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# Performance Index Model of Small Dam in Semi-Arid Area

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**Abstract**

The aim of this research is to build a model of small dam performance index in semi-arid areas by considering 4 aspects that are physical, institution, service, and operation and maintenance aspects. Research locations are 85 small dams that spread to 8 islands and 5 SWS in 22 regencies in Nusa Tenggara Timur Province. The data consists of secondary data from BWS NT II and primary data from survey results and survey blank filling to 85 locations of small dams in the field. The methodology consists of Structural Equation Modeling Partial Least Squares (SEM-PLS) and Generalized Reduced Gradient (GRG). The analysis result shows that physical; institution; service; and operation and maintenance aspects are significantly influenced by the performance index of small dams. The structural analysis expresses that physical; institution; service; and operation and maintenance aspects are positively and significantly influenced by the performance index of small dams. The novelty in this research is the performance index of small dams that is successfully developed and tested by using field data and GRG. In addition, this model gives accurate value to the performance index of small dams in semi-arid areas in Nusa Tenggara Timur Province. However, the performance index model of small dams in semi-arid areas is formulated as follows: IK physical = 0.093 KT + 0.128 KTE + 0.159 KBS + 0.087 BPL + 0.155 JD + 0.145 KBLY + 0.233 KBP; IK institution = 0.58 DOP + 0.42 RA; IK service = 0.56 KBL + 0.09 AM + 0.12 VG + 0.09 WK + 0.14 PA; IKOM = 0.360 PKOP + 0.515 PPE + 0.125 KSOP. The general formulation for performance index of small dams is I IDK-Pentewati = 0.15 IK physical + 0.12 IK institution + 0.20 IK service + 0.53 IK OM.

*Keywords:* Small Dam; Semi-Arid; Performance Index Model; NTT.

## 1. Introduction

As one of the provinces in the Indonesia Timor area, Nusa Tenggara Timur Province has a semi-arid climate and is the island's province with a short rainy season; however, rainfall is in great number but only in a short period. The rainfall intensity average is 1,200 mm/year with a long dry season, so it causes water source discharge to decrease dramatically. In addition, the topography condition in most of the Nusa Tenggara Timur province is hilly, so water discharge during the rainy season most of it is wasted and flowing back into the sea. However, the condition of hilly topography and lots of depressions can store rainfall. Based on the condition and the big potency of surface water run-off in rainy season, one of the water source supplying efforts for raw water supply, water for husbandry, and water for garden-yard is utilizing surface water by building a small dam as a water storage container in rainy season and then to be used in dry season. The main function of the small dam in Nusa Tenggara Timur province is prioritized for raw water, then it is followed by husbandry and garden plants. The small dam is very helpful for fulfilling society's water demand in surrounding small dams that do not have access to water sources, so the availability of the small dam in Nusa Tenggara Timur Province is very important.

Based on the Statistical Centre Institution (BPS) of NTT Province 2021, there are developed 3,658 small dams in NTT Province that spread in all of NTT Province. Many small dams that have been developed are damaged, and the

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function is decreasing. Remembering the role of small dams is to fulfill water demand in Nusa Tenggara Province, it is needed to evaluate the performance of the small dams. A small dam can be said to be a success if the physic does not damage and can be well functioned from the service aspect; it can service water demand in accordance with the small dam provision; however, from the operation and maintenance aspect, a small dam is said to be a success if the small dam can be well managed and all of them are running normally in accordance with the small dam, so the institution aspect is said to be a success too.

Some studies about the performance index [1, 2] have also been carried out for assessing the small dams' performance, such as the performance evaluation of a rice field small dam, which is focused on the physical aspect [3]. The performance evaluation of the Oeltua small dam is reviewed by using the approach system on the aspects of water availability, physics, utilization, operation, and maintenance (O & M), and management of the organization [4]. Study that is carried out by Bunganaen [5] in analyzing the performance of Oelomin small dam in Kupang Regency, it is only reviewed from the aspects of physic, utilization, operation, and maintenance (O & M), which the two studies referred to in the Guidance of Small Dam Design-Department of Indonesian General Work (PU). In the study of Karnawati et al., it analyzed the asset performance of Cijere Reservoir in Bandung Barat Regency that is seen based on the performances of physic, functional, utility, and monetary. The aspects are based on the Australian Aset Management Collaborative Group [6]. However, Situmorang et al. [7] evaluated the performance of Sei Gesek small dam by using 5 perspectives in measuring the performance of raw supplying because there isn't any yet the guidance of small dam performance assessment, so the variables that are used are still needed for further research. No one in this research above performs the performance index model of small dams that represents the mathematical assessment about the technical and non-technical aspects of small dams. From the research above, assessing the performance index of small dams is needed in the decision-making process for policymakers and the sustainability of small dams in the future.

Based on the discussion above, it can be concluded that the performance index assessments of small dams that have been carried out have not represented physical, service, institution, operation and maintenance aspects, technical, and non-technical aspects of the small dams. In addition, nobody has found the performance index model of a small dam. There is a performance index for the irrigation small dam but not for assessing the performance index for the small dam itself. To implement the work about the performance index of small dams, which refers to the technical guidance of small dams by the Indonesian Ministry of General Work and Public Housing-Directorate General of Water Resources 2020, in this rule there is not specifically regulation about the performance index assessment of small dams. So far, the assessment of small dam performance index still uses the rule for small dams that is modified in order to be able to be used in the implementation of the assessment of small dam performance.

The assessment of small dams' performance index is very needed to assess a small dam so it can be carried out optimal maintenance and the function is always well running. This performance index of small dams involves the influenced aspects of its function, the physical condition of the small dam in the field, the service condition, which is already running, the condition of the available institution, and how operation and maintenance are available so the small dam can give optimal benefit for user society. This research result aims to obtain a performance index model of small dams that can be used as a reference in managing small dams so accurate handling can be carried out in accordance with demand and condition in the field. By knowing the weight of each aspect, component, and indicator, it is known how far the influence of every parameter is on the performance of the small dam structure. By seeing the weight spread, it can be carried out the priority efforts for increasing the performance of small dam structures. The effectivity of resources used will become accurate if it is directed to the aspect, component, and indicator that has the biggest influence.

However, until now, there has not been guidance that regulates the performance index of small dams specifically; therefore, it is needed a model of small dam performance index by relating among the parameters for knowing the performance index value of small dams. The result of this research is a performance index model of small dams that is useful in carrying out the operation and maintenance of small dams.

## 2. Material and Methods

### 2.1. Management of Small Dam

The law No. 7-2004 about water resources mentions that maintenance is an activity for maintaining water sources and facilities of water sources, which is intended to guarantee the sustainability of water source function [8] and infrastructure of water sources.

The scope of network maintenance activity includes inventory, design, implementation of monitoring, and evaluation. The monitoring of a small dam is an inspection activity, inspection and monitoring the physical condition and the functional of mechanical components, electric, hydraulic, and civil, which are regularly carried out by a certain period; it should not be more than 3 months. The routine inspection involves the inspection of erosion, blockages, cracks, moving, avalanches, etc. that are related to the small dam's functional and safety [9]. In implementation inspection activity is carried out the assessment to the physical condition and the function of every structure component, which then will be used as the determination base of priority scale in preparing the plan of maintenance activity. The determination criteria of structure physical condition are as follows: a) Good condition, if the damage level < 10% of the initial condition; b) Light damage condition, if the damage level is from 10% until 20% of the initial condition; c) Moderate damage condition, if the damage level is from 21% until 40%; and d) Heavy damage condition, if the damage level is > 40%.

However, for determining the structure function, the determination criteria of classification are as follows: a) Well functioned, if the structure functional level is > 80% of the initial condition; b) Less, if the structure functional level is from 70% until 80% of the initial condition; c) Bad, if the structure functional level is from 40% until 69% of the initial condition; and d) Not functional, if the structure functional level is < 39% of the initial condition.

