Flood Modelling due to dam failure using HEC-RAS 2D with GIS overlay: case study of Karalloe dam in South Sulawesi Province Indonesia

By Zubair Saing

Flood Modelling due to dam failure using HEC-RAS 2D with GIS overlay: case study of Karalloe dam in South Sulawesi Province Indonesia

Riswal Karamma[1)], Sugiarto Badaruddin[2)], Rifaldi Mustamin[1)], Zubair Saing[3)]

[1]Civil Engineering Department, Hasanuddin University, P.O. Box 90245, South Sulawesi, Indonesia

[2]Civil Engineering Department, Politeknik Negeri Ujung Pandang, P.O. Box 90245, South Sulawesi, Indonesia

[3]Department of Civil Engineering, Universitas Muhammadiyah Maluku Utara, Ternate City, Indonesia

Email addresses:

Riswal Karamma: riswalchiwal@gmail.com (Corresponding Author)

Sugiarto Badaruddin: sugibadaruddin@poliupg.ac.id

Rifaldi Mustamin: aldirifal09@gmail.com

Zubair Saing: zubairsaing@ummu.ac.id

*Corresponding author at: Civil Engineering Department, Hasanuddin University, P.O. Box 90245, South Sulawesi, Indonesia. Email address: riswalchiwal@gmail.com (Riswal Karamma)

Highlights:

- Flood impact due to dam failure is investigated in this study
- The flood impact was modelled using HEC-RAS 2D with GIS overlay for mapping
- The simulation results showed that 22 villages will be affected by flash flood due to dam failure

Abstract

The impact of flooding caused by the failure of the Karalloe dam in Bone Regency, Indonesia, was explicitly examined in this study. The Creager graph validated the selected flood discharge by comparing the calculated discharge from several synthetic unit hydrograph methods (HSS) with the flood discharge measured on the automatic water level recorder (AWLR). Flooding was simulated using HEC-RAS 2D overlayed with ArcGIS. The results showed that the HSS SCS method was the design flood discharge value closest to the measured discharge value and Q1000 Creager. The flood discharge values obtained using the HSS SCS method were 322.70, 464.10, 560.40, 658.40, 682.70, 787.00, 885.70, and 1202.60 m^3/s for Tr 2, 5, 10, 20, 25, 50, 100, and 1000 years, respectively. According to the results, flooding will affect 22 villages, and the flood's fastest standby time is 12 minutes.

Keywords: Flood Modelling, Dam break, Synthetic Unit Hydrograph, HEC-RAS 2D.

1. Introduction

The dam is a piece of infrastructure beneficial to human life by promoting social and economic development. Dams serve many purposes, including irrigation, power generation, water supply, flood control, fishing, and recreation (de Paiva et al., 2020; Aureli et al., 2021). The Karalloe Dam is a rock-fill type with a concrete membrane and side spillway without a door with a maximum storage volume of 40.53 million m^3, which is used to meet water needs for irrigation of Kelara-Karalloe, covering an area of 7004 ha and is expected to be developed for hydropower potential of 4.5 MW, flood control (64.17 m^3/second), conservation of water resources, and tourism development (Hasbi et al., 2020; Rakhim and Sirajuddin, 2020; Sandi et al., 2020).

In addition to their numerous advantages, dams pose a significant risk of disaster in the event of a failure or collapse, which can result in loss of life and property as well as the destruction of existing infrastructure in the downstream area (Evangelista et al., 2013; Kyaw et al., 2020). The construction of a dam is frequently followed by the development of communities in the downstream area, which increases the risk of dam failure (Urzică et al., 2020). Dams can break or collapse due to overtopping, the overflow of water through the dam's top, causing erosion and landslides in the dam's body, particularly in embankment dams. The dam's failure will result in flash floods, in which the water stored in the dam will flow downstream with a giant flood discharge and at high speed (Perera et al., 2021).

Because of the conditions affecting dam stability and retention efficiency, a greater spread of awareness about risk factors affecting dam safety is required (Perera et al., 2021). Some negative factors include damaging spillway capacity that cannot drain flood discharge due to changes in weather patterns effectively and exacerbated extreme climates (Bocchiola and Rosso, 2014; Krzto et al., 2022). These factors can increase the risk of flooding in downstream areas due to dam failure, which is exacerbated by increased exposure to human settlements and the potential for high flood susceptibility (Li et al., 2018). Given the possibility of disasters caused by a dam collapse in response to conditions downstream of the dam, flood simulations are required to predict areas that will be affected downstream of the dam, particularly in a dam collapse (Ahmadi and Yamamoto, 2021).

This significant potential danger necessitates the creation of a detailed and effective emergency action plan (EAP). In general, dam break analysis is the primary input of EAP (Said et al., 2019). The source of data for compiling this EAP is the result of dam break analysis in the form of dam collapse simulation results (Said et al., 2019). In most downstream flood simulations caused by a dam failure, it is assumed that the dam collapses completely and unexpectedly (Azeez et al., 2020). Kheirkhah et al., 2021), SMPDBK (Nazif, 2019), FLDWAV (Kheirkhah et al., 2021), and HEC-RAS can be used to model water flow due to dam collapse (Kilania and Chahar, 2019). Among the many applications available, the 2D numerical model HEC-RAS is ideal for determining water depth, inundation area, flow velocity, and water level profile in two dimensions (Bharath et al., 2021).

Flood simulations due to the collapse of the Karalloe dam were performed in this study using HEC-RAS 2D and combined with ArcGIS for mapping. A flood flow pattern will be obtained from the simulation results, which will then be followed by flood tracing in flood-prone locations to serve as a guide for dam managers and governments in the affected areas to prepare anticipatory steps in the event of an emergency condition at the dam.

