Journal of the Civil Engineering Forum, May 2023, 9(2):151-160
DOI 10.22146/jcef.6126
Available Online at https://journal.ugm.ac.id/v3/JCEF/issue/archive

Establishing a Simple-yet-effective Approach of Early Warning System for Storm-Induced Earth-Filled Dam-Break Cases in Data-sparse Region

Doddi Yudianto[1*], Farrell Wiguna[1], Bobby Minola Ginting[1], Albert Wicaksono[1], Xie Yuebo[2]
[1]Center of Water Resources Engineering, Department of Civil Engineering, Universitas Katolik Parahyangan, Bandung, INDONESIA
Jalan Ciumbeluit No 94 Bandung
[2]Department of Hydrology and Water Resources Engineering, Hohai University, China
*Corresponding author: doddi_yd@unpar.ac.id

SUBMITTED 13 November 2022 **REVISED** 27 January 2023 **ACCEPTED** 31 January 2023

ABSTRACT Historically, the occurrence of dam-break cases has been proven to cause significant loss of life and economical damage. Apart from the catastrophic nature of dam-breaks, the absence of a robust disaster prevention system exacerbates the disasters that can be occurred in any situations. Considering the importance of such prevention system, this study is therefore aimed to propose an Early Warning System (EWS) to mitigate the impact of dam-break disasters. However, predicting the occurrence of such disasters is challenging, specifically in areas like Indonesia, where comprehensive data recording is lacking. While it may be difficult to predict the occurrence of a sunny day break, the storm-induced break is more predictable. In this study, a simple yet effective macro-based EWS is proposed for Earth-Filled Dam-Break Cases using a macro approach based on the Evacuation Clearance Time (ECT). By comparing the ECT value with the arrival time of the floods from the affected areas, additional evacuation time can be obtained, which will be used to determine the EWS. Cengklik Dam, as one of the oldest dams in Indonesia that was constructed in 1931, is then chosen as the case study. The proposed EWS for Cengklik Dam is given in three levels of warning indicated by the reservoir water level at +141.36 m, +141.40 m, and +141.45 m. With the proposed EWS, the results show that 100% of people are expected to reach the evacuation point safely. The case study shows that the proposed EWS can significantly reduce the risk impact of the dam-break events.

KEYWORDS Early Warning System, Dam-break, Evacuation Clearance Time, Data-sparse Region, Cengklik Dam

1 INTRODUCTION

Reservoirs are vital in Indonesia for managing water resources, serving various purposes such as irrigation, clean water supplies for municipal and industrial areas, hydropower generation, and flood control. Due to the increasing demand for water resources, the government has been constructing dams aggressively. Since 2015, Indonesia has built 65 earth-filled dams (Portal, 2021) and plans to build more in the future. Despite the benefits, the presence of a dam can pose a significant threat, particularly to downstream areas. Dam-break incidents occur when a dam fails partially or completely, causing a sudden release of enormous water and creating an uncontrolled inundation (Sun et al., 2014). Over the past decade, Indonesia had experienced two such incidents, one in 2009, when the Gintung Dam in Tangerang City collapsed, killing 99 people and flooding more than 10 hectares of downstream area (Tempo News Portal, 2021). This event prompted the government to implement better operation, maintenance, and monitoring systems for all dams in Indonesia. Another incident occurred in 2013, when the Way Ela Dam in Central Maluku Regency collapsed, injuring eight people, and severely damaging more than 470 houses, causing 5,227 people to evacuate to shelters for several weeks (Portal, 2013). Froehlich (2008) reported 71 dam-break events worldwide between 1876 to 1994, predominantly due to the overtopping and piping conditions. This significant number highlights the need for a strategic plan to prevent further losses due to dam-break events.

Several studies have focused on dam risk analysis to minimize threats. In 1988, a simple dam risk analysis was conducted using an empirical equation based on 24 dam-break events to estimate the loss of life by considering two factors, namely population at risk and warning time (Brown and Graham, 1988). However, this method is limited as it neglects several factors, such as dam-break failure, physical dam characteristics, downstream social and economic conditions, as well as evacuation processes. This method is based on the 24 dam-break events in the United States which occurred before 1988, there is a need to conduct further studies to ensure the relevance of this method for different places and time.

