Evaluation of Real Needs Number for Operation and Maintenance of Dams in Bali Province

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ABSTRACT

A 1.04% population increase and a 14.08% expansion in crop area in Bali Province have raised water demand. Dams are essential for securing water availability, but they require proper operation and maintenance (O&M) to function effectively. O&M costs should be regularly evaluated against actual needs to ensure efficiency. This study assessed the O&M suitability of four dams in Bali: Benel, Telaga Tunjung, Gerokgak, and Palasari. Their performance was evaluated based on physical condition, operational safety, and institutional aspects using a 0 to 100 scale. All four dams received an "enough" rating, indicating the need to reassess their actual O&M requirements. Gerokgak Dam had the highest real O&M cost at IDR 28.77 billion, with more than 90 percent of the budget allocated for dredging. Since dredging costs are heavily influenced by sediment volume, reducing sedimentation is crucial. Improving dam performance and irrigation support also requires better O&M efficiency. With limited operators and increasing demand, efforts to control sediment and manage water supply more efficiently must be strengthened in line with reservoir conditions.

Keywords: Dam, Evaluation, Maintenance, Operation, Real Needs Number.

1. INTRODUCTION

As the population grows and farmland expands, meeting water demand becomes more challenging. Rice makes up 69 percent of the water footprint from food due to its high-water use and high consumption in Indonesia. This highlights the need for water infrastructure like dams to help manage and secure water resources[1],[2]. So, a water infrastructure such as dam is needed to support water resources management.

Dams are structures built from earth, stone, or concrete to store water or contain waste, forming reservoirs [3]. They are classified as single-purpose (e.g., for irrigation) or multi-purpose (e.g., irrigation and drinking water) [4]. In Bali, single-purpose dams like Gerokgak (Buleleng) and Palasari (Jembrana) serve irrigation needs and operate in coordination with *subak* water user groups [5]. Multi-purpose dams such as Benel (Jembrana) and Telaga Tunjung (Tabanan) provide both irrigation and raw water. The location of the dams can be seen in Figure 1 and Figure 2**.**

The operation of the structures inside the dam will depend on their utilization. Such as the intake channel, which has the main purpose of drawing water from the reservoir and then delivering it to the irrigation channel so that it can be utilized according to water demand. In addition to this main function, there are 3 other functions, namely, to control the inflow of water, minimize silting of irrigation channels by controlling the inflow of sediment, and prevent blockage by dirt at the entrance [6]. Another structure is the outlet, which is distinguished by its hydraulic operation.

Figure 1. Location of operation and maintenance dam projects in Bali Province

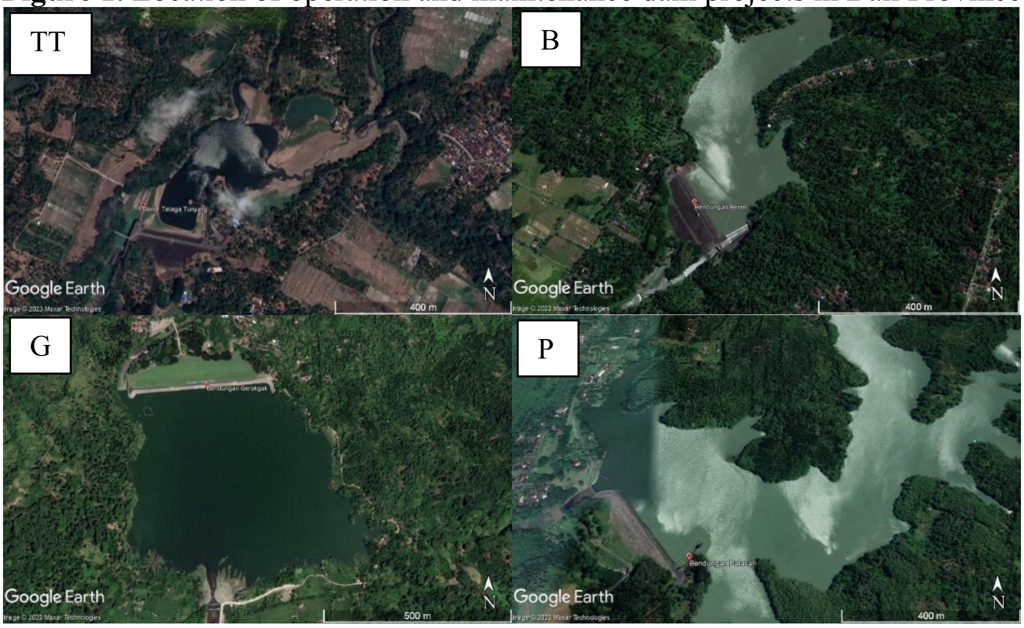

Figure 2. Satellite images of dams in Bali Province with Telaga Tunjung (TT), Benel (B), Gerokgak (G), and Palasari (P).

