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

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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

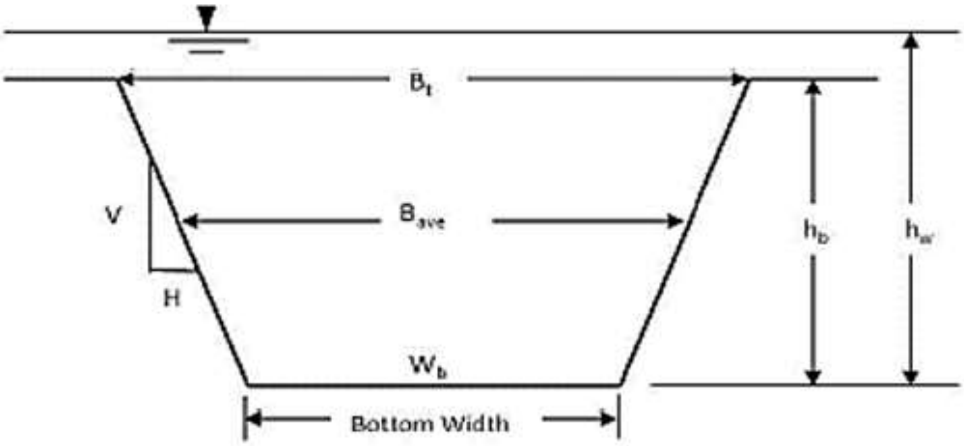


Figure 1. Fracture parameter overview

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:

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

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

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.

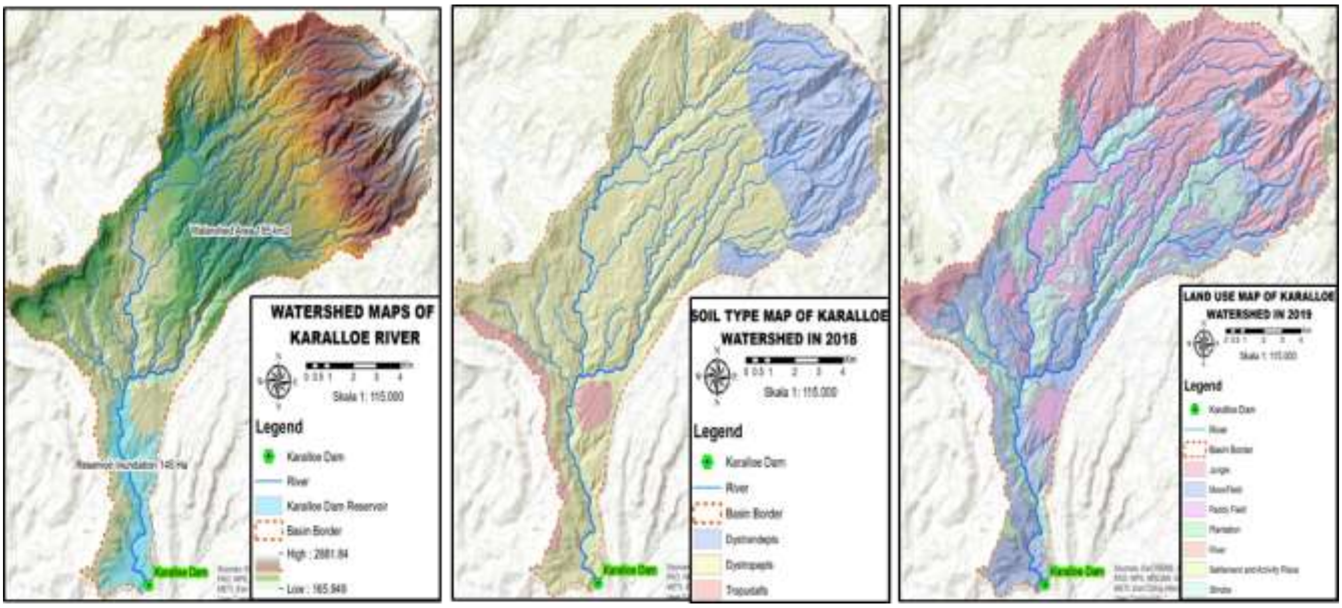


Figure 2. Map of Topographic, soil type and land use of the Karalloe Watershed

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

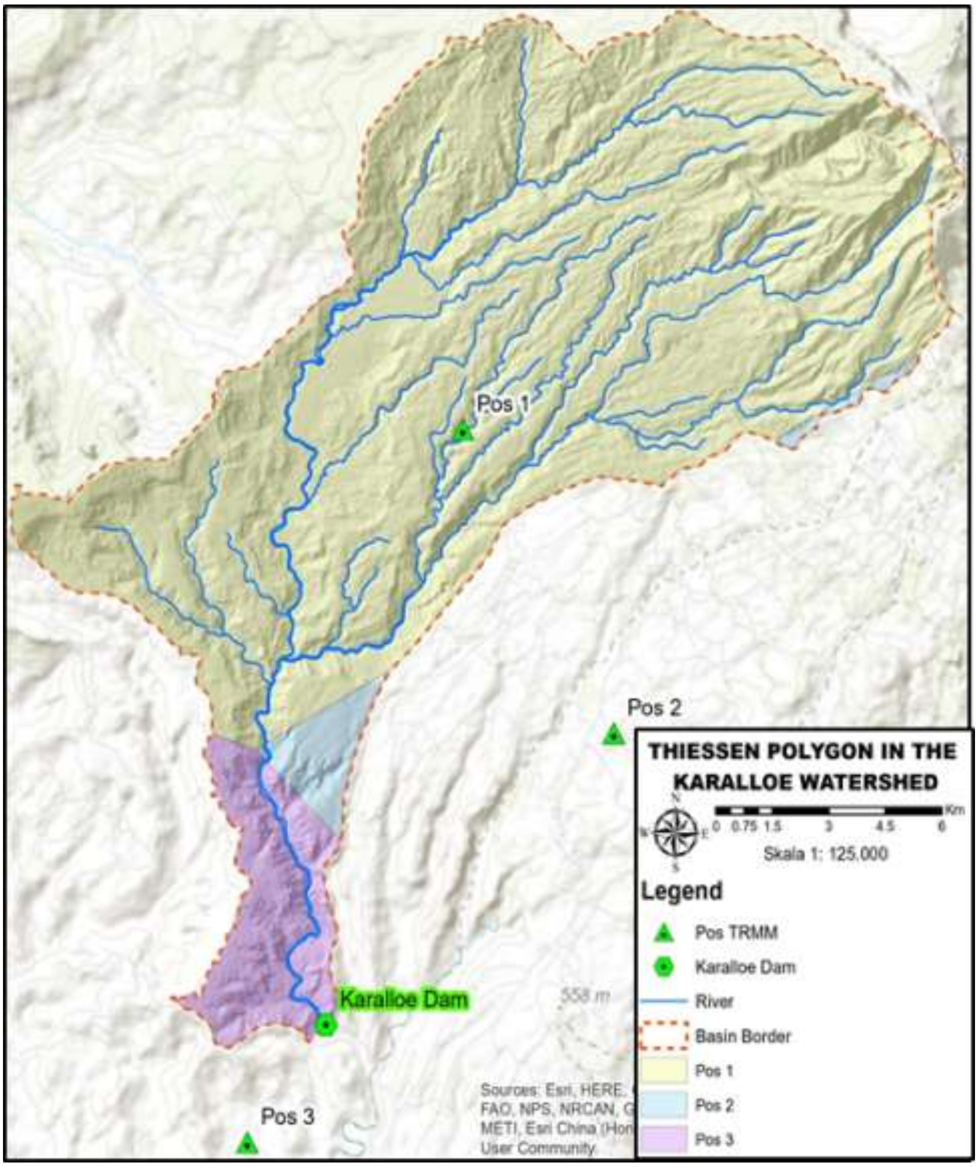


Figure 3. Thiessen polygon of the Karalloe watershed

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
2007	73	79	72
2008	72	72	96
2009	84	89	80
2010	111	134	101

Year	Maximum Daily Rainfall (mm)		
	Pos 1	Pos 2	Pos 3
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.

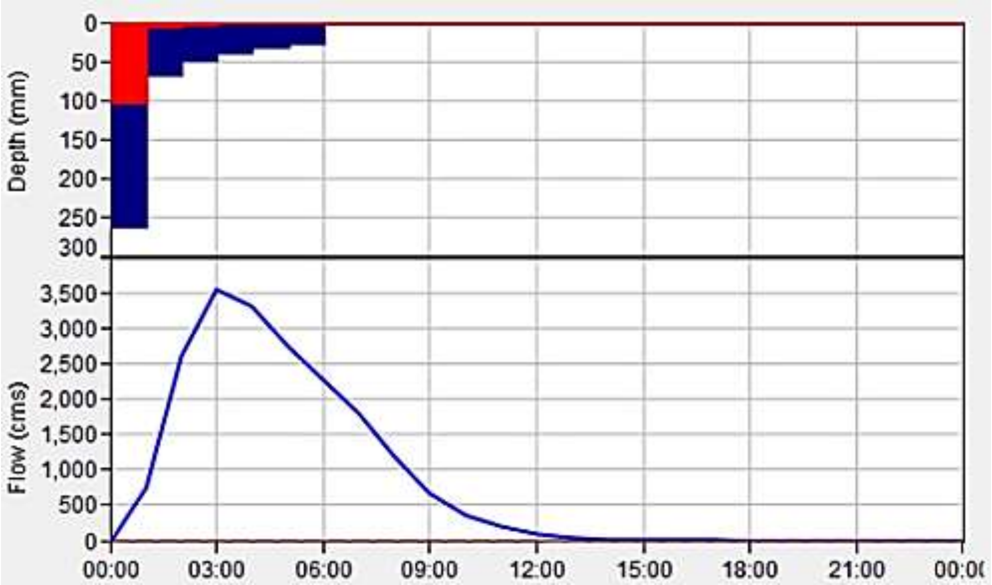
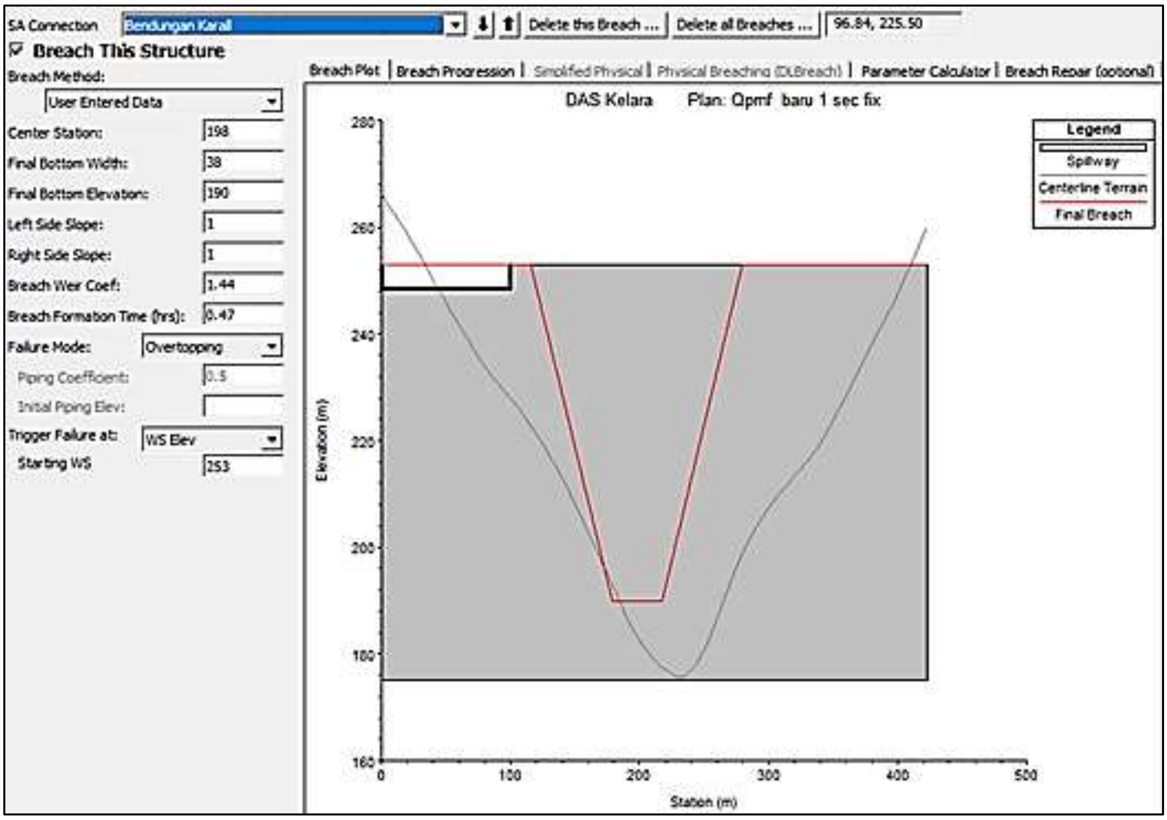


Figure 4. QPMF flood hydrograph of the Karalloe Watershed

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.


SA Connection: Bendungan Karall

☑ Breach This Structure

Breach Method: User Entered Data

Center Station: 198

Final Bottom Width: 38

Final Bottom Elevation: 190

Left Side Slope: 1

Right Side Slope: 1

Breach Weir Coef: 1.44

Breach Formation Time (hrs): 0.47

Failure Mode: Overtopping

Piping Coefficient: 0.5

Initial Piping Elev:

Trigger Failure at: WS Elev

Starting WS: 253

96.84, 225.50

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

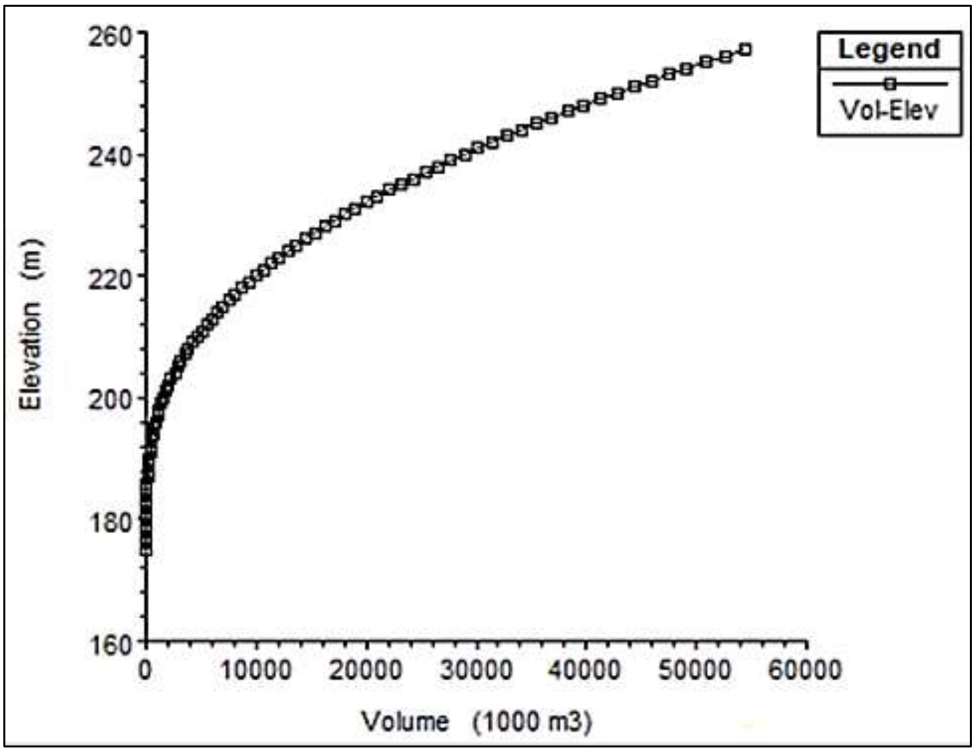


Figure 6. Curve capacity of the Karalloe dam's reservoir

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.

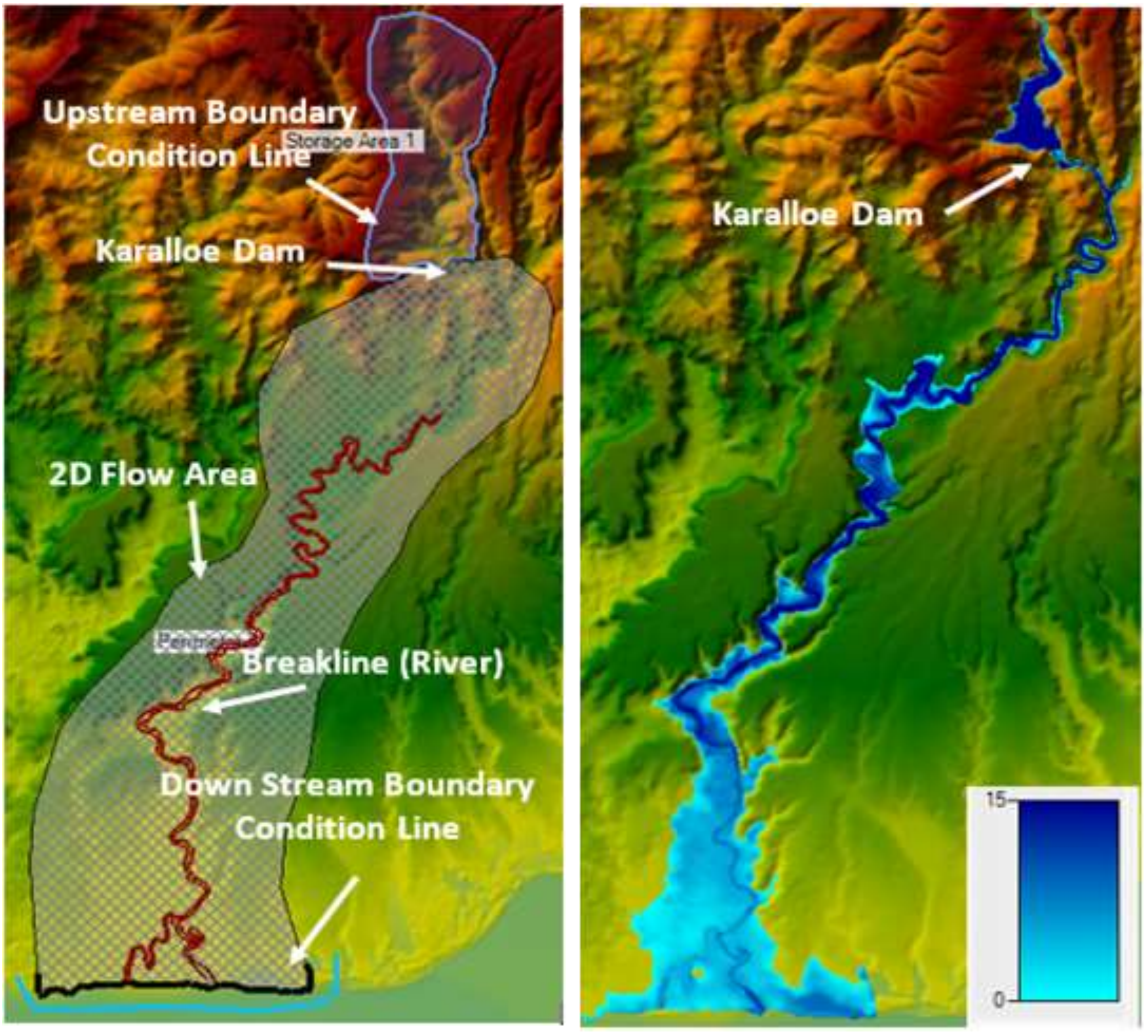


Figure 7. Map of DEM/boundary condition and simulation result of the Karalloe dam’s failure

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.