2. Materials and Method

2.1. Materials

Several data sets are required to carry out this research, including (1) TRMM rainfall data (Tropical Rainfall Measuring Mission). The National Institute of Aeronautics and Space obtained rain data from 1998 to 2020 (23 years) (LAPAN). (2) Karalloe Dam technical data in general, primary dam body, and spillway building data to determine dam characteristics. (3) The reservoir capacity curvature describes the reservoir in the reservoir that is used in the flood track. (4) For flood tracking, topographic and bathymetric data were combined with DEMNAS (National Bathymetry and Digital Elevation Model) with an 8.3 m spatial resolution. (5) Pompengan-Jeneberang river basin authority (BBWSPJ) soil type map from 2018. (6) The Geospatial Information Agency provided a map of the 2019 Land Use Pattern.

2.2. Flood discharge design

Flood discharge analysis is used to determine flood discharge design based on data from current conditions. The availability of flow data determines the method for designing flood discharge analysis. Because flow data is not available, the flood discharge in this study is calculated by converting rain into the flow (Karamma and Pallu, 2018). The design flood analysis was carried out using a synthetic unit hydrograph based on previous research that revealed that the HSS SCS method (HEC-HMS Application) was the closest to the Likupadde AWLR discharge and Crager Graph (Mustamin et al., 2021).

Data on land use, soil type, river topography, and TRMM rainfall were used in the hydrological analysis using the HEC-HMS application. TRMM is used in this study because it performs well for Indonesian territory and correlates with average daily rainfall observation data of 0.90 derived from various satellite rainfall data sources (Vernimmen et al., 2012).

2.3. Dam break analysis

The HEC-RAS 2D application was used to simulate the failure of the Karalloe Dam. In this case, an evaluation is also performed to determine whether flooding from the most recent rainfall can cause overtopping at the dam's top. Table 1 shows technical information about the Karalloe Dam.

Table 1. Technical data of Karalloe Dam

River's name	: Karalloe
Watershed area	: 195 km^2
Inundation area	: 145 Ha
Maximum storage volume	: 40.53 million m^3
Effective storage volume	: 29.50 million m^3
Off storage volume	: 11.03 million m^3
Flood water level	: + 252.40 m
Normal water level	: + 248.50 m
Low water level	: + 220.50 m
Type of dam	: Concrete membrane Stone backfill
Height of the dam from the foundation's base	: 82 m
Top elevation of dam	: + 253.00 m
Dam crest height	: 396 m

Dam crest width	: 10 m (Hot mix)
Spillway type	: Ogee
Overflow type	: Side overflow without door
Threshold elevation	: + 248.50 m
Overflow width	: 100 m

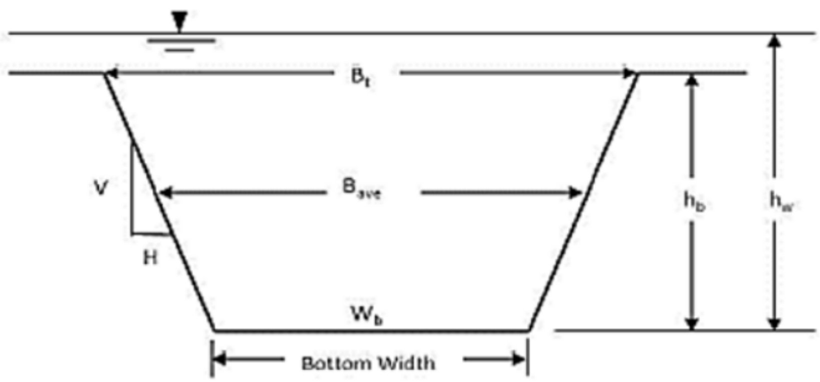

Figure 1. Fracture parameter overview

Fractures usually occur prior to the dam's total collapse (Figure 1). The following is Froehlich's (2022) regression equation for average fracture width and failure time:

$$B_{ave} = 0.27\ K_0 . Vw^{0.32} . hb^{0.04} \quad (1)$$

$$tf = 63.2 \sqrt{\frac{Vw}{ghb^2}} \quad (2)$$

Where, B_{ave} = The average width of the fracture (m)

K_o = Constant (1.3 for overtopping collapse)

Vw = Storage volume at collapse (m^3)

Hb = Final height of fracture (m)

g = Gravity constant (9,80665 m/s^2)

tf = Collapse time (detik)

According to Froechlich (2022), the mean side slope for overtopping failure should be horizontal to vertical (1:1).

2.4. Flood Mapping and Tracking

The flood simulation results from dam failure will be mapped using ArcGIS 10.8 software to identify flood-prone areas, which will then be classified based on a specific depth. Following the flood mapping, flood identification was performed to determine the affected location's distance from the dam, the depth of the flood, and the time of flood concentration from the dam to flood-prone locations.

3. Results and Discussion

3.1. Karalloe Dam Design Flood Discharge

Based on the Karalloe Dam's design data, a QPMF (i.e., flow discharge for the Probable Maximum Flood) of 2,020 m3/s was obtained in 2012, while the results of other researchers' analyses of the Karalloe Dam obtained a QPMF of 3307 m3/s in 2017. (Rakhim and Sirajuddin, 2020). Recognizing an increase in flood discharge necessary to analyze flood discharge using the most recent rainfall data to determine the increase in flood discharge, with the most significant discharge used as input for simulation to determine the impact of the Karalloe Dam failure.

Data on watershed characteristics such as topography, land use, and soil type are derived from the hydrological analysis using the SCS method (i.e., HEC-HMS) because they significantly impact rainwater that will become surface runoff. The map in Figure 2 can describe the characteristics of the Kelara watershed.

