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THE SELECTION PARAMETER FOR THE OPERATION AND MAINTENANCE DAM BASED ON ACTIVITY-BASED COSTING

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Potential risks to people exist if a dam collapses and has a significant impact on the downstream area. Many countries are now facing the problem of having to deal with deteriorated infrastructure due to a lack of maintenance budgeting. This paper presents the dominant parameter in an Operational and Maintenance (OM) dam to build a cost estimation model to maintain the service life of the dam. The method used to identify cost-triggering parameters is based on activity-based costing and dam performance assessments using a combination of the modified Andersen, International Commission of Large Dams (ICOLD), and Dam Commission. The parameter was collected from fourteen independent variables, namely: dam height, irrigation area, sedimentation volume, grass area, wood vegetation area, corrosion area, concrete area, daily worker, corrosion expert, concrete deterioration, hydromechanical, physical performance, operation performance, and safety performance. The results of the model indicate that height, wood vegetation area, concrete maintenance area, hydromechanical deterioration, and safety performance are variables that affect OM costs. The OM costs can be reduced if the safety performance variable increases. This condition implies that if the safety performance component consists of dam monitoring activities, periodic inspections, green belt maintenance, water quality maintenance, and public awareness, the OM costs will decrease by 10%.

Keywords: dam, operation and maintenance, performance, activity-based costing, safety

1 INTRODUCTION

One of the sustainability issues related to water resources is the increasing demand for water, which is driven by factors such as population growth [1], urbanization [2], industrialization, and changes in consumption patterns [3], leading to water scarcity [4], competition for water resources and conflicts over water allocation [5]. Dams have significantly contributed to human development by providing reliable sources of drinking water, irrigation, hydropower, recreation, navigation, income, and other essential benefits. However, dams, as heavy structures, may fail and pose a risk to human life, property, and the environment [6]. Therefore, dam maintenance is crucial for their management to ensure proper functioning and safety.

Many countries, including Indonesia, are now facing the problem of having to deal with large numbers of deteriorated infrastructures [7, 8]. In Indonesia, in general, as many as 65% of dams have a moderate-to-high risk score index or are categorized as close to severe damage, and 15% are damaged [9,10]. The main cause of the high level of dam damage is the condition of the dam, which is close to service life, sedimentation (11), and significant damage to the main components of the dam, such as the crest dam, upstream, downstream, inlet, outlet, and spillway.

One of the causes of this condition is dam operation and maintenance (OM). In the Dam Operation and Maintenance Activity, there is an activity serving the main function, the Assessment of Dam Condition, to keep the condition of the dam as the main building well-monitored and maintained [12]. Unfortunately, several activities cannot be carried out owing to errors in the cost planning. The difference between the required OM costs and estimated planned costs is very large, resulting in maintenance activities that are not in accordance with the standard code. Therefore, it is necessary to develop a model that can estimate the cost of OM, which aims to provide a budget for operation and maintenance activities.

Key budgeting and feasibility decisions are based on cost estimates prepared during the early stages of construction projects. As the project scope is not finalized during these conceptual phases, quantity take-off cannot be performed to form a detailed cost estimate. Although conceptual cost estimates are not expected to be precise, inaccurate estimates may lead to lost opportunities and lower returns than expected [13]. According to the American Association of Cost Engineering (AACEI), many methods can be used for cost estimation, the goal of which is the accuracy of the cost estimate [14,15]). There are many methodologies for cost estimation, such as Multilayer Taxonomy [16], Life Cycle Cost [17], artificial neural networks [18], and activity-based costing [19]. However, the simplest method is the regression method, which involves the entry of several important parameters based on previous data that are then processed using regression techniques [13].

Determining operational and maintenance (OM) costs is another critical aspect that should not be understated. As a dam manager, staying informed about a dam's condition is imperative and necessitates updated information. This is in line with the dam performance assessment regulations [20] outlined by the Ministry of Public Work, where the dam condition is an integral part of the overall dam performance assessment. With these insights, a dam manager can meticulously devise a comprehensive maintenance plan tailored to the specific conditions of the dam. This strategy ensures effective and efficient maintenance practices, promoting the long-term resilience and performance of dam structures.