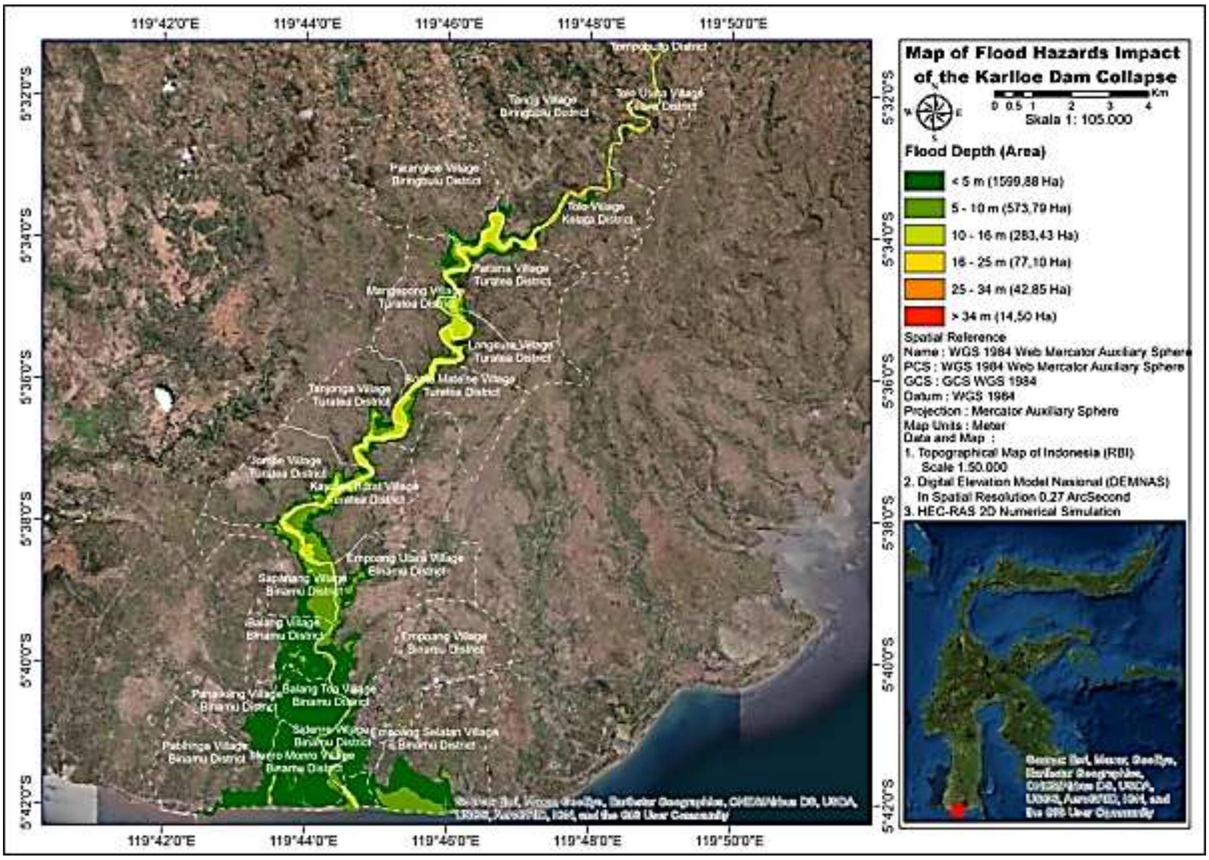


Figure 8. Map of flood hazards due to the collapse of the Karalloe dam

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

Affected areas		
Village	Districts	Regency
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

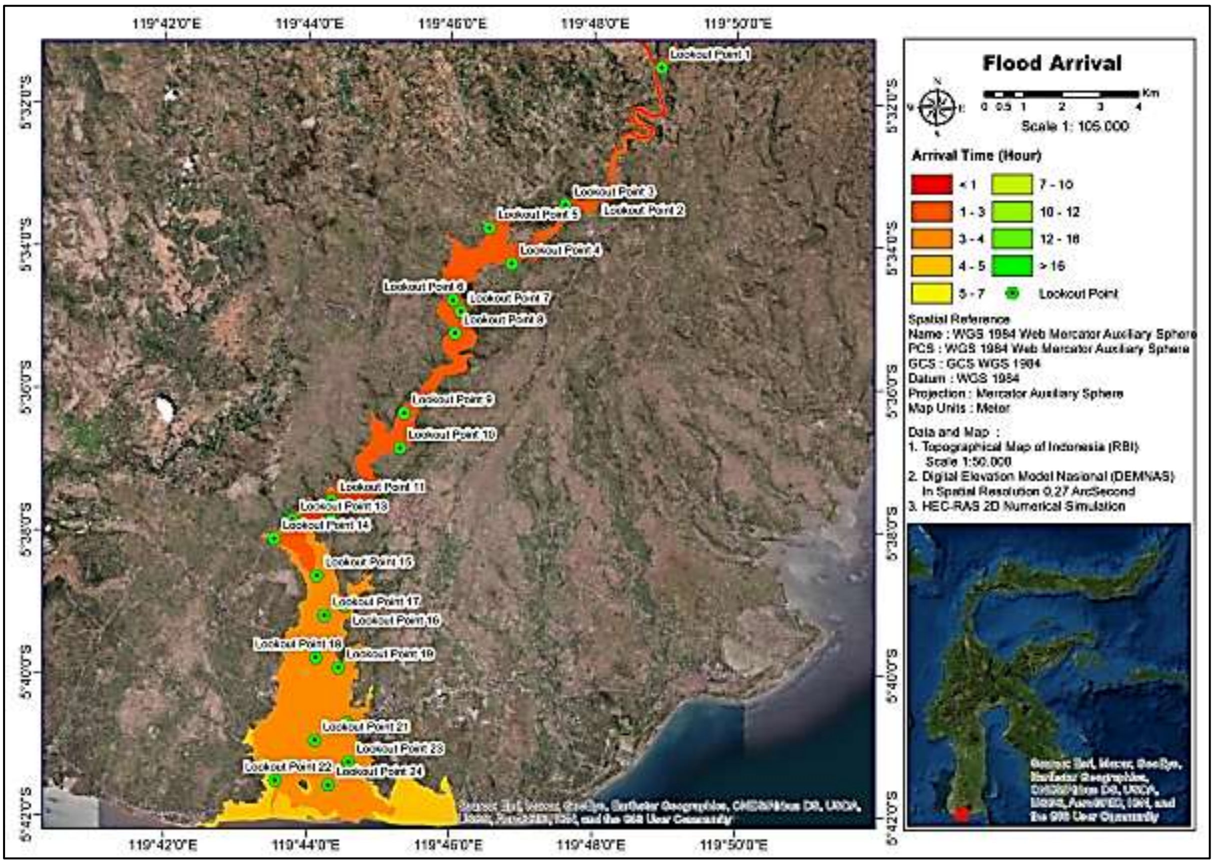


Figure 9. Map of Flood arrival time

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 & 119°46'3.36"E	Mangepong Village, Turatea District , Jeneponto Regency	17.628	32
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 ,	33.831	78

		Jeneponto Regency		
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.

3.4. Discussion

Dams currently provide numerous agricultural, social, and economic benefits, making dams an extremely vital infrastructure. Dams have also played an essential role in protecting human floodplain settlements (Romanescu and Stoleriu, 2017). Similarly, the Karalloe Dam serves an essential purpose for the surrounding community. Dams are critical in protecting against flood hazards because of extreme events such as the Lanina effect and uncontrolled population growth in flood-prone areas (Mihu-Pintilie et al., 20119). The results of this study, however, show that a dam collapse can generate a flood wave that is significantly larger in terms of volume released and velocity of the water generated than a natural-induced flood wave. This condition can cause more severe economic damage and casualties (Lukman et al., 2011). As a result, it is critical to conduct a complex and in-depth study of the dam collapse to provide an overview to the communities downstream of the dam about the impact and implement strategies to reduce the risks that may occur. The findings of this study should be used to develop mitigation strategies for watersheds with dams, such as the Karalloe Dam in Gowa Regency.

The Karalloe Dam itself is scheduled to begin construction in 2012, be completed in 2017, and be completed in 2021. The study analysis results found a 63.71% increase in planned discharge from 2012 to 2017 and a 6.9% increase from 2017 to 2021. This rise was caused by an increase in annual rainfall intensity and a rapid land clearing process. The main reason for the need for a dam collapse analysis is to develop a mitigation strategy to reduce losses in a dam failure. Dam failure is known to occur due to overtopping or piping failure. Overtopping refers to the elevation of the water level upstream of the dam that exceeds the elevation of the crest, causing the water to flow over the dam's crest, whereas piping refers to the condition of river water being blocked by the dam and unable to flow into the ground along the base and walls of the natural dam. The most likely outcome in the case of the Karalloe Dam with a type of rock fill with a concrete membrane is dam collapse due to overtopping. According to the simulation, with a discharge of QPMF = 3543 m^3/s on the Karalloe dam, it only takes 2 hours and 28 minutes to go from average to overtopping conditions, and due to the dam's collapse, there are 22 villages from 5 affected districts, namely Taring, Garing, North Tolo, Tolo, Paitana, Parangloe, Mangepong, Langkura, Bonto Mate'ne, Tanjonga, West Kayuloe, Jombe, Sapanang, North Empoang, Balang, Balang Toa, Empoang, Sidenre, Monro – Monro, South Empoang, Panaikang and Pabiringa. The simulation results can determine when the flood reaches the residential location, which can then be used to develop an early warning system for flood hazards. The simulation results also show that the distance from the dam and the topographical conditions of each settlement influence the time it takes for the flood to reach the residential location. Based on the findings of this analysis, 24 monitoring points can be established in densely populated areas, with the fastest time being at monitoring point 7 in Paitana Village, which is 16.4 km from the dam and has a time of 12 minutes. Furthermore, the longest time was recorded at monitoring point 22 in Pabiringa Village, 39,743 km from the dam. This outcome is expected to become a standard operating procedure (SOP) for dealing with flood hazards, allowing downstream communities to anticipate and evacuate to areas that are not flood-prone to minimize flood losses caused by the dam's collapse.

Several previous researchers have also conducted similar studies. For example, Shahrim and Ros (2020) emphasize the comparison of 1D and 2D models in dam failure simulations, as well as the comparison of flood arrival time, depth, and velocity due to piping and overtopping, and show that dam failure due to overtopping has higher depth and velocity values than piping. Murdiani et al. (2020) also used national digital elevation model data in a 2D simulation, with the results providing an overview of the affected areas and the time of arrival of floods in each village. This previous study is similar to the current research but differs in the effort to improve the model's accuracy, whereas in this study, data from measurements of riverbeds and reservoirs on the dam and monitoring points were used to mitigate the dam's collapse. The findings of this study show that 22 villages along 22 km of riverbank affected, and the present study will assist authorities in developing emergency response plans and preparing guidelines for flood mitigation plans in the research area.

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 2020 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.

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Evaluation Report

General Comments	**This manuscript addresses that the increase in flood discharge is essential for analyzing floods. Using the most recent rainfall data to determine the increase in flood discharge, the most significant discharge was used as input for simulation to assess the impact of the Karalloe Dam failure.**
Advantage & Disadvantage	**However, several important points need to be addressed to improve the quality of this manuscript further. Here are some remarks to be addressed.:** **Undoubtedly, this simulation can help the study area's dam and disaster management agencies. The information can be used as a basis for decision-making during an emergency. However, the weakness of this manuscript is that it does not show its significant contribution to the field of study. Does this manuscript try to describe a new mitigation procedure for the surrounding population based on the study's findings (i.e., an emergency route to higher ground)? Does this manuscript try to introduce a new dam management/planning model to be more efficient? Or does this manuscript present a new spatial analysis that researchers in the future can use?** **Next, this manuscript also does not put a strong justification for why the Karalloe dam is used in this study. Usually, before a dam is built, various analyses are carried out before the decision to build a dam is made. Among them is Environmental Impact Analysis (EIA). It considers various factors and parameters in seeing what the impact of the dam's construction is before the construction is carried out. GIS analysis is also involved during this phase. Therefore, the dam in the study area in this manuscript was chosen because it has unique characteristics that distinguish it from other dams?**

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Flood Modelling due to Dam Failure Using HEC-RAS 2D with GIS Overlay: Case Study of Karalloe Dam in South Sulawesi Province Indonesia

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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

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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

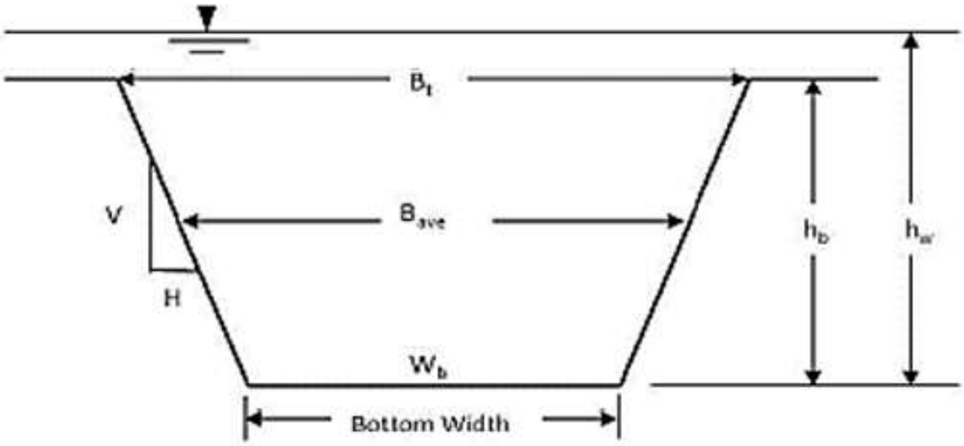


Figure 1. Fracture parameter overview

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:

$$B_{ave} = 0.27\,K_0.Vw^{0.32}.hb^{0.04} \tag{1}$$

$$tf = 63.2\sqrt{\frac{Vw}{ghb^2}} \tag{2}$$

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.

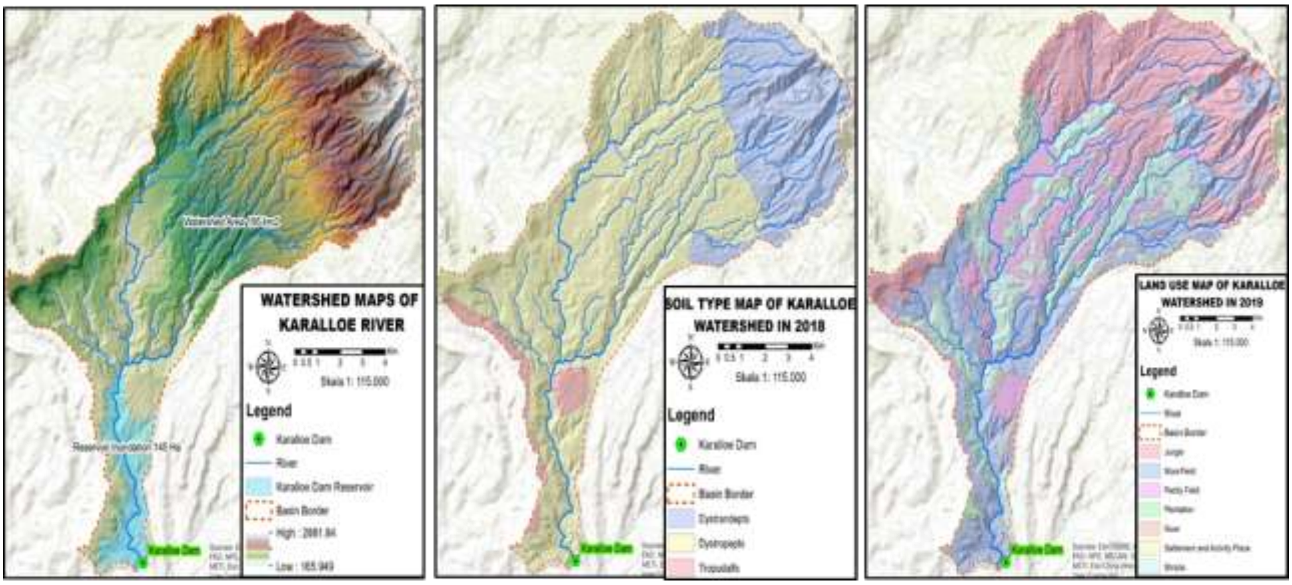


Figure 2. Map of Topographic, soil type and land use of the Karalloe Watershed

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

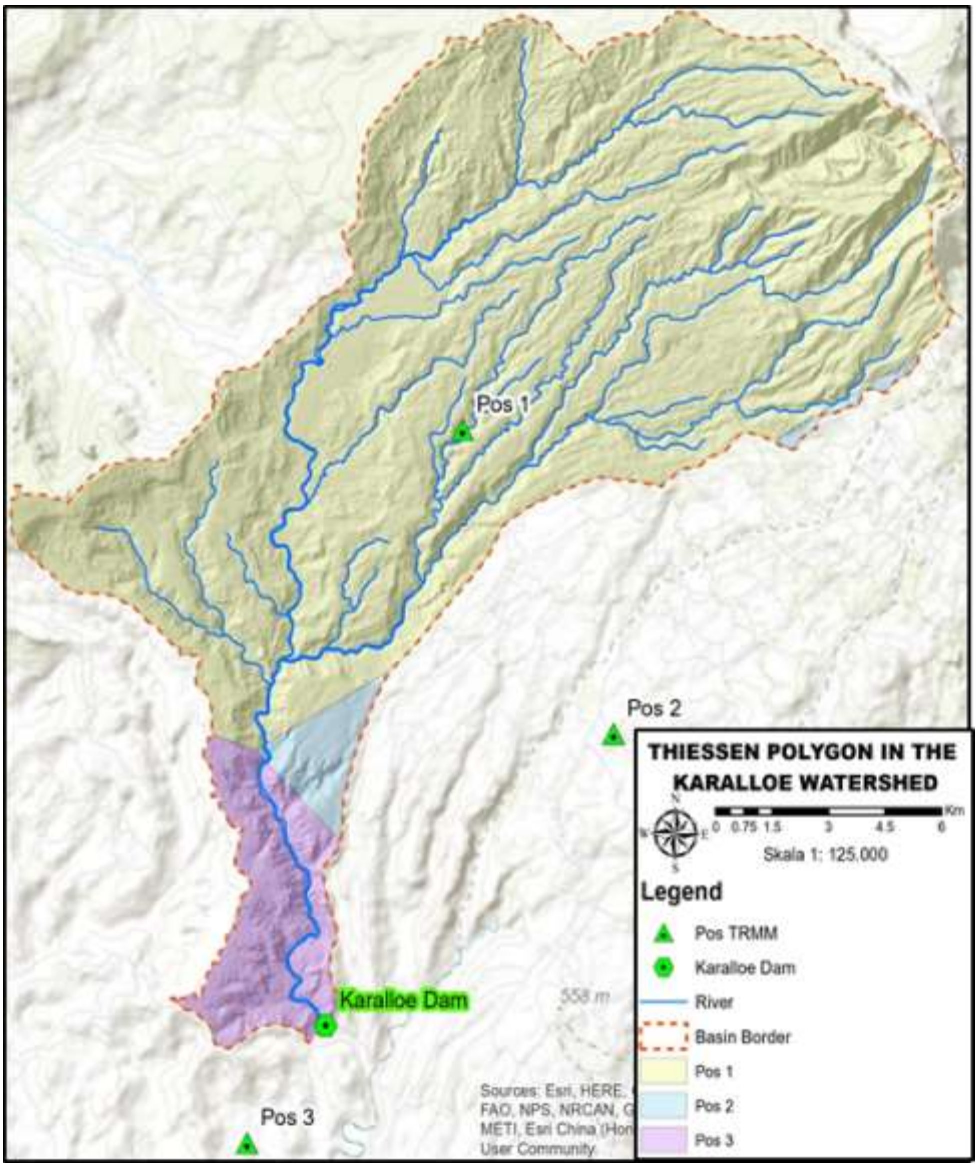


Figure 3. Thiessen polygon of the Karalloe watershed

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
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.