To address these limitations, a new method based on physical indicators, such as indicator-based dam risk analysis, called the True Risk Factor (TRF), was developed by Shi et al. (2009). The value of TRF can be obtained with a weighting system for several indicators, including dam structure factors, downstream conditions, and flood hazards due to rain. Li et al. (2018) and Ge et al. (2019) stated that other methods include adding indicators such as understanding the failure mode, building vulnerability, and type of downstream land use. A simple and precise method of determining the risk of a dam-break event in the form of quantitative parameters called Flood Risk Level (FRL) was proposed by Yudianto et al. (2021). FRL determines the level of risk into four index values by evaluating several factors such as flood depth, flow velocity, distance to shelter, people demography, and building types in the areas with minimal data availability, such as Indonesia. This approach successfully indicates the most vulnerable area during a dam-break.

Planning for a catastrophic dam-break event must include instructions with respect to the evacuation process through an Early Warning System (EWS). Unlike typical floods in adjacent areas, dam-break floods can flow through highly populated regions that have not experienced flooding before, depending on the topographical conditions. As a result, people living in these vulnerable areas may not be aware of the lurking dangers, and have low disaster preparedness (Yudianto et al., 2021). The EWS is crucial for reducing losses by rapidly generating and disseminating disaster-related information to affected individuals, communities, and organizations. Since dam-break events are highly unpredictable, predicting their risk accurately remains challenging (Sattar et al., 2011).

Dam-break events can generally be categorized into two types, namely sunny day and storm-induced breaks. When a dam collapses due to overtopping failure (storm-induced break), predicting the dam-break event involves monitoring the reservoir water level, which will cross the top of the earth-filled embankment dam level. This allows dam operators and residents downstream to prepare and evacuate. Detecting the possibility of a dam-break event is extremely challenging in the case of sunny day piping failure, especially for dams without advanced instrumentation records. Even with complete instrumentation data readings, no standard reference exists to predict dam-breach occurrences. Therefore, while predicting the occurrence of sunny day breaks remains challenging, storm-induced breaks are more likely to be predicted.

The available study on early warning systems (EWS) for dam-break events in data-sparse regions is limited. Previous study, such as those proposed by Huaizhi et al. (2012) and Su and Wen (2005), have proposed methods based on the seepage and deformation of dam body or hydrostatic pressure, calculated using the rescaled range analysis and fractal theory combined with a continuous automatic recording. However, these may not be applicable to dams without complete instrumentation records, which are common in Indonesia.

Another study has proposed an EWS model for a concrete arc dam based on hydrostatic pressure (Su et al., 2018). These studies did not include parameters to express community preparedness for downstream areas facing dam-break events. As a result, there is currently no method for determining an EWS for storm-induced dam-break events in data-sparse regions. This paper proposes a simple-yet-effective approach that determines an EWS based on the required evacuation time for downstream communities. Since dam-break events typically occur suddenly, people must have sufficient time to reach the evacuation shelter. The proposed approach is specifically designed for earth-filled dams and is validated using Cengklik Dam as a case study.

2 METHODS AND CASE STUDIES

The study proposed a method, as shown in Figure 1, that utilizes the Evacuation Clearance Time *(ECT)* to determine the timing of an early warn-