The physical structure of a small dam can be divided into several components: the small dam body, spillway, intake, outlet, inspection road, and structure or supporting facility, each of which is divided back into several sub-components. For the facility in implementation of the inspection in the field, there is a form for filling out the inspection activity for each component of the small dam structure. Figure 1 presents the illustration of a small dam with its components.

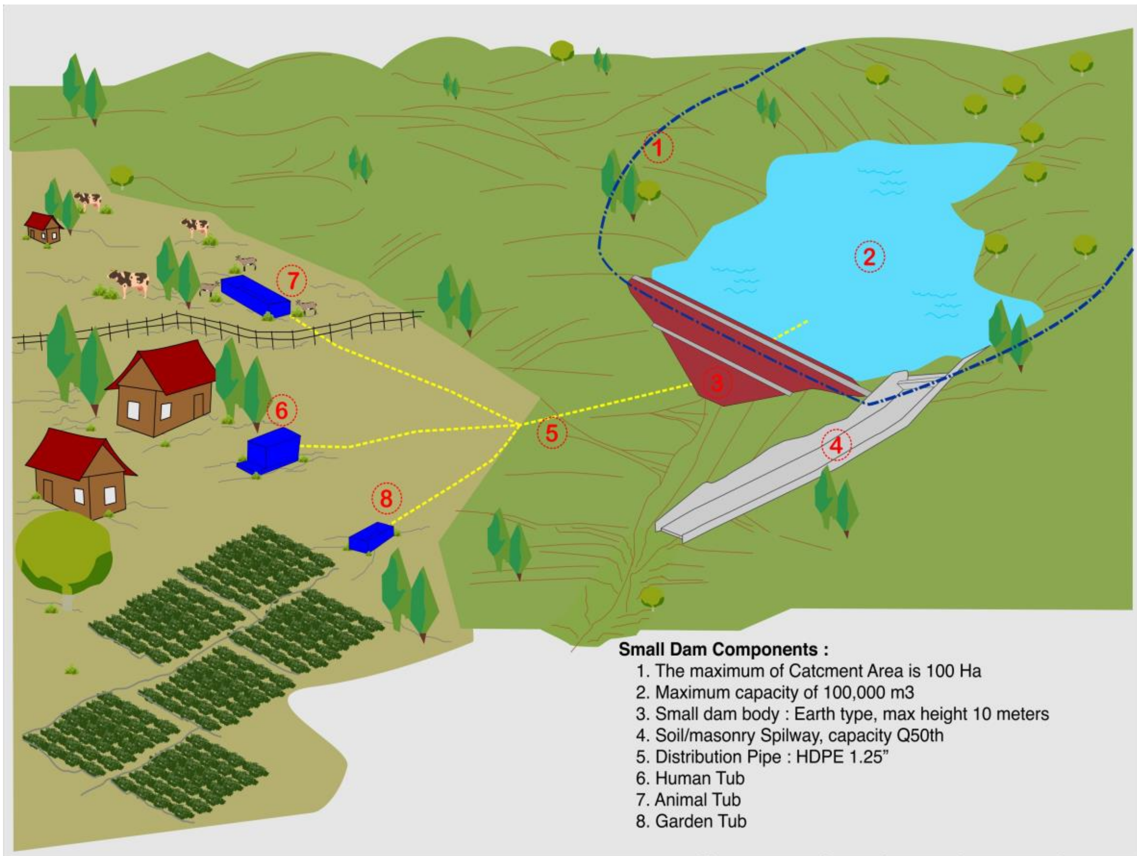


**Figure 1. Illustration of Small Dam and Its Component**

## 2.2. Research Concept

The linear equation will be applied for finding the relation and dimension of 4 aspects in the assessment of small dam performance that are aspects of physics, service, operation and maintenance, and institution. Figure 2 presents the design plan of the model development thinking scheme.

## 2.3. Research Location

The province of NTT (Nusa Tenggara Timur) has weir and small dams in very big quantities. However, it is only used for household water demand, agriculture, husbandry drinking, and storing water in the dry season. The climate of NTT province is affected by seasonal wind, so the climate is dry here, with a rainy season only from December until April (5 months) and a dry season from May until November (7 months). The selection of research location is conducted in 3 big islands in NTT province that are assumed to represent the natural condition of Nusa Tenggara Timur. The research location consists of small dams (85 units) and is able to represent semi-arid areas because the research locations are spread across Flores Island (13 locations), Sumba Island (15 locations), 3 locations in Rote Island, 3 locations in Sabu Island, in Timor Island (43 locations), in Alor Island (4 locations), and in Lembata Islands (4 locations) that are all developed by the River Region Institution of Nusa Tenggara II. The research location is spread and can be seen as in Figure 3.