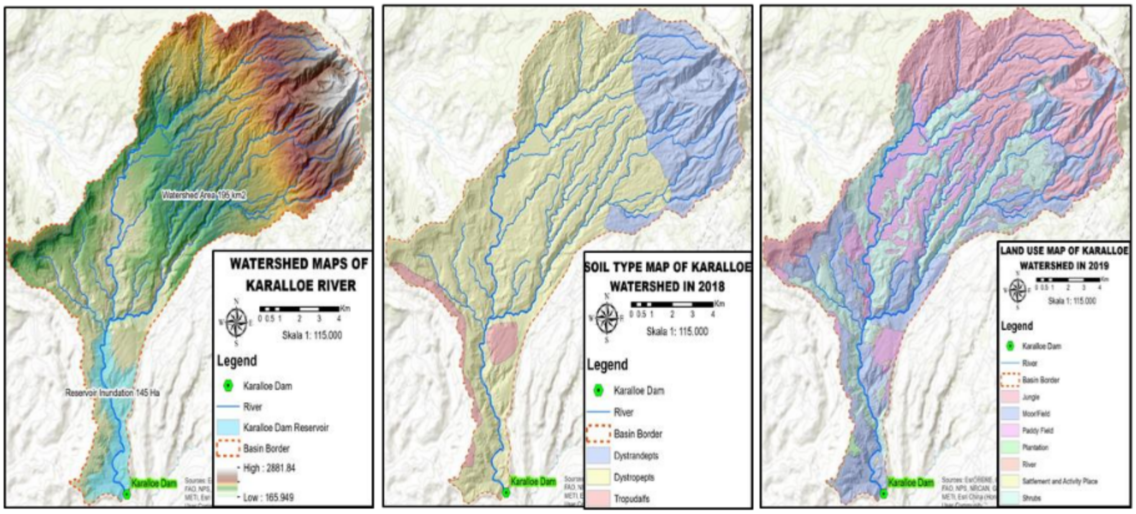

Figure 2. Map of Topographic, soil type and land use of the Karalloe Watershed

The characteristics of the Karalloe watershed can be seen in Figure 2, which shows that the watershed area is 195.23 km^2, the length of the main river is 27.27 km, the highest elevation is +848 masl, the lowest elevation is +165 masl, the average river slope is 0.026 percent, dystropepts dominate the soil type, and the land is dominated by forest. The input parameters for the HEC-HMS are derived from the results of the watershed characteristics analysis. Table 2 displays these parameters. Three TRMM posts collect rainfall data, which affects the Karalloe watershed. Figure 3 and Table 3 show the TRMM location and data.

Table 2. HEC - HMS Input Parameters

Physical Parameters	Value
Watershed Area (km^2)	195,23
Initial Abstraction (mm)	23,40
Impervious (%)	0,58
Curve Number (CN)	68
Lag Time (min)	124,17

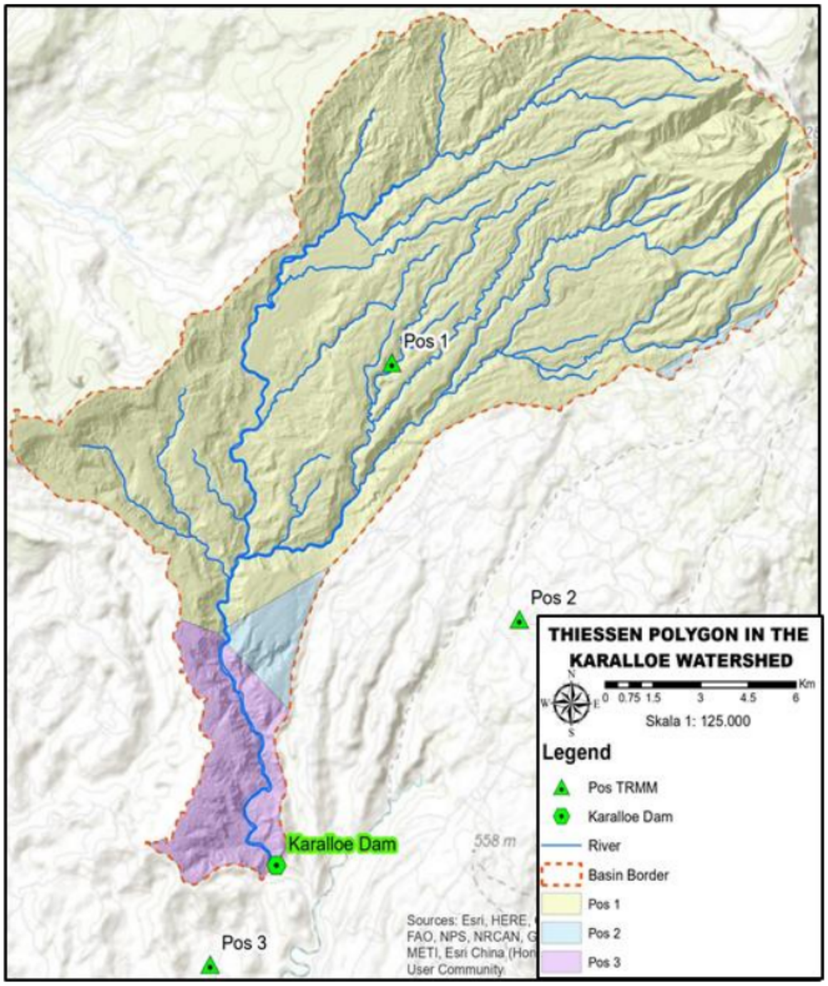

Figure 3. Thiessen polygon of the Karalloe watershed

Table 3. Maximum Daily Rainfall from TRMM posts

Year	Maximum Daily Rainfall (mm)		
	Pos 1	Pos 2	Pos 3
1998	87	64	80
1999	128	137	173
2000	108	112	96
2001	95	99	98
2002	75	75	83
2003	96	87	88
2004	102	103	96
2005	85	71	77
2006	129	123	97

Year	Maximum Daily Rainfall (mm)		
	Pos 1	Pos 2	Pos 3
2007	73	79	72
2008	72	72	96
2009	84	89	80
2010	111	134	101
2011	84	87	94
2012	70	73	81
2013	108	118	155
2014	74	79	96
2015	116	113	138
2016	80	82	101
2017	95	100	102
2018	80	76	78
2019	109	127	138
2020	89	100	74

The Probable Maximum Precipitation (PMP) analysis performed at the Karalloe Dam location yielded a value of 478.77 mm/day. In addition, a QPMF discharge analysis was performed using the HEC-HMS application, yielding a value of 3534.8 m^3/sec. Figure 4 depicts the outcome of the QPMF discharge analysis.

