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Model Development of Dam Break Risk Classification

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Abstract

This research intends to develop the risk classification assessment model of dam break based on the population number speed and land use change in the dam downstream. This research is conducted in 10 dams in Indonesia as follow: Bintang Bano, Rotiklot, Napungette, Lolak, Kuwil, Pandanduri, Batu Nampar, Kengkang, Sepit, and Jangkih Jawa. The methodology consists of data collecting, analysis of land use change, analysis of impacted area, analysis of risk class assessment due to dam break, than to build a model development pf dam break risk classification. The affected variables to the model ia analyzed by using SemPls and the model isbuilt by using the help of GRG. By using the coefficient values of variables and indicators, and the index weight of the variables, there is obtained the model development of dam break risk classification as follow:

$$FR_{tot} = 0{,}149\ FR_{k} + 0{,}11\ FR_{t} + 0{,}242\ FR_{e} + 0{,}252\ FR_{h} + 0{,}112\ FR_{pd} + 0{,}134\ FR_{pk}$$

The RMSE value for validation the model is 0.29 (close to zero), It shows that the model has high enough accuracy. By using the other method for validation such as NSE, it is obtained the value of NSE is about 0.56. It indicates that the model can be satisfied interpreted.

Keywords: Dam Break, Risk, Model, Risk Population, Land Use Change

Introduction

Dam, besides gives much benefit is also having the danger potency risk that can cause disaster if the dam experience failure or break [1][2]. Dam has to be maintained the operation performance, function, and the safety. Therefore, it is necessary to be carried out some activities of maintenance, improvement, and rehabilitation [3][4] in the dam that has already built and operated. The priority system in the activities implementation of improvement and rehabilitation can be arranged based on the status of dam break. In addition, the budget for dam rehabilitee activity has very limited budget. Based on the case, it is necessary to be carried out the risk assessment in the dam for estimating the risk of dam break or failure [5][6] due to the disaster or the other reason [7].

Based on the problem above, it is needed to assess the dam risk for estimating how big the danger risk or dam break risk. However, based on the guidance of risk analysis, the estimation of failure probability can be carried out by using two methods that are traditional and event tree method. Referring to the assessment risk analysis, the risk analysis of Kedungombo Dam (Indonesia) due to the traditional and event tree method each is about 4.010 x 10-1 and 1.548 x 10-3 which the boundary that can be accepted for maximum existing dam is 1.000 x 10-5. The value of Kedungombo Dam risk probability did not fulfill the conditions of the risk value that can be accepted. Therefore, there is needed the recommendation of risk decreasing action for the risk due to the assessment result.

The risk assessment is a process to reach a decision recommendation about the available risk can be tolerated or not and the action of risk controlling now has been enough or not [8], if not, the risk controlling alternative is allowed or not to be implemented. The scope of risk assessment is as the input and output of risk analysis and evaluation stages [9]. This research intends to develop the classification assessment of dam break based on the development of population number speed and land use change in the dam downstream.

Materials and Method

Research Location

The research locations are in the 10 dams as follow:

1. Bintangbano dam, located in the Bangket Monteh village, Brang Rea district, Sumbawa Barat regency, Nusa Tenggara Barat Province-Indonesia
2. Rotiklot dam, located in the Futuketi village, Kakuluk Mesak district, Belu regency, Nusa Tenggara Timur province-Indonesia
3. Napungete dam, located in the Ilin Medo village, Waiblama district, Sikka regency, Nusa Tenggara Timur province-Indonesia
4. Lolak dam, located in the Pindol village, Lolak district, Bolmong regency, Sulawesi Utara province-Indonesia
5. Kuwil Kawangkoan dam, located in the Kalawat district, Minahasa Utara regency, Sulawesi Utara province-Indonesia
6. Pandanduri dam, located in the Sakra district, Lombok Timur regency, Nusa Tenggara Barat province-Indonesia
7. Batu Nampar dam, located in the Batu Nampar village, Keruak district, Lombok Timur regency, Nusa Tenggara Barat province-Indonesia.
8. Kengkang dam, located in the Sekotong Tengah village, Sekotong district, Lombok Barat regency, Nusa Tenggara Barat province-Indonesia
9. Sepit dam, located in the Pengembur village, Praya Barat district, Lombok Tengah regency, Nusa Tenggara Barat province-Indonesia
10. Jangkih Jawa dam, located in the Mangkung village, Praya Barat district, Lombok Tengah regency, Nusa Tenggara Barat province-Indonesia

