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Performance Index Model of Raw Water Infrastructure

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Abstract

This research intends to build a performance index model of raw water infrastructure mathematically by considering technical, non-technical, and environmental aspects. The research location is in Lombok and the Sumbawa Islands. Data is collected by field surveys and questionnaires that are distributed to 160 respondents related to raw water infrastructure in 21 locations. The methodology consists of Partial Least Squares (PLS) and Generalized Reduced Gradient (GRG). The results show that technical, non-technical, and environmental aspects have a significant influence on the performance index of raw water infrastructure. The structural analysis shows that the technical, non-technical, and environmental variables have a positive and significant influence on the performance index. The performance index of raw water infrastructure is successful enough to be developed and tested by using field data and GRG. The evaluation result shows that the model gives an accurate estimation of raw water infrastructure performance in Nusa Tenggara Barat province. The performance index model for raw water infrastructure is as follows: 0.521 IK_{TK} + 0.305 IK_{NT} + 0.174 IK_{Li} with the sum of square residual (SSR) is 83.21, the root mean square error (RMSE) is 0.44, the mean square error (MSE) is 3.97, and the accuracy level is 95.25%. This research provides the development of an evaluation method for raw water infrastructure performance and a valuable outlook for policymakers in managing and maintaining raw water infrastructure to support sustainable water resources in the future. Considering some aspects of this, it is hoped the efforts to increase the quality of raw water infrastructure can be more directed and effective, contributing to increasing society's prosperity and a sustainable environment in the region.

Keywords: Performance Index; Variable; Technic; Non-Technic; Environment.

1. Introduction

The sustainable raw water supply system becomes attention for fulfilling clean water demand, mainly for drinking water. The demand for clean water is an important thing in human life, and one of the factors is sufficient water availability that is suitable in quantity as well as quality. The fulfillment of water availability is not missed by the performance of the raw water infrastructure that takes water from the source towards the distribution service. However, the performance of raw water can be seen from the service function of the main structure in supplying raw water. The service function in this case is meant the ability of the raw water structure to take water from the source towards the raw water acceptor. The performance of raw water can generally be measured in terms of reliability, availability, capacity, and customer satisfaction.

The assessment of raw water condition and performance has been carried out due to SE Dirjen SDA (Directorate General of Water Resources)-Indonesia No. 03/SE/D/2021 about the preparation guidelines for raw water infrastructure operation and maintenance, which generally include some assessment parameters for raw water condition and performance [1]. However, the categories that are included in this assessment are technical physics (design and construction period), physics and performance (operation period), environment, and operation, and there are some

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parameters in each category. Parameters in this category are different with the research that will be carried out. This research is divided into 3 categories: technical, non-technical, and environmental, with different parameters. The performance index assessment of raw water infrastructure is needed to determine the system functionality of raw water supply from intake until IPA. Mainly in this research, it is intended as a reference in the performance management of the raw water supply system to obtain the decision that the building or infrastructure is needed to rehabilitate or that it is enough by funding the operation maintenance. So far, the performance of raw water infrastructure is based on the condition of the field physical structure but has not yet aimed at the sustainable condition of the infrastructure, so a performance index assessment is needed by seeing some indicators that influence the system.

The management of raw water also includes ensuring an adequate drinking water supply, which can impact the economic condition. Research by Raihan et al. found that disrupted water supply is caused by technical problems, water pollutants, and climate effects, all of which have economic impacts that cause losses, especially in business regions. Attention to water supply is needed due to changes in laws or regulations and policies, the increasing demands of company management, appropriate water pricing, and advancements in alternative water management technology [2]. This indicates the importance for decision-makers to implement accurate policies that consider the impact of climate change at the watershed level to prevent potential disruptions in water supply, which may become more frequent in the future. In line with this, research by Molinos-Senante et al. expressed the need for an efficient assessment of drinking water supply. Their application of regression analysis showed that raw water sources, percentage of service, population size, and water losses are significant environmental variables influencing the efficiency of drinking water management institutions [3].

According to Ibrahim et al., predicting water source and quality efficiency requires water quality modeling using Principal Component Analysis (PCA) to make decisions from a dataset of water quality parameters. This is done by selecting the most influential variables using an Artificial Neural Network (ANN) and then validating and verifying the results with the determination coefficient and Root Mean Square Error (RMSE) [4]. Based on this and other research, performance assessment of raw water infrastructure is essential for decision-making by policymakers to ensure sustainable water sources in the future. This research focuses on the conditions of water sources, socio-economic and cultural factors, and infrastructure asset management that have not been thoroughly addressed in previous studies, ensuring that the infrastructure is aligned with its expected lifespan.