The technical data of the four dams in Table 1 show significant differences in storage volume. According to the data in the Table 1, it is known that Palasari Dam has the largest storage followed by Gerokgak Dam. Compared to these two dams, the storage of Benel and Telaga Tunjung Dams is smaller.

Table 1. Current Technical data of Bali Province Dams with B for Benel, TT for Telaga Tunjung, G for Gerokgak, and P for Palasari.

Name	**Type**	**Year**	**Irriga-tion (ha)**	**Raw Water (lt/s)**	**Latest Update**	**Dead Storage (Million m^3)**	**Effective Storage (Million m^3)**	**Total Storage (Million m^3)**
B	Multi	2008	1.047	64	2017	0,01	1,43	1,47
TT	Multi	2006	1.185	20	2020	0,02	0,63	0,69
G	Single	2000	737	-	2018	0,32	2,16	2,48
P	Single	1989	933	-	2018	0,08	6,96	7,2

Dams, as large-scale infrastructure, require careful management, as failures can be fatal. In Indonesia, operational, maintenance, and safety challenges demand targeted solutions. Proper use and upkeep are essential to ensure functionality and extend service life. Equipment failures raise operating costs and heighten the risk of environmental harm due to malfunctions or disruptions [7], [8].

An Operation and Maintenance (O&M) Manual is a detailed written document of procedures and protocols for ensuring that a dam is operated and maintained properly and timely to avoid further health deterioration, prolong its life, maintain a safe structure and extend service life of these assets [9], [10]. Therefore, operation and maintenance (O&M) must be carried out optimally, with costs evaluated regularly. These costs are referred to as the Real Needs Number for Operation and Maintenance (RNM O&M). RNM O&M reflects the actual cost required to implement O&M activities [11]. These costs play a critical role in ensuring sustainable water system management, where effective strategies help minimize expenses while maintaining system reliability and efficiency. [12].

The suitability of Real Needs for Operation and Maintenance (RNM O&M) is crucial for sustaining dam and reservoir services, ensuring a reliable water supply. Dam performance assessment serves as a key tool to evaluate RNM O&M appropriateness. If performance is high, the current RNM O&M may be sufficient. Identifying the most influential O&M activities is therefore essential, especially for dams in Bali. Total performance scores are determined by assigning weighted values to each performance aspect, as shown in Table 2, starting from the most significant.

Table 2. The Weight of Building Performance

`Performance	**Weighted (%)**
Physical	40
Operational	30
Security	15
Institutional	15

2. REAL NEEDS NUMBER FOR OPERATION AND MAINTANANCE

In accordance with the purpose of RNM O&M, which is to provide an estimate and evaluation of the O&M activities to be carried out so that the methods and costs can be arranged properly [9], the calculation of RNM O&M for Bali Province Dam is carried out based on the results of the assessment of field conditions and performance in each aspect of the dam component. The scope of the calculation is divided into three based on the frequency needs of O&M, including (A) Annual Routine Maintenance Needs, (B) Special Maintenance Needs, and (C) Periodic Maintenance Needs [13].

2.1 Performance Assessment

Performance assessment is the first step in the preparation of RNM O&M [11], [14], which is divided into 4 performances, namely physical, operational, security, and institutional performance. Physical performance assessment is carried out on the physical condition of the building. The assessment of physical conditions is very decisive, if the assessment from a physical point of view is feasible the performance assessment from other aspects can be carried out [15].

Physical performance assessment on dams has differences in its components. The components of the physical performance assessment of dams are generally divided into (1) Main Structure, (2) Intake channel, (3) Discharge channel, (4) Spillway.

2.2 Evaluation of Real Cost of Operation and Maintenance

RNM O&M costs are calculated using coefficients derived from the analysis of dam operation and maintenance (O&M) activities. After determining these coefficients, a Unit Price Analysis (UPA) is conducted to estimate the cost of labor, materials, and equipment for each type of work. The UPA results, combined with the frequency of annual, special, and periodic O&M activities, form the basis for calculating total RNM O&M costs, which are the sum of annual (A), special (B), and periodic (C) costs. This analysis helps identify the dam with the highest O&M requirements, which is then compared with factors such as storage capacity, service area, and performance score. The final recapitulation reveals which O&M work item contributes the most to total RNM O&M costs, providing valuable insight for maintenance planning and prioritization.