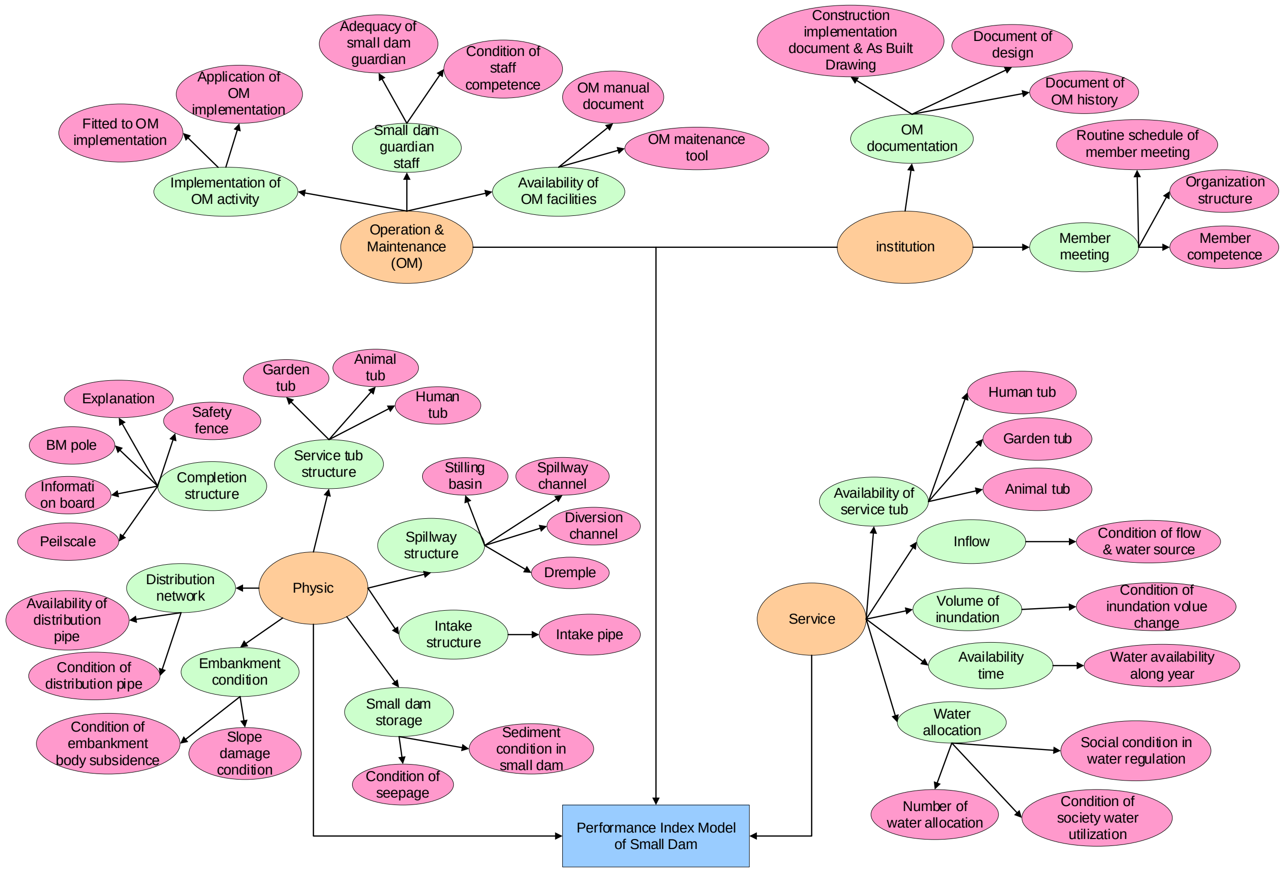


**Figure 2. Design Plan on Mind Frame of Model Development**

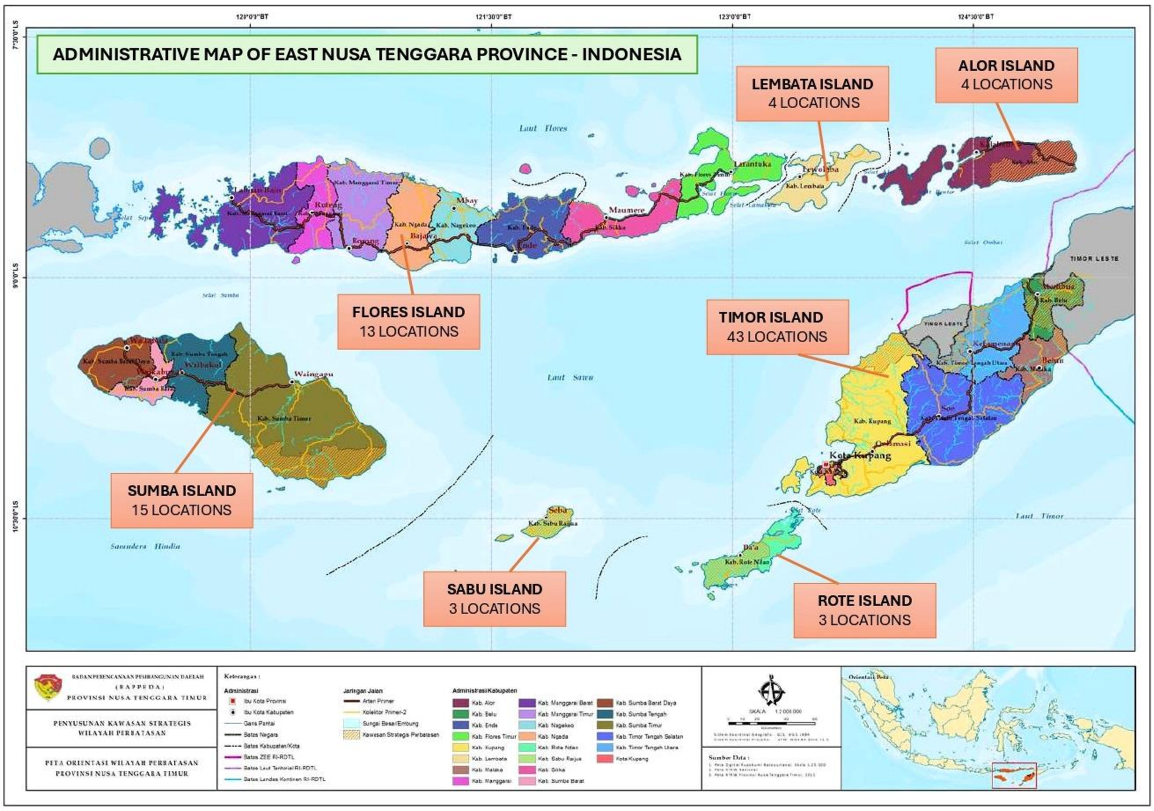


**Figure 3. Map of Research Location: (Bapedda, NTT Province 2022)**

Besides that, the location plan of primary data in small dams in Nusa Tenggara is based on the river region. From 85 locations, it is known that the 5 locations of river regions are Flores, Flotim Kepulauan, Lembata Alor, Noelmina, Sumba, and Benanain. Unit Map of River Region (SWS) in NTT can be seen as in Figure 4 below.


**Figure 4. River Region in Nusa Tenggara Timur (NTT): (President Decision of Indonesia, 2012)**

## 2.4. Aspects and Components for Small Dam Assessment

This research uses the variables for supporting the research result as follow:

***A. Dependent Variable:***

a. Physical index of small dam (IK $_{\text{Physic}}$);
b. Organization management index (IK $_{\text{Institution}}$);
c. Service index of small dam (IK $_{\text{Service}}$);
d. Operation and Maintenance index (IK $_{\text{Operation and Maintenance}}$).

***B. Independent Variable:***

a. Physical index weight (α);
b. Institution index weight (β);
c. Service index weight (δ);
d. Operation and maintenance index weight (γ);
e. Condition of embankment (KT);
f. Condition of small dam storage (KTE);
g. Condition of spillway structure (KBS);
h. Condition of intake structure (BPL);
i. Condition of distribution network (JD);
j. Condition of service tub (KBLY);
k. Condition of completion structure (KBP);
l. Condition of service tub availability (KBL);
m. Condition of inflow (AM);
n. Condition of inundation volume (VG);
o. Condition of time availability (WK);
p. Condition of water allocation (PA);
q. Condition of OM activity implementation (PKOP);
r. Condition of small dam guardian staff (PPE);

s. Condition of O & M facility availability (KSOP);
t. Condition of O & M documentation (DOP);
u. Condition of member meeting (RA).

## 2.5. Methods and Step of Research Design

Methods and step of research design is as follow (Figure 5):

- Literature study.
- Analysis of data and existing small dam condition based on the rules that are published by Indonesian Ministry of General Work and Public Housing.
- Arrangement of the parameter's performance index assessment of small dam.
- To arrange the model of small dam performance index by using SEM with Smart-PLS [10, 11].
- Validation.
- To build the model of small dam performance index with Solver Excel GRG.

