* 4(2), 109-120.

Udom, N., 2018, Evaluation of Flood Risk Reduction Project at Tenggang River, Semarang City, Central Java Province, Indonesia, *Journal of the Civil Engineering Forum* 4(2), 159-166.

Wijayanti, P., Suprapto, M., Saido, A. P., 2013, Analisis Keruntuhan Bendungan Pacal, *Jurnal Matriks Teknik Sipil* 1(4), 488-495.

Yakti, B. P., Adityawan, M. B., Farid, M., Suryadi, Y., Nugroho, J., Hadihardaja, I. K., 2017, *2D Modeling of Flood Propagation due to the Failure of Way Ela Natural Dam*, MATEC Web of Cenferences 147, 03009.