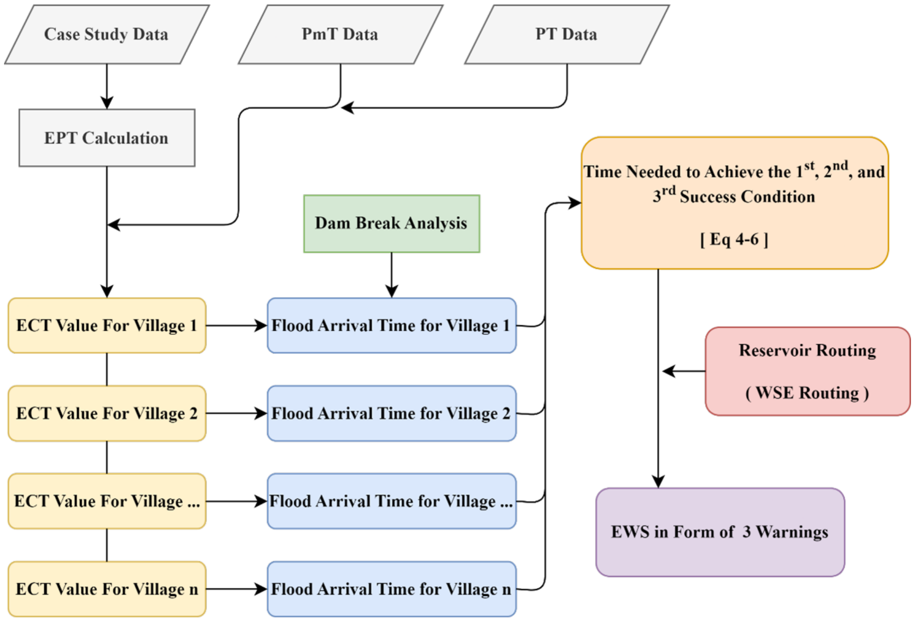

Figure 1 EWS establishment methodology

ing system (EWS) for downstream communities in the event of a dam-break. The ECT is comprised of three components, namely Pre-movement Time *(PmT)*, Preparation Time *(PT)*, and Evacuation Process Time *(EPT)*. By comparing the *ECT* value with the arrival time of floodwaters in the affected areas, the appropriate timing for warning communities downstream can be determined. The EWS is comprised of three warning levels, each corresponding to the reservoir's water level.

Comparing *ECT* values with flood arrival time data is useful for evaluating the risk of flooding in various villages. Assuming the flood arrival time is slower than or equal to the *ECT*, the village is considered at low risk or relatively safe. However, the village is at high risk when the flood arrival time is faster than the *ECT* value. An Extra Time Needed (ETN) parameter is introduced to determine which areas are at high risk. The *ECT* value for each village can be obtained by subtracting the flood arrival time from the *ECT*. A smaller or zero *ECT* value for a village indicates a lower risk. Furthermore, to obtain flood arrival data, a dam-break flood can be simulated assuming the dam collapses (hypothetical dam-break). This hypothetical dam-break can occur during overtopping conditions or when the reservoir water level surpasses the top of the dam during the smallest flood return period. On the other hand, assuming the dam has been verified to be safe against overtopping even during the Probable Maximum Flood (PMF) conditions, then the hypothetical dam-break can be assumed to occur when the reservoir water level is at its maximum condition.

The development of an Early Warning System actual storm-induced piping dam-break events may occur before the hypothetical dam-break point. Therefore, to consider this possibility, the EWS is planned to achieve several evacuation success conditions. The first or critical condition is that 100% of the affected population can successfully be evacuated. The second success condition is that 100% of the affected population can successfully be evacuated before the hypothetical dam collapses. The third or ideal condition is that 100% of the affected population evacuates further before the hypothetical dam collapses. In this study, the ideal condition is represented by 2.5 times the maximum *ETN* value. The constant value of 2.5 act as a safety factor that expectedly can accommodate several possibilities, such as residents who receive the warning late or the slow evacuation process. Considering that the proposed EWS is made with a time/*ECT* approach, the time required to achieve the three success conditions needs to be known. The equation used to find the time required to achieve each condition is shown In Equation (1) to Equation (3), respectively. Hence, these three values indicate when a warning should be given, e.g., to achieve the first success condition, a warning should be given with a value of max*ETN* hour(s) before the dam-break event. The passage describes the development of an Early Warning System (EWS) to address the risk of a piping dam break caused by a storm. The EWS includes several evacuation success conditions to account for the possibility of the dam breaking before the hypothetical dam-break point. The first success condition requires 100% of the affected population to be evacuated successfully. The second condition requires 100% of the population to evacuate before the hypothetical dam collapse. The third or ideal condition requires the population to evacuate 2.5 times the maximum ETN value before the dam collapses, providing a safety factor for potential issues such as delayed warnings or slow evacuation. The time required to determine when to issue a warning for each condition is calculated using equations (1) to (3). For example, to meet the first success condition, a warning must be given with a value of max(ETN) hour(s) before the dam-break event, as determined by the EWS's time/ECT approach.

Time needed to achieve the 1st success condition

$$= Max(ETN) \quad (1)$$

Time needed to achieve the 2nd success condition

$$= Max(ECT) \quad (2)$$

Time needed to achieve the 3rd success condition

$$= Max(ETN)x2.5 \quad (3)$$

It is necessary to establish a physical condition parameter for the dam to facilitate the creation of an easily implementable EWS. This parameter will serve as a reference for the dam administrator to issue downstream warnings. By conducting reservoir routing based on the hypothetical dam-break case, the Water Surface Elevation (WSE) curve before the dam-break event can be determined. Therefore, the WSE is chosen as the physical condition parameter. Combining the known WSE curve with the time required to achieve the first, second, and third success conditions will yield an EWS that comprises three warnings. The first warning is issued to achieve the third or ideal success condition, the second warning is for the second success condition, and the third warning is for the first or minimum success condition. It should be noted that the conditions for warnings and successes are inversely related. The first warning is given when the third success condition is met, while the third warning is given when the first success condition is met. In addition, Figure 2 shows the visualization of this process.