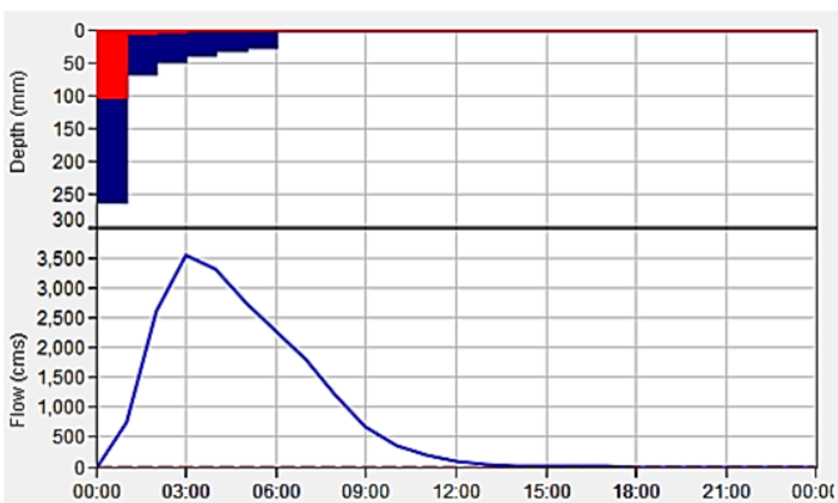

Figure 4. QPMF flood hydrograph of the Karalloe Watershed

3.2. Simulation of dam failure

In this study, data are required to support the simulation to run HEC-RAS 6.0.1 and obtain the results of the dam collapse analysis. Figures 5 and 6 show the primary data and scenarios used in general.

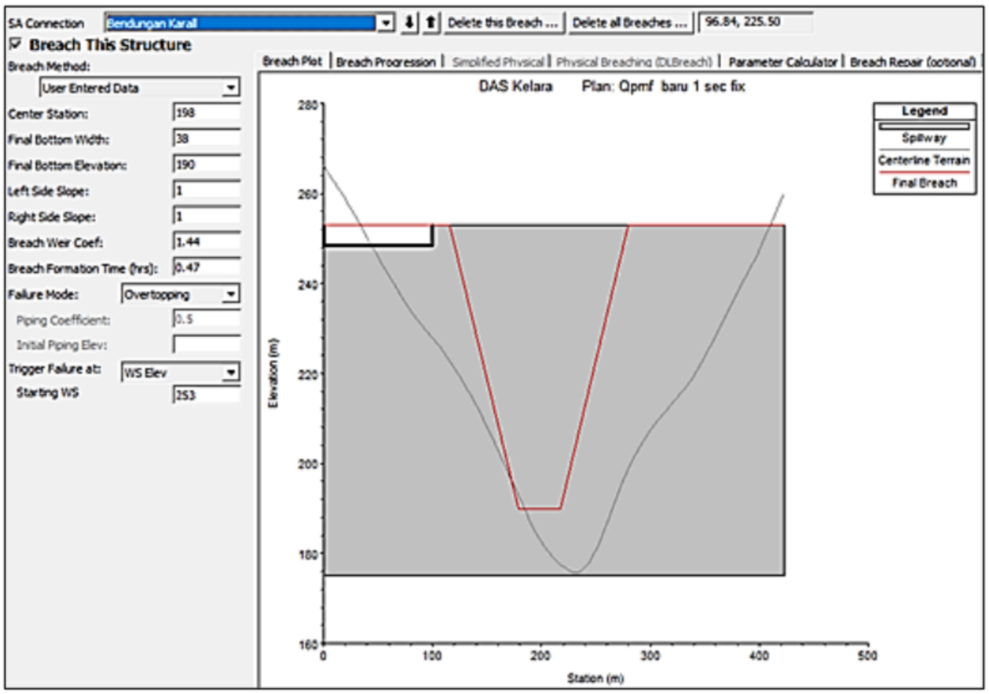

Figure 5. Dam breach parameter plan option is considered a steady Flow

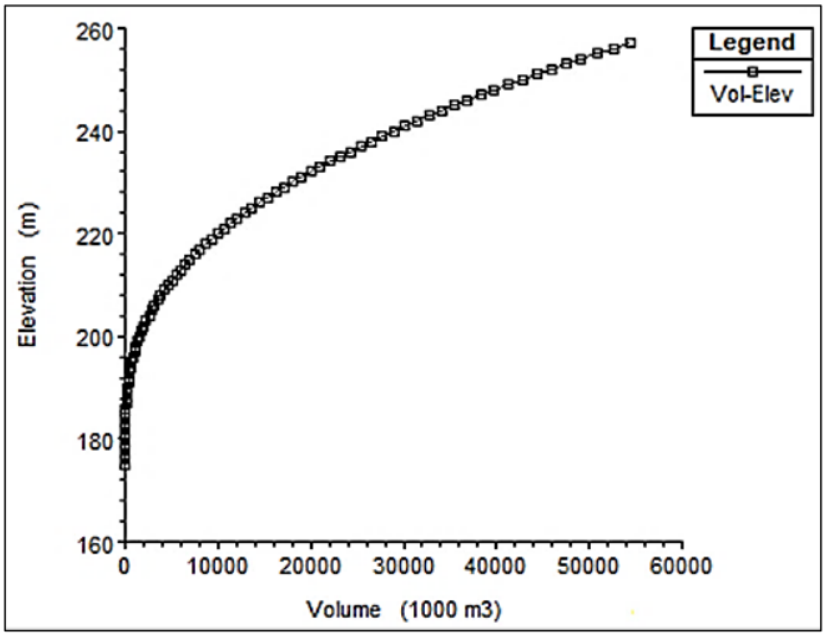

Figure 6. Curve capacity of the Karalloe dam's reservoir

The simulation results of a dam collapse carried out not only produce the distribution of flood inundation but also provide information on the depth at the point to be reviewed, the velocity of the flood flow, and the flood arrival time at a particular location. In general, the flooding visualization due to the collapse of the Karalloe Dam at its top condition can be seen in Figure 7 as follows.