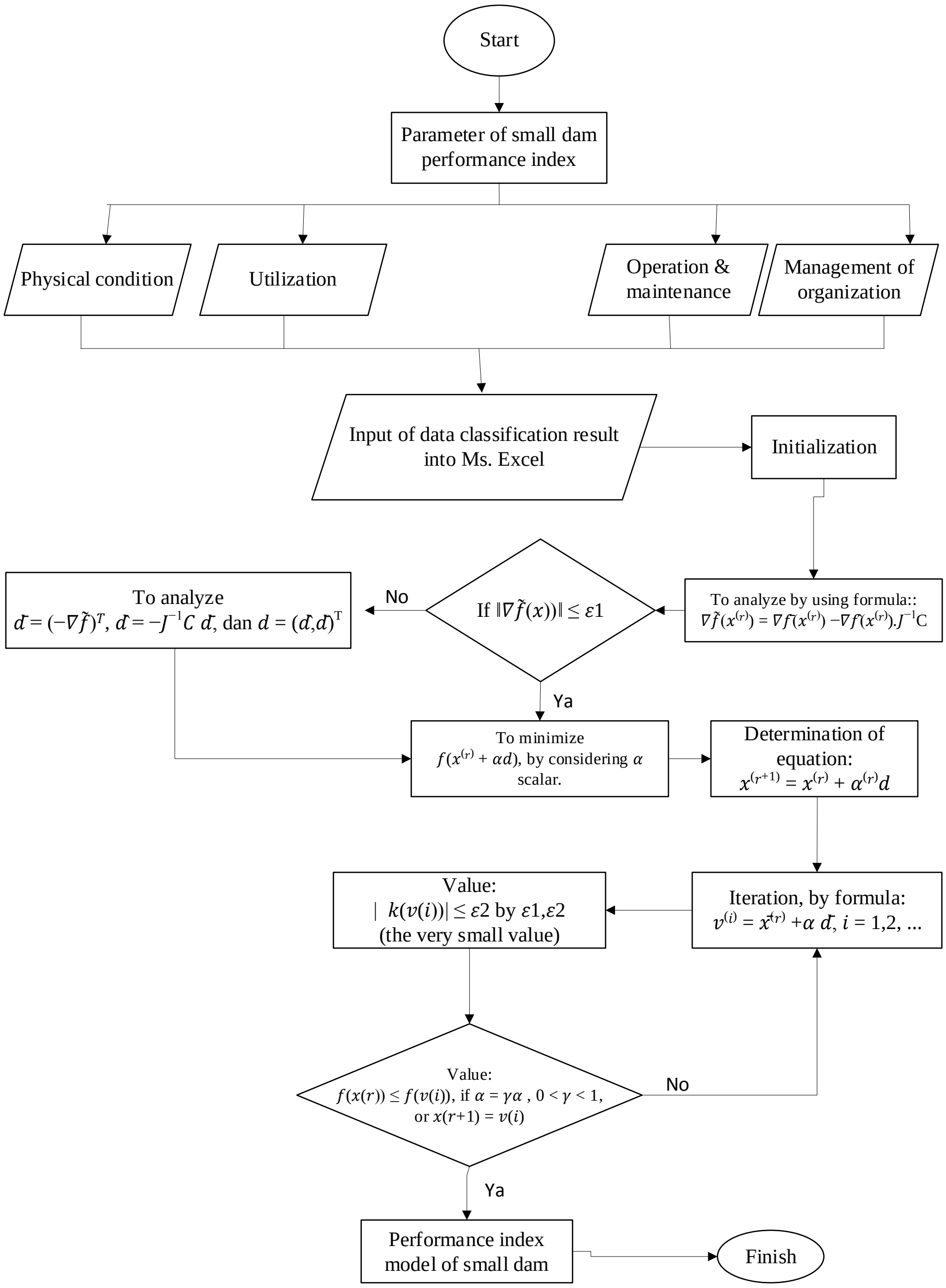


**Figure 5. Flow Chart of Small Dam Performance Index Model**

After statistical validation, the model can then be used to assess the performance index of small reservoirs. In addition, these results can be a basis for providing opinions regarding the findings that emerge in small dams as well as further efforts to estimate the actual performance values of small dams.

## 3. Results and Discussion

In carrying out the assessment of small dam performance index, assessment is carried out to 4 aspects that are technical aspect, service aspect, operation and maintenance aspect, and institution aspect. The percentage value that is represented by each aspect is the result of this research that will be answered in the performance index model of small dams in semi-arid areas. In initial research, the data that is used consists of 4 aspects and 40 indicators. The physical aspect consists of 7 components and 19 indicators; the service aspect consists of 4 components and 9 indicators; the operation and maintenance aspects consist of 3 components and 6 indicators; and the institution aspect consists of 3 components and 6 indicators. Detain aspect, component, and indicator can be seen in Table 1.

**Table 1. Indicator of Smart-PLS Before and After Validity Test**

| No | Aspect | Component | Symbol of Component | No. | Indicator | Analysis of SmartPLS | |
|---|---|---|---|---|---|---|---|
| | | | | | | Before | After |
| 1 | Aspect of Physic | Condition of embankment | KT | 1 | Condition of embankment body subsidence | KT1 | KT1 |
| | | | | 2 | Condition of slope damage | KT2 | KT2 |
| | | Condition of small dam storage | KTE | 1 | Condition of seepage | KTE1 | KTE1 |
| | | | | 2 | Condition of sediment | KTE2 | KTE2 |
| | | Condition of spillway structure | KBS | 1 | Drempple | KBS1 | KBS1 |
| | | | | 2 | Approach channel | KBS2 | KBS2 |
| | | | | 3 | Spillway channel | KBS3 | KBS3 |
| | | | | 4 | Stilling basin | KBS4 | KBS4 |
| | | Intake structure | BPL | 1 | Inlet pipe | BPL1 | BPL1 |
| | | Distribution network | JD | 1 | Condition of distribution pipe | JD1 | JD1 |
| | | | | 2 | Availability of distribution pipe | JD2 | JD2 |
| | | Condition of service tub | KBLY | 1 | Human tub | KBLY1 | KBLY1 |
| | | | | 2 | Animal tub | KBLY2 | KBLY2 |
| | | | | 3 | Garden tub | KBLY3 | KBLY3 |
| | | Condition of completion structure | KBP | 1 | Safety hence | KBP1 | KBP1 |
| | | | | 2 | Peil Scale | KBP2 | KBP2 |
| | | | | 3 | Information board | KBP3 | KBP3 |
| | | | | 4 | BM pole | KBP4 | KBP4 |
| | | | | 5 | explanation | KBP5 | Dropped |
| 2 | Aspect of service | Availability of service tub | KBL | 1 | Human tub | KBL1 | KBL1 |
| | | | | 2 | Animal tub | KBL2 | KBL2 |
| | | | | 3 | Garden tub | KBL3 | KBL3 |
| | | Inflow | AM | 1 | Condition of flow and water source | AM1 | AM1 |
| | | Volume of inundation | VG | 1 | Condition of inundation volume change | VG1 | VG1 |
| | | Availability of time | WK | 1 | Availability of water along year | WK1 | WK1 |
| | | Water allocation | PA | 1 | Social in water regulation | PA1 | Dropped |
| | | | | 2 | Society water utilization | PA2 | PA2 |
| | | | | 3 | Number of water utilization | PA3 | PA3 |
| 3 | Aspect of Operation and Maintenance (O&M) performance | Implementation of O&M activity | PKOP | 1 | Suitability of O & M activity | PKOP1 | PKOP1 |
| | | | | 2 | Application of O & M implementation | PKOP2 | PKOP2 |
| | | Small dam guardian staff | PPE | 1 | Adequacy of small dam staff | PPE1 | PPE1 |
| | | | | 2 | Condition of staff competence | PPE2 | PPE2 |
| | | Availability of O & M facility | KSOP | 1 | Manual document of O & M | KSOP1 | KSOP1 |
| | | | | 2 | Maintenance tool of O & M | KSOP2 | KSOP2 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 4 | Aspect of small dam institution | Documentation of O & M | DOP | 1 | Document of small dam design | DOP1 | Dropped |
| | | | | 2 | Document of O & M history | DOP2 | DOP2 |
| | | | | 3 | Document of implementation | DOP3 | DOP3 |
| | | Member meeting | RA | 1 | Structure of organization | RA1 | RA1 |
| | | | | 2 | Member competence | RA2 | RA2 |
| | | | | 3 | Routine schedule of meeting | RA3 | RA3 |

*Note:* Aspect of physic consists of 7 components with each indicator; aspect of service consists of 4 components with each indicator; aspect of operation and maintenance consists of 3 components with each indicator; and aspect of small dam institution consists of 2 components with each indicator.

### 3.1. The Role of SEM- PLS in Finding Parameters of Small Dam Performance Index

Analysis of data is carried out two times with descriptive and inferential methods. The method of data analysis descriptively intends to give an illustration about the condition and characteristic of questionnaire responses. Descriptive analysis makes it possible that every response from the respondent is more specifically presented. However, data analysis inferential uses Structural Equation Modeling (SEM). This equation is modeled using Smart Partial Least Squares (Smart-PLS) software. PLS uses a three-stage iteration process, in which every stage produces estimation, so then there are 3 categories of parameter estimation. The first stage produces a weight estimate, the second stage produces a path estimate for the inner model and outer model, and the third stage produces a means estimate and location (constant). First category, weight estimate is used for creating latent variable value. The second one, path estimate, relates the inter-latent variable and block variable (loading). The third one is related to means and parameter location (constant value of regression) for variables and latent variables.