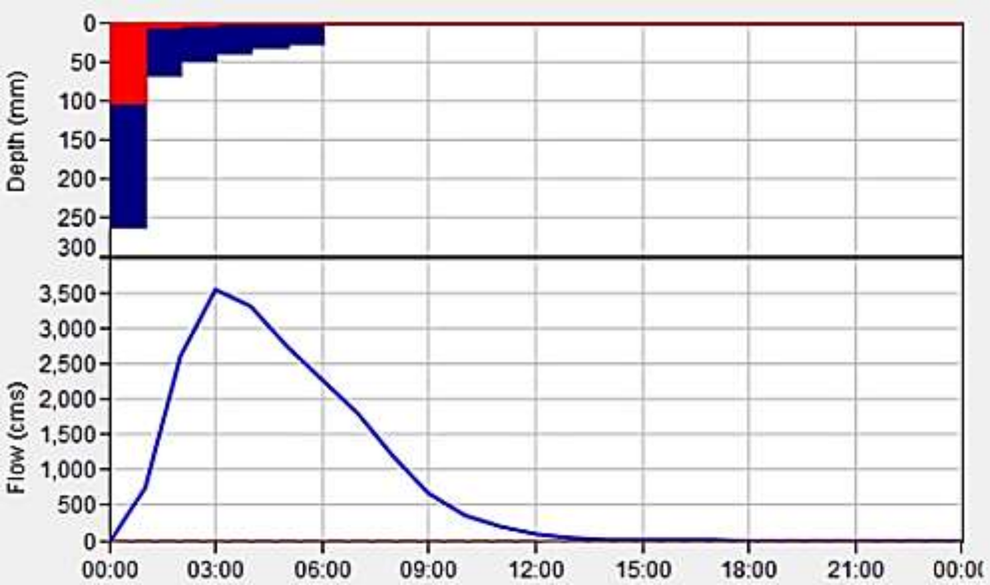
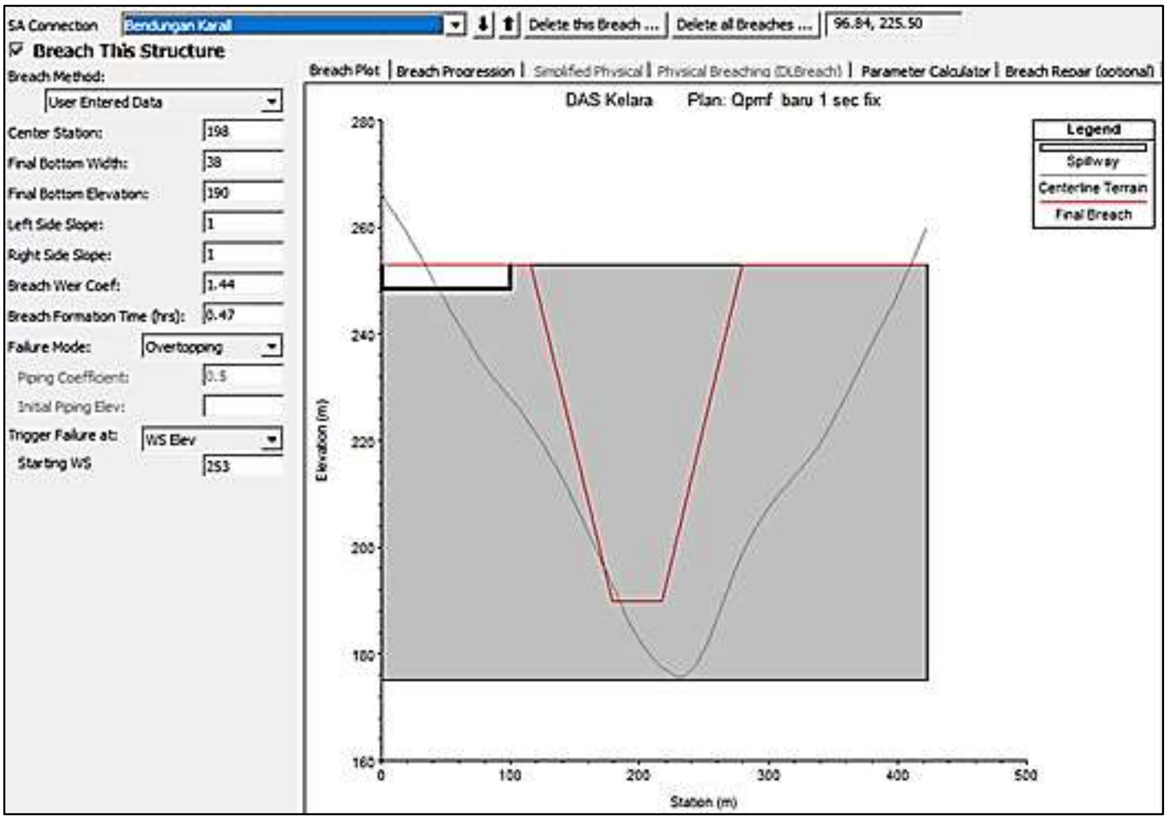


Figure 4. QPMF flood hydrograph of the Karalloe Watershed

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.


SA Connection: Bendungan Karall

☑ **Breach This Structure**

Breach Method: User Entered Data

Center Station: 198

Final Bottom Width: 38

Final Bottom Elevation: 190

Left Side Slope: 1

Right Side Slope: 1

Breach Weir Coef: 1.44

Breach Formation Time (hrs): 0.47

Failure Mode: Overtopping

Piping Coefficient: 0.5

Initial Piping Elev:

Trigger Failure at: WS Elev

Starting WS: 253

96.84, 225.50

DAS Kelara   Plan: Qpmf baru 1 sec fix

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

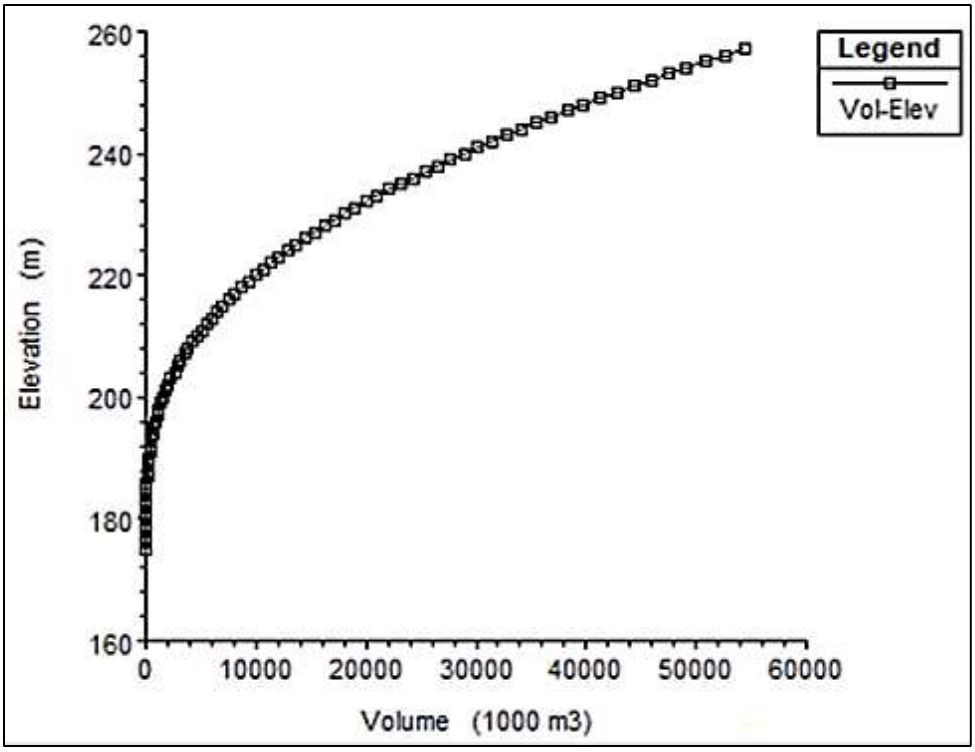


Figure 6. Curve capacity of the Karalloe dam’s reservoir

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.

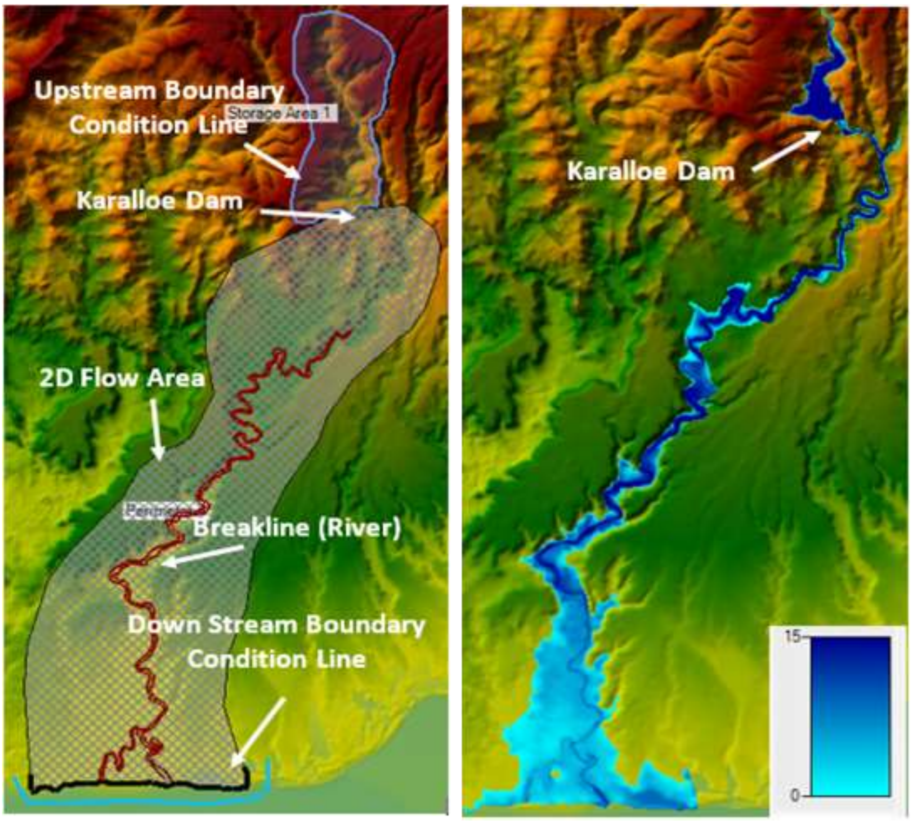


Figure 7. Map of DEM/boundary condition and simulation result of the Karalloe dam’s failure

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.

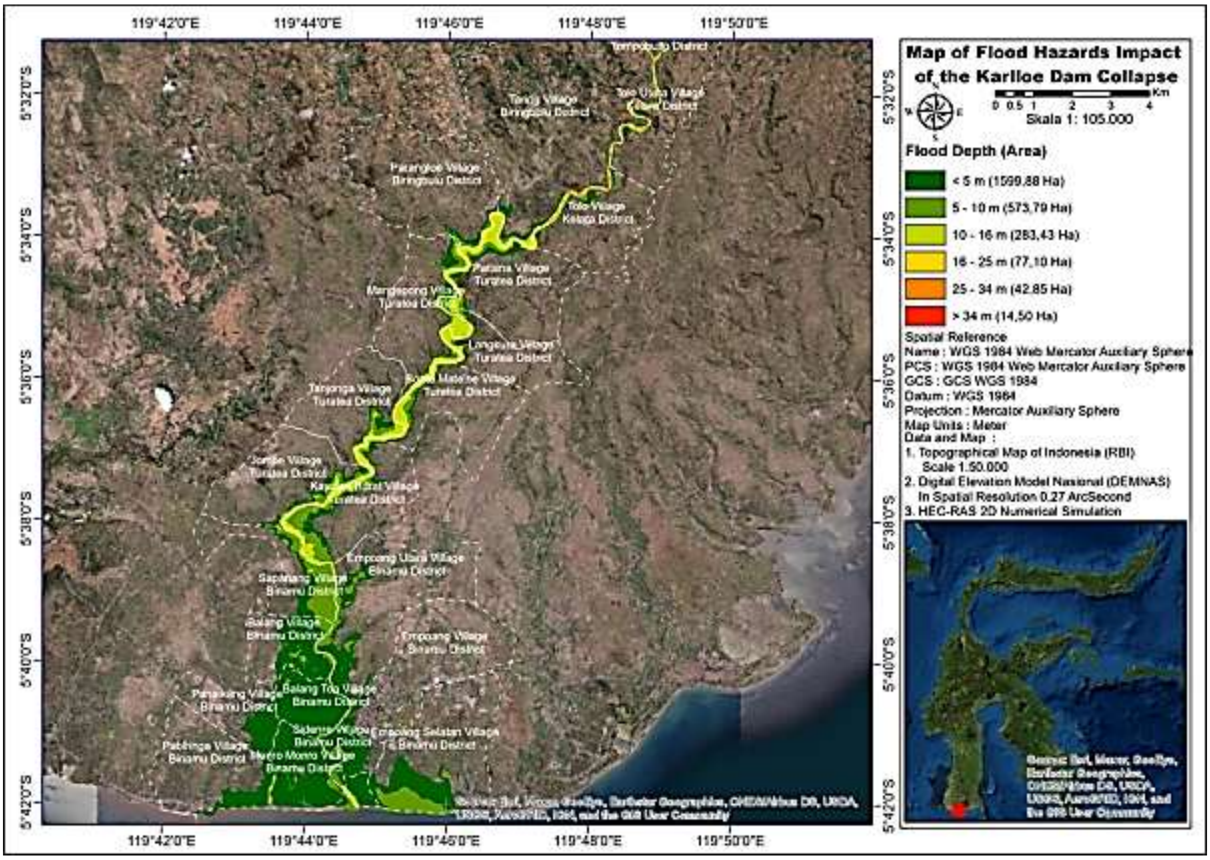


Figure 8. Map of flood hazards due to the collapse of the Karalloe dam

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

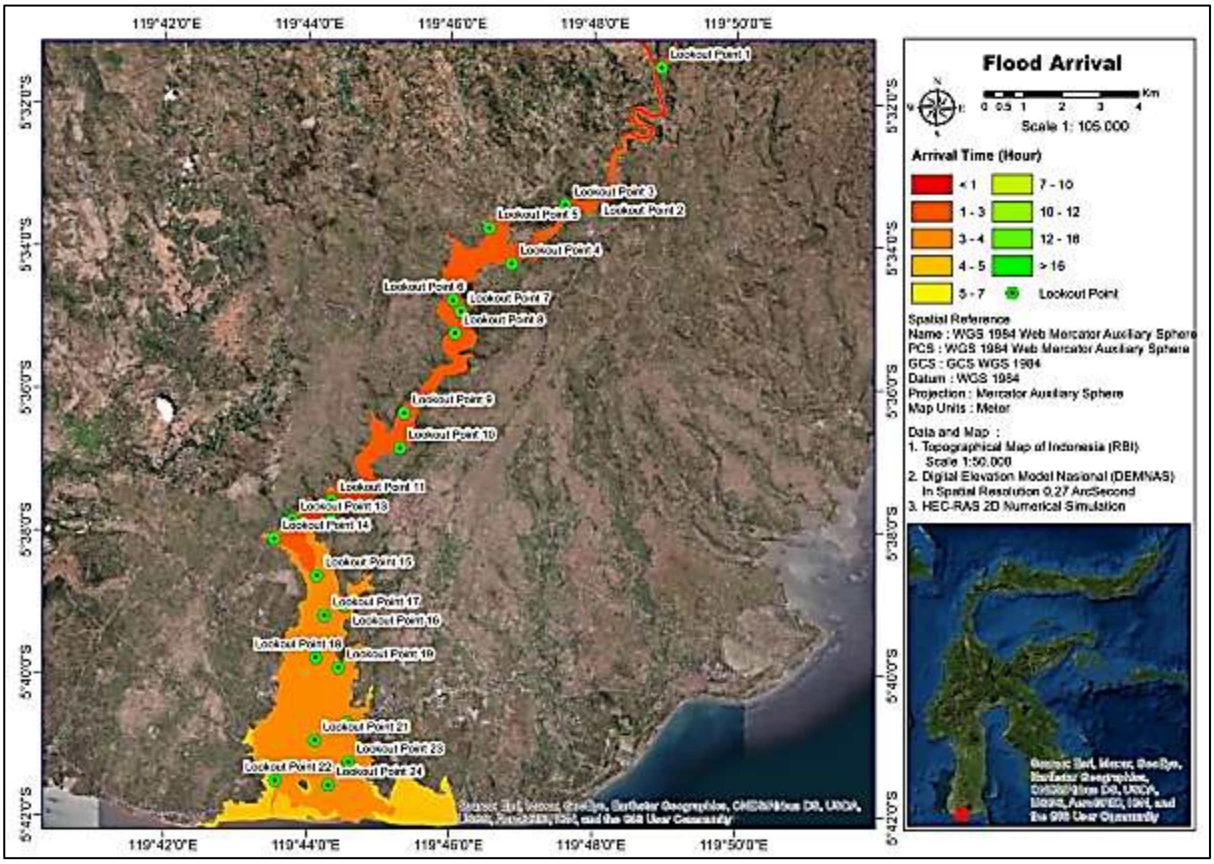


Figure 9. Map of Flood arrival time

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 & 119°46'3.36"E	Mangepong Village, Turatea District , Jeneponto Regency	17.628	32
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.

3.4. Discussion

Dams currently provide numerous agricultural, social, and economic benefits, making dams an extremely vital infrastructure. Dams have also played an essential role in protecting human floodplain settlements (Romanescu and Stoleriu, 2017). Similarly, the Karalloe Dam serves an essential purpose for the surrounding community. Dams are critical in protecting against flood hazards because of extreme events such as the Lanina effect and uncontrolled population growth in flood-prone areas (Mihu-Pintilie et al., 20119). The results of this study, however, show that a dam collapse can generate a flood wave that is significantly larger in terms of volume released and velocity of the water generated than a natural-induced flood wave. This condition can cause more severe economic damage and casualties (Lukman et al., 2011). As a result, it is critical to conduct a complex and in-depth study of the dam collapse to provide an overview to the communities downstream of the dam about the impact and implement strategies to reduce the risks that may occur. The findings of this study should be used to develop mitigation strategies for watersheds with dams, such as the Karalloe Dam in Gowa Regency.