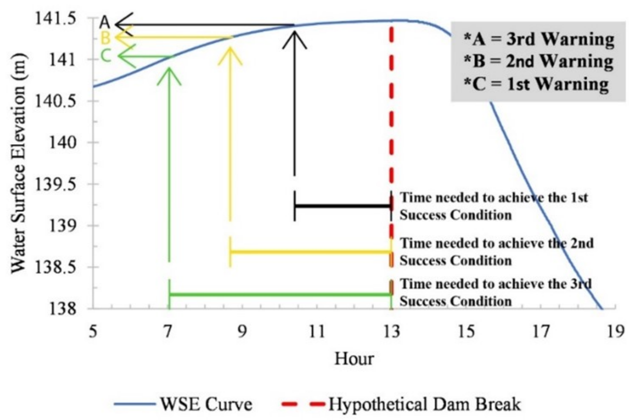

Figure 2 Implementation of EWS visualized

2.1 Evacuation Clearance Time *(ECT)*

This study employs a macro approach to determine the estimated time required for residents to reach a shelter safely in different disaster situations. The study is based on the works of Cheng et al. (2011), Lindell et al. (2020), and Shi et al. (2009) but modifies the PmT and EPT parameters to suit the Indonesian study location better. The present study refers to this estimated time as the *ECT*, representing the duration between receiving a disaster warning and safely reaching the shelter. Equation (4) proposes a formula for calculating the values of *ECT*, with further details about each index available in subsequent chapters.

$$ECT = PmT + PT + Max(EPT_{walk}, EPT_{MV}) \quad (4)$$

Where *ECT* is Evacuation Clearance Time (hour), *PmT* is Pre-movement Time (hour), *PT* is Preparation Time (hour), and *EPT* is Evacuation Process Time (hour).

2.1.1 Pre-movement Time *(PmT)*

The definition of *PmT*, according to Shi et al. (2009), is the time between the first sounding of a disaster alarm and the start of the movement by affected residents. Shi et al. (2009) also noted that humans require time to react during emergencies, and this reaction time, known as *PmT*, is affected by multiple factors, including age, education level, disaster preparedness, and the location

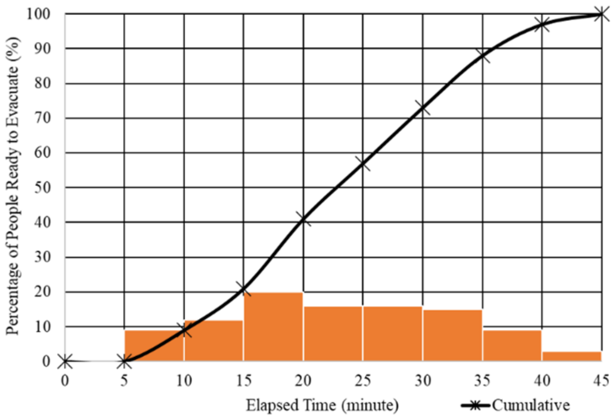

Figure 3 Preparation Time *(PT)* distribution curve (Lindell et al., 2020)

(e.g., houses, schools, high rise buildings). However, Shi et al. (2009) reported a 20 to 120 seconds range for *PmT* values, depending on the preparedness factor and location. This study used a *PmT* value of 120 seconds to account for worst-case scenarios.

2.1.2 Preparation Time *(PT)*

The second component of PT is the time needed for the affected residents to prepare before leaving the disaster zone (Lindell et al., 2020). Previous studies have indicated that *PT* generally includes tasks such as leaving work, commuting from work to home, gathering people for group evacuation, packing essential items, safeguarding property, and turning off utilities (Cheng et al., 2011; Lindell et al., 2020) . To consider these activities during evacuation preparation, Lindell et al. (2020) empirically estimated the *PT* distribution, as shown in Figure 3. It also presumes that the *PT* distribution applies to the case study as no prior analysis has examined a comparable distribution for this particular location, to the author's knowledge.

2.1.3 Evacuation Process Time *(EPT)*

EPT is the last component, which represents the time the affected residents take to reach the safe zone or shelter from the start of the evacuation. The *EPT* value is influenced by the distance from the affected zone to the shelter and the evacuation method. In regions with limited local institutional capacity, infrastructure, and standard operational procedures for evacuation, such as Indonesia, the evacuation process relies heavily on the affected residents due to the lack of facilities, infrastructure, and standard operational procedures. Consequently, this study simplifies the *EPT* variable by dividing the evacuation method into two categories by foot and motorized vehicles, including passenger cars and motorcycles.