2 MATERIALS AND METHODS

2.1 Management of operation and maintenance dam

Within the framework of dam O&M management [21], effective management involves following a carefully designed work plan. This plan was established considering various factors, including a reservoir operation pattern, the current state of the dam, and insights gleaned from regular inspections conducted on a weekly, monthly, and 5-year basis [20,22,23]. This comprehensive approach integrates operational strategies with condition-based assessments, enabling the implementation of timely and informed decisions to ensure optimal dam performance and safety. The operation management and maintenance of the dam is divided into several activities, as follows: a) operation: activity pattern of dam operation according to the need, b) maintenance: dam maintenance activities (preventive and corrective), and c) monitoring of dam behavior through dam instrumentation and visual inspection [24,25].

Based on the Regulation of the Minister of Public Works and Public Housing [20] concerning dams, dam management aims to 1) ensure the functions and benefits of the dam through dam operation and reservoir operations, 2) ensure the sustainability of the dam's prime condition through maintenance of the dam, and 3) ensure the sustainability of dam safety through operation, maintenance, observation, monitoring, inspection, maintenance, and rehabilitation [26].

2.2 Dam performance

As previously discussed, the condition of a dam greatly affects its performance from a physical, operational, and safety point of view, and, of course, it will impact maintenance costs. Likewise, the performance of the dam also affects the OM costs. Therefore, in dam management, it is necessary to assess the condition of a dam based on its performance.

One method often used is the rating method published by the American Society of Civil Engineering in ASCE Manuals and Reports on Engineering Practice No. 135 of 2018 [21]. This method is often used in many countries because the indicators produced are formulated based on their order of importance, making it easier for managers or stakeholders to make decisions in the context of priority [27,28]. The aspects reviewed in this rating are safety, operation, and physical condition in Indonesia, which have not been integrated with maintenance costs [9].

Broadly speaking, this condition assessment is widely used to assess the condition of a building [29], where the data used are the result of visual inspection. The condition assessment for each subcomponent is based on the assessment of the dam manager, who has certified expertise. The assessment of the condition is then given a weight, which is then added to the total assessment index. The final stage was to determine the criteria for the assessment results, whether in good, moderate, low, or poor conditions. In general, there are three approaches to dam assessment criteria: modified ICOLD [30], Modified Andersen [31], and the Dam Safety Commission [24]. For the ICOLD, the assessment criteria are more concerned with the risk of dam failure by adding an assessment of the number of people affected. Andersen focused more on the potential for structural dam failure owing to overtopping, external erosion, piping, and slope stability [32]. The last approach is the Dam Safety Commission, which is outlined in the Dam Performance Assessment Guidelines. This assessment is a combination of the ICOLD and Andersen. The potential assessment was based on data obtained from periodic visual inspections, major inspections every five years, and monitoring instruments.

In this study, the dam performance assessment approach uses a combination of the Andersen and Dam Safety Commission, where the assessment is divided into three parts: Physical Performance, Operational Performance, and Safety Performance, as shown in Table 1.

Table 1. Dam performance assessment aspects*

Performance	Component	Good	Mildly damaged	Severely damaged	Poor
Physical Performance	Main Dam	Properly functioning 80-100%	Properly functioning 70-≤80%	Properly functioning 55-≤70%	Functioning < 55%
	Inlet				
	Outlet				
	Spillway				
	Toe				

Performance	Component	Good	Mildly damaged	Severely damaged	Poor
Operation Performance	Operation	Non-conformance ≤20%	Non-conformance 20-30%	Non-conformance 30-40%	Non-conformance ≥40%
	Emergency	Updated every 5 years	Updated > 5 years	Updated > 5 years	Updated > 5 years
Safety Performance	Instrumentation assessment	Safe 80-100%	Safe 70-80%	Safe 55-70%	Safe <55%
	Inspection	Implemented on schedule 80% -100%	Implemented on schedule 70% - <80%	Implemented on schedule 55% - <70%	Implemented on schedule <55%
	Reservoir	Properly functioning 80-100%	Properly functioning 70-≤80%	Properly functioning 55-≤70%	Functioning < 55%
	Greenbelt	Open space 80-100%	Open space 70% - <80%	Open space 55% - <70%	Open space <55%
	Community	Public safety awareness 80-100%	Public safety awareness 70% - <80%	Public safety awareness 55% - <70%	Public safety awareness <55%

*Compared with new construction

2.3 Methods

2.3.1 Study Location

This study was conducted in the Bengawan Solo River Basin Territory, Central Java, Indonesia. Data were obtained from 32 single-purpose dams (Fig 1).