The Karalloe Dam itself is scheduled to begin construction in 2012, be completed in 2017, and be completed in 2021. The study analysis results found a 63.71% increase in planned discharge from 2012 to 2017 and a 6.9% increase from 2017 to 2021. This rise was caused by an increase in annual rainfall intensity and a rapid land clearing process. The main reason for the need for a dam collapse analysis is to develop a mitigation strategy to reduce losses in a dam failure. Dam failure is known to occur due to overtopping or piping failure. Overtopping refers to the elevation of the water level upstream of the dam that exceeds the elevation of the crest, causing the water to flow over the dam's crest, whereas piping refers to the condition of river water being blocked by the dam and unable to flow into the ground along the base and walls of the natural dam. The most likely outcome in the case of the Karalloe Dam with a type of rock fill with a concrete membrane is dam collapse due to overtopping. According to the simulation, with a discharge of QPMF = 3543 m^3/s on the Karalloe dam, it only takes 2 hours and 28 minutes to go from average to overtopping conditions, and due to the dam's collapse, there are 22 villages from 5 affected districts, namely Taring, Garing, North Tolo, Tolo, Paitana, Parangloe, Mangepong, Langkura, Bonto Mate'ne, Tanjonga, West Kayuloe, Jombe, Sapanang, North Empoang, Balang, Balang Toa, Empoang, Sidenre, Monro – Monro, South Empoang, Panaikang and Pabiringa. The simulation results can determine when the flood reaches the residential location, which can then be used to develop an early warning system for flood hazards. The simulation results also show that the distance from the dam and the topographical conditions of each settlement influence the time it takes for the flood to reach the residential location. Based on the findings of this analysis, 24 monitoring points can be established in densely populated areas, with the fastest time being at monitoring point 7 in Paitana Village, which is 16.4 km from the dam and has a time of 12 minutes. Furthermore, the longest time was recorded at monitoring point 22 in Pabiringa Village, 39,743 km from the dam. This outcome is expected to become a standard operating procedure (SOP) for dealing with flood hazards, allowing downstream communities to anticipate and evacuate to areas that are not flood-prone to minimize flood losses caused by the dam's collapse.

Several previous researchers have also conducted similar studies. For example, Shahrim and Ros (2020) emphasize the comparison of 1D and 2D models in dam failure simulations, as well as the comparison of flood arrival time, depth, and velocity due to piping and overtopping, and show that dam failure due to overtopping has higher depth and velocity values than piping. Murdiani et al. (2020) also used national digital elevation model data in a 2D simulation, with the results providing an overview of the affected areas and the time of arrival of floods in each village. This previous study is similar to the current research but differs in the effort to improve the model's accuracy, whereas in this study, data from measurements of riverbeds and reservoirs on the dam and monitoring points were used to mitigate the dam's collapse. The findings of this study show that 22 villages along 22 km of riverbank affected, and the present study will assist authorities in developing emergency response plans and preparing guidelines for flood mitigation plans in the research area.

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 2020 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.

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Flood Modelling due to Dam Failure Using HEC-RAS 2D with GIS Overlay: Case Study of Karalloe Dam in South Sulawesi Province Indonesia

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Abstract A dam is one of the water structures that have many benefits for humans. However, flood disasters caused by dam break may have a very bad impact on human life. This study specifically analyzed the impact of flooding caused by the failure of the Karalloe dam in Bone Regency, South Sulawesi Province, Indonesia. The selected flood discharge was verified using the Creager graph by comparing the calculated discharge from several synthetic unit hydrograph methods (HSS) with the flood discharge measured on the automatic water level recorder (AWLR) at the monitoring point. The impact of flooding due to dam break was simulated using HEC-RAS 2D combined with ArcGIS for mapping. The calculation results of the design flood discharge based on rainfall data using the methods of HSS Nakayasu, HSS ITB I, HSS ITB II, and HSS SCS (HEC-HMS) as well as the calculation of the designed flood discharge based on the discharge data showed that the design flood discharge value which is closest to the measured discharge value and Q1000 Creager was the HSS SCS method. The flood discharge values obtained based on the HSS SCS method for Tr (return period) 2 years, Tr 5 years, Tr 10 years, Tr 20 years, Tr 25 years, Tr 50 years, Tr 100 years, and Tr 1000 years were 322.70 m^3/s, 464.10 m3/s, 560.40 m^3/s, 658.40 m^3/s, 682.70 m^3/s, 787.00 m^3/s, 885.70 m^3/s, and 1202.60 m^3/s, respectively. The simulation results showed that 22 villages will be affected by flooding due to the failure of the Karalloe dam and the fastest standby time of the flood is 12 minutes, namely at Lookout Point 7 in Paitana Village. This result suggests that early warning system should be installed at the downstream of the dam and flood disaster mitigation should be adopted and applied to these threatened area.

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

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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 [1,2]. 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/s), conservation of water resources, and tourism development [3-5].

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 [6,7]. The construction of a dam is frequently followed by the development of communities in the downstream area, which increases the risk of dam failure [8]. 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 [9].

Because of the conditions affecting dam stability and retention efficiency, a greater spread of awareness about risk factors affecting dam safety is required [9]. Some negative factors include damaging spillway capacity that cannot drain flood discharge due to changes in weather patterns effectively and exacerbated extreme climates [10,11]. 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 [12]. 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 [13].

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 [14]. The source of data for compiling this EAP is the result of dam break analysis in the form of dam collapse simulation results [14]. In most downstream flood simulations caused by a dam failure, it is assumed that the dam collapses completely and unexpectedly [15]. Kheirkhah et al. [16], SMPDBK [17], FLDWAV [16], and HEC-RAS can be used to model water flow due to dam collapse [18]. 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 [19].

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 [20]. 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 [21].

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 [22].

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

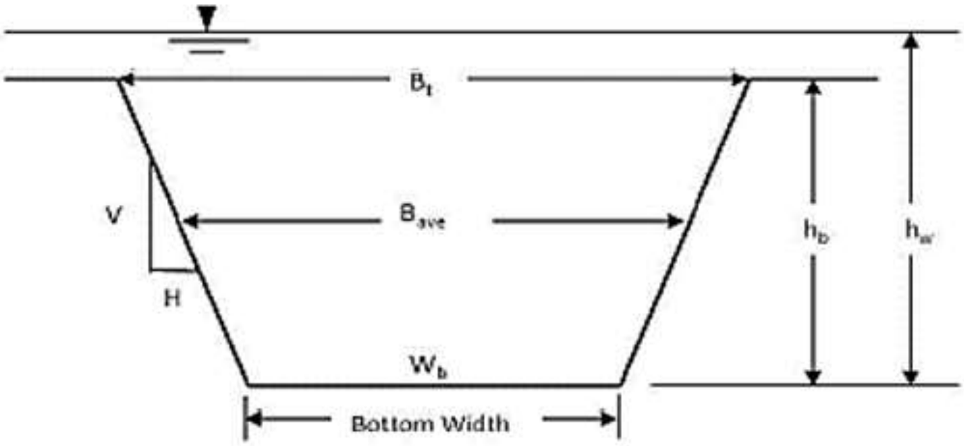


Figure 1. Fracture parameter overview

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:

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

$$tf = 63.2\sqrt{\frac{Vw}{ghb^2}} \tag{2}$$

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 [23], 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 m^3/s was obtained in 2012, while the results of other researchers' analyses of the Karalloe Dam obtained a QPMF of 3307 m^3/s in 2017 [4]. It is 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.

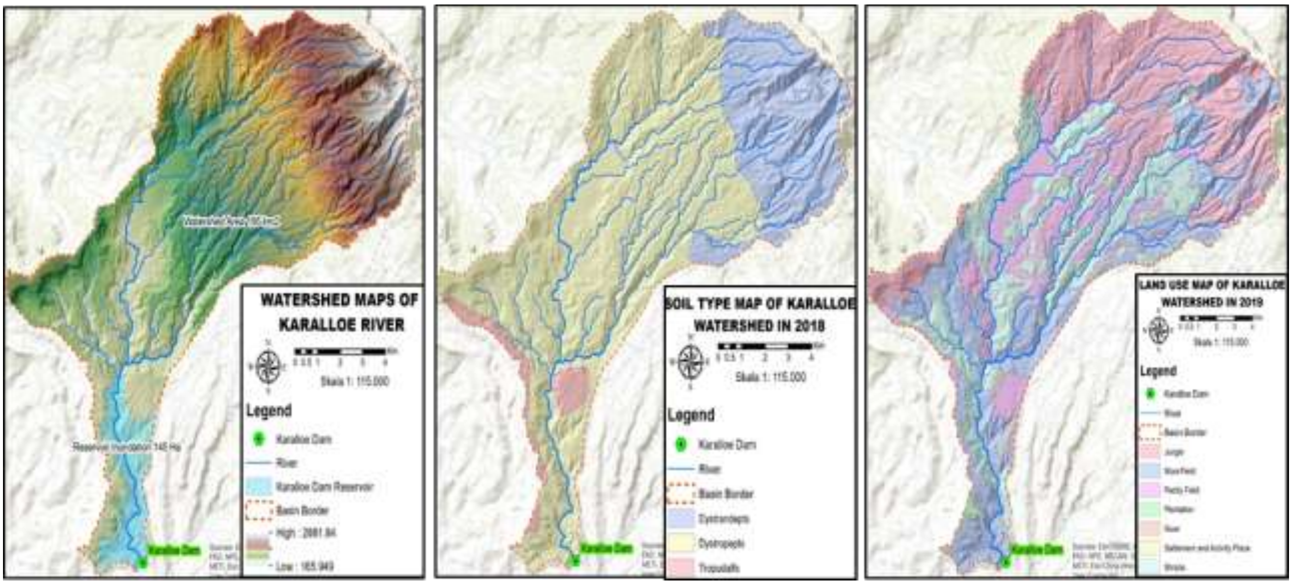


Figure 2. Map of Topographic, soil type and land use of the Karalloe Watershed

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

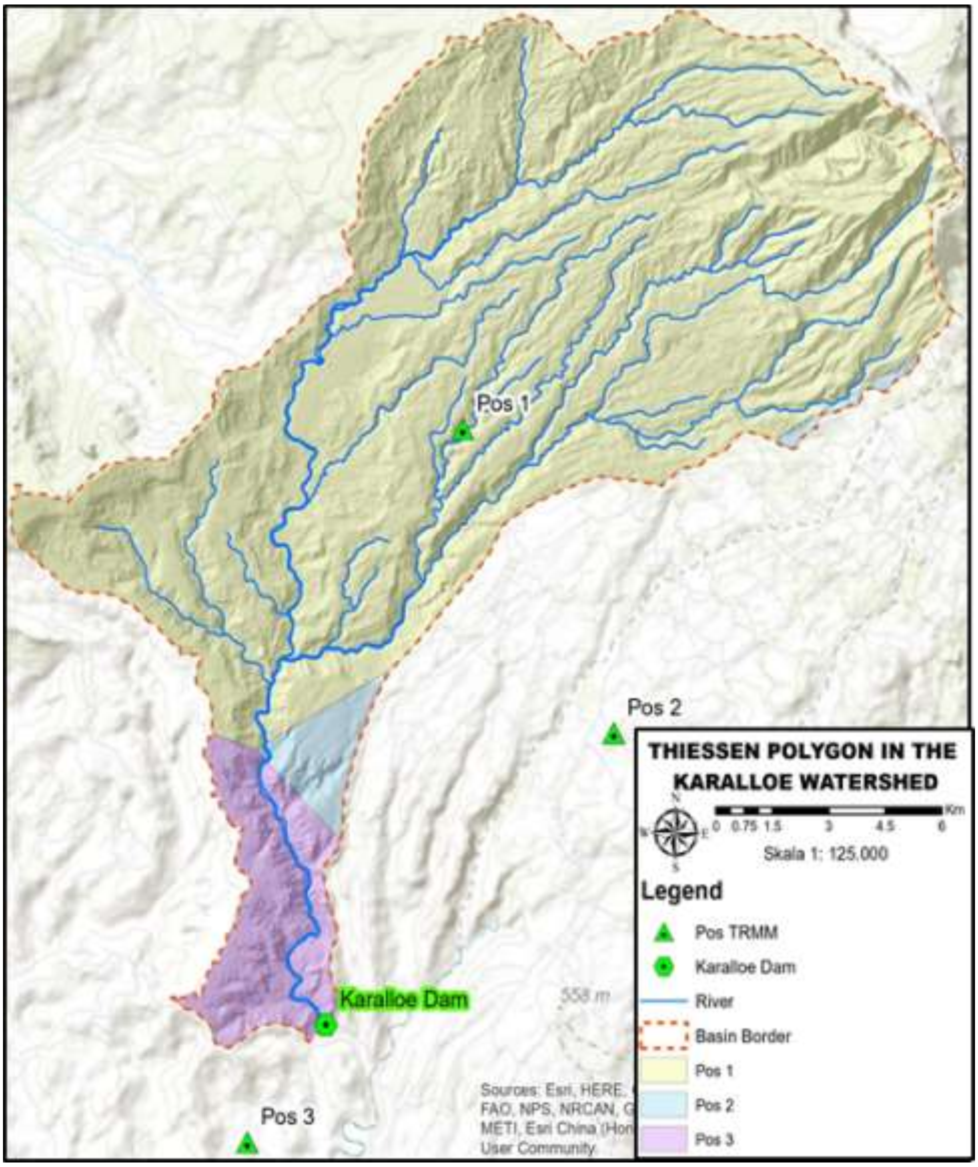


Figure 3. Thiessen polygon of the Karalloe watershed

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
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.

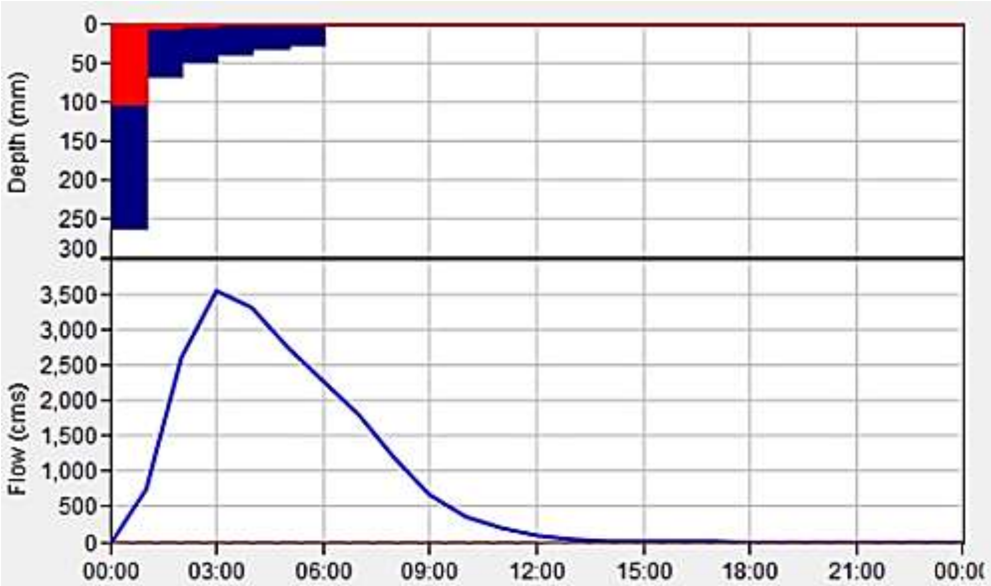
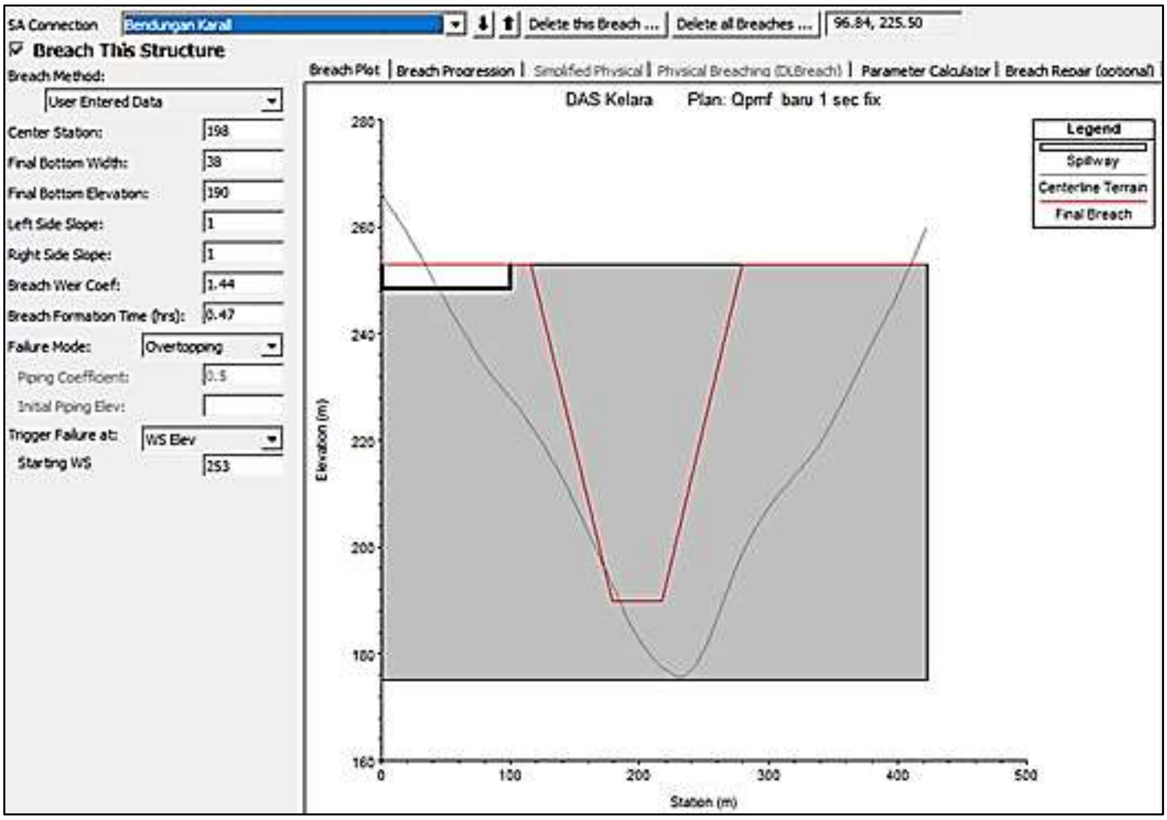


Figure 4. QPMF flood hydrograph of the Karalloe Watershed

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.



SA Connection: Bendungan Karall

☑ **Breach This Structure**

Breach Method: User Entered Data

Center Station: 198

Final Bottom Width: 38

Final Bottom Elevation: 190

Left Side Slope: 1

Right Side Slope: 1

Breach Weir Coef: 1.44

Breach Formation Time (hrs): 0.47

Failure Mode: Overtopping

Piping Coefficient: 0.5

Initial Piping Elev:

Trigger Failure at: WS Elev

Starting WS: 253

96.84, 225.50

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

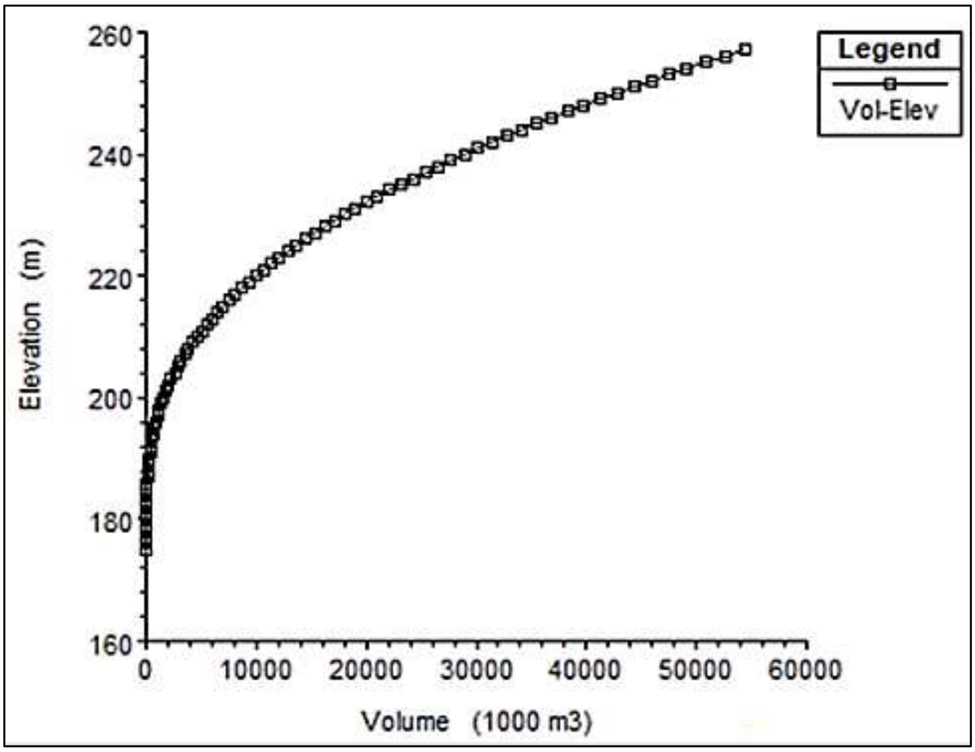


Figure 6. Curve capacity of the Karalloe dam's reservoir

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.