2.3 METHODS

The evaluation of the four dams is based on their performance assessment results, which serve as the basis for determining updated RNM O&M values. Dams rated below "Good" undergo a re-analysis to adjust their RNM O&M costs accordingly. Data for the assessment were collected through field surveys conducted from February to August, including visual inspections, questionnaires, operational history, and bathymetric measurements. This re-analysis serves as an evaluation of the previous RNM O&M, producing revised cost estimates that cover three main activities: annual (A), special (B), and periodic (C) maintenance. These activities are then analyzed by cost, broken down into sub-activities, and compared across dams. Each sub-activity is further examined in relation to specific dam characteristics, allowing for the identification of correlations between dam features and the magnitude of associated maintenance costs.

3. RESULTS AND DISCUSSION

The first thing to look for is a building performance assessment, so that the dam to be evaluated for RNM O&M can be determined. The RNM O&M that has been analyzed is then identified as the biggest contributor to the cost of the RNM O&M that has been analyzed.

3.1 Dam Performance Values

The results of the performance assessment, along with the total score based on its weight are shown in Table 3. The Scores are presented in order of best/largest.

Table 3. Dams Performance Assessment

Dam	Physical	Operation	Security	Instutional	Total	Criteria
Telaga Tunjung (TT)	73,3	82,44	76,7	75,31	76,85	Enough
Palasari (P)	75,46	81,99	69,61	76,7	76,73	Enough
Gerokgak (G)	72,52	81,08	72,06	71,84	74,91	Enough
Benel (B)	66,29	80,96	76,07	76,11	73,63	Enough
Average	71,89	81.62	73,61	74,99	75,53	Enough

All buildings showed an average score of 75.53 (enough). This indicates that the four dams to be re-analyzed for RNM O&M in an effort to improve O&M activities.

3.2 Real Needs Number for Operation and Maintenance Evaluation

The cost obtained after the analysis is the result of calculations which will then be re-evaluated. The results of the analysis in Table 4 show that the cost of RNM O&M is between 13 – 28 billion (IDR). The cost of periodic O&M activities (C) has the highest value in the four dams.

Table 4. Result Real Needs Number of Operation and Maintenance (RNM O&M) of Dams

Code	Activities	Cost (Billion IDR)			
		B	TT	G	P
A	**Total Routine Operation & Maintenence**	**1,50**	**1,78**	**1,38**	**1,97**
B	**Special Operations and Maintenance**	**0,06**	**0,19**	**0,40**	**0,02**
C	**Periodic Operation and Maintenance**	**14,87**	**11,79**	**26,99**	**18,49**
	2-Year Operations and Maintenance	0.004	0.004	0.004	0.004
	5-Year Operations and Maintenance	3.17	3.17	3.17	3.17
	20-Year Operations and Maintenance	11.7	8.62	23.82	1.65
Total		**16,42**	**13,76**	**28,77**	**20,48**

The value of C compared to A and B is illustrated In Figure 3, which is a graph of the percentage of A, B, and C costs to total costs. The cost of activity C dominates the overall RNM O&M cost structure in the four dams.

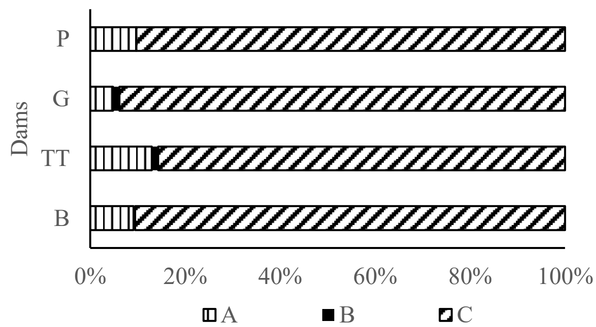

Figure 3. Percentage of O&M Activity in RNM O&M Arrangement

3.3 Identification of Activity Costs at Real Needs Number for Operation & Maintenance

The activities arranged in C as in Table 4, show the cost of O&M 20-annual as the most dominant (highest) cost. This is because the 20th annual O&M has dredging costs with the highest value compared to other sub-activity costs, as shown in the graph in Figure 4.