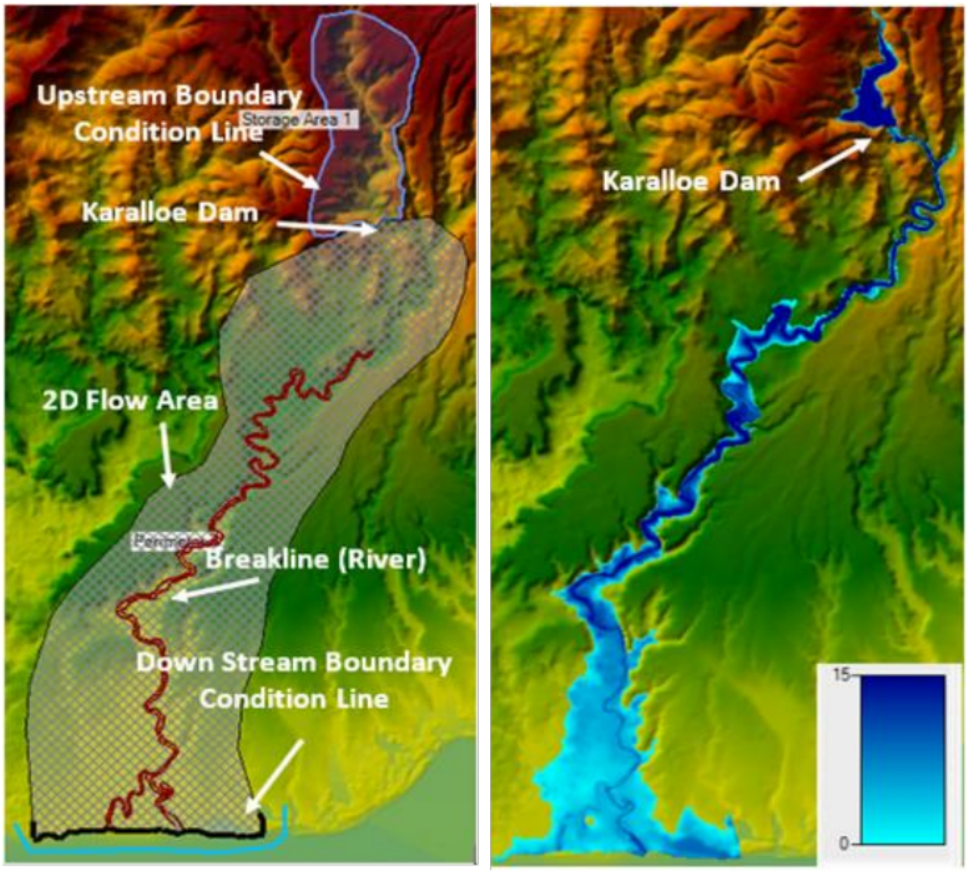

Figure 7. Map of DEM/boundary condition and simulation result of the Karalloe dam's failure

The Karalloe dam failure simulation results show that the dam collapsed at 2:28:01 with a QPMF discharge of 3534.8 m^3/s (simulation time). The floodwater depth level downstream of the Karalloe Dam has decreased as the distance traveled and the time for the flood has increased.

3.3. Affected area and population

A flood hazard map was created as a reference based on the simulation results of the Karalloe dam's failure to determine the extent of the flood impact caused by the dam's collapse. The flood hazard map is intended to provide information on areas that will be flooded due to a dam failure. The local government and dam managers can coordinate the notification (warning) process for residents and evacuation procedures for residents who are at risk based on this flood hazard map. Figure 8 depicts the area affected by the collapse of the Karalloe Dam in greater detail.

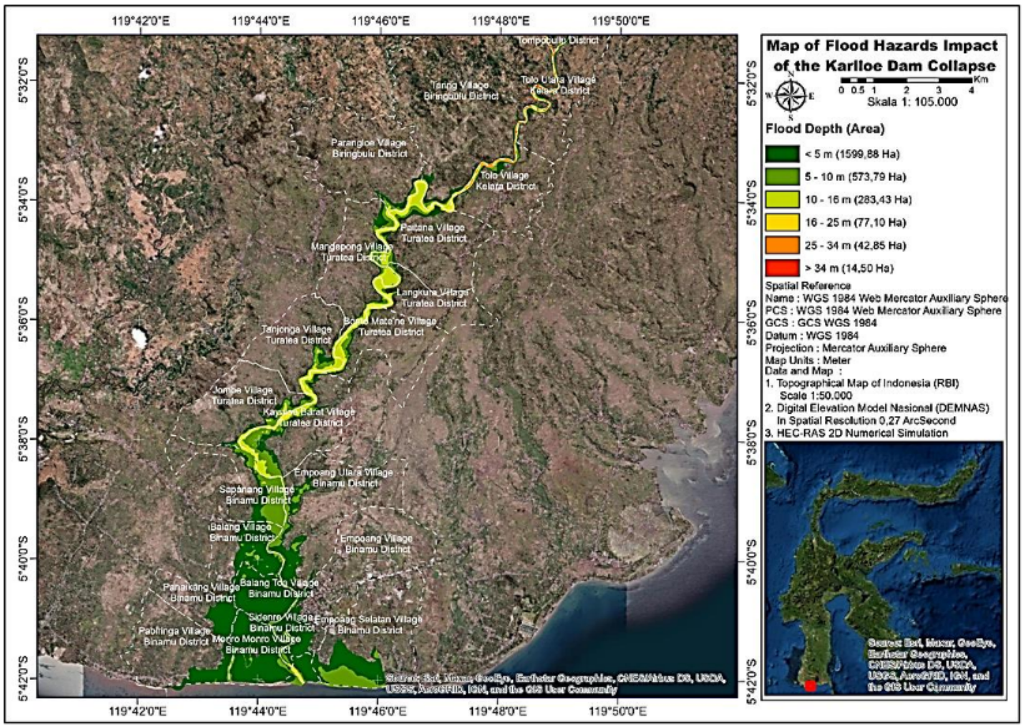

Figure 8. Map of flood hazards due to the collapse of the Karalloe dam

Figure 8 shows that the collapse of the Karalloe Dam has affected 22 villages from 5 sub-districts. Table 4 shows the affected areas in greater detail. Aside from flood-prone maps, simulation results can also provide information on how long it takes floods to reach each area based on distance and topographical conditions. Monitoring points in densely populated areas must be established to provide information on flood travel times and increase community preparedness in a dam emergency to mitigate the impact of the Karalloe dam's collapse. For more information, see Figure 9 and Table 5. They show flood tracking in the affected areas.