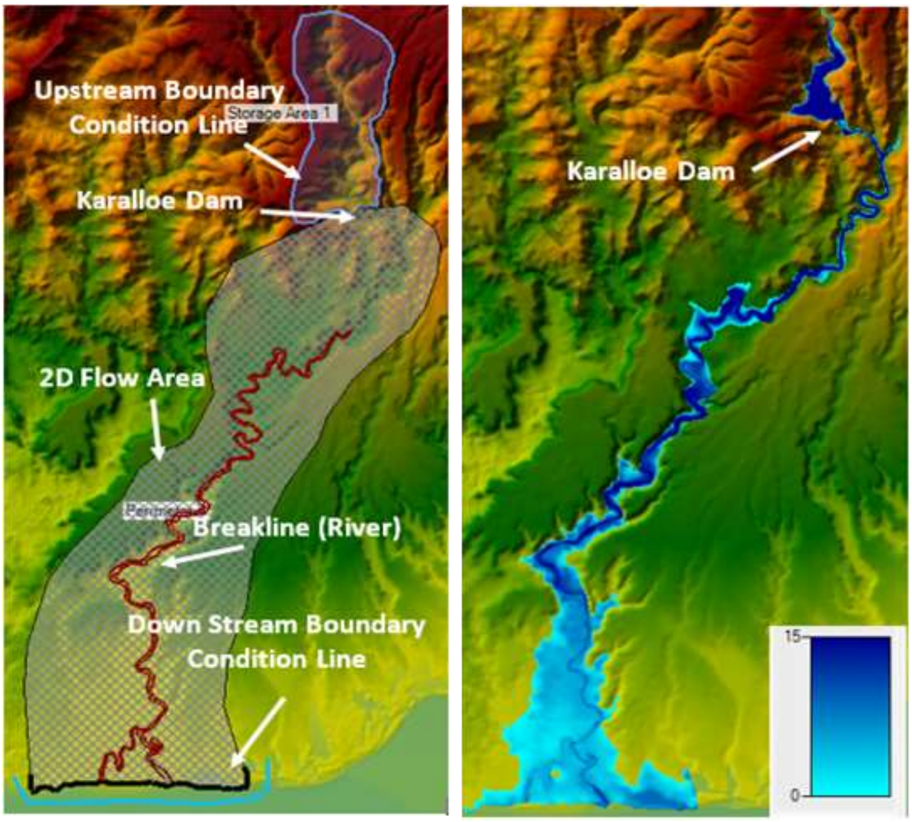


Figure 7. Map of DEM/boundary condition and simulation result of the Karalloe dam's failure

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 travelled 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.

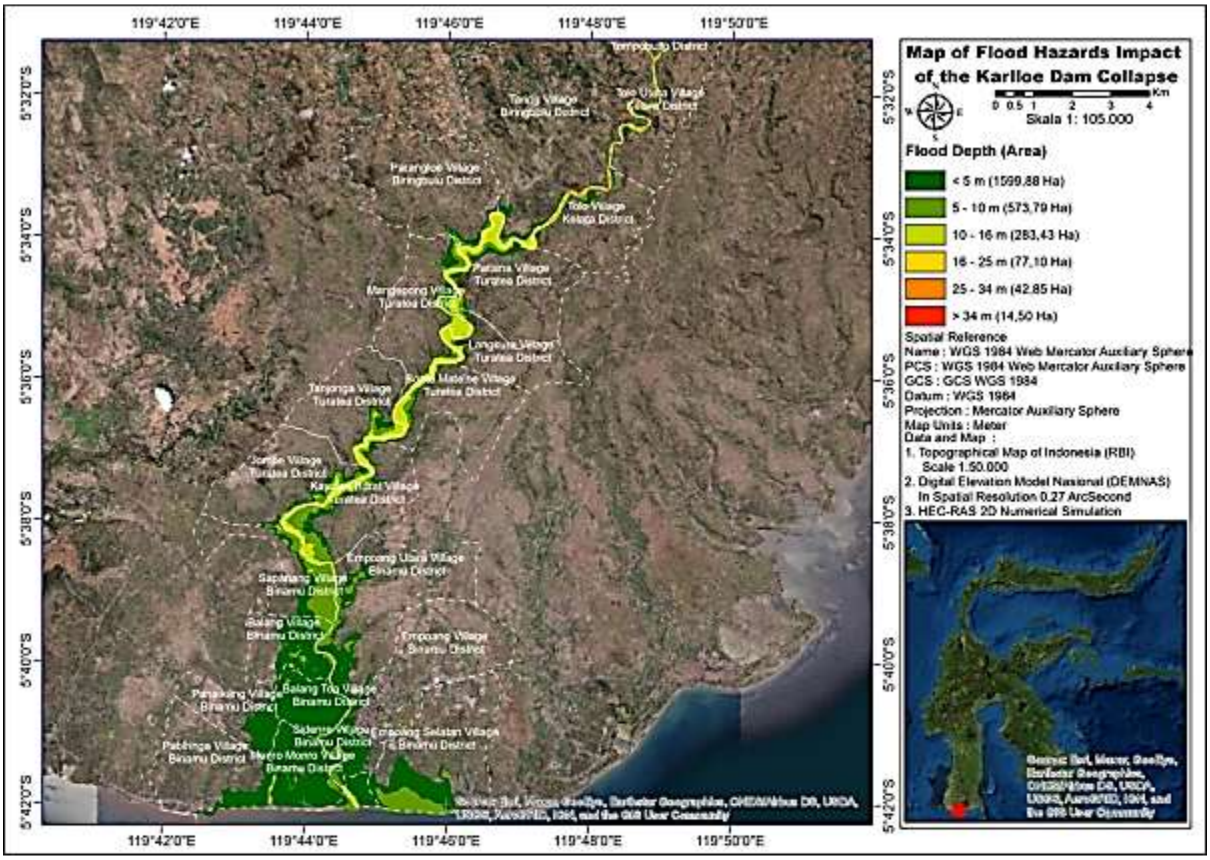


Figure 8. Map of flood hazards due to the collapse of the Karalloe dam

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

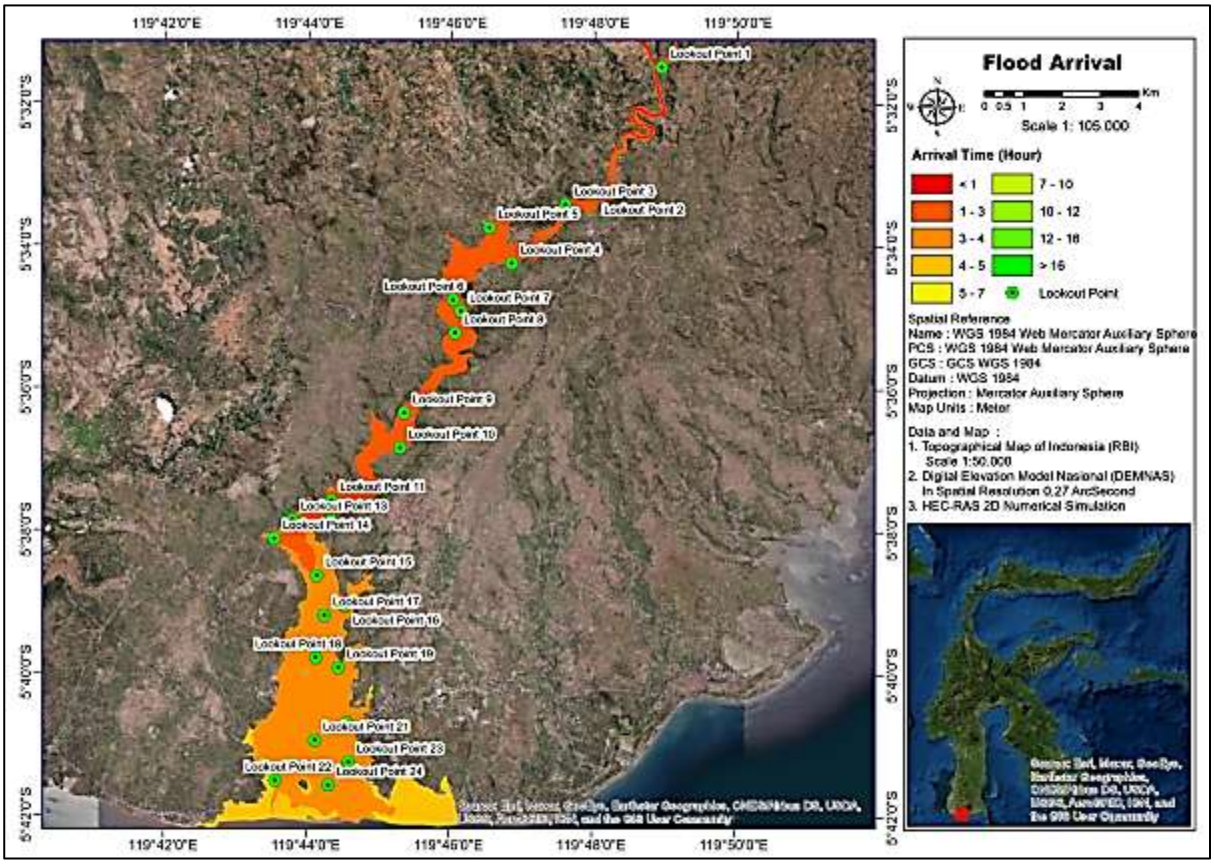


Figure 9. Map of Flood arrival time

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 & 119°46'3.36"E	Mangepong Village, Turatea District , Jeneponto Regency	17.628	32
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.

3.4. Discussion

Dams currently provide numerous agricultural, social, and economic benefits, making dams an extremely vital infrastructure. Dams have also played an essential role in protecting human floodplain settlements [24]. Similarly, the Karalloe Dam serves an essential purpose for the surrounding community. Dams are critical in protecting against flood hazards because of extreme events such as the Lanina effect and uncontrolled population growth in flood-prone areas [25]. The results of this study, however, show that a dam collapse can generate a flood wave that is significantly larger in terms of volume released and velocity of the water generated than a natural-induced flood wave. This condition can cause more severe economic damage and casualties [26]. As a result, it is critical to conduct a complex and in-depth study of the dam collapse to provide an overview to the communities downstream of the dam about the impact and implement strategies to reduce the risks that may occur. The findings of this study should be used to develop mitigation strategies for watersheds with dams, such as the Karalloe Dam in Gowa Regency.

The Karalloe Dam itself is scheduled to begin construction in 2012, be completed in 2017, and be completed in 2021. The study analysis results found a 63.71% increase in planned discharge from 2012 to 2017 and a 6.9% increase from 2017 to 2021. This rise was caused by an increase in annual rainfall intensity and a rapid land clearing process. The main reason for the need for a dam collapse analysis is to develop a mitigation strategy to reduce losses in a dam failure. Dam failure is known to occur due to overtopping or piping failure. Overtopping refers to the elevation of the water level upstream of the dam that exceeds the elevation of the crest, causing the water to flow over the dam's crest, whereas piping refers to the condition of river water being blocked by the dam and unable to flow into the ground along the base and walls of the natural dam. The most likely outcome in the case of the Karalloe Dam with a type of rock fill with a concrete membrane is dam collapse due to overtopping. According to the simulation, with a discharge of QPMF = 3543 m^3/s on the Karalloe dam, it only takes 2 hours and 28 minutes to go from average to overtopping conditions, and due to the dam's collapse, there are 22 villages from 5 affected districts, namely Taring, Garing, North Tolo, Tolo, Paitana, Parangloe, Mangepong, Langkura, Bonto Mate'ne, Tanjonga, West Kayuloe, Jombe, Sapanang, North Empoang, Balang, Balang Toa, Empoang, Sidenre, Monro – Monro, South Empoang, Panaikang and Pabiringa. The simulation results can determine when the flood reaches the residential location, which can then be used to develop an early warning system for flood hazards. The simulation results also show that the distance from the dam and the topographical conditions of each settlement influence the time it takes for the flood to reach the residential location. Based on the findings of this analysis, 24 monitoring points can be established in densely populated areas, with the fastest time being at monitoring point 7 in Paitana Village, which is 16.4 km from the dam and has a time of 12 minutes. Furthermore, the longest time was recorded at monitoring point 22 in Pabiringa Village, 39,743 km from the dam. This outcome is expected to become a standard operating procedure (SOP) for dealing with flood hazards, allowing downstream communities to anticipate and evacuate to areas that are not flood-prone to minimize flood losses caused by the dam's collapse.

Several previous researchers have also conducted similar studies. For example, Shahrim and Ros [27] emphasize the comparison of 1D and 2D models in dam failure simulations, as well as the comparison of flood arrival time, depth, and velocity due to piping and overtopping, and show that dam failure due to overtopping has higher depth and velocity values than piping. Murdiani et al. [28] also used national digital elevation model data in a 2D simulation, with the results providing an overview of the affected areas and the time of arrival of floods in each village. This previous study is similar to the current research but differs in the effort to improve the model's accuracy, whereas in this study, data from measurements of riverbeds and reservoirs on the dam and monitoring points were used to mitigate the dam's collapse. The findings of this study show that 22 villages along 22 km of riverbank affected, and the present study will assist authorities in developing emergency response plans and preparing guidelines for flood mitigation plans in the research area.

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 2020 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.

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Flood Modelling due to Dam Failure Using HEC-RAS 2D with GIS Overlay: Case Study of Karalloe Dam in South Sulawesi Province Indonesia

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Abstract A dam is one of the water structures that have many benefits for humans. However, flood disasters caused by dam break may have a very bad impact on human life. This study specifically analyzed the impact of flooding caused by the failure of the Karalloe dam in Bone Regency, South Sulawesi Province, Indonesia. For the first time, the selected flood discharge used in the dam break analysis was verified using the Creager graph by comparing the calculated discharge from several synthetic unit hydrograph methods (HSS) with the flood discharge measured on the automatic water level recorder (AWLR) at the monitoring point. The impact of flooding due to dam break was simulated using HEC-RAS 2D combined with ArcGIS for mapping. The calculation results of the design flood discharge based on rainfall data using the methods of HSS Nakayasu, HSS ITB I, HSS ITB II, and HSS SCS (HEC-HMS) as well as the calculation of the designed flood discharge based on the discharge data showed that the design flood discharge value which is closest to the measured discharge value and Q1000 Creager was the HSS SCS method. The flood discharge values obtained based on the HSS SCS method for Tr (return period) 2 years, Tr 5 years, Tr 10 years, Tr 20 years, Tr 25 years, Tr 50 years, Tr 100 years, and Tr 1000 years were 322.70 m^3/s, 464.10 m3/s, 560.40 m^3/s, 658.40 m^3/s, 682.70 m^3/s, 787.00 m^3/s, 885.70 m^3/s, and 1202.60 m^3/s, respectively. The simulation results showed that 22 villages will be affected by flooding due to the failure of the Karalloe dam and the fastest standby time of the flood is 12 minutes, namely at Lookout Point 7 in Paitana Village. This result suggests that early warning system should be installed at the downstream of the dam and flood disaster mitigation should be adopted and applied to these threatened area.

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

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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 [1,2]. 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/s), conservation of water resources, and tourism development [3-5].

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 [6,7]. The construction of a dam is frequently followed by the development of communities in the downstream area, which increases the risk of dam failure [8].

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 [9].

Because of the conditions affecting dam stability and retention efficiency, a greater spread of awareness about risk factors affecting dam safety is required [9]. Some negative factors include damaging spillway capacity that cannot drain flood discharge due to changes in weather patterns effectively and exacerbated extreme climates [10,11]. 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 [12]. 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 [13].

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 [14]. The source of data for compiling this EAP is the result of dam break analysis in the form of dam collapse simulation results [14]. In most downstream flood simulations caused by a dam failure, it is assumed that the dam collapses completely and unexpectedly [15]. Kheirkhah et al. [16], SMPDBK [17], FLDWAV [16], and HEC-RAS can be used to model water flow due to dam collapse [18]. 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 [19].

The Karalloe Dam itself was scheduled to begin construction in 2012, continued to be built in 2017, and completed in 2021. The Karalloe Dam is located in Garing Village, Datara Village, and Taring Village, Gowa Regency, South Sulawesi Province. This location is located approximately 137 km to the southeast of Makassar City. Karalloe Dam is a large dam which is one of the assets belonging to the Government of the Republic of Indonesia [4]. The dam with a maximum storage volume of 40.53 million m^3 is one of the National Strategic Projects with a high level of risk and potential danger. On January 22, 2019 there was a flood at the Karalloe Dam. This flood resulted in water from the Kelara River being able to pass through the coffer dam which was made to hold water. Mitigation of the possibility of a dam failure is very necessary to be done as an effort to prevent the occurrence of large losses both in terms of human and material casualties.

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. For the first time, the flood discharge used in the dam break analysis was verified using the Creager graph by comparing the calculated discharge from several synthetic unit hydrograph methods (HSS) with the flood discharge measured on the automatic water level recorder at the monitoring point. 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 [20]. 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 [21].

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 [22].

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

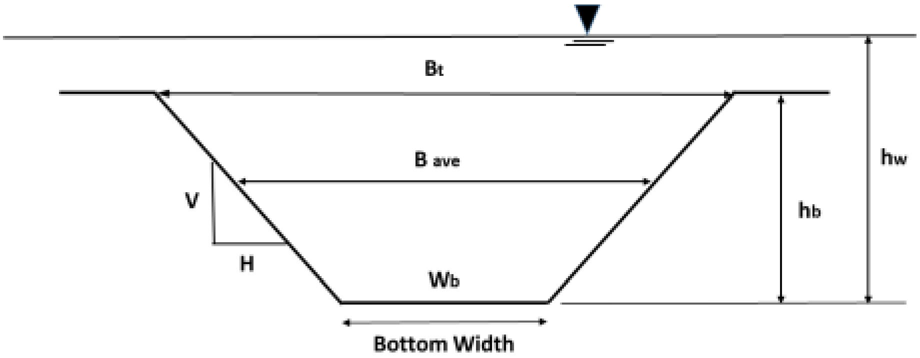


Figure 1. Fracture parameter overview

Fractures usually occur prior to the dam's total collapse (Figure 1). The following is Froehlich's [23] 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 [23], the mean side slope for overtopping failure should be horizontal to vertical (1:1).