The closest distance between the affected area and the shelter is divided by the walking speed to calculate the EPT for evacuating by foot, as shown in Equation (5).

$$EPT_{Walk} = \frac{L}{V} \tag{5}$$

Where EPTWalk is Evacuation Process Time by walking (hour), *L* is the distance from the affected area to the shelter (km), and *V* is the walking speed (km/hour).

The *L* variable for the formulas can be obtained by conducting field measurements or using Geographic Information System (GIS) software. Walking speed varies according to the age range, which is categorized as follows 1.08 m s^{-1} for children (4-14 years old), 1.27 m s^{-1} for adults (15-64 years old), and 1.04 m s^{-1} for the elderly (> 65 years old) (Shi et al., 2009). For the *EPT* variable with the evacuation method by motorized vehicle, the shortest distance between the affected area and the shelter is divided by the corrected vehicle speed, shown in Equation (6). Therefore, the *EPT* variable with the motorized vehicle evacuation method is calculated using Equation (7) (Cheng et al., 2011). While completing these formulas, several constants remain the same as in the original study. Assumptions based on the similar characteristics between the location in Cheng et al. (2011) and the ones in this study are made, such as *Lavg* is 4.5 m, *Lo* is 1.5 m, μ is 0.5, *C* is 0.5, and γ is 0.6.

$$V' = U_0/2 + \sqrt{(U_0)^2 - Q * U_0/K_m} \tag{6}$$

$$EPT_{MV} = \frac{L}{V'} \tag{7}$$

Where *EPTmv* is evacuation process time for motorized vehicle method (hour), *L* is the distance from the affected area to shelter (km), *V'* is corrected speed (km $hour^{-1}$), *Uo* is travelling speed when the capacity is null (km $hour^{-1}$), *Uo* = γ * μ * *Vo* , Q is traffic capacity (vehicle $second^{-1}$), *Km* is

Figure 4 Cengklik Dam aerial view

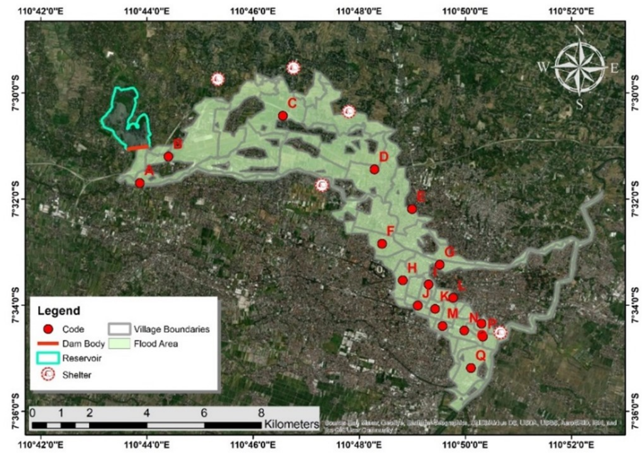

Figure 5 Cengklik Dam-Break flood area map

traffic jam density, $Km = \gamma * C * 1000 * \frac{n}{(L+L_0)}$, γ is mixed traffic coefficient, μ is the number of lanes, *Vo* is designed speed (km hour^{-1}), *C* is intersection correction, *Lavg* is average vehicle length (m), and *Lo* is the average distance between vehicles (m).

2.2 Case Study

The Cengklik Dam, situated in the Boyolali Regency of Indonesia, is a homogeneous earth-filled dam constructed in 1931. Its geographical location is 110° 43'58,22 "S; 7° 31'1,11 " E, and it has a catchment area of 10.69 km^2 and was built on the Bengawan Solo River. Figure 4 depicts the Cengklik Dam's areal photographic, physical feature, and downstream area condition. The dam has a total length of 1,693 m, 14.5 m (the crest elevation of +142.44 m), and a 30 m broad crested spillway (crest elevation of +140.54 m or 1.9 m beneath the crest). The dam's storage capacity is 9.7 million m^3, mainly serving 1,578 ha of irrigation area (Engineerig, 2020). However, as shown in Figure 4, the Cengklik Dam is located near urban areas, where residential areas and various public facilities, including the Adi Sumarmo International Airport, are the majority of land use types in the downstream area. This proximity of the dam to these high-risk areas increases the danger associated with its presence.