Determination Method of Danger Level

The danger degree of a dam is determined based on the number of population that are caught the risk. The risk population is the whole population in the dam downstream area who are threatened danger if there is happened the dam break or dam failure. Risk population is calculated as the cummulative number of population that are threatened danger in the whole part of dam downstream. The risk population can be identified and classified from the inundation map as the result of dam break or dam failure study. Table 1 presents the number of population that is caught the dam break or dam failure risk for each class of dam break and Table 2 presents the consequence equality relation between dam downstream Area and the dam break classification

Table 1 Number of Population that is Caught the Dam Break Risk for Each Class of Dam Break

Number of risk population (person/cumulative)	Distance from dam (km) 0-5	0-10	0-20	0-30	>30
0	1	1	1	1	1
1-100	3	3	2	2	2
101-1000	4	4	4	3	3
>1000	4	4	4	4	4

Source: General Work Ministry, 2011

Table 2 Consequence Equality Relation between Dam Downstream Area and the Dam Break Classification

Consequence of downstream area	Dangerous level	Dangerous class
Small	Low	1
	Moderate	2
Big	High	3
	Very high	4

Source: General Work Ministry, 2011

Analysis of Risk Class Classification

The risk of dam break can be analyzed by usiang the formula as follow:

$$FR_{tot} = FR_k + FR_t + FR_e + FR_h$$

Where:

FR_{tot}= total risk factor
FR_k= influenced risk factor of reservoir capacity
FR_t= influenced risk factor of dam height
FR_e= risk factor of evacuation need
FR_h= degree risk factor of damage in the downstream, it is obtained from the guidance of dam break classification

The table of risk factor for evaluating the dam safety becomes as in the Table 3.

Table 3 Risk Factor for Evaluation of Dam Safety

Risk Factor	Weight value in brackets				
	Extreme	High		Moderate	Low
Capacity (10^6 m^3) (FR_k)	>1000 (6)	100 – 1.5 (4)		1.00 – 0.125 (2)	<0.125 (0)
Height (m) (FR_t)	>45 (6)	45 - 30 (4)		30 - 15 (2)	<15 (0)
Evacuation demand (number of person) (FR_e)	>1000 (12)	1000 - 100 (8)		100 – 1 (4)	0 (0)
Level of downstream damage (FR_h)	Very high (12)	high (10)	Rather high (8)	Moderate (4)	none (0)

Population Growth

The population growth rate (PGR) is a figure that indicates the percentage increase of the population within a certain period of time.

Table 4 Category of Population Growth Rate in Indonesia

PGR	Category
< 1%	Low
1 – 2%	Moderate
>2%	Hight

Source: Central Agency on Statistics; Statistics Indonesia

Land Use Change

Land use change is a modification that occurs in the type of use of a land over time, such as a change from forest to agricultural land or from agricultural land to residential or industrial areas

Table 5 Category of Deforestation Rate in Indonesia

Deforestation Rate / years		Category
Ha	%	
100 – 1.000	0.02 - 0.22	Low
1.000 – 5.000	0.22 - 1.11	Moderate
5.000 – 10.000	1.11 - 2.22	Hight
> 10.000	>2.22	Extreme

Source: Indonesia Deforestation Calculation Book; Ministry of Forestry; 2012

Result and Discussion

Statistical Analysis by Using SEM-Pls

The technique of data analysis by using the SEM-Pls method is based on the Partial Least Square (PLS) [13]. There are some analysis stages that are carried out which is obtained from the initial analysis by using computer program of Smart-PLS

Item Validity Test

The Item Validity Test, for each tested indicator in SEM-Pls, refers to its outer loading value. The limit of outer loading value > 0.5 is still acceptable as long as the construct's validity and reliability meet the requirements and the model is still in the early development stage [14]. Based on the simulation result of SEM-Pls, the value of loading factor in each indicator is presented as in the Table 6.