2.4. Flood Mapping and Tracking

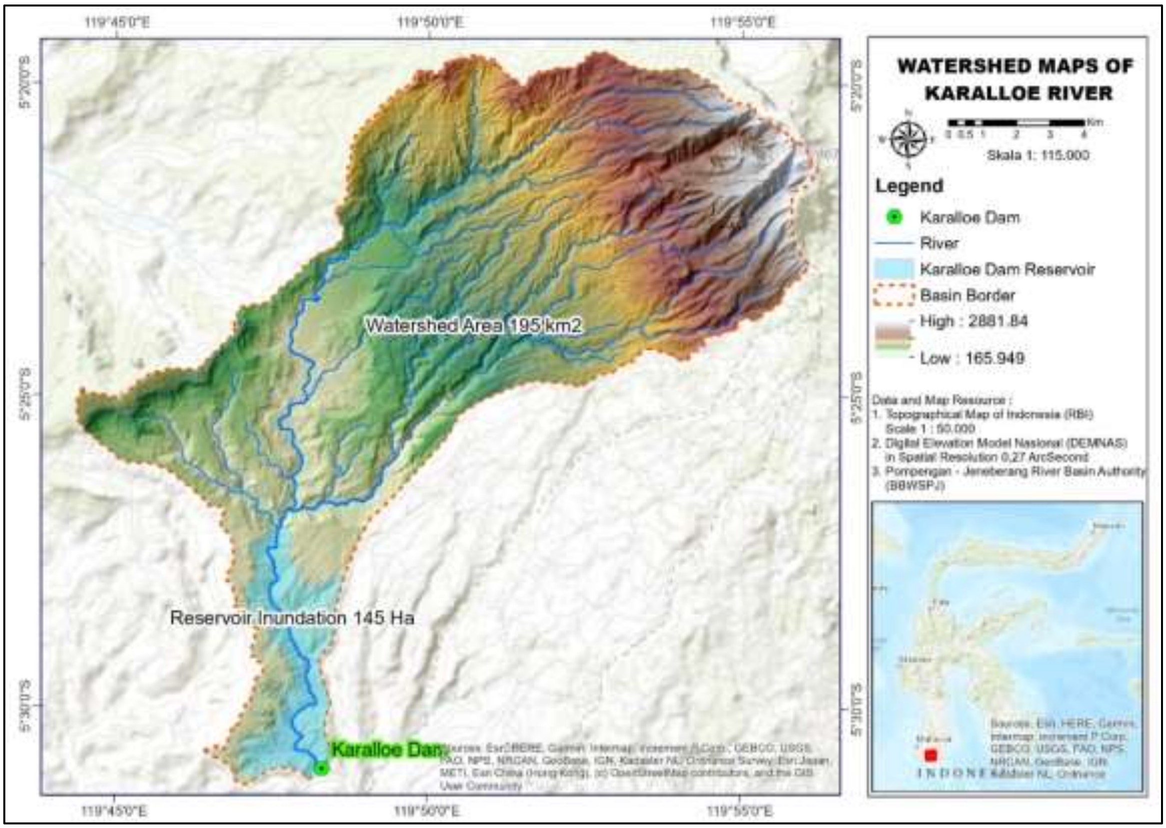
The flood simulation results from dam failure will be mapped using ArcGIS 10.8 software to identify flood-prone areas, which will then be classified based on a specific depth. Following the flood mapping, flood identification was performed to determine the affected location's distance from the dam, the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

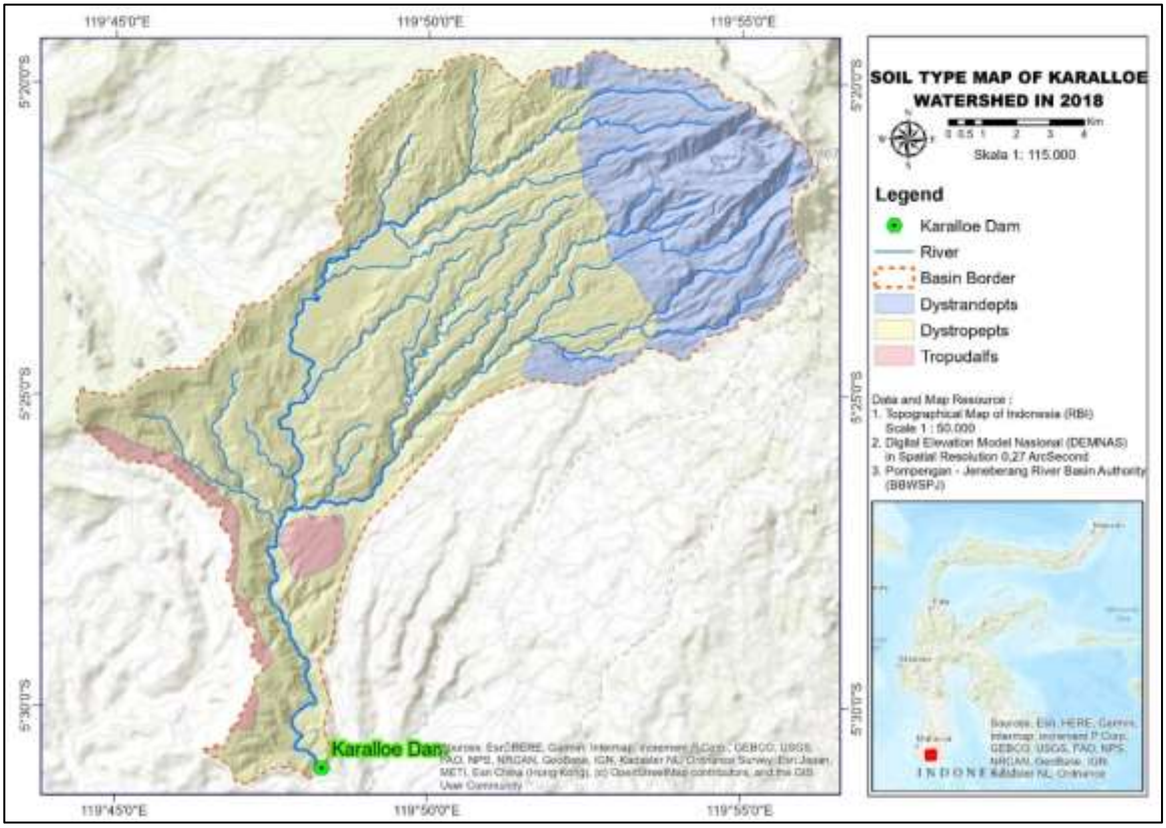
3. Results and Discussion

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 m^3/s was obtained in 2012, while the results of other researchers' analyses of the Karalloe Dam obtained a QPMF of 3307 m^3/s in 2017 [4]. It is 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.


119°45'0"E
119°50'0"E
119°55'0"E
5°20'0"S
5°25'0"S
5°30'0"S
Watershed Area 195 km2
Reservoir Inundation 145 Ha
Karalloe Dam
WATERSHED MAPS OF KARALLOE RIVER
0 0.5 1 2 3 4 Km
Skala 1: 115.000
Legend
Karalloe Dam
River
Karalloe Dam Reservoir
Basin Border
High : 2881.84
Low : 165.949
Data and Map Resource :
1. Topographical Map of Indonesia (RBI) Scale 1 : 50.000
2. Digital Elevation Model Nasional (DEMNAS) in Spatial Resolution 0,27 ArcSecond
3. Pompengan - Jeneberang River Basin Authority (BBWSPJ)
INDONE


119°45'0"E
119°50'0"E
119°55'0"E
5°20'0"S
5°25'0"S
5°30'0"S
Karalloe Dam
SOIL TYPE MAP OF KARALLOE WATERSHED IN 2018
0 0.5 1 2 3 4 Km
Skala 1: 115.000
Legend
Karalloe Dam
River
Basin Border
Dystrandepts
Dystropepts
Tropudalfs
Data and Map Resource :
1. Topographical Map of Indonesia (RBI) Scale 1 : 50.000
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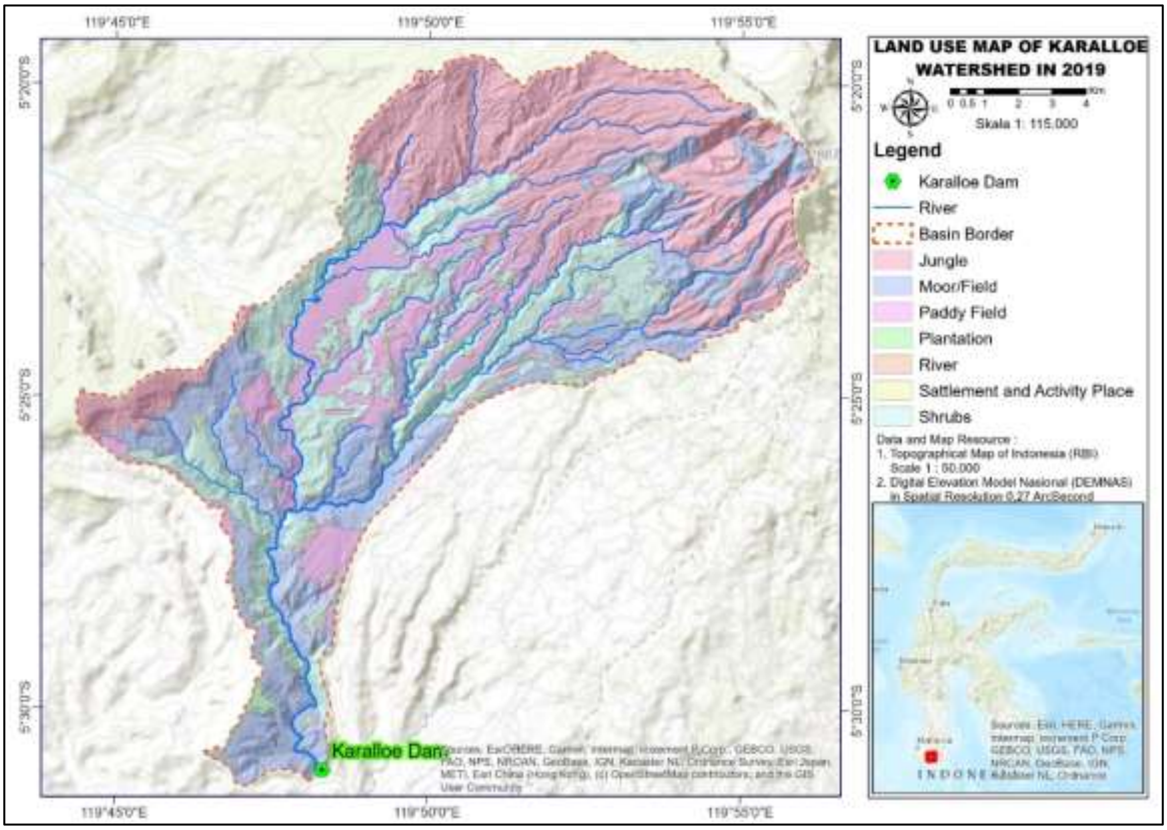


Figure 2. Map of Topographic, soil type and land use of the Karalloe Watershed

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

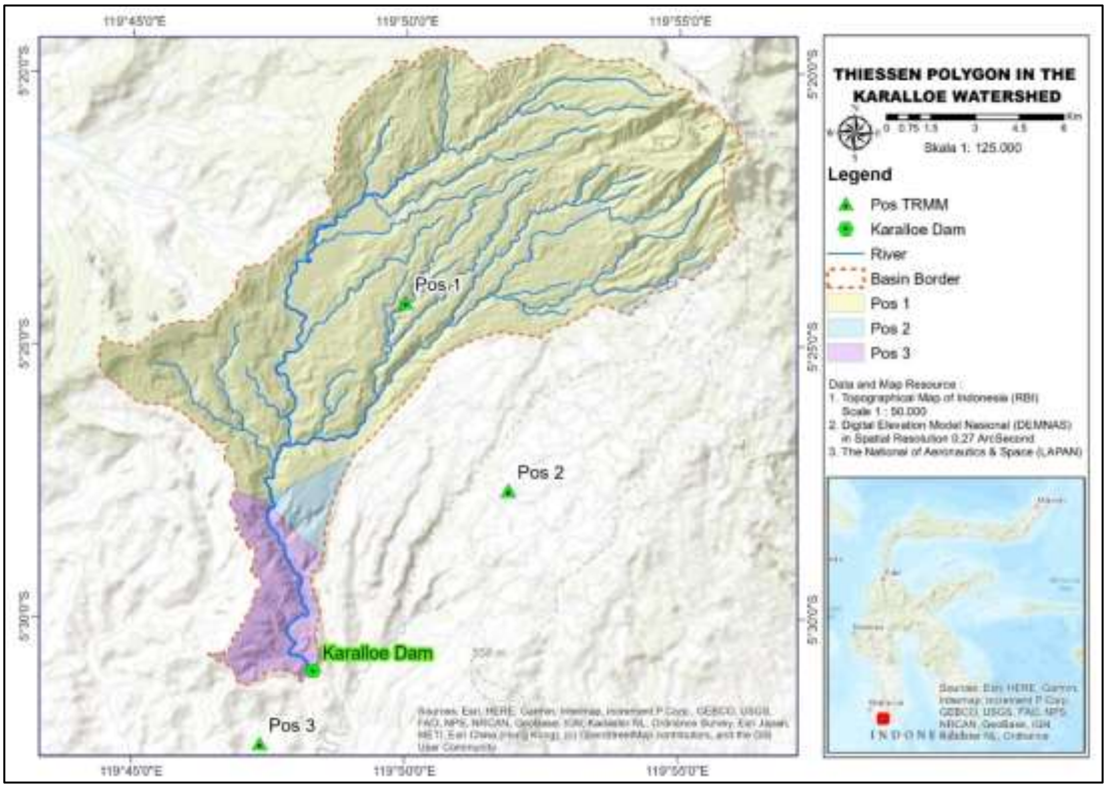


Figure 3. Thiessen polygon of the Karalloe watershed

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
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.

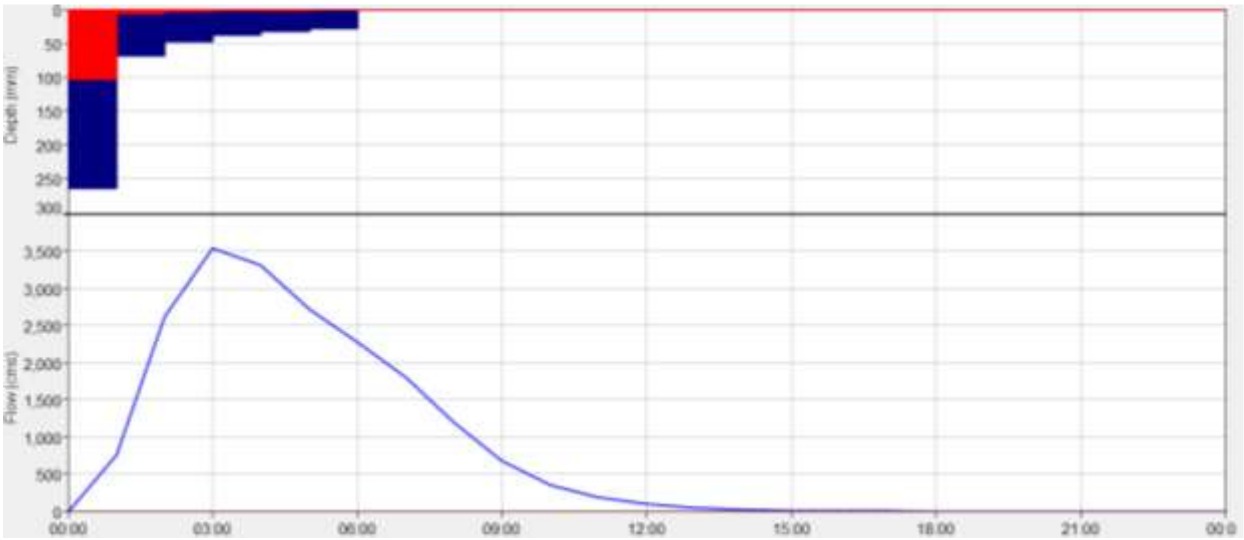
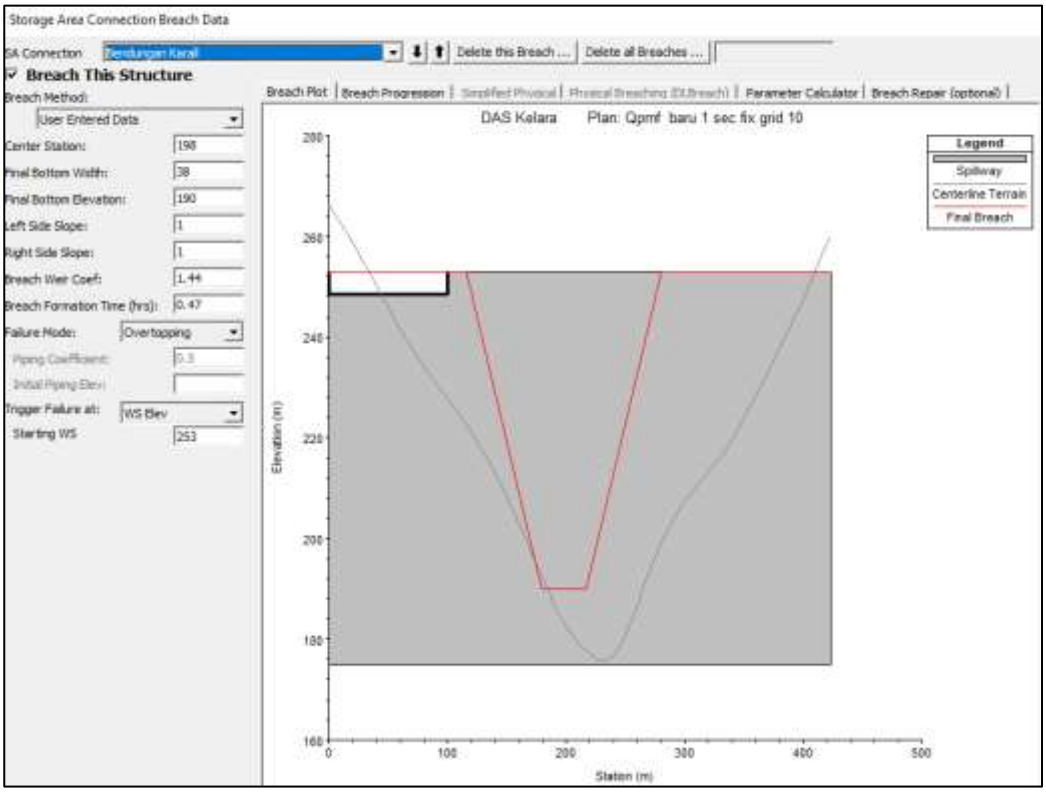


Figure 4. QPMF flood hydrograph of the Karalloe Watershed

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.