In the stage of weight estimation and the process of iteration, variables and latent variables are needed as deviations of the average value. Inside and outside approximation estimation is carried out in the algorithmic process of variable iteration. The process is started with the analysis of outside approximation estimation by summation of indicators in blocks with equal weight. In accordance with the scope of the data sample number (n), the variant unit value of the latent variable is obtained through iteration, scaling every weight. Then, the process is continued with inside approximation estimation in latent variable estimation by using the value that has been obtained in the previous process. Besides weighting of latent variables, the other thing that is needed in numerical modeling is path analysis. Inter latent variable in PLS is related to three types of inter-relations: inner model, outer model, and measurement model. The relation inters latent variable is schemed in the inner model or is often mentioned as a structural model. The relation between the latent variable and the variables is explained in the measurement model, and the caustic values that follow the latent variable can be estimated through the weight relation.

From the PLS analysis, the selected variable, dimension, and indicator are as presented in Table 1.

### 3.2. Reliability Test

Based on the analysis research, it can be seen the composite reliability. The condition is said reliable if $\rho c > 0.8$ (the reliability value is > 0.8). If the reliability value is less than 0.8, it can still be classified as enough reliable value for the value between 0.6 to 0.8 [12]. The AVE (Average Variance Extracted) value is mentioned as reliable if the value is >0.50. The reliability value for overall variables of research is presented as in Table 2.

**Table 2. Analysis Result of Reliability Test**

| Variable | Dimension | Composite Reliability | Average Variance Extracted (AVE) | Conclusion |
|---|---|---|---|---|
| Aspect of physic | Condition of embankment | 0.729 | 0.582 | High reliability |
| | Condition of small dam storage | 0.741 | 0.593 | High reliability |
| | Condition of spillway structure | 0.805 | 0.513 | High reliability |
| | Intake structure | 1.000 | 1.000 | High reliability |
| | Distribution network | 0.977 | 0.954 | High reliability |
| | Condition of service tub | 0.875 | 0.713 | High reliability |
| | Condition of completion structure | 0.818 | 0.538 | High reliability |
| Aspect of Operation & Maintenance Performance | Implementation of O & M activity | 0.877 | 0.782 | High reliability |
| | Small dam guardian staff | 0.842 | 0.732 | High reliability |
| | Availability of O & M facility | 0.896 | 0.813 | High reliability |
| Aspect of small dam institution | Documentation of O & M | 0.724 | 0.571 | High reliability |
| | Member meeting | 0.821 | 0.611 | High reliability |
| Aspect of service | Availability of service tub | 0.796 | 0.571 | High reliability |
| | Inflow | 1.000 | 1.000 | High reliability |
| | Volume of inundation | 1.000 | 1.000 | High reliability |
| | Time availability | 1.000 | 1.000 | High reliability |
| | Water allocation | 0.700 | 0.534 | High reliability |

Table 2 presents the result of the reliability test that can also be presented as a diagram in the chart form for the values of AVE (Average Variance Extracted) and CR (Composite Reliability) as presented in Figures 6 and 7.

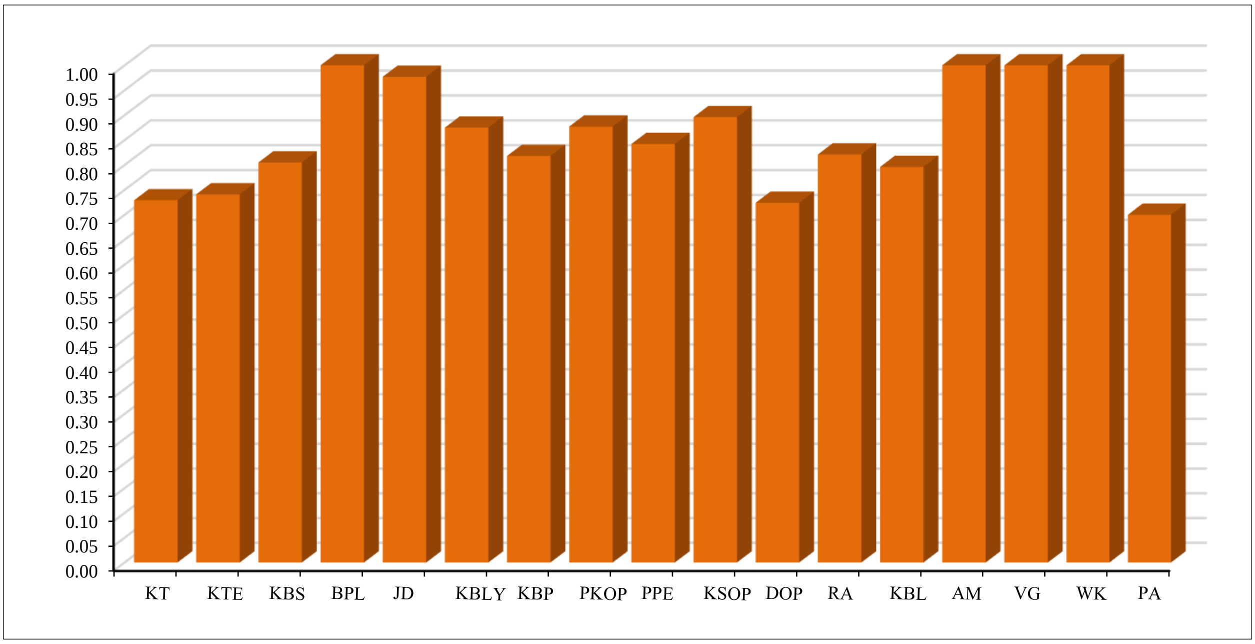


**Figure 6. Chart of Average Variance Extracted (AVE)**

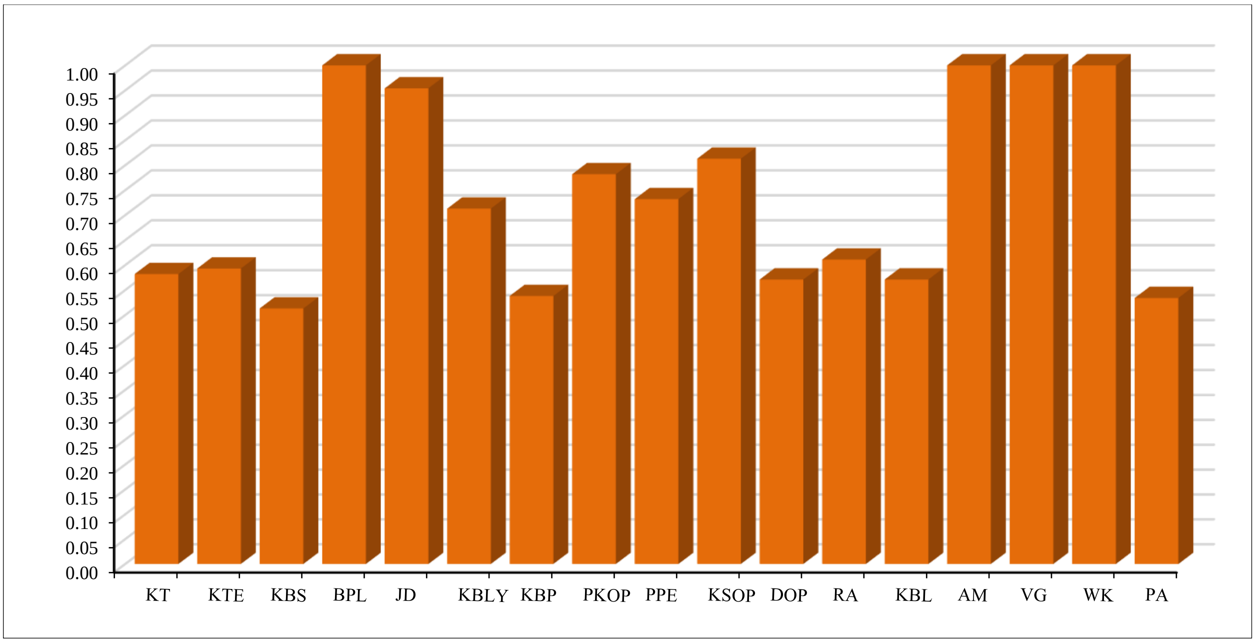


**Figure 7. Chart of Composite Reliability (CR)**

The result of the reliability test as presented in Figures 6 and 7 shows that all of the research variables are fitted as the measurer, and the test of reliability can use the criteria of AVE (Average Variance Extracted) or CR (Composite Reliability). Based on Table 2 and the test of reliability, it shows that the overall variables and the question in this research are reliable.

