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A New Approach to Estimate the Potential Assets Loss due to Dam-Break Event in Indonesia

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ABSTRACT

A dam break is a devastating natural catastrophe that can lead to huge losses. In general, the severity of a disaster can be determined by the amount of damage it causes. The greater the loss, the more severe the disaster and vice versa. However, determining the potential asset loss as a result of a disaster is a challenging task. So far, there is no method for calculating potential asset loss that is specifically made for dam-break disasters. Therefore, this study proposes a new approach in calculating the potential asset loss for a dam-break. In this study, the potential asset loss is calculated by considering four factors, namely the Potential Loss of Lives (PLOL), Potential Loss of Incomes (PLOI), Potential Loss of Houses Damage (PLOHD), and Potential Loss of Productive Land (PLOPL). In addition, the study calculates the potential asset loss of the Ketro Dam dam-break disaster. Based on the evaluation results, the PLOL might reach Rp. 26,419,715,661. PLOI might reach maximum value of Rp. 1,185,600,000. PLOHD might reach maximum value of Rp. 4,255,325,000. And lastly , PLOPL might reach maximum value of Rp. 25,375,080,780. Thus, the potential asset loss for the Ketro Dam dam-break disaster based on the analysis can reach Rp. 57,235,721,441 or USD 4,026,304.

Keywords : dam-break, Ketro Dam, potential asset loss, loss of life, infrastructure asset management

INTRODUCTION

Infrastructure Asset Management (IAM) is about managing an infrastructure to be always capable to execute its function well, in economic, efficient, and effective way. Pertinent risk must be considered (Suprayitno & Soemitro, 2018). Dam-break is an important risk. Therefore the economic risk of a dam-break should be able to be calculated. Risk calculation of dam-break must be formulated.

At all costs, humans wish to stay away from disasters. Even if a tragedy may still occur in the end, humans make every effort to reduce the loss or any detrimental effect. Among the other calamities, a dam-break is one of the most significant and destructive disasters (Sun et al., 2014). The dam, which was meant to make human works easier, can end up becoming a serious threat. A dam-break, by definition, happens when a dam infrastructure breaks owing to certain factors such as piping or overtopping, resulting in an instantaneous and huge outflow of stored water, which later causes floods in numerous places (Sun et al., 2014). In fact, this disaster occurs rather frequently; between 2019 and 2020, five dam-break disasters were recorded, including Brumadinho Dam (Brazil), Spencer Dam (US), Tiware Dam (India), Sanford Dam (US), and Edenville Dam (US) (Campbell, 2019; Ennes, 2021; Hayes, 2021; Ratnagiri, 2019). The Edenville Dam, which was built more than a century ago, collapsed on May 18, 2021, owing to heavy rain. The rain was so heavy that the dam couldn't hold it back, resulting in floods up to 7.3 meters high. More than 10,000 people were forced to flee their homes as a result of the disaster, and 2,500 homes and businesses were damaged. The incident was believed to have cost $200 million in asset damages (Hayes, 2021).