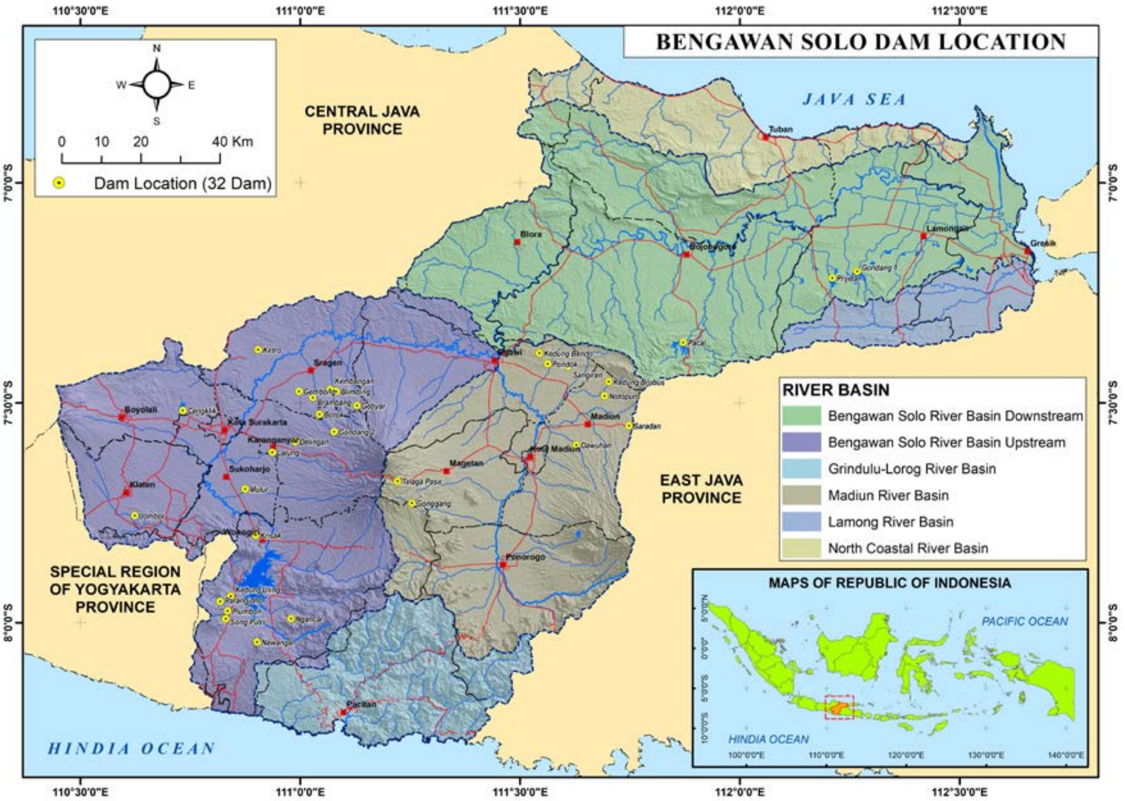

Fig. 1. Research Location
(Source: Bengawan Solo Regional Basin Territory, 2022)

These dams vary with the age of construction: 67% of dams are over 50 years old, 21% of dams are between 20-50 years old, and 12% are under 20 years old.

Some of the problems that often arise in management are that the sedimentation rate is very fast every year, so it is categorized as heavy, there is a lot of damage to the instrumentation equipment, and some dam components experience minor-to-moderate damage. For the main dam, the damage that occurs is cracks, downward movement, and damage to the asphalt, including riprap reduction, reduced riprap density, and landslides [21]. In the inlet or uptake building components, the damage that often occurs is the corrosion of channels, bridges, and cracks in hydromechanics. Similarly, for spillways, the most common damage occurs in concrete walls and fractures in the spillway [33].