### 3.3. Model Inner Value and Structural Model

The value of structural model analysis can be used to evaluate hypotheses. The evaluation base is the standardized path coefficient; however, the significant level of path coefficient comes from the $t\text{-}_{Calculated}$ value.

The threshold that is used for evaluating hypotheses is $t\text{-}_{calculated}$ from the factor load or the parameter that shows a correlation and generally is mentioned as the loading factor or the same with the critical threshold that is 1.663 based on the table of $t\text{-}_{calculated}$ (5%) with 85 respondents or research sample. The tests are carried out by using the significant level, or the alpha value is 0.05. The analysis result of program Smart-PLS by bootstrapping analysis on the inner model or research model ($t_{-calculated}$) as presented in Figure 8 and Table 3.

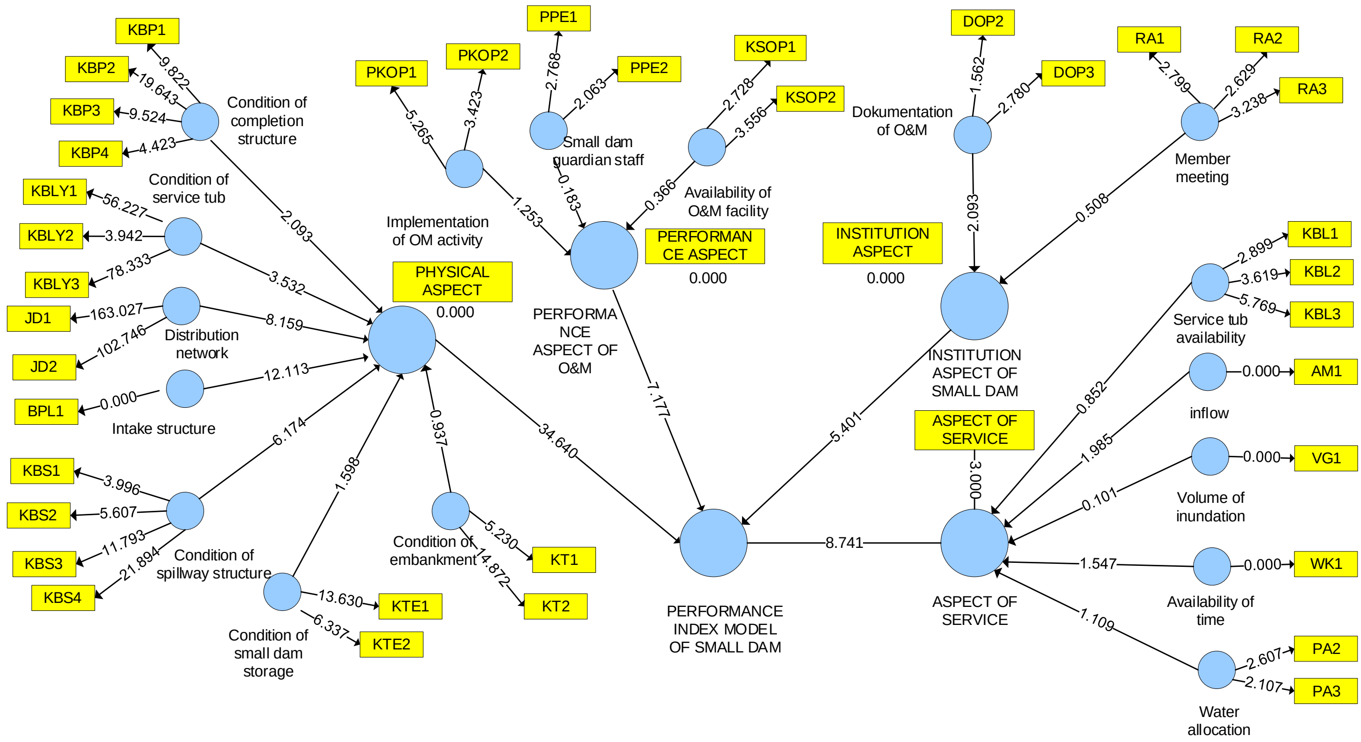


**Figure 8. Analysis Result of PLS_t value (Bootsrapping)**

**Table 3. Path Coefficient**

| No. | Path Coefficients | Original Sample | Sample Mean | Standard Deviation | T Statistics | P Values |
|---|---|---|---|---|---|---|
| (1) | (2) | (3) | (4) | (5) | (6) | (7) |
| 1 | Aspect of physic → Performance Index Model of Small Dam | 0.879 | 0.879 | 0.025 | 34.640 | 0.000 |
| 2 | Aspect of institution → Performance Index Model of Small Dam | 0.167 | 0.166 | 0.031 | 5.401 | 0.000 |
| 3 | Aspect of service → Performance Index Model of Small Dam | 0.099 | 0.100 | 0.011 | 8.741 | 0.000 |
| 4 | Aspect of Operation & Maintenance performance → Performance Index Model of Small Dam | 0.105 | 0.105 | 0.015 | 7.177 | 0.000 |

Each aspect has $t_{calculated}$ more than critical value (≥1.663) with significance level (α) = 0.05 and/or p value is zero and it is under critical value (≤ 0.05). Significant level of physical aspect gives the biggest value, which is 34.640 (>1.663); it is due to the number of valid physical aspect indicators from 19 becomes 18. The institution aspect has a significant value of 5.401 (>1.663); it is due to the number of valid institution aspect indicators from 6 becomes 5. Then, the significant value of the service aspect is 8.741 (> 1.663); it is due to the number of valid service aspect indicators from 9 becomes 8, and the significant value of the operation and maintenance aspect is 7.177 (> 1.663); it is due to the number of valid operation and maintenance aspect indicators from 6 still survives 6.

Based on the running result of Smart-PLS, it is known that the parameters of small dam index can be seen in Table 4.

From Table 4, the performance index parameters for small dams are obtained, which consist of 4 aspects 17 components and 37 indicators, of which the Physical Aspect consists of 7 components and 18 indicators, the Service Aspect has 5 components and 8 indicators, the operation and maintenance aspect has 3 components and 6 indicators, and the institutional aspect has 2 components and 5 indicators with details as in Table 4.