The estimation of asset losses is frequently linked to a disaster (Hattum et al., 2020). When the worth of losses is calculated, this number can be used to indicate the severity of a disaster (the more severe a disaster, the greater the loss value). As a result, in terms of asset management, the method of measuring losses is critical. Decision-makers can identify the strategic actions needed both legislatively and executively by knowing the potential asset losses prior to a disaster (Faturahman, 2018). Several research on the calculation of flood losses have been conducted in recent years. The methods used to calculate flood losses are fairly varied. For example, some research uses a statistical approach to quantify the value of flood-related asset losses (Prayoga, 2020). Based on the magnitude of rainfall, the study predicts the number of houses that will be affected. The extreme value theory method was used to calculate the expected number of damaged dwellings in this study, which was based on previous flood data. In this situation, the study's findings can only be used within the study area, and the end product is not in currency units. On the other hand, there is a study that calculated the flood disaster's asset losses using a different yet straightforward method, namely the land use method (Nurdin, 2018). Specifically, the loss value is calculated by multiplying the flood-affected area by the land's selling price. Despite the fact that the approach for estimating disaster losses has a large tolerance value, it is thought to be lacking in essential factors, one of which is the damage building's value. On the other hand, the technique developed by the Economic Commission for Latin America and the Caribbean (ECLAC) is frequently employed in many research (Hutauruk et al., 2020; Jayantara, 2020; Muin et al., 2015; Sesunan, 2014; Wismana Putra et al., 2020). Essentially, this method evaluates asset losses by factoring in the effects of building damage (Jayantara, 2020). For example, (Hutauruk et al., 2020; Jayantara, 2020; Muin et al., 2015; Sesunan, 2014; Wismana Putra et al., 2020) have successfully estimated economical asset losses in various Indonesian cities, including Bandung, Samarinda, and Bandar Lampung. Even though the ECLAC approach has become widely employed, the Authors believe there is still room for improvement. This improvement aims to include additional factors that are equally essential to building damage factors, such as loss of life, productivity loss, and income loss. Furthermore, the flood cases analyzed in the aforementioned study are primarily based on historical data and surveys. Unfortunately, this means that the estimated loss can only be determined after the flood, whereas the stakeholders require the estimated asset loss value before the tragedy.

In a more specific scenario, the Authors discovered just a few studies that explored the possible asset losses associated with dam failures. The recent study related to calculation of potential asset damage due to dam-break events was conducted for Rukoh Reservoir, where the HEC-RAS and InaSAFE software was implemented to simulate the flood propagation and calculate potensial asset damage (Ariq et al., 2021). Indonesia, Australia, and the World Bank developed the InaSAFE software, which is a Free and Open Source Software (FOSS) for disaster impact simulation. The economic asset losses in InaSAFE are calculated mainly with the severity of building damage (BPBD Kota Makassar, 2019). Potential asset losses due to normal floods and dam-break floods, according to the author, should be calculated differently. This is due to the fundamental distinctions between the two types of floods. Dam-break floods have a significantly greater destructive power than typical floods, hence the loss of life must be factored in. Furthermore, because dam-break floods cover a larger area than regular floods, the loss of income and the loss of productive land are critical (Huaizhi et al., 2012). However, those methods only calculated the loss of buildings. According to these observations, it is reasonable to conclude that a method for evaluating potential asset loss in dam-break cases is still needed to be developed by including potential loss of lives, incomes, and productive lands.

The novelty of this paper is a holistic approach in estimating the potential loss of assets (in units of currency) caused by a dam-break disaster in form of loss of life, loss of income, loss of houses damage, loss of public facilities, and loss of productive land (rice fields). Loss of lives is intended as a quantifying value of a family losing its main source of income. Loss of incomes is intended as a replacement value for the loss of income of residents during the impact of the dam-break flood. The loss of the houses damage is intended as a quantification value of the damage to residential buildings due to the dam-break flood disaster. Finally, the loss of productive lands is intended as a replacement value for the damage to productive land that occurs. The sum of the four aspects above will be the value of the potential loss of assets due to a dam-break flood. To be able to produce a representative value, several assumptions will be used. These values will be explained further in the following sections of this paper.

To verify the proposed concept, Ketro dam was chosen as case study, where a dam risk analysis had recently been completed in (PT Metanna Engineering, 2020a). According to this analysis, the hypothetical Ketro dam failure impacted eleven villages. This manuscript is divided into four sections: an introduction (section 1), a description of the study location (section 2), a calculation of the potential asset loss and implementation on Ketro Dam (section 4) , and the study's final results (section 4).