Table 4. Areas affected by flooding due to Karalloe dam collapse

Affected areas		
Village	Districts	Regency
Taring	Biringbulu	Gowa
Garing	Biringbulu	Gowa
Tolo Utara	Kelara	Jeneponto
Tolo	Kelara	Jeneponto
Paitana	Turatea	Jeneponto
Parangloe	Biringbulu	Gowa
Mangepong	Turatea	Jeneponto
Langkura	Turatea	Jeneponto
Bonto Mate’ne	Turatea	Jeneponto
Tanjonga	Turatea	Jeneponto
Kayuloe Barat	Turatea	Jeneponto
Jombe	Turatea	Jeneponto
Sapanang	Binamu	Jeneponto
Empoang Utara	Binamu	Jeneponto
Balang	Binamu	Jeneponto
Balang Toa	Binamu	Jeneponto
Empoang	Binamu	Jeneponto
Sidenre	Binamu	Jeneponto
Monro - Monro	Binamu	Jeneponto
Empoang Selatan	Binamu	Jeneponto
Panaikang	Binamu	Jeneponto
Pabiringa	Binamu	Jeneponto

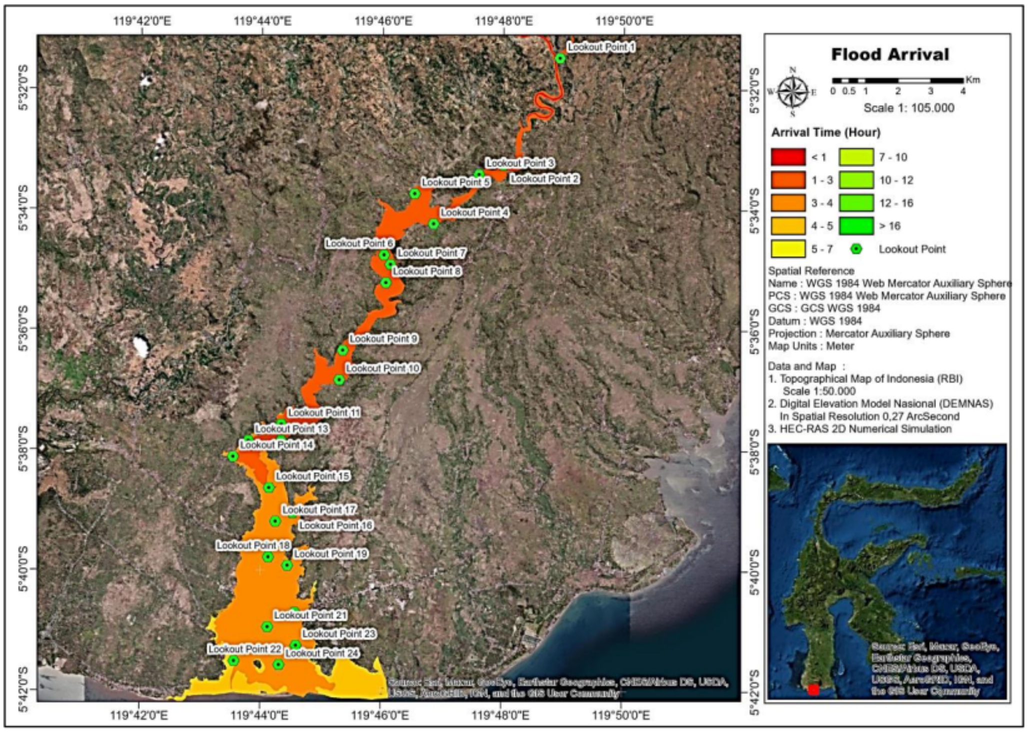

Figure 9. Map of Flood arrival time

Table 5. Flood travel time due to the collapse of the Karalloe dam

Code	Coordinates	Location	Distance from the dam (Kilometers)	Flood arrival time (minutes)
Lookout Point 1	5°31'28.79"LS & 119°48'56.18"E	Tolo Utara Village, Kelara District , Jeneponto Regency	1.903	17
Lookout Point 2	5°33'15.68"LS & 119°48'0.13"E	Taring Village, Biringbulu District , Gowa Regency	8.026	26
Lookout Point 3	5°33'25.20"LS & 119°47'35.77"E	Taring Village, Biringbulu District , Gowa Regency	8.874	32
Lookout Point 4	5°34'14.46"LS & 119°46'50.66"E	Paitana Village, Turatea District , Jeneponto Regency	11.463	35
Lookout Point 5	5°33'44.42"LS & 119°46'31.80"E	Parangloe Village, Biringbulu District , Gowa Regency	12.855	40
Lookout Point 6	5°34'45.73"LS & 119°46'1.55"E	Mangepong Village, Turatea District , Jeneponto Regency	16.057	32
Lookout Point 7	5°34'55.27"LS & 119°46'8.12"E	Paitana Village, Turatea District , Jeneponto Regency	16.409	12
Lookout Point 8	5°35'13.26"LS &	Mangepong Village,	17.628	32