**Table 4. Parameters of Small Dam Index After Smart-PLS Running**

| No. | Aspect | Components | Indicator |
|---|---|---|---|
| 1 | Aspect of physic | Embankment condition | Condition of slope damage |
| | | | Condition of embankment body subsidence |
| | | Distribution pipe | Availability of distribution pipe |
| | | | Condition of distribution pipe |
| | | Completion structure | Safety hence |
| | | | BM pole |
| | | | Information board |
| | | | Peil-scale |
| | | Service tub structure | Human tub |
| | | | Animal tub |
| | | | Garden tub |
| | | Spillway structure | Stilling basin |
| | | | Spillway channel |
| | | | Approach channel |
| | | | Dremple |
| | | Intake structure | Inlet pipe |
| | | Small dam storage | Sediment condition in small dam |
| | | | Seepage condition |
| 2 | Aspect of service | Service tub availability | Human tub |
| | | | Animal tub |
| | | | Garden tib |
| | | Inflow | Condition of flow and water source |
| | | Volume of inundation | Condition of inundation volume change |
| | | Time availability | Water availability along year |
| | | Water allocation | Society water utilization |
| | | | Number of water utilization |
| 3 | Aspect of Operation & Maintenance | Implementation of O & M activity | Suitability of O & M implementation |
| | | | Application of O & M implementation |
| | | Small dam staff | Adequacy of small dam guardian |
| | | | Condition of small dam staff |
| | | Facility availability | Manual document of O & M |
| | | | Maintenance tool of O & M |
| 4 | Aspect of institution | Documentation | Supporting of construction implementation and as built drawing |
| | | | Document of O & M history |
| | | Member meeting | Routine schedule of member meeting |
| | | | Structure of organization |
| | | | Member competence |

## 3.4. Model of Small Dam Index

The analysis result of weight from each variable, component, and indicator is necessary to be known for seeing how big the influence of every parameter (aspect, component, and indicator) is on the performance index of a small dam. By seeing the weight spread, it can be carried out the priority efforts for increasing the performance of small dam structures. The effectivity of resource usage will become accurate if it is directed to the variable that has the biggest influence. To find this weight value, it is carried out by using Generalized Reduced Gradient (GRG) by using a solver in Microsoft Excel.

To carry out the iterative model arrangement of aspect, component, and indicator, the boundary condition is needed as follows:

- $0 \leq IK_{Physic} \leq 4$
- $0 \leq IK_{Institution} \leq 4$
- $0 \leq IK_{Service} \leq 4$
- $0 \leq IK_{Operation\ and\ Maintenance} \leq 4$
- KT + KTE + KBS + BPL + JD + KBLY + KBP = 1
- DOP + RA = 1
- KBL + AM + VG + WS + PA = 1
- PKOP + PPE + KSOP = 1
- $0 \leq IK \leq 4$
- $\alpha + \beta + \delta + \gamma = 1$

## 3.5. The Relation of Aspect, Component, and Indicator

The performance index model of small dams is a performance value approach that consists of 4 aspects. The components, in accordance with its classification, are forming variables and are to be arranged from the indicators that have been determined based on their suitability. The GRG method, through the application of a solver, is used for explaining the relations.

### 1. *Physical Aspect:*

Physical aspect is formulated as follow:

$$IK_{Physical} = a_1.\ KT + a_2.\ KTE + a_3.\ KBS + a4.\ BPL + a_5.\ JD + a_6.\ KBLY + a_6.\ KBP \tag{1}$$

where $KT\ is$ $a_{11}.KT_1 + a_{12}.KT_2$ (condition of embankment), $KTE\ is$ $a_{21}.KTE_1 + a_{22}.KTE_2$ (condition of small dam storage), *KBS* is $a_{31}.KBS_1 + a_{32}.KBS_2 + a_{33}.KBS_3 + a_{34}.KBS_4$ (condition of Spillway structure), *BPL* is $a_{41}.BPL_1$ (condition of intake structure), *JD* is $a_{51}.JD_1 + a_{52}.JD_2$ (condition of distribution network), *KBLY* is $a_{61}.KBLY_1 + a_{62}.KBLY_2 + a_{63}..KBLY_3$ (condition of service tub), *KBP* is $a_{71}.KBP_1 + a_{72}.KBP_2 + a_{73}.KBP_3 + a_{74}.KBP_4$ (condition of completion structure).

### 2. *Service Aspect:*

Service aspect is formulated as follow:

$$IK_{Service} = c_1, KBL + c_2\ , AM + c_3, VG + c_4\ , WK + c_5, PA \tag{2}$$

where $KBL$ is $c_{11}.KBL_1 + c_{12}.KBL_2 + c_{13}.KBL_3$, $AM$ is $c_{21}.AM_1$, $VG$ is $c_{31}.VG_1$, $WK$ is $c_{41}.WK_1$, $PA$ is $c_{51}.PA_2 + c_{52}.PA_3$

### 3. *Operation and Maintenance Aspect:*

Operation and maintenance aspect are formulated as follow:

$$IK_{OP} = d_1.PKOP + d_2\ .PPE + d_3.KSOP \tag{3}$$

where $PKOP$ is $d_{11}.PKOP_1 + d_{12}.PKOP_2$, $PPE$ = $d_{21}.PPE_1 + d_{22}.PPE_2$, $KSOP$ is $d_{31}.KSOP_1 + d_{32}.KSOP_2$.

### 4. *Institution Aspect:*

Institution aspect is formulated as follow:

$$IK_{Institution} = b_1.\ DOP + b_2.\ RA \tag{4}$$

where DOP is $b_{11}.\ DOP_2 + b_{12}.\ DOP_3$, RA is $b_{21}.\ RA_1 + b_{22}.\ RA_2 + b_{23}.\ RA_3$.

## 3.6. The Value of Small Dam Performance Index

The Generalized Reduced Gradient (GRG) method with solver tools in Microsoft Excel is used in this analysis to obtain the weight of each parameter. The performance index of a small dam is obtained by analyzing the index average of physics, institution, service, and operation and maintenance variables with fulfilling the data sample. Tables 5 and 6 present the values.

**Table 5. Physical Indicator Value of Physical Small Dam**

| KT | | KTE | | KBS | | | | BPL | JD | |
|---|---|---|---|---|---|---|---|---|---|---|
| 0.093 | | 0.128 | | 0.159 | | | | 0.087 | 0.155 | |
| KT1 | KT2 | KTE1 | KTE2 | KBS1 | KBS2 | KBS3 | KBS4 | BPL1 | JD1 | JD2 |
| 0.1123 | 0.1551 | 0.1543 | 0.1139 | 0.1255 | 0.1268 | 0.1192 | 0.1465 | 0.1165 | 0.1584 | 0.1541 |

| KBLY | | | KBP | | | | F calculated |
|---|---|---|---|---|---|---|---|
| 0.1450 | | | 0.2326 | | | | |
| KBLY1 | KBLY2 | KBLY3 | KBP1 | KBP2 | KBP3 | KBP4 | 0.1477 |
| 0.1042 | 0.1826 | 0.1073 | 0.1371 | 0.1514 | 0.1749 | 0.2179 | |

**Table 6. Indicator value of Institution, Service, and Operation & Maintenance on Small Dam**

| DOP | | RA | | | K calculated |
|---|---|---|---|---|---|
| 0.5836 | | 0.4163 | | | 0.1179 |
| DOP2 | DOP3 | RA1 | RA2 | RA3 | |
| 0.7900 | 0.2272 | 0.5861 | 0.6397 | 0.3114 | |

| KBL | | | AM | VG | WK | PA | | L calculated |
|---|---|---|---|---|---|---|---|---|
| 0.5570 | | | 0.0906 | 0.1242 | 0.0862 | 0.1417 | | 0.1983 |
| KBL1 | KBL2 | KBL3 | AM1 | VG1 | WK1 | PA2 | PA3 | |
| 0.3194 | 0.2325 | 0.2434 | 0.1835 | 0.2224 | 0.2080 | 0.2512 | 0.1288 | |

| KOP | | PPE | | KSOP | | O calculated |
|---|---|---|---|---|---|---|
| 0.360 | | 0.515 | | 0.125 | | 0.5361 |
| PKOP1 | PKOP2 | PPE1 | PPE2 | KSOP1 | KSOP2 | |
| 0.3639 | 0.3916 | 0.4530 | 0.5675 | 0.4856 | 0.4470 | |

Based on the analysis result, a weight value is obtained for each indicator, component, and aspect based on the long enough analysis process, beginning with an assessment of the field condition based on the weight in accordance with technical guidance for obtaining the existing value. The assessment is caried out to each indicator condition and weight that has the biggest value for each aspect as follows:

The physical aspect has 7 components with 18 indicators; the indicator weight that has the biggest value is BM (KBP.4) with the value of 0.22, and the component of completion structure condition (KBP) with the value of 0.23, which BM is a part of the completion structure component. It happened because BM is a position point reference of small dam location and reference point of height to the whole main and completion structures in all small dams for seeing the condition of height, embankment subsidence, sediment measuring, water level height (many pel-scale are missing), spillway height, position of distribution network, and service tub.