2.3.2 Dam Performance

The average physical performance of the dam was in a low-moderate condition, whereas the average operational performance was moderately severe (Fig 2). The safety performance assessment results were moderate.

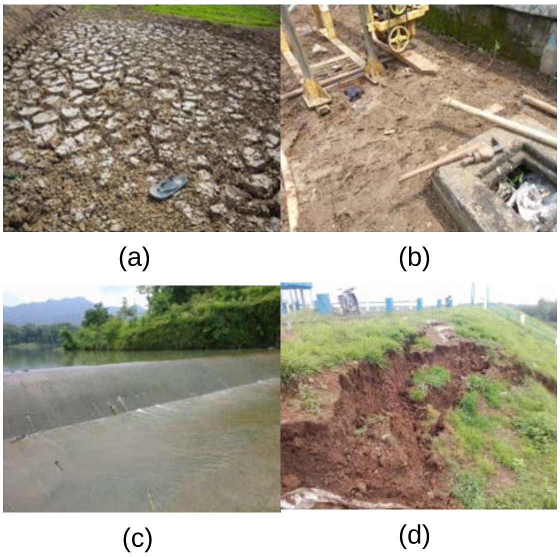

Fig. 2. Deterioration: (a) sedimentation, (b) instrumentation and hydromechanical, (c) spillway, and (d) body dam

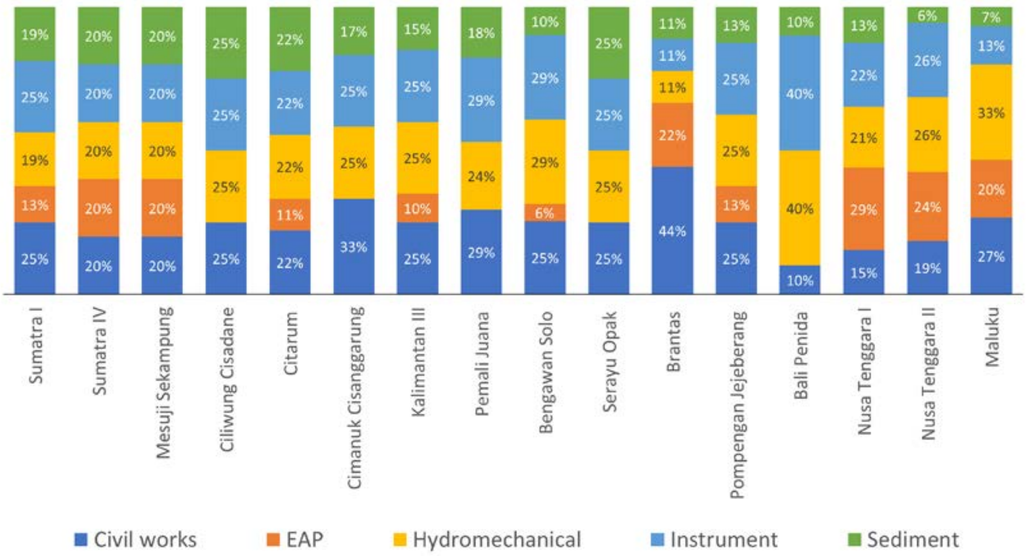

Fig. 3. Issues related to the deterioration of dam

Based on the dam inspection results for the dams in the River Basin Authority in Sumatra, Java, Bali, West Nusa Tenggara, and Maluku Islands, the dam issues related to deterioration are sedimentation, hydromechanics, dam instruments, lack of operation and maintenance (OM), emergency action plan update (EAP), and civil work (Fig. 3).