Storage Area Connection Breach Data

SA Connection: Bendungan Karali

☑ Breach This Structure

Breach Method: User Entered Data

Center Station: 198

Final Bottom Width: 38

Final Bottom Elevation: 190

Left Side Slope: 1

Right Side Slope: 1

Breach Weir Coef: 1.44

Breach Formation Time (hrs): 0.47

Failure Mode: Overtopping

Piping Coefficient: 0.5

Initial Piping Elev:

Trigger Failure at: WS Elev

Starting WS 253

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

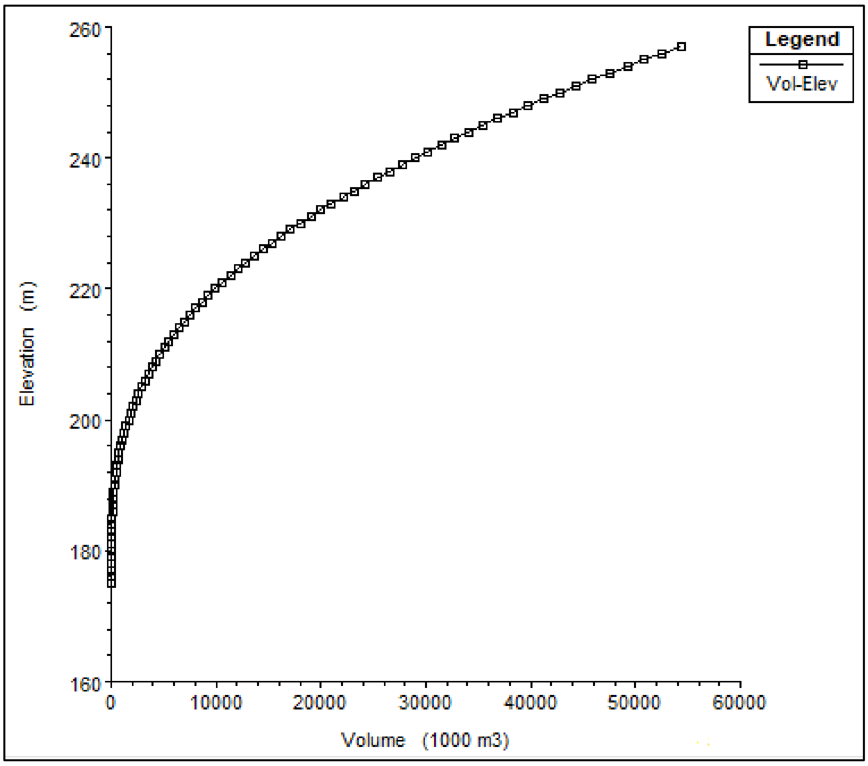


Figure 6. Curve capacity of the Karalloe dam's reservoir

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.

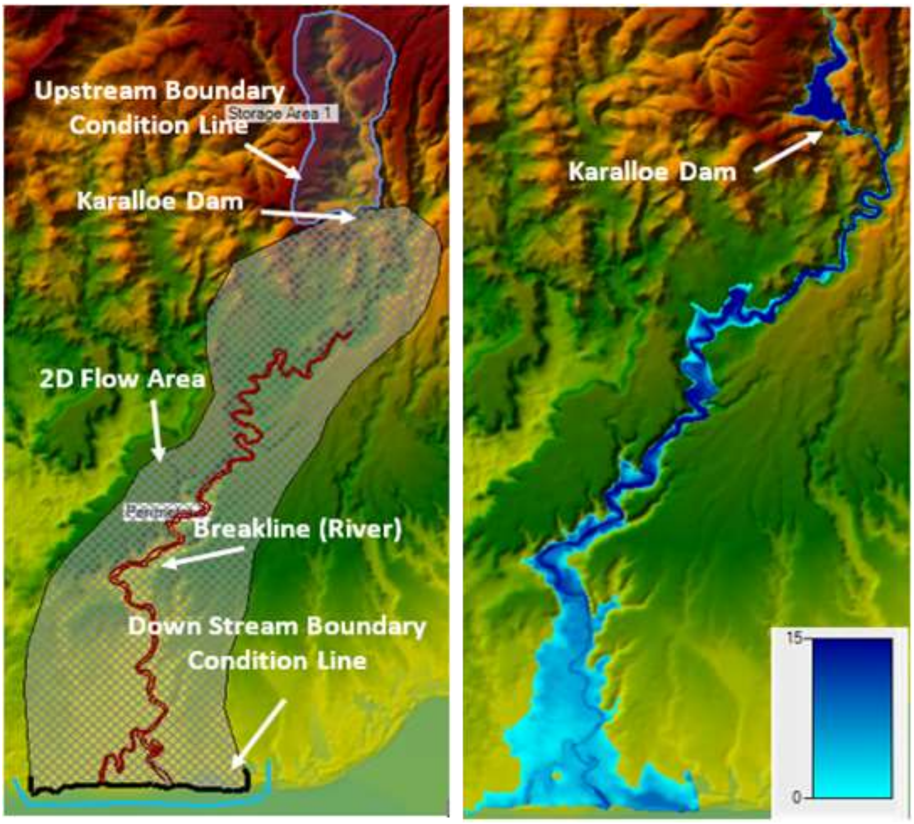


Figure 7. Map of DEM/boundary condition and simulation result of the Karalloe dam's failure

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 travelled 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.

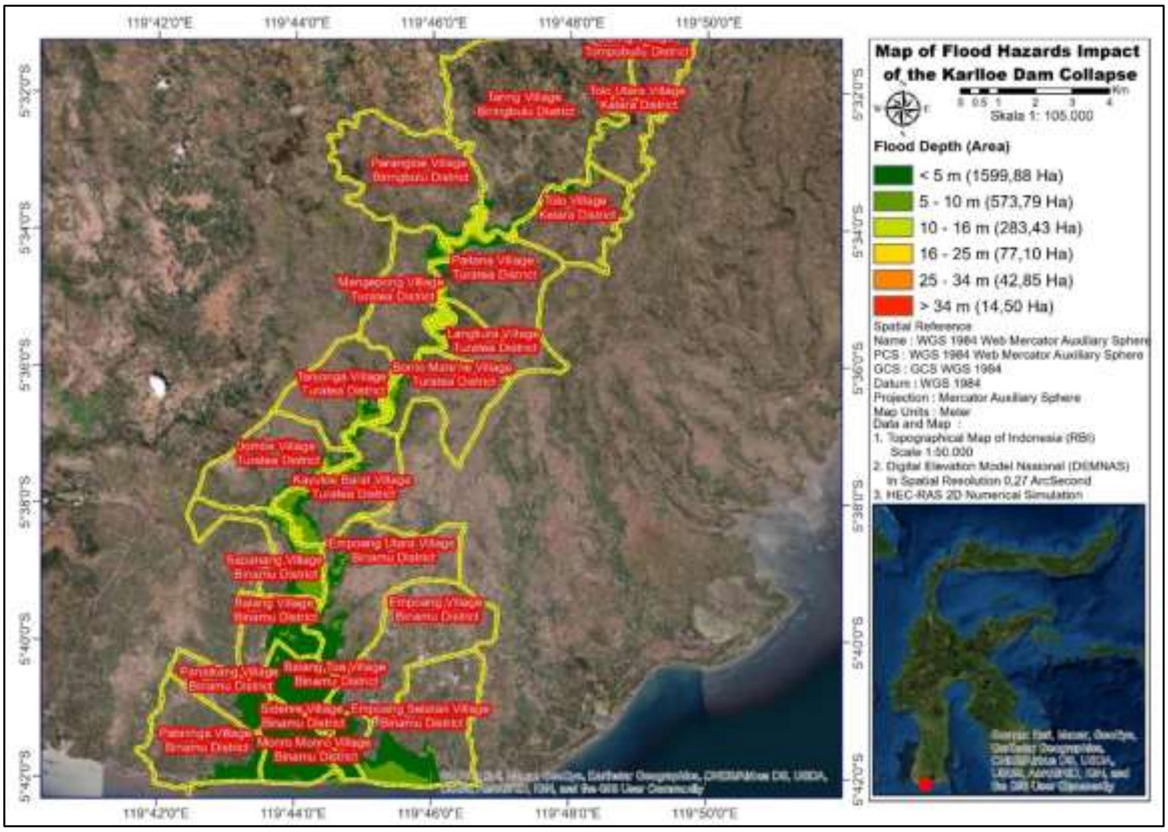


Figure 8. Map of flood hazards due to the collapse of the Karalloe dam

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

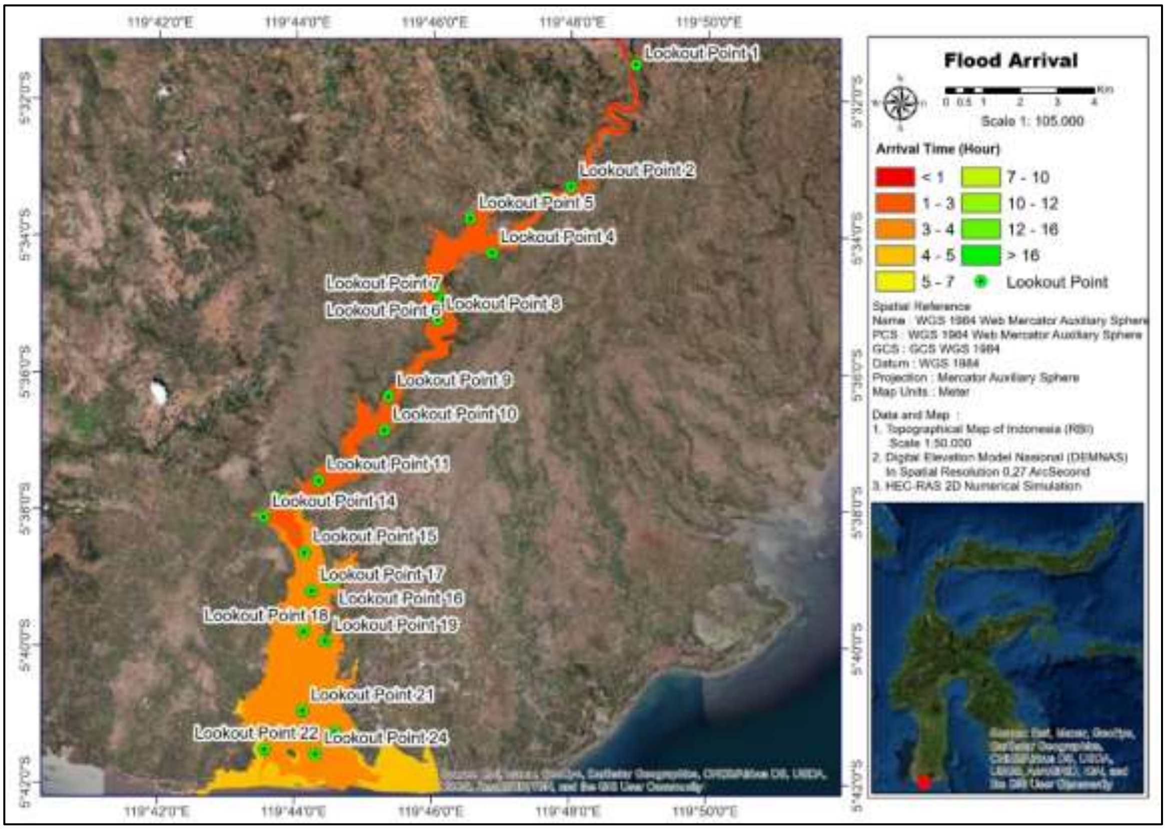


Figure 9. Map of Flood arrival time

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 & 119°46'3.36"E	Mangepong Village, Turatea District , Jeneponto Regency	17.628	32
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.

3.4. Discussion

Dams currently provide numerous agricultural, social, and economic benefits, making dams an extremely vital infrastructure. Dams have also played an essential role in protecting human floodplain settlements [24]. Similarly, the Karalloe Dam serves an essential purpose for the surrounding community. Dams are critical in protecting against flood hazards because of extreme events such as the Lanina effect and uncontrolled population growth in flood-prone areas [25]. The results of this study, however, show that a dam collapse can generate a flood wave that is significantly larger in terms of volume released and velocity of the water generated than a natural-induced flood wave. This condition can cause more severe economic damage and casualties [26].

As a result, it is critical to conduct a complex and in-depth study of the dam collapse to provide an overview to the communities downstream of the dam about the impact and implement strategies to reduce the risks that may occur. The findings of this study should be used to develop mitigation strategies for watersheds with dams, such as the Karalloe Dam in Gowa Regency.

The study analysis results found a 63.71% increase in planned discharge from 2012 to 2017 and a 6.9% increase from 2017 to 2021. This rise was caused by an increase in annual rainfall intensity and a rapid land clearing process. The main reason for the need for a dam collapse analysis is to develop a mitigation strategy to reduce losses in a dam failure. Dam failure is known to occur due to overtopping or piping failure. Overtopping refers to the elevation of the water level upstream of the dam that exceeds the elevation of the crest, causing the water to flow over the dam's crest, whereas piping refers to the condition of river water being blocked by the dam and unable to flow into the ground along the base and walls of the natural dam. The most likely outcome in the case of the Karalloe Dam with a type of rock fill with a concrete membrane is dam collapse due to overtopping. According to the simulation, with a discharge of QPMF = 3543 m^3/s on the Karalloe dam, it only takes 2 hours and 28 minutes to go from average to overtopping conditions, and due to the dam's collapse, there are 22 villages from 5 affected districts, namely Taring, Garing, North Tolo, Tolo, Paitana, Parangloe, Mangepong, Langkura, Bonto Mate'ne, Tanjonga, West Kayuloe, Jombe, Sapanang, North Empoang, Balang, Balang Toa, Empoang, Sidenre, Monro – Monro, South Empoang, Panaikang and Pabiringa. The simulation results can determine when the flood reaches the residential location, which can then be used to develop an early warning system for flood hazards. The simulation results also show that the distance from the dam and the topographical conditions of each settlement influence the time it takes for the flood to reach the residential location. Based on the findings of this analysis, 24 monitoring points can be established in densely populated areas, with the fastest time being at monitoring point 7 in Paitana Village, which is 16.4 km from the dam and has a time of 12 minutes. Furthermore, the longest time was recorded at monitoring point 22 in Pabiringa Village, 39,743 km from the dam. This outcome is expected to become a standard operating procedure (SOP) for dealing with flood hazards, allowing downstream communities to anticipate and evacuate to areas that are not flood-prone to minimize flood losses caused by the dam's collapse.

Several previous researchers have also conducted similar studies. For example, Shahrim and Ros [27] emphasize the comparison of 1D and 2D models in dam failure simulations, as well as the comparison of flood arrival time, depth, and velocity due to piping and overtopping, and show that dam failure due to overtopping has higher depth and velocity values than piping. Murdiani et al. [28] also used national digital elevation model data in a 2D simulation, with the results providing an overview of the affected areas and the time of arrival of floods in each village. This previous study is similar to the current research but differs in the effort to improve the model's accuracy, whereas in this study, data from measurements of riverbeds and reservoirs on the dam and monitoring points were used to mitigate the dam's collapse. The findings of this study show that 22 villages along 22 km of riverbank affected, and the present study will assist authorities in developing emergency response plans and preparing guidelines for flood mitigation plans in the research area.

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 2020 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.

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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

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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. 7 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.

8

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

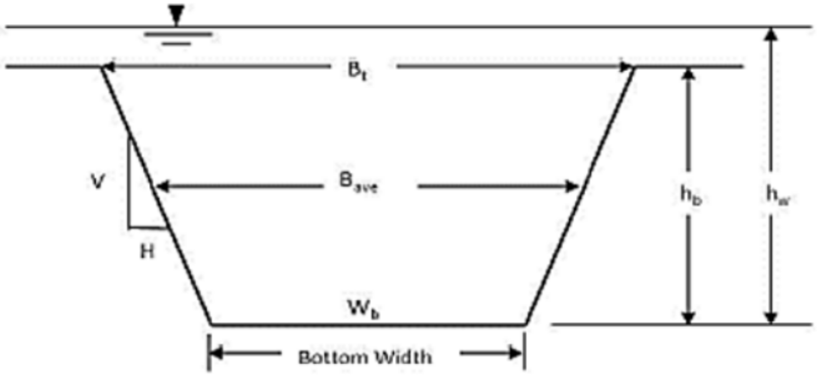


Figure 1. Fracture parameter overview

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.

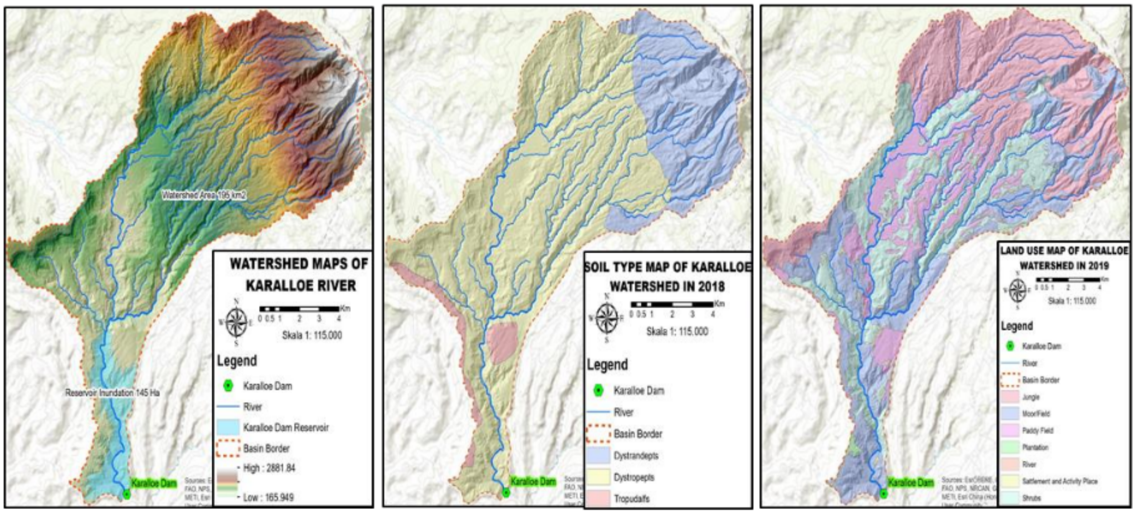


Figure 2. Map of Topographic, soil type and land use of the Karalloe Watershed

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

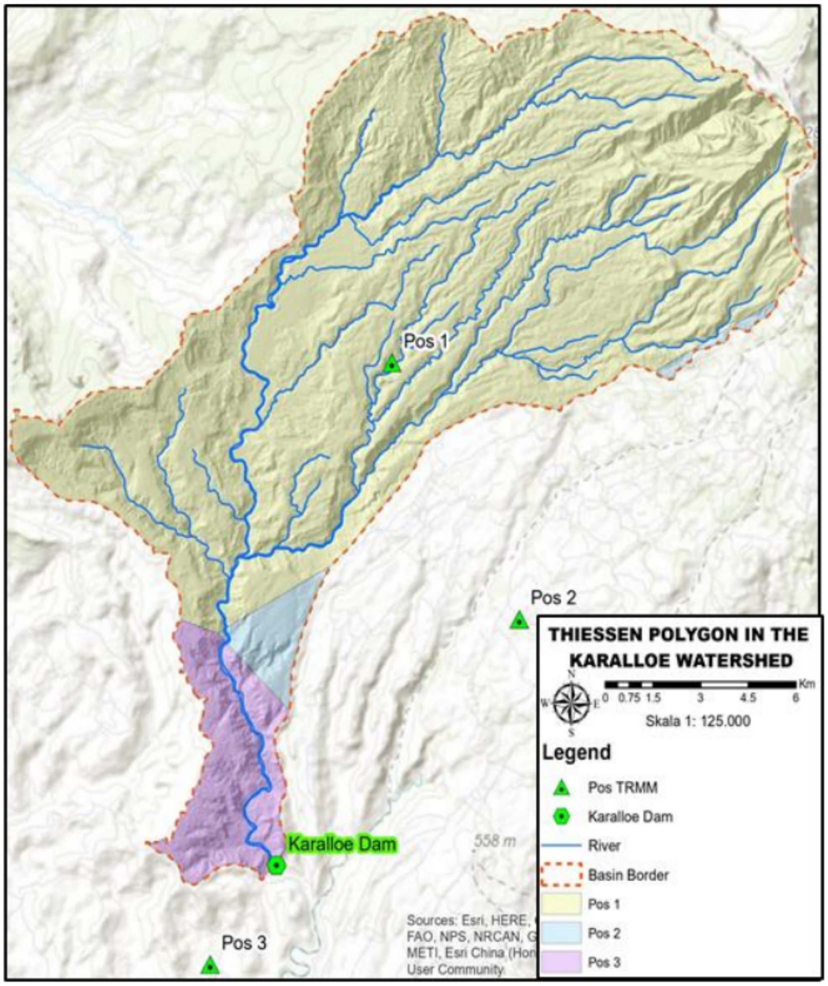


Figure 3. Thiessen polygon of the Karalloe watershed

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.