The hypothetical situation where the safety of the Cengklik Dam was examined by Engineerig (2020) and found to be secure against overtopping failure. However, the possibility of the dam-breaking due to storm-induced piping failure is considered. The scenario assumes that the dam breaks at the maximum reservoir water level of +141.47 m during the Probable Maximum Flood (PMF) event. Based on the flood inundation map in Figure 5, an Early Warning System (EWS) for the Cengklik Dam was constructed. The dam break flood is estimated to affect 58 villages, 367,290 m of roads, and 274 public facilities such as airports, bridges, government offices, schools, and places of worship. Only 17 villages or points are represented in Figure 5 and Table 1 to simplify the presentation. The estimated inundation area is approximately 3,617 ha, and the number of lives at risk is estimated to be 168,097.

3 RESULTS AND DISCUSSION

Determining the distance between the affected village and the shelter, which could be defined from field measurements or GIS software, is a crucial parameter in the *EPT* component. However, in areas like the Cengklik Dam, where data is scarce, using pathfinding tools algorithm is not feasible due to the unavailability of road network data (Lahoorpoor and Levinson, 2019). The study uses a simplified approach to address this issue by calculating the average distance between the furthest and closest distances of the affected village to the shelter, as stated in Equation (8). While a single average distance may oversimplify the analysis, it is still a useful representation of the situation in the area.

$$L = \frac{L_{max} + L_{min}}{2} \quad (8)$$

Where *L* is the average distance from the affected area to shelter (m), *Lmax* is the furthest distance

Table 1. Affected villages from Cengklik Dam-Break

Symbol	Affected Village	Coordinate		Flood Arrival Time (minute)
		Latitude	Longitude	
A	Bolon	7°31’41”S	110°43’52”E	±84.0
B	Ngesrep	7°31’12”S	110°44’24”E	±45.0
C	Dibal	7°30’25”S	110°46’33”E	±180.0
D	Sawahan	7°31’26”S	110°48’17”E	±160.2
E	Kadipiro	7°32’11”S	110°48’59”E	±124.2
F	Sumber	7°32’50”S	110°48’25”E	±300.0
G	Gilingan	7°33’14”S	110°49’31”E	±420.0
H	Mangkubumen	7°33’32”S	110°48’49”E	±444.0
I	Kestalan	7°33’36”S	110°49’18”E	±120.0
J	Timuran	7°34’00”S	110°49’06”E	±480.0
K	Keprabon	7°34’04”S	110°49’26”E	±240.0
L	Kepatihan Kulon	7°33’51”S	110°49’66”E	±570.0
M	Kauman	7°34’23”S	110°49’34”E	±564.0
N	Kedunglumbu	7°34’28”S	110°49’34”E	±550.2
O	Gadegan	7°34’20”S	110°50’18”E	±564.0
P	Sangkrah	7°34’35”S	110°50’20”E	±559.8
Q	Semanggi	7°35’35”S	110°50’06”E	±720.0

Figure 6 Dibal Village evacuation route

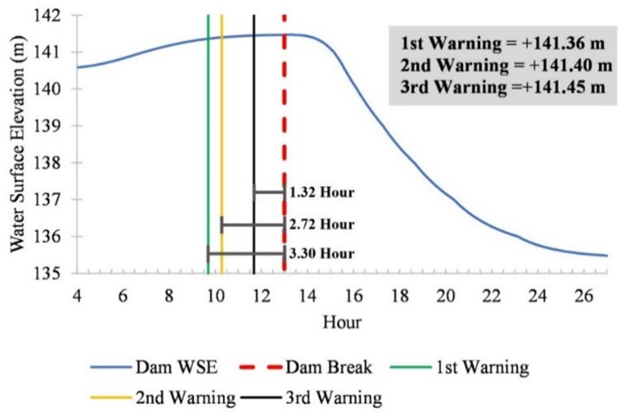

Figure 7 Cengklik Dam early warning system parameter

from a certain village to shelter (m), and *Lmin* is the closest distance from a certain village to shelter (m).