2.4 Development Model

The selection of the parameters to be used as the independent variable in this study was carried out using activity-based costing (ABC), which is an activity approach in dam management that functions as a cost driver (Fig.4). Based on the results of the ABC analysis and preliminary statistical tests, 18 parameters can potentially trigger costs: 1. Age, 2. Inundation, 3. Storage Capacity, 4. Length, 5. Height, 6. Irrigation, 7. Sedimentation, 8. Grass, 9. Woody

Vegetation, 10. Corrosion Area, 11. Concrete Deterioration, 12. Worker, 13. Corrosion Expert, 14. Coating Material, 15. Hydromechanical Maintenance, 16. Physical Performance; 17. Operational Performance, and 18. Safety Performance.

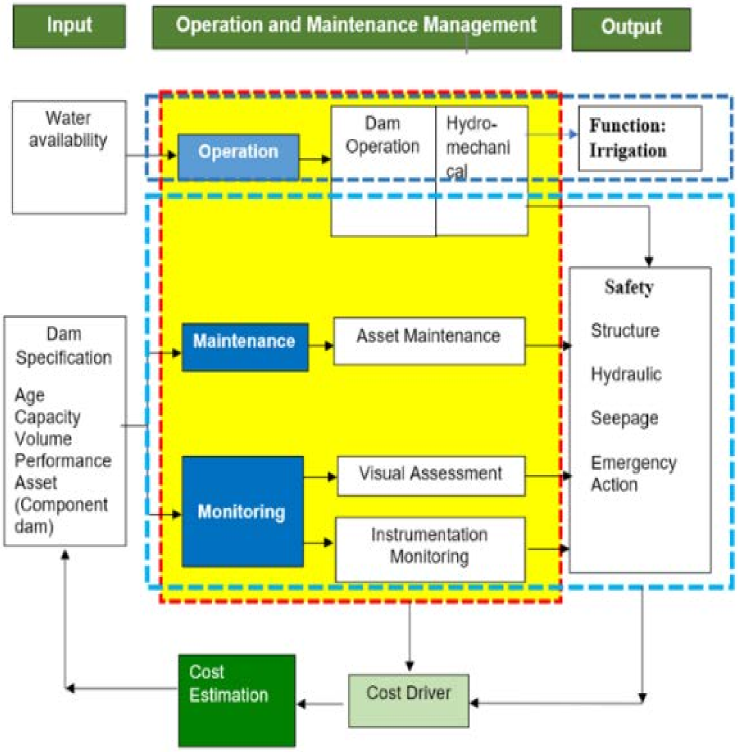

Fig. 4. Activity-Based Costing in Management of OM Dam

The operational costs and annual maintenance (Y) of the dam are parameters that will be used as dependent variables. Cost calculations are carried out according to the regulations and guidelines of the Ministry of Public Works and Public Housing [34,35]. The next stage is to conduct a linearity test that aims to determine whether the model specifications used are correct by testing the bias changes across the reference values. The variables that pass the significance testing are those that have a *p-value* <0.05, and R^2> 0.6, so it can be said that the estimate is significant or accepts the null hypothesis (36). Based on the statistical test results, 4 variables did not pass the test: Age, Inundation, Storage Capacity, and Length. Hence, the remaining 14 variables that will be modeled are Height (X_1), Irrigation (X_2), Sedimentation (X_3), Grass (X_4), Woody Vegetation (X_5), Corrosion Area (X_6), Concrete Deterioration (X_7), Worker. (X_8), Corrosion Expert (X_9), Coating Material (X_{10}), Hydromechanical Maintenance (X_{11}), Physical Performance (X_{12}), Operational Performance (X_{13}), and Safety Performance (X_{14}). To identify the data that significantly influence the dam component on the OM cost, we utilized Pearson's product-moment correlation coefficient (37) to explore how each independent attribute relates to the OM cost. The correlation coefficient can be calculated as follows:

$$C = \frac{\sum_{i=1}^{n}(a_i - \bar{a})(b_i - \bar{b})}{\sqrt{\sum_{i=1}^{n}(a_i - \bar{a})^2}\sqrt{\sum_{i=1}^{n}(b_i - \bar{b})^2}} \quad (1)$$

where 'n' represents the sample size, and ai and bi stand for the data values, while $\bar{a}$ and $\bar{b}$ represent the mean values. The coefficient (C) values range from -1 to +1. Values approaching +1 indicate a robust positive correlation, those near -1 signify a marked negative correlation, and those closest to 0 denote a negligible or no relationship.