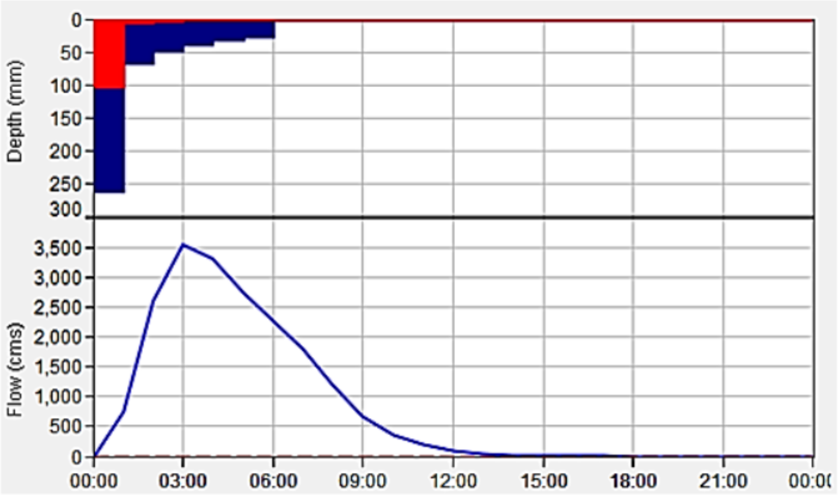
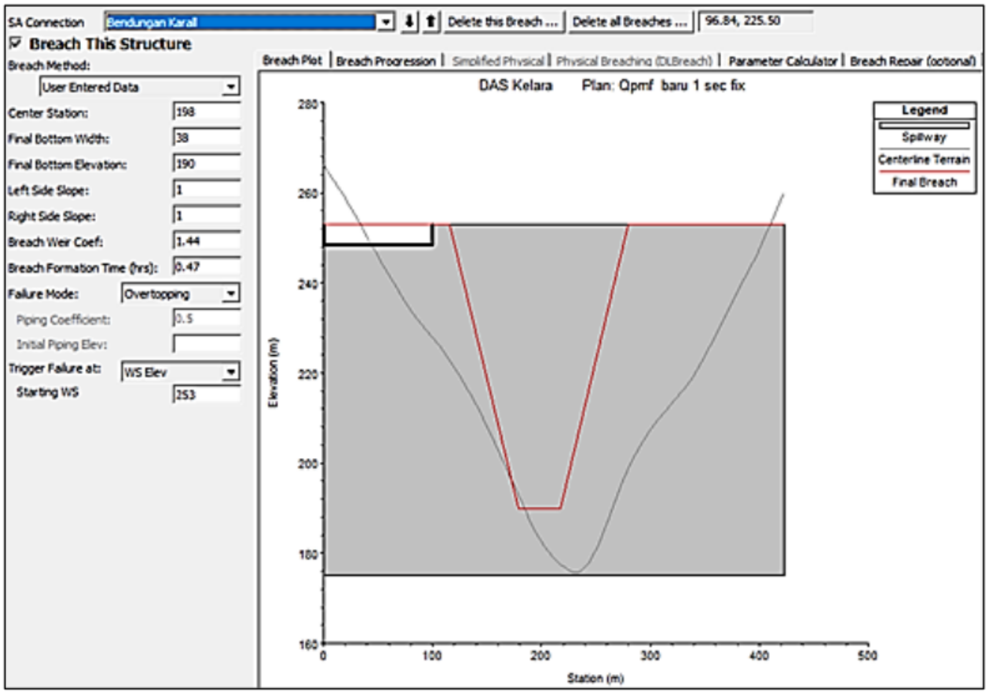


Figure 4. QPMF flood hydrograph of the Karalloe Watershed

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.



SA Connection: Bendungan Karall

☑ Breach This Structure

Breach Method: User Entered Data

Center Station: 198

Final Bottom Width: 38

Final Bottom Elevation: 190

Left Side Slope: 1

Right Side Slope: 1

Breach Weir Coef: 1.44

Breach Formation Time (hrs): 0.47

Failure Mode: Overtopping

Piping Coefficient: 0.5

Initial Piping Elev:

Trigger Failure at: WS Elev

Starting WS: 253

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

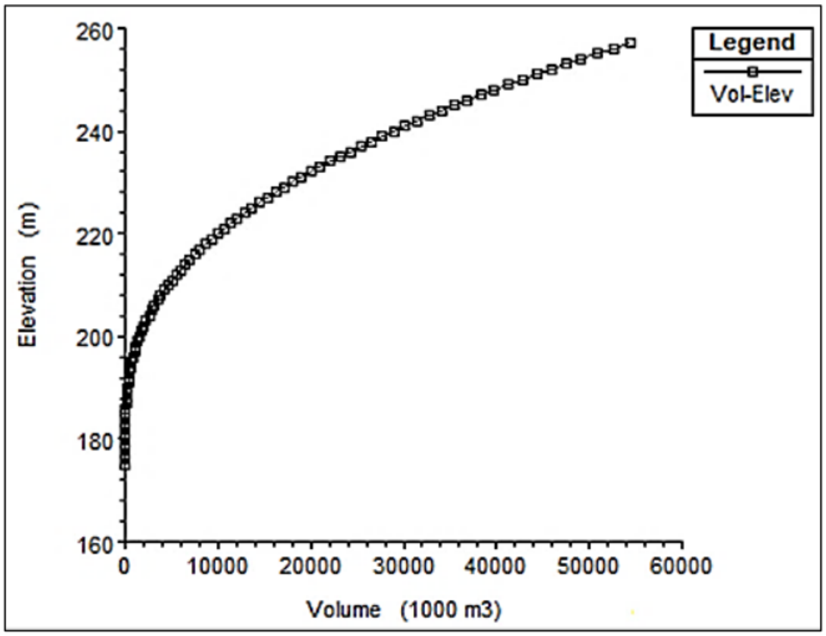


Figure 6. Curve capacity of the Karalloe dam's reservoir

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.

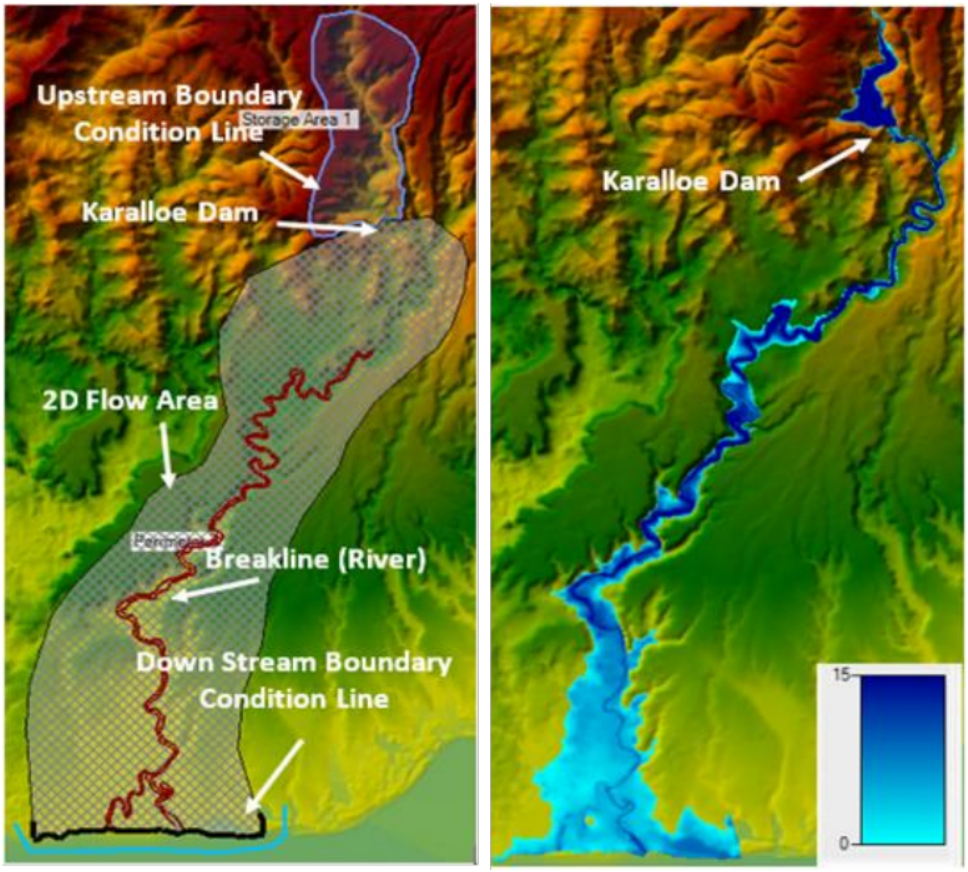


Figure 7. Map of DEM/boundary condition and simulation result of the Karalloe dam's failure

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.

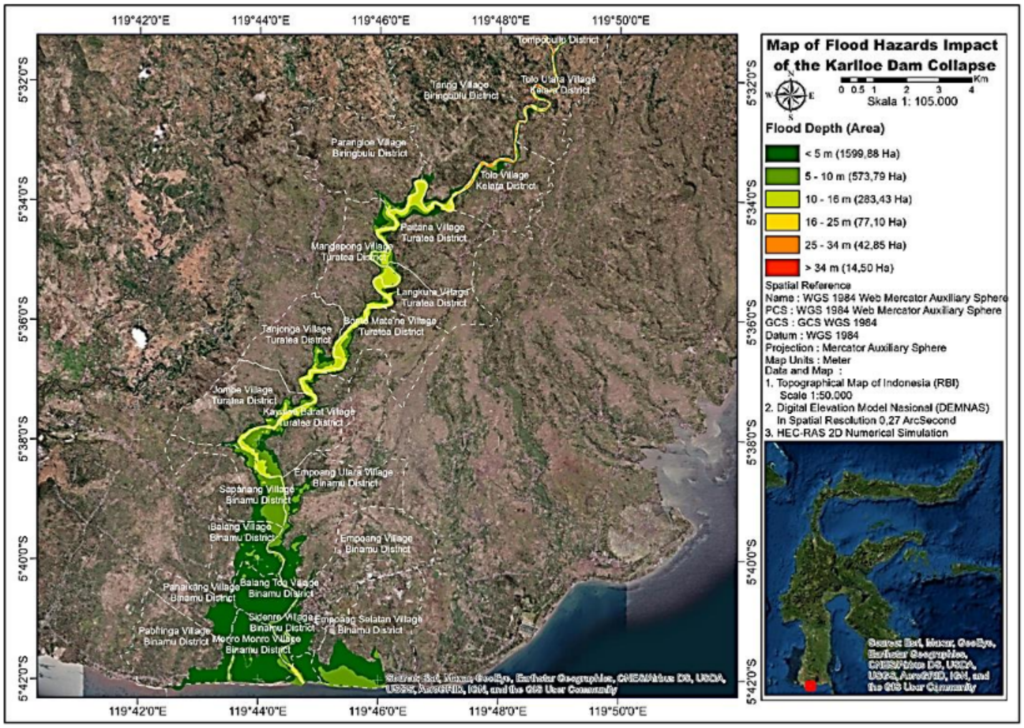


Figure 8. Map of flood hazards due to the collapse of the Karalloe dam

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

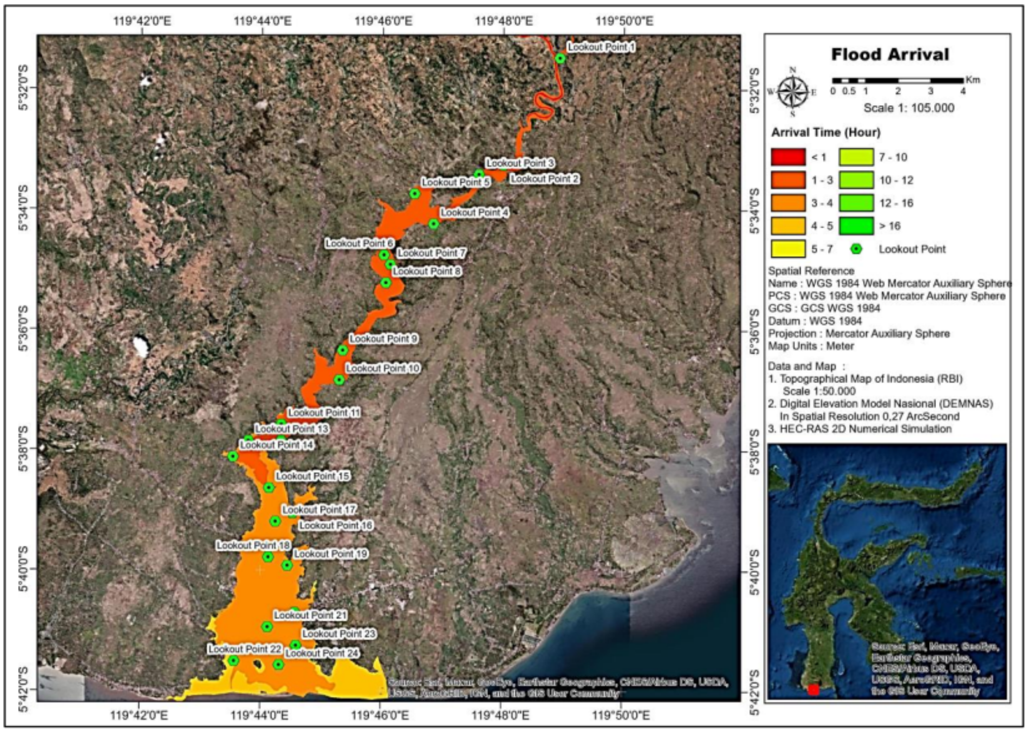


Figure 9. Map of Flood arrival time

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.

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<u>Cover Letter-Revision Notes</u>

Flood Modelling due to Dam Failure Using HEC-RAS 2D with GIS Overlay: Case Study of Karalloe Dam in South Sulawesi Province Indonesia

Manuscript ID: 14828870

The authors have summarized their replies to the Reviewer's comments in this response letter in a two column format. A revised manuscript is submitted addressing all the comments to the Civil Engineering and Architecture Journal for possible publication.

	Reviewer Comments	*Authors Response*
1	The citation style should follow the journal guidelines. http://www.hrpub.org/journals/jour_guidelines.php?id=48	The authors appreciate the reviewer's comment. We have revised the citation style as per journal guidelines, as in page 15 (references section of revised manuscript.
2	The abstract is short. Please extend the length to 200-350 words. The abstract shall recapitulatively state the background of the research, purpose, methodologies, principal results, major conclusions and its contributions to the field. It should emphasize new or important aspects of the study. Research limitations/implications, practical implications, and social implications should also be included, if relevant to your manuscripts.	The authors appreciate the reviewer's comment. We have revised the abstract as per the reviewer comments, as in page 1 of the revised manuscript.
3.	In addition to necessary revisions, please note that the similarity index of the revised version should be lower than 18% and similarity from a single source should not exceed 5%.	The authors appreciate the reviewer's comment. We have made for similarity index check using Ithenticate software as attached.
4	This manuscript addresses that the increase in flood discharge is essential for analyzing floods. Using the most recent rainfall data to determine the increase in flood discharge, the most significant discharge was used as input for simulation to assess the impact of the Karalloe Dam failure..	The authors appreciate the reviewer's comment.
5	Undoubtedly, this simulation can help the study area's dam and disaster management agencies. The information can be used as a basis for decision-making during an emergency. However, the weakness of this manuscript is that it does not show its significant contribution to the field of study. Does this manuscript try to describe a new mitigation procedure for the surrounding population based on the study's findings (i.e., an emergency route to higher ground)? Does this manuscript try to introduce a new dam management/planning model to be more efficient? Or does this manuscript present a new spatial analysis that researchers in the future can use?	This study try to describe a new mitigation procedure for the surrounding population based on the study's findings and to introduce a new dam management/planning model to be more efficient, 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 (page 2 of revised manuscript)

6	Next, this manuscript also does not put a strong justification for why the Karalloe dam is used in this study. Usually, before a dam is built, various analyses are carried out before the decision to build a dam is made. Among them is Environmental Impact Analysis (EIA). It considers various factors and parameters in seeing what the impact of the dam's construction is before the construction is carried out. GIS analysis is also involved during this phase. Therefore, the dam in the study area in this manuscript was chosen because it has unique characteristics that distinguish it from other dams?	Yes, the Karalloe dam has unique characteristics from other dams.
7	This manuscript also states that the method proposed in this study can be used to identify potential areas for flooding. However, the method is not specifically stated in this manuscript. Next, any new method should be compared with the previous methods to identify the differences in the advantages and disadvantages of the methods.	The results of methods used was compared with others results in discussions section of revised manuscript (pages: 12-13)
8	The author also stated that previous studies are similar to the research conducted in this manuscript. The difference is that the research in this manuscript improves the accuracy of the findings. However, no scientific comparison was made with previous studies to support this statement. If there is, it is most likely the main contribution or strength of the results of this manuscript.	The scientific comparison was elaborates in discussions section of revised manuscript (pages: 12-13)
9	The study's findings are good. However, this manuscript must emphasize the study's contributions or any new elements it presents. This revision will enhance the quality of this manuscript.	The authors appreciate the reviewer's comment. We have revised the manuscript as per reviewers comments in revised manuscript.

The authors appreciate the valuable comments from the Reviewers.

Gmail **Zubair Saing <zubairsaing.ummu@gmail.com>**

Fwd: Acceptance Letter & Advice of Payment (ID:14828870)-Flood Modelling due to Dam Failure Using HEC-RAS 2D with GIS Overlay: Case Study of Karalloe Dam in South Sulawesi Province Indonesia

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Acceptance Letter

Dear Riswal Karamma ,

Congratulations! As a result of the reviews and revisions, we are pleased to inform you that your following paper has been accepted for publication.

Paper Title:	Flood Modelling due to Dam Failure Using HEC-RAS 2D with GIS Overlay: Case Study of Karalloe Dam in South Sulawesi Province Indonesia
Paper ID:	14828870
Contributor (s):	Riswal Karamma, Sugiarto Badaruddin, Rifaldi Mustamin, Zubair Saing

It is scheduled for publication on Civil Engineering and Architecture , Vol 10 , No 7 .

The publication fee $ 480 should be paid within 2 weeks.

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From: zubairsaing@ummu.ac.id
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Subject: Re: Acceptance Letter & Advice of Payment (ID:14828870)-Flood Modelling due to Dam Failure Using HEC-RAS 2D with GIS Overlay: Case Study of Karalloe Dam in South Sulawesi Province Indonesia

Dear Anthony Robinson,

Thank you for your acceptance letter notification email. We have made the payment fee, and sent it with publication agreement as attached. Kindly check the attachment file below. We are waiting for your response as soon as possible.

Kind regards,

Zubair Saing
The author

Quoting Anthony Robinson <revision.hrpub@gmail.com>:

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