STUDY LOCATION

Characteristics of Ketro Dam

Ketro Dam, which has been in operation since 1984, is administered by Bengawan Solo River Basin Organization (BBWS Bengawan Solo). It is located in the Tanon District of the Sragen Regency of Central Java Province. Holds water from a 7.33 km^2 river catchment area. It has a normal storage capacity of 2.88 million m^3 and is utilized to irrigate 400 hectares paddy fields. Because the majority of the dam's downstream area is residential and rice fields, a dam-break could be devastating (PT Metanna Engineering, 2020a). Ketro Dam and the physical dam features are shown in Figure 1.

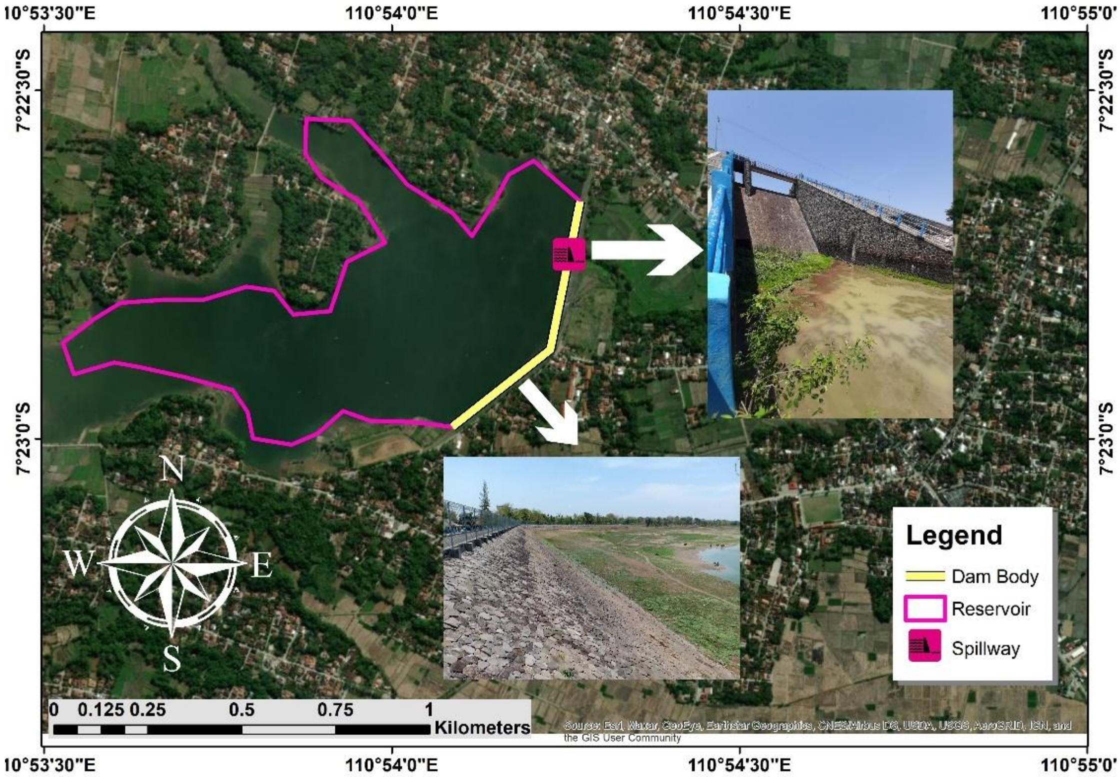

Figure 1. Ketro Dam Location

Hypothetical Dam Break Case and Flood Area

The hypothetical dam break case used in this analysis is based on (PT Metanna Engineering, 2020a), which found that the Ketro Dam is safe against overtopping failure. As a result, the dam-break incident was thought to have occurred as a result of piping failure. When the Probable Maximum Flood (PMF) occurred, the maximum reservoir water level (+100.5 m) created such a catastrophe. The flood propagation of the dam-break incident was analyzed using NUFSAW2D (Numerical simUlation of Free surface ShAllow Water 2D) in conjunction with the MERIT Hydro Digital Elevation Model (DEM) to produce a flood inundation map (see Figure 2 and Table 1). NUFSAW2D is a numerical model used to predict the dam-break flood that has been proven efficient, robust, and accurate (B. M. Ginting, 2017, 2019a, 2019b; B. M. Ginting et al., 2020, 2018; B. M. Ginting & Ginting, 2020; B. M. Ginting & Mundani, 2019; B. Ginting & Mundani, 2018; Minola & Herli, 2019). According to the inundation map, the dam-break flood flow will reach the farthest village ie. Kecik in approximately 146 minutes and reach the nearest village ie. Bonagung in 14 minutes (see Figure 2). The predicted inundation area is 1,002.71 hectares, putting up to 9,019 people in danger. The number of people affected is calculated by layering the inundation map over population data from Worldpop (https://www.worldpop.org/). The study does not use the Central Statistics Agency of the Republic of Indonesia (BPS) national census data since there is a significant difference between the actual population in the field and the national census value, according to (PT Metanna Engineering, 2020b). Furthermore, Worldpop is deemed accurate social demographic data since it covers population density statistics, peer-reviewed confirmed data output, and a resolution of 100 x 100 m. In order to better describe dam-break flood conditions, the population at risk is divided into three groups based on the predicted flood depth: class 1 (less than 0.5 m), class 2 (0.5 - 1.5 m), and class 3 (more than 1.15 m), see Table 1. There are two things to consider based on this information. To begin with, Gabugan Village has the highest risk population, whilst Slogo Village has the lowest. This is because the majority of floods that travel through Gabugan Village pass through residential areas, whereas the majority of floods that pass in Slogan Village pass through productive areas or rice fields. Second, Kalikobok Village has a higher class 3 risk population than Gabugan Village, despite Gabugan Village having the highest risk population.