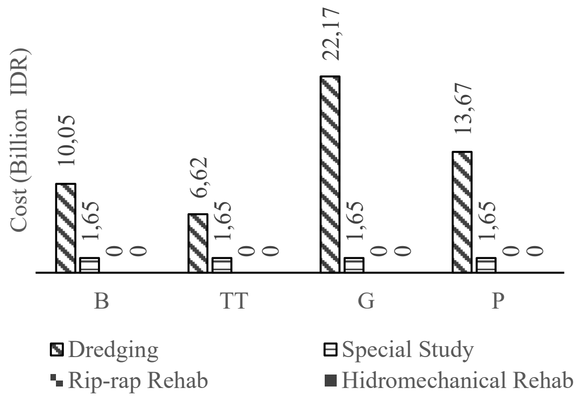

Figure 4. Sub-activity Costs in the 20th Annual O&M

The significance of dredging work can be seen from the graph in Figure 5 which shows the comparison of dredging costs with the overall cost of RNM O&M.

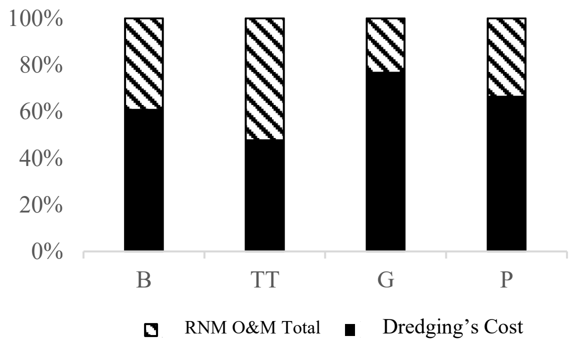

Figure 5. Comparison of Dredging Cost with RNM O&M Cost.

3.4 Analysis of Dredging Finance

Dredging involves relocating sediment from a water body to a containment area. Though costly, its use is expected to rise with increasing water demand [16]. As part of sediment management, dredging supports long-term storage recovery, particularly by restoring dead storage within reservoirs [17]. In O&M planning, it is classified as a 20-year periodic maintenance activity and must follow applicable regulatory guidelines. [18].

Mechanical dredging uses equipment like excavators, backhoes, or clamshell buckets to remove coarse materials such as gravel and rock. It's ideal for near-shore areas with space for machinery and requires multiple support units like loaders and trucks, making it labor-intensive with complex logistics [19].

There are two types of sediment disposal using hydrosuction: hydrosuction dredging and bypassing. This method deposits dredged sediment transported downstream, into containment basins, or treatment basins as shown in [20].

Dredging analysis involves two stages: calculating dredging volume and unit price. Volume is determined by comparing the latest reservoir storage curve with the design curve. Unit price depends on the dredging method (mechanical or hydraulic) and includes sediment transport distance. Table 5 shows Gerokgak Dam has the highest dredging volume, likely due to high sedimentation relative to its dead storage. Meanwhile, Palasari Dam has the highest unit price due to different method or transport conditions.

Table 5. Dam Dredging Activities

Dam	B	TT	G	P
Latest Dead Storage Volume (billion m^3)	0.01	0.005	0.23	0.08
Sediment Rate Calculation Period	2010 - 2017	2015 - 2020	1999 - 2018	1989 -2018
Sediment Rate of Dead Impoundment (billion m^3/year)	0.0029	0.003	0.016	0.0066
Dredging Volume (billion m^3)	47.232	59.967	93.036	52.107
Unit Price Dredging (IDR)	212.736	116.235	238.282	262.263

Optimal operation and maintenance are essential for sustaining a dam's functionality, yet many reservoirs fail to meet their intended purpose due to sedimentation caused by upstream erosion, which significantly impairs performance [21]. Effective sedimentation management is critical to preserving reservoir capacity, as accumulated sediment reduces storage volume, compromises irrigation supply, and increases flood risk. Therefore, addressing sedimentation is a key priority to ensure reservoirs continue to operate effectively [22].

4. CONCLUSIONS

Based on the results of the RNM O&M preparation of dams carried out on 3 activities, namely routine (A), special (B), and periodic (C) O&Ms, the following conclusions were obtained:

1. All four dams failed to meet the "Good" performance standard, prompting a reassessment of their Real Needs for Operation and Maintenance (RNM O&M) to accurately determine the necessary costs for sustaining functionality.
2. Gerokgak Dam recorded the highest RNM O&M cost at over IDR 28.7 billion, mainly due to its large dredging volume (93,036 m^3), not high unit prices. This highlights how structural and operational differences significantly affect maintenance needs and costs.
3. Periodic O&M activities, especially dredging, accounted for over 90 percent of total RNM O&M costs. The dredging volume, rather than unit price, was the main cost driver, underscoring the need to maintain reservoir capacity in areas with high sedimentation.

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