Table 6 The Value of Loading Factor in each Indicator

Indicator	Loading Factor	Reliability degree
FRt	0.893	Very reliable
FRk	0.890	Very reliable
FRe	0.567	Reliable enough
FRh	0.850	Very reliable
FRpd	0.513	Reliable enough
FRpk	0.552	Reliable enough

Therefore, based on the validity of the outer loading of the six tested indicators > 0.5, it can be concluded that all items or indicators are valid in terms of item validity.

Validity and Construct Reliability Test

The validity and construct reliability are measured to determine the level of reliability of latent variables (the model under study).

- Internal Consistency Reliability

The consistency reliability test intend to know how far the items of questionnaire that is arranged can represent the variable that is being measured. The reliability test uses Cronbach's alpha from PLS analysis which is obtained the whole question items that fulfill the suggested value, so the used indicator for measuring the variable in this research has the reliability or important role in the variable assessment what is meant is.

The value of Cronbach's alpha in the dam risk factor model is 0.8063, which is greater than 0.8. This indicates that the indicators composing the dam risk factor model have a high level of reliability, thus they can represent the conditions of the dam risk factor model under study with high reliability

- Unidimensionality Model

Unidimensionality testing is conducted to ensure that there are no issues with the measurement. The unidimensionality test is carried out using composite reliability indicators with a cut-value of 0.7 [14].

The test result of Composite Reliability in the dam risk factor model is 0.867, which is greater than 0.7. This indicates that indicators composing the dam risk factor model considered acceptable, and the instrument is considered to have good unidimensionality.

- Convergent validity

Convergent validity of a construct with reflective indicators is evaluated using Average Variance Extracted (AVE). The value of AVE can be said good if greater than 0.5 [15].

The value of Average Variance Extracted (AVE) in the dam risk factor model is 0.533, which is greater than 0.5. This indicates that the variable the dam risk factor model considered to have good convergent validity and are used to ensure data quality in SEM PLS analysis.

The result of Validity and Construct Reliability Test shows that the six indicators have the reliability, so all of the indicators can be used for building the model without being eliminated.

The Value of Inner Model and Structural Model

The hypothesis test is based on the value is the structural model analysis, the significance level of path coefficient is obtained from the value of $t_{calculated}$ and the standardized path coefficient. Table 7 presents the coefficient of path.

Table 7 Path Coefficient

	Original Sample (O)	Sample Mean (M)	Standard Deviation (STDEV)	T Statistics (|O/STDEV|)	P Values
FRTot <- FRtot	1.000	1.000	0.000		
FRh <- dam risk	0.850	0.854	0.083	10.234	0.000
FRk <- dam risk	0.890	0.882	0.101	8.832	0.000
FRpd <- dam risk	0.513	0.507	0.270	1.900	0.008
FRpk <- dam risk	0.552	0.558	0.224	2.460	0.014
FRt <- dam risk	0.893	0.898	0.081	10.988	0.000
Fre <- dam risk	0.567	0.546	0.320	1.872	0.007

Source: own study

Based on the result above, the six indicators have the positive effect and significant to the assessment of dam break risk level. It is shown in the result of $t_{statistic} > 1.812$.

Model development of Dam Break Classification Assessment

Based on the assessment above, there is carried out the GRG analysis [16] for obtaining the coefficient of each variable or indicator, then it is used for determining the development of dam break classification assessment. Then, the index value of analysis result will be checked with the field index which the analysis is close each other with the minimum error. The constraints that are used as the parameter of solver is as the amount of coefficient value for each indicator as follow: 1 ($X_1 + X_2 + X_3 + X_4 + X_5 + X_6 = 1$). However, the iteration result by using solver and the value of criteria coefficient is presented as in the Table 8.