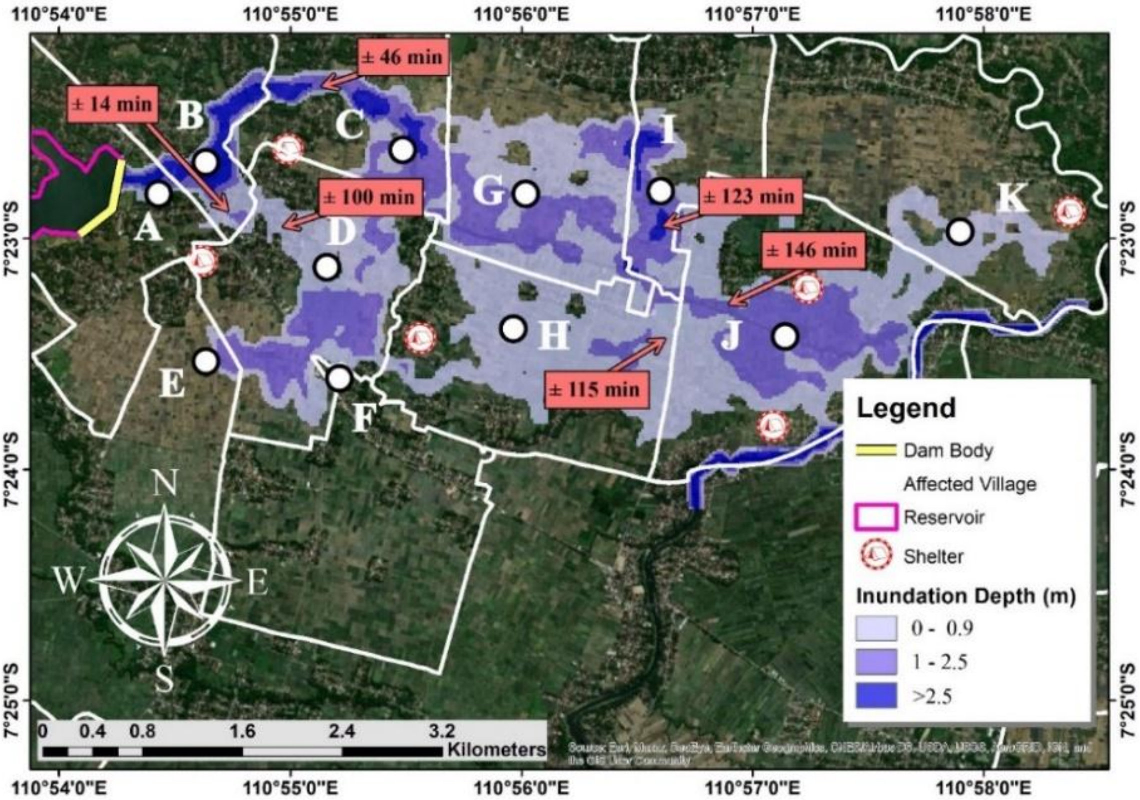

Figure 2. Ketro Dam-Break Inundation Map

Table 1. Affected Villages From Ketro Dam-Break

Symbol	Affected Village	People at Risk			Total
		Class 1 (<0 .5 m)	Class 2 (0.5 - 1.5 m)	Class 3 (> 1.15 m)	
A	Ketro	78	52	49	179
B	Bonagung	174	142	295	611
C	Kalikobok	157	234	352	743
D	Gabugan	861	685	273	1,819
E	Slogo	26	17	25	68
F	Jono	154	163	16	333
G	Tanon	299	524	64	887
H	Padas	1084	546	23	1,653
I	Suwatu	79	97	154	330
J	Kecik	902	770	289	1,961
K	Pengkol	351	39	45	435
Total					9,019

POTENTIAL ASSET LOSS (PAL) CALCULATION AND IMPLEMTATION ON KETRO DAM

1. General

In the event of a dam-break, the potential loss of assets must be measurable in a single universal value. That value in this study was decided to be “currency”. As a novelty, the new approach used in this study is intended to be able to compute and assess the impact of a dam failure in Indonesia. The potential loss of assets from a dam failure is separated into four categories: Potential Loss of Lives (PLOL), Potential Loss of Incomes (PLOI), Potential Loss of Houses Damage (PLOHD), and Potential Loss of Productive Land (PLOPL). The PAL can be calculated with equation **Error! Reference source not found.**.The next section will go over each aspect's explanation and calculating process in greater detail.

PAL=PLOL+ PLOI+PLOHD+PLOPL …(1)

Where :

PAL : Potential asset loss
PLOL : Potential Loss of Lives
PLOI : Potential Loss of Incomes
PLOHD : Potential Loss of Houses Damage
PLOPL : Potential Loss of Productive Land

2. Potential Loss of Lives (PLOL)

The PLOL is calculated in assumptions that are commonly used in the calculation of life insurance premiums in Indonesia. This assessment is based on the principle that "the family's main source of income is the head of the family." In addition, several assumptions will be applied. First, loss of lives is calculated if the family source of income is lost (in this case it is assumed that the head of the family has suffered loss of life due to the Ketro dam disaster). Second, the normal condition is achieved when the family regains the main source of income. This normal condition can be achieved in a certain amount of time, which can be estimated by the time it takes for the average age of children in the community to reach productive age, or so-called Recovery Time (RT). As a result, by multiplying RT with the family's annual expenditure, the PLOL for one family can be estimated. Third, the annual expenditure of a household is adjusted from the minimal regional wage. Finally, the regional inflation rate is taken into consideration. All of the above explanations have been formulated into equation.

$$LOL = f \times MRW \times \frac{(1+i)^n+1}{i} \quad \text{…(2)}$$

Where :

$PLOL$: Potential Loss of Lives (IDR),
f : number of families at risk,
MRW : minimum regional wage (IDR),
i : inflation rate (in decimal), and
n : Recovery Time (RT) in years.