Dibal Village is depicted in Figure 6 as one of the affected villages, where the flood flows through the residential areas and the rice fields. The distance calculation only considers the residential areas. However, the residential area marked with the letter A is the furthest from the shelter, with a distance of 3,384 m, while the residential area marked with the letter B has the closest location to the shelter, with a distance of 851m. The study calculates the average distance from Dibal Village to the shelter, which is 2,117.5 m. The *EPT* calculation continues by determining the evacuation method,

Table 2. ECT summary for Cengklik Dam-Break

Village	Symbol	ECT (Hour)	Flood Arrival (Hour)	ETN (Hour)	% of Evacuation When Flood Comes
Bolon	A	2.72	1.40	1.32	50
Ngesrep	B	2.05	0.75	1.30	47
Dibal	C	1.32	3.00	0.00	100
Sawahan	D	1.42	2.67	0.00	100
Kadipiro	E	2.02	2.07	0.00	100
Sumber	F	1.85	5.00	0.00	100
Gilingan	G	1.98	7.00	0.00	100
Mangkubumen	H	2.25	7.40	0.00	100
Kestalan	I	1.72	2.00	0.00	100
Timuran	J	1.85	8.00	0.00	100
Keprabon	K	1.68	4.00	0.00	100
Kepatihan Kulon	L	1.38	9.50	0.00	100
Kauman	M	1.58	9.40	0.00	100
Kedunglumbu	N	1.42	9.17	0.00	100
Gadegan	O	1.08	9.40	0.00	100
Sangkrah	P	1.00	9.33	0.00	100
Semanggi	Q	1.32	12.00	0.00	100

Table 3. Cengklik Dam's EWS reference

EWS	Reservoir Water Surface Elevation (m)	Evacuation Time (hour)	Condition
1st Warning	141.36	3.3	Ideal evacuation time (estimated based on 2.5 x maximum ETN value)
2nd Warning	141.40	2.72	Required evacuation time (estimated based on the maximum ECT value)
3rd Warning	141.45	1.32	Critical evacuation time (estimated based on the maximum ETN value)

assuming that the local institution may have limited infrastructures and vehicles for the evacuation process. The evacuation procedure is carried out by walking or using private vehicles without government assistance.

The total population affected by the Cengklik dam-break event is 519,587, where the passenger car ownership in the area and motorbikes are 6, 289 and 20,266 units, respectively (*Kabupaten Sragen Dalam Angka 2019*, 2020). Assuming that each car can accommodate four people and the motorbike can accommodate two people, the motorized vehicles can evacuate up to 65,688 people, which is equivalent to 12% of the population in the affected areas. The remaining 88% of the population will be evacuated on foot. However, this 12 percent figure is only a preliminary estimation, and further simulation is necessary to account for potential traffic surges and jams during evacuation. Based on the age distribution data obtained from the Central Bureau of Indonesia Statistics (*Kabupaten Sragen Dalam Angka 2019*, 2020). Equation (5) was used to classify the *EPT* for the population evacuated on foot into three categories. Using this information, the study generated *ECT* and *ETN* values for each village, and Table 2 shows the results of the *ECT* and *ETN* calculations for the affected villages.

The study added the extra time required to evacuate 100% of citizens in the Bolon Village (max *ETN* value) to determine the third/critical warning reference time (1.32 hours), as shown in Table 3. For the second warning reference time (2.72 hours), the study used the longest time to achieve 100% evacuation before the dam-break occurred in the Bolon village (max *ECT* value). Finally, the first/ideal warning reference time (3.3 hours) was calculated by multiplying the extra time required to evacuate 100% of citizens by 2.5 (max *ETN* value times 2.5). These reference times were then correlated with the water level in the reservoir for the PMF condition, and the reference water level for each warning level is shown in column 2 of Table 3. The process of obtaining these reference water levels is illustrated in Figure 7. By implementing these three warnings as an EWS, the study predicts that 100% of the population affected by the Cengklik dam-break flood can be saved.

4 CONCLUSION

This study proposed and tested a novel method to determine an early warning system (EWS) in the context of the Cengklik Dam. The potential impact of a dam-break event at the Cengklik Dam could affect 58 villages, including critical infrastructure such as the Adi Sumarmo International Airport. To determine the *EWS*, *ECT* values for each village were generated and compared to the flood arrival times. The analysis results led to the developing of a three-tiered warning system when the reservoir water level reached +141.36 m, +141.40 m, and +141.45 m. It should be noted that in real-world scenarios, when the water elevation has reached +141.36, it is possible that the water level may not continue to rise to +141.40 and +141.45 after the first warning. While the proposed EWS can ensure the safety of 100% of the affected population, further investigations are required to determine its applicability to different cases and locations.

The study has demonstrated the effectiveness of a simple, early warning system (EWS) in mitigating the risk of dam-break events. Nonetheless, further study is needed to refine the *ECT* calculation and examine its applicability in different settings, such as urban and rural areas, as well as to consider physical factors related to dam conditions. Additionally, future studies may need to incorporate the economic cost of disasters, which is a crucial aspect of disaster prevention planning.