3 RESULT AND DISCUSSION

The result of the relationship between variables to find the important parameter of OM cost using 14 activity variables and Equation 1 can be seen in Table 2.

Table 2. Correlation among activity variables

	Cost (Y)	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}	X_{13}	X_{14}
X_1	0.821	1.000	0.401	0.568	0.185	0.365	0.698	0.186	0.483	0.336	0.254	0.461	-0.079	0.021	-0.479
X_2	0.700		1.000	0.536	-0.010	0.252	0.391	0.482	0.056	0.158	0.486	0.723	0.053	-0.201	-0.303
X_3	0.622			1.000	0.158	0.094	0.653	0.092	0.114	0.128	0.227	0.562	-0.031	-0.216	-0.277
X_4	0.174				1.000	0.116	0.146	0.420	0.238	-0.050	0.031	0.102	-0.460	-0.095	0.141
X_5	0.464					1.000	0.308	-0.044	0.022	-0.144	-0.121	0.411	-0.295	-0.188	-0.273
X_6	0.638						1.000	0.129	0.063	0.095	0.056	0.586	0.004	0.040	-0.317
X_7	0.410							1.000	0.201	0.368	0.432	0.376	-0.217	0.063	-0.051
X_8	0.407								1.000	0.546	0.369	-0.170	-0.167	0.068	-0.275
X_9	0.338									1.000	0.547	-0.125	0.283	0.174	0.024
X_{10}	0.486										1.000	0.150	0.239	-0.102	-0.205
X_{11}	0.735											1.000	-0.224	-0.091	-0.436
X_{12}	-0.159												1.000	-0.012	0.223
X_{13}	-0.100													1.000	0.089
X_{14}	-0.612														1.000

The multicollinearity test aims to determine whether a regression model correlates with independent (independent) variables. A good regression model should not correlate with the independent variables. Multicollinearity testing was performed using the Variance Inflation Factor (VIF) and tolerance. If the tolerance value was ≥ 0.10, or the VIF value was ≤ 10, there was no multicollinearity in the regression model. The VIF was calculated using the following formula:

$$VIF=\frac{1}{1-R_i^2} \tag{2}$$

Based on the multicollinearity test results [38], the tolerance value of each independent variable is above 0.10, and the VIF value is below 10. This indicates that there was no multicollinearity in the regression model.

Meanwhile, a partial test is carried out to show how far the influence of each independent variable individually influences or explains the dependent variable Routine Cost (Y). Based on the test results, several variables have a significant value of <0.005 and $t_{stat} < t_{table}$ value; therefore, these variables do not show a positive relationship with OM costs. Variables that passed the T-test and showed a positive relationship with OM costs were height (X_1), Wood Vegetation (X_5), Coating Material (X_{10}), mechanical maintenance (H_{11}), and Safety Performance (X_{14}). The results of the VIF value, Significance Level of Coefficient, and R^2 Value for the Final Model are shown in Table 3.

Table 3. Collinearity diagnostic

	Unstandardized Coefficients		t	Sig	Collinearity Statistics	
	B	St. Error			T*	VIF
X_1	672.46	71.03	7.19	0	0.63	1.577
X_5	2.14	0.29	2.54	0.02	0.73	1.361
X_{10}	0.05	0.02	5.58	0	0.86	1.162
X_{11}	0.076	0.137	5.72	0	0.669	1.496
X_{14}	0.004	0.001	-2.14	0.042	0.702	1.424
R^2	0.927					

*Tolerance

After all the tests are performed and meet the requirements of a model, the regression equation is:

$$Y= \alpha+\beta_1 (X_1) +\beta_5(X_5) +\beta_{10} (X_{10}) +\beta_{11}(X_{11}) +\beta_{14}(X_{14}) \tag{3}$$

$$Y= 671.458 + 2.142 (X_1) + 0.056 (X_5) + 0.765 (X_{10}) +0.004 (X_{11}) - 1.964 (X_{14}) \tag{4}$$

Where the independent variables are:

X_1: Height

$X5$: Wood Vegetation

$X10$: Coating Material

X_{11}: Hydromechanical Maintenance

X_{14}: Safety Performance

The independent variable that has the greatest effect on dam maintenance operation costs is the height of the dam, which is indicated by its correlation value and is close to 1. This is in line with the International Commission on Large Dam (ICOLD) standard and regulation [20], which states that the height of the dam is used as a reference for categorizing large and small dams and determining the dam risk score [39].