	119°46'3.36"E	Turatea District , Jeneponto Regency		
Lookout Point 9	5°36'20.50"LS & 119°45'20.81"E	Bonto Mate'ne Village, Turatea District , Jeneponto Regency	22.620	41
Lookout Point 10	5°36'50.12"LS & 119°45'17.38"E	Bonto Mate'ne Village, Turatea District , Jeneponto Regency	23.853	43
Lookout Point 11	5°37'34.48"LS & 119°44'20.07"E	Jombe Village, Turatea District , Jeneponto Regency	27.114	52
Lookout Point 12	5°37'50.66"LS & 119°44'19.75"E	Kayuloe Village, Turatea District , Jeneponto Regency	27.507	54
Lookout Point 13	5°37'51.00"LS & 119°43'47.13"E	Jombe Village, Turatea District , Jeneponto Regency	28.333	55
Lookout Point 14	5°38'7.01"LS & 119°43'32.05"E	Sapanang Village, Binamu District , Jeneponto Regency	28.886	61
Lookout Point 15	5°38'37.83"LS & 119°44'8.01"E	Sapanang Village, Binamu District , Jeneponto Regency	30.339	63
Lookout Point 16	5°39'2.95"LS & 119°44'31.24"E	Empoang Utara Village, Binamu District , Jeneponto Regency	31.564	67
Lookout Point 17	5°39'11.32"LS & 119°44'14.44"E	Sapanang Village, Binamu District , Jeneponto Regency	31.802	70
Lookout Point 18	5°39'47.04"LS & 119°44'7.35"E	Balang Village, Binamu District , Jeneponto Regency	33.227	76
Lookout Point 19	5°39'55.44"LS & 119°44'26.34"E	Empoang Utara Village, Binamu District , Jeneponto Regency	33.831	78
Lookout Point 20	5°40'42.15"LS & 119°44'33.74"E	Balang Toa Village, Binamu District , Jeneponto Regency	35.615	83
Lookout Point 21	5°40'56.76"LS & 119°44'6.81"E	Balang Toa Village, Binamu District , Jeneponto Regency	36.860	97
Lookout Point 22	5°41'30.63"LS & 119°43'33.45"E	Pabiringa Village, Binamu District , Jeneponto Regency	39.743	117
Lookout Point 23	5°41'14.98"LS & 119°44'35.16"E	Sidenre Village, Binamu District , Jeneponto Regency	37.704	98
Lookout Point 24	5°41'34.50"LS & 119°44'18.23"E	Monro - Monro Village, Binamu District , Jeneponto Regency	38.511	105

According to Table 5, the arrival time of flooding to residential areas, namely the fastest standby time, is within 12 minutes at Lookout Point 7 in Paitana Village. Furthermore, the longest time is 1 hour and 57 minutes at Lookout Point 22 in Paitana Village. This information is critical for the local government in developing a rescue plan for the people affected by the Karalloe dam failure.

4. Conclusions

Based on the findings of this study, it is possible to conclude that the analysis of flood discharge using the HSS SCS method (i.e., HEC-HMS) with a PMF return period (likely maximum flood) yielded a peak discharge Q inflow of 3534.8 m^3/s. This analysis produced a QPMF value more significant than the designed PMF value of Karalloe Dam, which was 2,020 m^3/s in 2012, and the results of other researchers, who produced a QPMF of 3307 m^3/s in 2017. The map of flood-prone areas obtained in this study shows that 22 villages from 5 sub-districts have been affected by the collapse of the Karalloe Dam, namely: the villages of Parangloe, Taring, Garing, Monro, Pabiringa, Panaikang, Epoang Selatan, Balang Toa, Balang, Empoang, Empoang Utara, Sapanang, Kayuloe Barat, Jombe, The collapse occurred at 2:28:01 according to the flood simulation results using HEC-RAS, which is simulated using the QPMF value (simulation time). The floodwater depth level downstream of the Karalloe dam has decreased as the distance traveled and the time for the flood has increased. There are 24 monitoring points planned in densely populated areas affected by the dam collapse to provide information on flood travel times and time to improve community preparedness in an emergency condition at the dam. According to the analysis results, the quickest standby time is at Lookout Point 7 in Paitana Village within 12 minutes, while the longest time is at Lookout Point 22 in Paitana Village within 1 hour 57 minutes. Therefore, the method proposed in this study yields significant results for describing the potential for flooding caused by dam failure. It assists stakeholders in developing disaster prevention policies and provides new insights into the development of disaster prevention technologies, particularly flood prevention technologies.

Acknowledgments

The authors wish to thank the head of Civil Engineering Department of Hasanuddin University for supporting this research. We also gratefully acknowledge the suggestions of anonymous reviewers. This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

References

Ahmadi, S. M., & Yamamoto, Y. (2021). A New Dam-Break Outflow-Rate Concept and Its Installation to a Hydro-Morphodynamics Simulation Model Based on FDM (An Example on Amagase Dam of Japan). Water, 13(13), 1759.

Aureli, F., Maranzoni, A., & Petaccia, G. (2021). Review of Historical Dam-Break Events and Laboratory Tests on Real Topography for the Validation of Numerical Models. Water, 13(14), 1968.

Azeez, O., Elfeki, A., Kamis, A. S., & Chaabani, A. (2020). Dam break analysis and flood disaster simulation in arid urban environment: The Um Al-Khair dam case study, Jeddah, Saudi Arabia. Natural Hazards, 100(3), 995-1011.

Bharath, A., Shivapur, A. V., Hiremath, C. G., & Maddamsetty, R. (2021). Dam break analysis using HEC-RAS and HEC-GeoRAS: A case study of Hidkal dam, Karnataka state, India. Environmental Challenges, 5, 100401.

Bocchiola, D., & Rosso, R. (2014). Safety of Italian dams in the face of flood hazard. Advances in water resources, 71, 23-31.

de Paiva, C. A., da Fonseca Santiago, A., & do Prado Filho, J. F. (2020). Content analysis of dam break studies for tailings dams with high damage potential in the Quadrilátero Ferrífero, Minas Gerais: technical weaknesses and proposals for improvements. Natural Hazards, 104(2), 1141-1156.

Evangelista, S., Altinakar, M. S., Di Cristo, C., & Leopardi, A. (2013). Simulation of dam-break waves on movable beds using a multi-stage centered scheme. International Journal of Sediment Research, 28(3), 269-284.

Froehlich, D. C. (2022). Peak Flood Discharge from a Landslide Dam Outburst. Natural Hazards Review, 23(2), 04022001.