Based on equation **Error! Reference source not found.**, the PLOL value can be calculated by knowing several variables, namely the number of families at risk, minimum regional wage, inflation rate, and Recovery Time (RT). The dam-break flood is projected to have impacted 8,941 persons, as seen in table 1. The variable f, or families at risk, can be determined using the assumption that one family consists of five persons (based on INASAFE). In addition, the MRW is set at Rp. 1,673,500, which is the 2019 city's minimum wage. The regional inflation rate follows the Sragen Regency inflation rate (based on data in BPS, the highest inflation rate experienced by Sragen Regency is at 2.80 percent). Lastly, the average age of children in the community in 11 villages at risk of flooding is seven years old. To reach productive age (15 years), it takes 8 years for each family to return to normal income conditions. Therefore, number 8 will be considered as RT or n value. The result of the PLOL calculation for Ketro Dam can be seen in Table 2.

Table 2. PLOL Calculation For Ketro Dam

Population at Risk	f	MRW **(IDR)**	i	$PLOL/Family$ **(IDR)**	$PLOL$ **(IDR)**
9,019	1,788	Rp. 1,673,500	0.028	Rp. 14,776,127	Rp. 26,419,715,661

Note : Rp = Rupiah, Indonesian currency

3. Potential Loss of Incomes (PLOI)

Although the dam-break tragedy occurs quickly, flooding can cause inundation for a long time. One of the impacts of the flooding was that residents were unable to go to work. As a result, the Potential Loss of Income (PLOI) must be considered. The PLOI is based on a number of factors, including the length of the disaster (days), the daily minimum pay, and the number of productive age population. PLOI is calculated using all of these factors (see equation).

$$PLOI = D \times P \times DMW \qquad \ldots(3)$$

Where :
$PLOI$: Potential Loss of Incomes (IDR),
D : duration of inundation (days),
P : number of populations working age, and
DMW : daily minimum wage (IDR).

According to the dam-break flood analysis, the inundation induced by this disaster lasts for a maximum of 20 hours after the occurrence happened. Thus, by rounding up, the duration of flood is considered 2 days. Furthermore, the number of populations on working age is 5,928 people and the daily minimum wage is Rp. 100,000 per person (PT Metanna Engineering, 2020b). The result of the PLOI calculation for Ketro Dam can be seen in Table 3.

Table 3. PLOI Calculation For Ketro Dam

D **(Days)**	P	DMW **(IDR)**	$PLOI$ **(IDR)**
2	5,928	Rp. 100,000	Rp. 1,185,600,000

4. Potential Loss of Houses Damage (PLOHD)

Another impact of the dam-break incident is the damage to buildings or houses of local residents. Therefore, Potential Lost of Houses Damages (PLOHD) is a substitute value that can be used by the community to carry out renovations or repairs. Due to the different variations of each resident, determining the building's loss price is quite difficult in its application. In this study, PLOHD was calculated using the damage factor variables based on flood cases as introduced in (Huizinga et al., 2017). The value of the damage factor and the equations used to calculate PLOHD can be seen in equation …(4) and Table 4.

$$PLOHD = \sum_{t=1}^{t=3} C_t \times DF \times A \quad \ldots(4)$$

Where :

$PLOHD$: Potential Loss of Houses Damage (IDR),
C_t : number of families in class t,
DF : flood damage factor, and
A : representative value of average family's asset.

Table 4. Flood Damage Factor

Flood Classes	Flood Damage Factor
Class 1 (<0 .5 m)	0.330
Class 2 (0.5 - 1.5 m)	0.500
Class 3 (> 1.15 m)	0.785

Source : Huizinga et al., 2017

The total value of assets owned by each household (per head of family with 5 family members) is calculated using the value of goods that are commonly owned by each household, such as furniture, television sets, beds, mattresses, refrigerators, and stoves. When these objects are flooded, they are most likely to be damaged. The average representative asset value of these products in Indonesia is Rp. 5,000,000 (PT Metanna Engineering, 2020b). The result of the PLOHD calculation for Ketro Dam can be seen in Table 5.