The description standard of the dam definition is as follows.

- A dam with a height greater than 15 (fifteen) meters was measured from under the foundation to the top.
- A dam with a height of 10 (ten) meters to 15 (fifteen) meters is measured from the bottom of the deepest foundation provided that:
  - the length of the top of the dam is at least 500 (five hundred) meters.
  - reservoir capacity was at least 500,000 (five hundred thousand) cubic meters.
  - the maximum flood discharge calculated is at least 1000 (one thousand) cubic meters per second.

The dam risk class elements are as follows:

- very high risk: above 45 meters
- high risk: 30 - 45 meters
- moderate: 15-30 meters
- low: below 15 meters

Thus, height is an important variable in dam management because it is related to dam safety. The higher the dam, the higher the risk level experienced when there is a dam failure.

Another variable that influences is hydromechanical. Almost all dams have problems with hydromechanical equipment, which functions as a water regulator in both the rainy and dry seasons and directly impacts safety performance. Examples of intake door hydromechanical components and their subcomponents include valves, threads, ladders, handlebar turning doors, and blowers.

The next variable affecting OM costs was wood vegetation. It can be understood that the damage to the dam was caused by quite a lot of vegetation, especially single-rooted vegetation. Arrangement of areas or zones that do not allow the presence of plants. This is because of the influence of the roots, which can potentially damage the dam.

Trees and woody vegetation are considered dangerous for growth in stockpile areas. Problems caused by the growth of trees and woody vegetation include fallen trees producing large cavities and reduced freeboard, reduced maintenance stability, root rot creating seepage paths and internal erosion problems, interference with dam safety monitoring, inspection, and maintenance for seepage, cracks, drain holes, slumping, settling, deflection, and other signs of stress. The last variable that has an effect is security performance, where the security performance assessment consists of five components: 1) performance assessment of instrumentation observations, 2) performance results of dam inspection, 3) boundary and greenbelt conditions, 4) reservoir conditions, and 5) condition of the surrounding community.

This component indicates that the instrumentation dam is very important in dam safety because, through the reading of the instrumentation, the behavior of the dam can be seen, as well as indicators of changes that indicate the potential for dam damage. Unfortunately, almost all instrumentation tools have been damaged or even lost.

4 CONCLUSIONS

The application of Activity-Based Costing (ABC) in the context of dam operation and maintenance presents a fundamental shift in the management approach, emphasizing a more precise and nuanced understanding of cost allocation. Throughout this manuscript, the investigation into the selection parameters for the operation and maintenance of dams based on ABC has revealed key insights. The findings highlight the efficacy of ABC in providing a more accurate and comprehensive cost assessment, leading to informed decision-making. This study underscores the significance of selecting appropriate parameters within ABC for the effective management of dam operations and maintenance. A more refined and strategic approach can be implemented by identifying the specific activities that directly contribute to costs. Such a method not only enhances cost control but also enables resource optimization and improves overall performance. The parameters that influence the operating and maintenance costs of the dam are height, wood vegetation, coating material, hydromechanical maintenance, and safety performance. This model indicates that the safety performance of a dam is an important parameter for OM cost. This implies that safety performance components such as monitoring activities, periodic inspections, maintenance of dam boundaries and greenbelts, maintenance of reservoir quality, and increasing awareness of the surrounding community should be included in dam OM management to minimize the level of dam damage. In conclusion, the utilization of ABC in determining the selection parameters for the operation and maintenance of dams presents a pivotal advancement in the 10% reduction in OM cost. This manuscript advocates for a meticulous selection of parameters that align with the unique operational and maintenance activities of dams.

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