The institution aspect has 2 components with 5 indicators; the indicator that has the biggest value is the history document of operation and maintenance, with a value of 0.79 (DOP2), and the document component of operation and maintenance (DOP), with a value of 0.58. It happened because the history document of operation and maintenance implementation at the small dam is very influential on the process of rehabilitation and maintenance that is carried out by the decision-maker.

The service aspect has 5 components with 8 indicators; the indicator that has the biggest weight is availability of human tub (KBL11), with a value of 0.32, and the component that has the biggest weight is availability of service tub (KBL), with a value of 0.56. It happened because the availability of human tub is one of the main services of a small dam. It is due to the fact that one main function of a small dam to be developed is to fulfill the raw water demand of society that does not have access to clean water sources from surface water as well as groundwater.

The operation and maintenance aspect has 3 components with 6 indicators. The indicator that has the biggest weight is staff competence condition (PPE2) with the value of 0.57, and the component that has the biggest weight is guard officer of small dam (PPE) with the value of 0.52. It happened because in the implementation, operation, and maintenance of small dams, the staff competence is very needed so they can give real data about small dam conditions in the field so it can be carried out the accurate maintenance and can regulate water usage of small dams in accordance with water availability conditions in small dams, so the small dams remain sustainable.

### 3.7. Weight and Value of Index

After being carried out 2 steps of analysis through SEM with Smart PLS and the GRG Method with Microsoft Excel Solver, the formulation is as follows:

$$IK_{SD\text{-}Pentewati} = 0.15\ IK_{Physic} + 0.12\ IK_{Institution} + 0.20\ IK_{Service} + 0.53\ IK_{OM} \tag{5}$$

That is known as the "Small Dam Performance Index," with each formula as follows:

$$IK_{Physic} = 0.093\ KT + 0.128\ KTE + 0.159\ KBS + 0.087\ BPL + 0.155\ JD + 0.145\ KBLY + 0.233\ KBP \tag{6}$$

$$IK_{Institution} = 0.58\ DOP + 0.42.\ RA \tag{7}$$

$$IK_{Service} = 0.56.KBL + 0.09\ .AM + 0.12.VG + 0.09\ .WK + 0.14.PA \tag{8}$$

$$IK_{OM} = 0.360.PKOP + 0.515.PPE + 0.125.KSOP \tag{9}$$

Based on the analysis above, the performance index of a small dam (IK) consists of 15% of the physical performance index, 12% of the institution performance index, 20% of the service performance index, and 53% of the operation & maintenance performance index. However, each performance index—physical performance index, institution performance index, service performance index, and operation & maintenance performance index—is presented as in Equations 2 to 5.

Based on the $IK_{SD\text{-}Pentewati}$ above, it shows that the activity of operation and maintenance determines the performance of a small dam, with the biggest value of 0.53. It is due to the small dam being a simple structure, so the effort of maintenance to maintain the small dam overall is important if compared with the initial physical condition. This result is different with big structures in which the physical aspect dominates, like the study of irrigation [13], drainage [2], system of polder [14], Sabo dam [15], JIAT [16], and river [17]. It is seen in the analysis result that although the physical aspect that is assessed consists of 7 components and 18 indicators, the operation and maintenance aspect consist of 3 components and 6 indicators. However, the analysis result shows that for small dams, aspects of operation and maintenance have the biggest influence on the performance of the small dam. It is due to small dams being very attentive to operation and maintenance, including the suitability of operation and maintenance implementation, adequacy of small dam guard staff, condition of staff competence, manual document of operation and maintenance, and maintenance equipment of operation and maintenance.

### 3.8. Validation

A two-way t-test is used to validate the model analysis of the small dam performance index by comparing the analysis of the $t_{Value}$ with the value of the $t_{Table,}$ so the value is obtained as a point on the distribution curve. The value will show there is an effect between variables or not. The value of $t_{Calculated}$ in the not-accepted area ($H_o$) indicates that there is no effect between variables. Result of $t_{Calculated} = 0.0541 < t_{Table} = 1.29$ (the model is valid).

So, the value of the small dam performance index is as follows:

$$IK_{EK\text{-}Pentewati} = 0.15\ IK_{Physic} + 0.12\ IK_{Institution} + 0.20\ IK_{Service} + 0.53\ IK_{OM} \tag{10}$$

The performance index of small dams (IK) consists of 15% of the physical performance index, 12% of the institution performance index, 20% of the service performance index, and 53% of the operation & maintenance performance index. The quantity of coefficient percentage is 15% + 12% + 20% + 53% = 100%, so this performance index model is rational.

## 4. Conclusion

After carrying out the analysis by using Smart-PLS software, the result shows that there are 7 components with 18 indicators in the physical aspect; 4 components with 8 indicators in the service aspect; 3 components with 6 indicators in the operation and maintenance aspect; and 2 components with 5 assessment elements in the institution aspect. The parameters that have the biggest weight in the analysis of small dams' performance index are as follows: in the physical aspect, completion structure condition (0.23); in the institution aspect, component of operation and maintenance (0.58); in the service aspect, component availability of service tub (0.56); and in the operation and maintenance aspect, component of small dam guard officer (0.52). However, these results are different from previous studies regarding the assessment of the performance index for small dams in Indonesia because these results have been adjusted specifically for small semi-arid dams published by the Ministry of Public Works and Public Housing (PUPR), which are still common for assessing the performance of dams and irrigation dams.

Based on the results of the analysis, which is a novelty in this research, it is known that the performance index for small dams in semi-arid areas is influenced by physical aspects, service aspects, operation and maintenance aspects, and institutional aspects, which can be formulated as follows:

$$IK_{Physic} = 0.0931\ KT + 0.1276\ KTE + 0.1594\ KBS + 0.087\ BPL + 0.1553\ JD + 0.145\ KBLY + 0.2326\ KBP \quad (11)$$

$$IK_{Institution} = 0.58.DOP + 042.RA \quad (12)$$

$$IK_{Service} = 0.56.KBL + 0.09\ .AM + 0.12.VG + 0.09\ .WK + 0.14.PA \quad (13)$$

$$IK_{OM} = 0.36.PKOP + 0.52.PPE + 0.13.KSOP \quad (14)$$

With the equation for small dam performance index is as follow: (15)

$$IK_{Small\ Dams\ Pentewati} = 0.15\ IK_{Physic} + 0.12\ IK_{Institution} + 0.20\ IK_{Service} + 0.53\ IK_{OM} \quad (16)$$

It is known as the Small Dam Performance Index. However, it is meant that the performance index of small dams Pentewati (IK) consists of 15% of the physical performance index, 12% of the institution performance index, 20% of the service performance index, and 53% of the operation & maintenance performance index, with each equation of the physical, institution, service, operation & maintenance performance index presented as the formulations above.

The mathematical model of small dam performance index that has been produced in this research can be used for analyzing the performance index of small dams in the other area that has the same criteria as the small dam in the research location. However, if there are different criteria from the research location, it is needed for further adjustment and research.

## 5. Declarations

### 5.1. Author Contributions

Conceptualization, P.P. and P.T.J.; methodology, P.P.; validation, P.P.; formal analysis, P.P.; investigation, P.P and P.T.J.; resources, P.P. and L.M.L.; data curation, P.P. and M.S.; writing—original draft preparation, P.P. and P.T.J.; writing— review and editing, L.M.L. and M.S.; visualization, L.M.L. and M.S. All authors have read and agreed to the published version of the manuscript.

### 5.2. Data Availability Statement

The data presented in this study are available in article.

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### 5.4. Conflicts of Interest

The authors declare no conflict of interest.

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