DISCLAIMER

The authors declare no conflict of interest.

ACKNOWLEDGMENTS

The authors are grateful to the Institute for Research and Community Service (Lembaga Penelitian dan Pengabdian kepada Masyarakat) of Parahyangan Catholic University for supporting this work with a funding number III/LPPM/2020-03/99-P.

REFERENCES

Brown, C. A. and Graham, W. J. (1988), 'Assessing The Threat to Life from Dam Failure 1', *JAWRA Journal of the American Water Resources Association* **24**(6), 1303–1309.

Cheng, C., Qian, X., Zhang, Y., Wang, Q. and Sheng, J. (2011), 'Estimation of The Evacuation Clearance Time Based on Dam-break Simulation of The Huaxi Dam in Southwestern China', *Natural Hazards* **57**, 227–243.

Engineerig, P. M. (2020), 'Laporan Pendahuluan; Persiapan dan Penetapan Ijin Operasi Bendungan Cengklik, Ketro, dan Delingan Serta Uji Model Fisik Bendungan Pacal'.

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

Ge, W., Jiao, Y., Sun, H., Li, Z., Zhang, H., Zheng, Y., Guo, X., Zhang, Z. and van Gelder, P. (2019), 'A Method for Fast Evaluation of Potential Consequences of Dam Breach', *Water* **11**(11), 2224.

Huaizhi, S., Jiang, H. and Zhongru, W. (2012), 'A Study of Safety Evaluation and Early-warning Method for Dam Global Behavior', *Structural Health Monitoring* **11**(3), 269–279.

Kabupaten Sragen Dalam Angka 2019 (2020). Accessed 14 July 2022.
URL: *https://sragenkab.bps.go.id/publication/2019/09/26/87106db4f14f6695172086f7/kecamatan-tanon-dalam-angka-2019*

Lahoorpoor, B. and Levinson, D. M. (2019), 'The Transit Travel Time Machine: Comparing Three Different Tools for Travel Time Estimation'.

Li, Z., Li, W. and Ge, W. (2018), 'Weight Analysis of Influencing Factors of Dam Break Risk Consequences', *Natural Hazards and Earth System Sciences* **18**(12), 3355–3362.

Lindell, M. K., Sorensen, J. H., Baker, E. J. and Lehman, W. P. (2020), 'Community Response to Hurricane Threat: Estimates of Household Evacuation Preparation Time Distributions', *Transportation research part D: transport and environment* **85**, 102457.

Portal, K. N. (2021), ‘Jokowi: Ada 65 Bendungan yang Telah Dibangun Sejak 6 Tahun Lalu’.

Portal, R. N. (2013), ‘Bendungan Way Ela Jebol, Ribuan Masyarakat Mengungsi’.

Sattar, A., Konagai, K., Kiyota, T., Ikeda, T. and Johansson, J. (2011), ‘Measurement of Debris Mass Changes and Assessment of The Dam-break Flood Potential of Earthquake-triggered Hattian Landslide Dam’, *Landslides* **8**, 171–182.

Shi, L., Xie, Q., Cheng, X., Chen, L., Zhou, Y. and Zhang, R. (2009), ‘Developing a Database for Emergency Evacuation Model’, *Building and Environment* **44**(8), 1724–1729.

Su, H.-Z. and Wen, Z.-P. (2005), Intelligent Early-Warning System of Dam Safety, *in* ‘2005 International Conference on Machine Learning and Cybernetics’, Vol. 3, IEEE, pp. 1868–1877.

Sun, R., Wang, X., Zhou, Z., Ao, X., Sun, X. and Song, M. (2014), ‘Study of The Comprehensive Risk Analysis of Dam-break Flooding Based on The Numerical Simulation of Flood Routing. Part I: Model Development’, *Natural Hazards* **73**, 1547–1568.

Tempo News Portal (2021), ‘27 Maret 12 Tahun Lalu, Bencana Tanggul Situ Gintung Jebol, Tewaskan 99 Orang.’.
URL: *https://metro.tempo.co/read/1446492/27-maret-12-tahun-lalu-bencana-tanggul-situ-gintung-jebol-tewaskan-99-orang/*

Yudianto, D., Ginting, B. M., Sanjaya, S., Rusli, S. R. and Wicaksono, A. (2021), ‘A Framework of Dam-Break Hazard Risk Mapping for a Data-Sparse Region in Indonesia’, *ISPRS International Journal of Geo-Information* **10**(3), 110.