Table 5. PLOHD Calculation For Ketro Dam

Flood Classes (t)	C_t	DF	$PLOHD/family$ (IDR)	$PLOHD$ (IDR)
Class 1 (<0 .5 m)	834	0.330	Rp. 1,650,000	Rp. 1,376,100,000
Class 2 (0.5 - 1.5 m)	654	0.500	Rp. 2,500,000	Rp. 1,635,000,000
Class 3 (> 1.15 m)	317	0.785	Rp. 3,925,000	Rp. 1,244,225,000
Total				Rp. 4,255,325,000

5. Potential Loss of Productive Lands (PLOPL)

The last factor to consider is the loss of productive land or rice fields. This is significant since the dam's downstream region typically contains a lot of agricultural land, such as rice farms. The equation used to calculate PLOPL can be seen in equation …(5). Because the PLOPL calculation results in losses per year, whereas flooding only affects one planting season, the value of two in equation …(5) is entered (assuming one year have two planting seasons).

$$PLOPL = \frac{FA \times PR \times PP}{2} \quad \dots(5)$$

Where :

$PLOPL$: Potential Loss of Productive Lands (IDR),
FA : flooded land area (ha),
PR : production rate of rice (100 kg/ha), and
PP : production price of rice (IDR/kg).

According to the dam-break analysis, 886.76 hectares of rice fields were flooded. Furthermore, the downstream section of the Ketro Dam produces 12,718 kg of rice per hectare, with a rice production price of Rp. 4,500 per kg. The result of the PLOPL calculation for Ketro Dam can be seen in **Table 6**.

Table 6. PLOPL Calculation For Ketro Dam

FA (Hectare)	PR ($100\ kg/ha$)	PP (IDR/kg)	$PLOPL \times 2$ (IDR)	$PLOPL$ (IDR)
886.76	127.18	Rp. 4,500	Rp. 50,750,161,560	Rp. 25,375,080,780

6. Potential Asset Loss (PAL)

Based on the calculation from 2 to 5, the value of PAL of Ketro Dam dam-break cases can be estimated. The result of the PAL estimation for Ketro Dam can be seen in Table 7. As seen in that table, the predicted PAL for Ketro Dam is Rp. 57,235,721,441 or USD 4.026.304 (1 USD = Rp. 14,215, according to currency exchange on 11 October 2021) . The largest contribution comes from PLOL because the dam break affected 1,788 people. The smallest is from PLOI since the flooding only occurs for two days.

Table 7. PAL Estimation For Ketro Dam

Type of Potential Loss	Costs
PLOL (IDR)	Rp. 26,419,715,661
PLOI (IDR)	Rp. 1,185,600,000
PLOHD (IDR)	Rp. 4,255,325,000
PLOPL (IDR)	Rp. 25,375,080,780
PAL (IDR)	Rp. 57,235,721,441
PAL (USD)	$ 4.026.304

CONCLUSIONS

Many approaches have been implemented to predict or estimate the potential asset loss. However, those methods can still be improved. A novel approach to determine an approach to estimate Potential Assets Loss for dam-break cases in Indonesia was proposed and evaluated in this study. The four aspects of loss have been successfully obtained based on the evaluation results, with the following values: In the event of a dam failure at the Ketro Dam, the PLOL might reach Rp. 26,419,715,661. PLOI might reach maximum value of Rp. 1,185,600,000. PLOHD might reach maximum value of Rp. 4,255,325,000. And lastly , PLOPL might reach maximum value of Rp. 25,375,080,780. The total value of these four aspects, also known as Potential Assets Loss (PAL), comes to Rp. 57,235,721,441. Based on the results of this calculation, it is apparent that the PLOL and PLOPL aspects of the dam-break disaster have caused the most impact. The PLOI aspect receives the smallest loss. Implementation of this new approach could accommodate all potential losses that could be happened and should be concerned.

This study is able to show a simple method in calculating PAL for dam-break cases. Indeed, further research needs to be conducted more detail, for example, taking into account other aspects such as the loss of public facilities, loss of commercial buildings, and evacuation costs.

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