Table 8 The Value of Criteria Coefficient

X_1	0.149
X_2	0.110
X_3	0.242
X_4	0.252
X_5	0.112
X_6	0.134

By using the value of variable or indicator coefficients, so there is obtained the formulation as follow:

$$FR_{tot} = 0{,}149\ FR_k + 0{,}11\ FR_t + 0{,}242\ FR_e + 0{,}252\ FR_h + 0{,}112\ FR_{pd} + 0{,}134\ FR_{pk}$$

Model Validation

Model validation of dam break classification assessment development is carried out for evaluating the model validity to the output. Validation of output is carried out by using Root Mean Square Error (RMSE) and Nash-Sutcliffe Efficiency (NSE).

Root Mean Squared Error (RMSE)

Root Mean Squared Error (RMSE) is one of the ways to evaluate the linear regression model by measuring the accuracy level of a model estimation result. RMSE is analyzed by quadrating the error (prediction-observation) and divided by number of data (= average), then it is rooted. RMSE is as the error level of prediction result which the getting smaller (close to zero) of RMSE value, so the prediction result will be getting accurate. By using the assessment data of each dam and the assessment model of dam break risk level, the data of assessment is presented each as in the Table 10.

Table 9 Data of Assessment for 10 Researched Dams

Dam location	FRt 0.149	FRk 0.110	FRe 0.242	FRh 0.252	FRpd 0.112	FRpk 0.134	FRtot	New model	Existing (based on the SE)	
Bintangbano	4	3	4	4	4	3	3.76	Extreme	34	Extreme
Rotiklot	3	3	4	4	4	4	3.74	Extreme	32	Extreme
Napungete	4	3	4	4	4	4	3.89	Extreme	34	Extreme
Lolak	4	3	4	4	2	2	3.40	Extreme	34	Extreme
Kuwil	4	3	4	4	2	2	3.40	Extreme	34	Extreme
Pandanduri	3	3	4	4	4	4	3.74	Extreme	32	Extreme
Batu Nampar	2	2	2	4	2	4	2.77	Extreme	24	High
Kengkang	2	2	4	4	4	4	3.48	Extreme	26	High
Sepit	1	2	4	4	2	4	3.11	Extreme	26	High
Jangkih Jawa	2	2	4	4	1	4	3.15	Extreme	26	High

The scoring range of dam risk assessment based on the SE and model is not the same, so it is needed to be customized. Table 10 presents the customization of assessment due to the new model to the existing model due to the assessment based on the SE.

Table 10 Customization of Scoring Rang between Assessment of New Model and Based on the SE (Existing Model)

Dam location	New model		Existing (based on the SE)		Score conversion based on the SE becomes as scale of 4	
Bintangbano	3.76	Extreme	34	Extreme	3.78	Extreme
Rotiklot	3.74	Extreme	32	Extreme	3.56	Extreme
Napungete	3.89	Extreme	34	Extreme	3.78	Extreme
Lolak	3.40	Extreme	34	Extreme	3.78	Extreme
Kuwil	3.40	Extreme	34	Extreme	3.78	Extreme
Pandanduri	3.74	Extreme	32	Extreme	3.56	Extreme
Batu Nampar	2.77	High	24	High	2.67	High
Kengkang	3.48	Extreme	26	High	2.89	High
Sepit	3.11	Extreme	26	High	2.89	High
Jangkih Jawa	3.15	Extreme	26	High	2.89	High

However, the analysis of validation test is presented as in the Table 11.

Table 11 Analysis of Validation

Name of Dam	New Model (Y)		Score conversion based on the SE becomes as scale of 4 (X)		(X-Y)2
Bintangbano	3.76	Extreme	3.78	Extreme	0.00
Rotiklot	3.74	Extreme	3.56	Extreme	0.03
Napungete	3.89	Extreme	3.78	Extreme	0.01
Lolak	3.40	Extreme	3.78	Extreme	0.15
Kuwil	3.40	Extreme	3.78	Extreme	0.15
Pandanduri	3.74	Extreme	3.56	Extreme	0.03
Batu Nampar	2.77	High	2.67	High	0.01
Kengkang	3.48	Extreme	2.89	High	0.35
Sepit	3.11	Extreme	2.89	High	0.05
Jangkih Jawa	3.15	Extreme	2.89	High	0.07
			Total		0.85
			Mean		3.36
			n		10
			RMSE		0.291551

Based on the analysis above, the RMSE value that is obtained is 0.29 (close to zero). It indicates that the model development of dam break risk classification has the high enough accuracy.