Hasbi, M., Mappanyompa, M., & Bakri, B. (2020). The construction of Karalloe multipurpose dam for the Kellara technical irrigation development. In IOP Conference Series: Earth and Environmental Science (Vol. 419, No. 1, p. 012133). IOP Publishing.

Karamma, R., & Pallu, M. S. (2018). Comparison of Model Hidrograf Synthetic Units (HSS) with the Model of Hidrograf Observations on DAS Jeneberang Gowa Regency, Indonesia. International Journal of Innovative Science and Research Technology, 3(2), 617-623.

Kheirkhah Gildeh, H., Halliday, A., Arenas, A., & Zhang, H. (2021). Tailings dam breach analysis: a review of methods, practices, and uncertainties. Mine Water and the Environment, 40(1), 128-150.

Kilania, S., & Chahar, B. R. (2019). A dam break analysis using HeC-RAs. In World Environmental and Water Resources Congress 2019: Hydraulics, Waterways, and Water Distribution Systems Analysis (pp. 382-389). Reston, VA: American Society of Civil Engineers.

Krztoń, W., Walusiak, E., & Wilk-Woźniak, E. (2022). Possible consequences of climate change on global water resources stored in dam reservoirs. Science of The Total Environment, 154646.

Kyaw, P. P. S. S. (2020). Modeling approach for earthen dam breach analysis in North Yamar Dam, Myanmar. American Academic Scientific Research Journal for Engineering, Technology, and Sciences, 69(1), 59-72.

Li, Z., Li, W., & Ge, W. (2018). Weight analysis of influencing factors of dam break risk consequences. Natural Hazards and Earth System Sciences, 18(12), 3355-3362.

Mustamin, M. R., Maricar, F., & Karamma, R. (2021). Hydrological Analysis In Selecting Flood Discharge Method In Watershed Of Kelara River. INTEK: Jurnal Penelitian, 8(2), 141-150.

Nazif, H. M. (2019). Advance Mosul Dam Break Analysis by Integrated Hydrologic Modeling and Gene-Expression Programming. Zanco Journal of Pure and Applied Sciences, 31(s3), 423-429.

Perera, D., Smakhtin, V., Williams, S., North, T., & Curry, A. (2021). Ageing water storage infrastructure: An emerging global risk. UNU-INWEH Report Series, 11.

Rakhim, A., & Sirajuddin, A. (2020). Evaluasi perencanaan teknis dan analisa stabilitas konstruksi tubuh bendungan Karalloe. Teknik Hidro, 13(1), 18-27.

Sandi, R., Rasyidi, E. S., & Fikruddin, M. (2020). Landslide Of Karalloe Dam Site Gowa Regency, South Sulawesi Province. Jurnal Ilmiah Ecosystem, 20(1), 34-40.

Said, N. F. M., Mohd Sidek, L., Mustafa, Z., Mansor, F. H., & Jamal, M. (2019, November). Emergency Action Plan for Public Safety Around the Juaseh Dam, Johor. In International Conference on Dam Safety Management and Engineering (pp. 115-124). Springer, Singapore.

Urzică, A., Mihu-Pintilie, A., Stoleriu, C. C., Cîmpianu, C. I., Huţanu, E., Pricop, C. I., & Grozavu, A. (2020). Using 2D HEC-RAS Modeling and Embankment Dam Break Scenario for Assessing the Flood Control Capacity of a Multi-Reservoir System (NE Romania). Water, 13(1), 57.

Vernimmen, R. R. E., Hooijer, A., Aldrian, E., & Van Dijk, A. I. J. M. (2012). Evaluation and bias correction of satellite rainfall data for drought monitoring in Indonesia. Hydrology and Earth System Sciences, 16(1), 133-146.

Flood Modelling due to dam failure using HEC-RAS 2D with GIS overlay: case study of Karalloe dam in South Sulawesi Province Indonesia

ORIGINALITY REPORT

4%
SIMILARITY INDEX

PRIMARY SOURCES

1	link.springer.com Internet	22 words	1%
2	assets.researchsquare.com Internet	17 words	< 1%
3	www.mdpi.com Internet	16 words	< 1%
4	jurnal.poliupg.ac.id Internet	11 words	< 1%
5	opensiuc.lib.siu.edu Internet	10 words	< 1%
6	www.iwmi.cgiar.org Internet	10 words	< 1%
7	Burhan Niyazi, Abdul A. Khan, Milad Masoud, Amro Elfeki, Jalal Basahi, Syed Zaidi. "Morphological-hydrological relationships and the geomorphological instantaneous unit hydrograph of Makkah Al-Mukarramah watersheds", Arabian Journal of Geosciences, 2021 Crossref	8 words	< 1%

8	T U Karunia, M. Faisi Ikhwali. "Effects of population and land-use change on water balance in DKI Jakarta", IOP Conference Series: Earth and Environmental Science, 2021 Crossref	8 words — < 1%
9	Yadong Zhang, Zongkun Li, Wei Ge, Xudong Chen, Hongyin Xu, Hongyan Guan. "Evaluation of the impact of extreme floods on the biodiversity of terrestrial animals", Science of The Total Environment, 2021 Crossref	8 words — < 1%
10	lra.le.ac.uk Internet	8 words — < 1%
11	nhess.copernicus.org Internet	8 words — < 1%
12	A Bharath, Anand V Shivapur, C G Hiremath, Ramesh Maddamsetty. "Dam break analysis using HEC-RAS and HEC-GeoRAS: A case study of Hidkal dam, Karnataka State, India", Environmental Challenges, 2021 Crossref	7 words — < 1%
13	Akhmad Azis, Sugiarto Badaruddin, Zulvyah Faisal, Muh.Taufik Iqbal, Haeril Abdi Hasanuddin. "Numerical Model on the Application of Sand Columns in Recharge Reservoir", Groundwater for Sustainable Development, 2018 Crossref	6 words — < 1%

EXCLUDE QUOTES	OFF	EXCLUDE SOURCES	OFF
EXCLUDE BIBLIOGRAPHY	ON	EXCLUDE MATCHES	OFF