Nash-Sutcliffe Efficiency (NSE)

NSE (Nash-Sutcliffe Efficiency) shows how good the plotting of observation value (measurable) if compared with the value of prediction-simulation is suitable with the line 1:1, the value is in the range from ∞ -

to 1. The getting big of NSE value means the model performance is better. This method is generally used in the hydrology modelling for illustrating the compatibility between model and field discharge. The NSE value is close to 1.0, it indicates that the model discharge is the same with the field discharge. If the value is less than zero, so the compatibility is bad. The NSE value is in the range from ∞ until 1.0 with the value criteria based on the interpretation is presented as in the Table 12.

Table 12 Criteria of Validation Test Based on the NSE

NSE	Interpretation
0.75 < NSE, 1.00	Very good
0.65 < NSE < 0.75	Good
0.50 < NSE < 0.65	Satisfactory
NSA < 0.050	Unsatisfactory

However, the model development validation of dam break risk classification assessment is presented as in the Table 13.

Table 13 Validation Test by Using NSE

Mane of Dam	New model (Y)		Score conversion based on the SE becomes as scale of 4 (X)		(X-Y)2	(X-Xrt)2
Bintangbano	3.76	Extreme	3.78	Extreme	0.00	0.18
Rotiklot	3.74	Extreme	3.56	Extreme	0.03	0.04
Napungete	3.89	Extreme	3.78	Extreme	0.01	0.18
Lolak	3.40	Extreme	3.78	Extreme	0.15	0.18
Kuwil	3.40	Extreme	3.78	Extreme	0.15	0.18
Pandanduri	3.74	Extreme	3.56	Extreme	0.03	0.04
Batu Nampar	2.77	High	2.67	High	0.01	0.47
Kengkang	3.48	Extreme	2.89	High	0.35	0.22
Sepit	3.11	Extreme	2.89	High	0.05	0.22
Jangkih Jawa	3.15	Extreme	2.89	High	0.07	0.22
			Total		0.85	1.92
			Mean		3.36	
			n		10	
			NSE		0.55751	

Based on the analysis above, by using NSE method there is obtained the NSE value about 0.56. It shows that the model development of dam break risk classification assessment is satisfied interpreted.

Conclusion

Based on the research result that is carried out to the 10 dams which refers to the SE in Indonesia, there are 6 dams with the damage level in the downstream show the very high danger level and the evaluation of dam classification are extreme. The dams in this condition are Bintang

Bano, Rotiklot, Napungette, Lolak, Kuwil, and Pandanduri. However, the 4 other dams also show the very high danger level but there are included in the high dam assessment classification (not extreme). The dams in this condition are Batu Nampar, Kengkang, Sepit, and Jangkih Jawa.

To evaluate the data quality in the simulation result of SEM-Pls is used the composite reliability and arrange variant extracted. The value of composite reliability can be said good if the value of composite reliability ρc > 0.8, so it is said that the construct has the high reliability or reliable and ρc > 0.6 is said reliable enough and the good value of Average Variance Extracted (AVE) is > 0.50. The test result of reliability for all of the variables show the value of composite reliability is about 0.867 (> 0.6) that indicate that the data that is analyzed is reliable and the AVE is 0.533 (> 0.5) which can be meant that the data that is analyzed has the good reliability and can be used. The result above shows that the six indicators have the reliability, so all of the indicators can be used for building the model without being eliminated. By using the value of variable or indicator coefficients, so there is obtained the formulation as follow:

$$\mathbf{FR_{tot} = 0{,}149\ FR_k + 0{,}11\ FR_t + 0{,}242\ FR_e + 0{,}252\ FR_h + 0{,}112\ FR_{pd} + 0{,}134\ FR_{pk}}$$

The RMSE value that is obtained is 0.29 (close to zero). It indicates that the model development of dam break risk classification has the high enough accuracy. By using NSE method there is obtained the NSE value about 0.56. It shows that the model development of dam break risk classification assessment is satisfied interpreted.

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