In Odwori's [5] research, he stated that graphical theory technology, based on the decomposition principle and raw water allocation system coordination and topology analysis, can be used for allocating complex raw water [6]. The combination of the decomposition principle and topology analysis is employed to ensure a reliable water supply by estimating and predicting the allocation model of water structure type and water demand [7, 8]. Similar research conducted in the last five years has focused on the performance index of urban drainage [9], groundwater [10], and polder systems [11], utilizing both technical and non-technical aspect variables. However, the performance indices for rivers [12] and Sabo dams [13] incorporate technical, regulatory, and social aspects. The performance index for irrigation systems includes aspects of both the main and tertiary irrigation systems [14]. This research aims to study and develop a performance index model for raw water infrastructure based on technical, non-technical, and environmental aspects, using SMART-PLS to identify influential factors and GRG to build the performance index model.

2. Material and Methods

2.1. The Limitation of Research

The limitations of this research are as follows:

- The research location is in Nusa Tenggara Barat Province, which is Lombok Island and Sumbawa Island. The characteristic is a difference in the availability of water sources, the pattern of water use, rainfall, topography, and socio-culture;
- The infrastructure of the water source and intake is the transmission pipe network, not including the reservoir, IPA, and water distribution network;
- The method of raw water performance assessment that is used in this research is the method that is usually used in Indonesia, and there has been work on the performance assessment method of irrigation infrastructure;
- The method that is used in this research is based on the SE Dirjen SDA (Directorate General of Water Resources)-Indonesia No. 03/SE/D/2021, primary and secondary data;
- The analysis of water availability in the water source (intake) is based on the field data, including the water quality section, and does not carry out the sample taking (only as secondary data).

2.2. Research Location

The research location is in Nusa Tenggara Barat Province, which has two big islands, Lombok Island and Sumbawa Island. Each island is selected for the raw water infrastructure that is still functioning, and some locations have been carried out by the management-by-management institution, which is the local general institution. There are some reasons for consideration in selecting the research locations on two big islands, as follows:

- Lombok Island has flat topography that is hilly and steep in some areas. The average rainfall per year is 1,441 mm/year. The distribution of water sources is uneven; there are many sources in western and northern areas, however, and in the middle and eastern areas, they tend to be less. The fluctuation of water availability in some sources is not significant due to the flow pattern of the raw water supply system, most of which is gravitational. The water source discharge of Lombok Island on the raw water unit is estimated for discharge > 20 *l/s*.
- Sumbawa Island has hilly topography in some areas and is steep. The average rainfall is 1,176 mm per year; the distribution of water sources is uneven; the western part has enough water sources; however, further east, there is no water source. The fluctuation of water availability in the water source is significant enough that even in dry seasons, the water source is dry. The flow pattern of the raw water supply system uses more pumps than gravitation. Water source discharge in the research location is estimated to the range > 20 *l/s*.
- Based on points 1 and 2, it can be known that Lombok Island tends to be wet with more rainfall than Sumbawa Island, which is included as a dry area. Sumbawa Island is a dry area in Nusa Tenggara Barat Province, so raw water demand is dependent on groundwater sources and water sources from dams.

Table 1 and Figure 1 present the research location in relation to the developed raw water infrastructure that has been functional.

Table 1. Research Location- Database Airbaku, 2023

No.	Unit of raw water	Regency	Type of source	Type of intake structure
		Lombok Island		
1	Lembah Sempaga	West Lombok	Water source	Broncaptering
2	Sarasuta	West Lombok	Water source	Broncaptering
3	Remening	West Lombok	River	Intake of weir
4	Serepak	West Lombok	River	Intake of weir
5	Sesera	Middle Lombok	Water source	Broncaptering
6	Rangat	West Lombok	Water source	Broncaptering
7	Pandanduri	East Lombok	Dam	Intake of dam
8	Sekeper	Northern Lombok	River	Intake of weir
9	Tibu Ulik	East Lombok	Small dam	Intake of small dam
10	Sordang	East Lombok	River	Free Intake
11	Singang Pitu Nai	Northern Lombok	River	Free Intake
12	Jonplanka	Northern Lombok	Water source	Broncaptering
13	Otak Aik	West Lombok	Water source	Broncaptering
		Sumbawa Island		
1	Semongkat	Sumbawa	River	Intake of weir
2	Brangdalap	Sumbawa	River	Intake of weir
3	Tiu Pasai	Sumbawa	Small dam	Intake of small dam
4	Labangka	Sumbawa	Dam	Intake of dam
5	Mongglenggo	Dompu	River	Intake of weir
6	Ncoha	Bima	Small dam	Intake of small dam
7	Patula	Bima	River	Intake of weir
8	Rababaka	Dompu	River	Intake of weir

Figure 1 shows the research location in relation to Table 1 above, where the locations are in Nusa Tenggara Barat Province, such as Lombok and the Sumbawa Islands, with 21 research locations. There are 13 locations on Lombok Island and 8 locations on Sumbawa Island, and all of them have been managed by the General Institution of Drinking Water Region (PDAM).

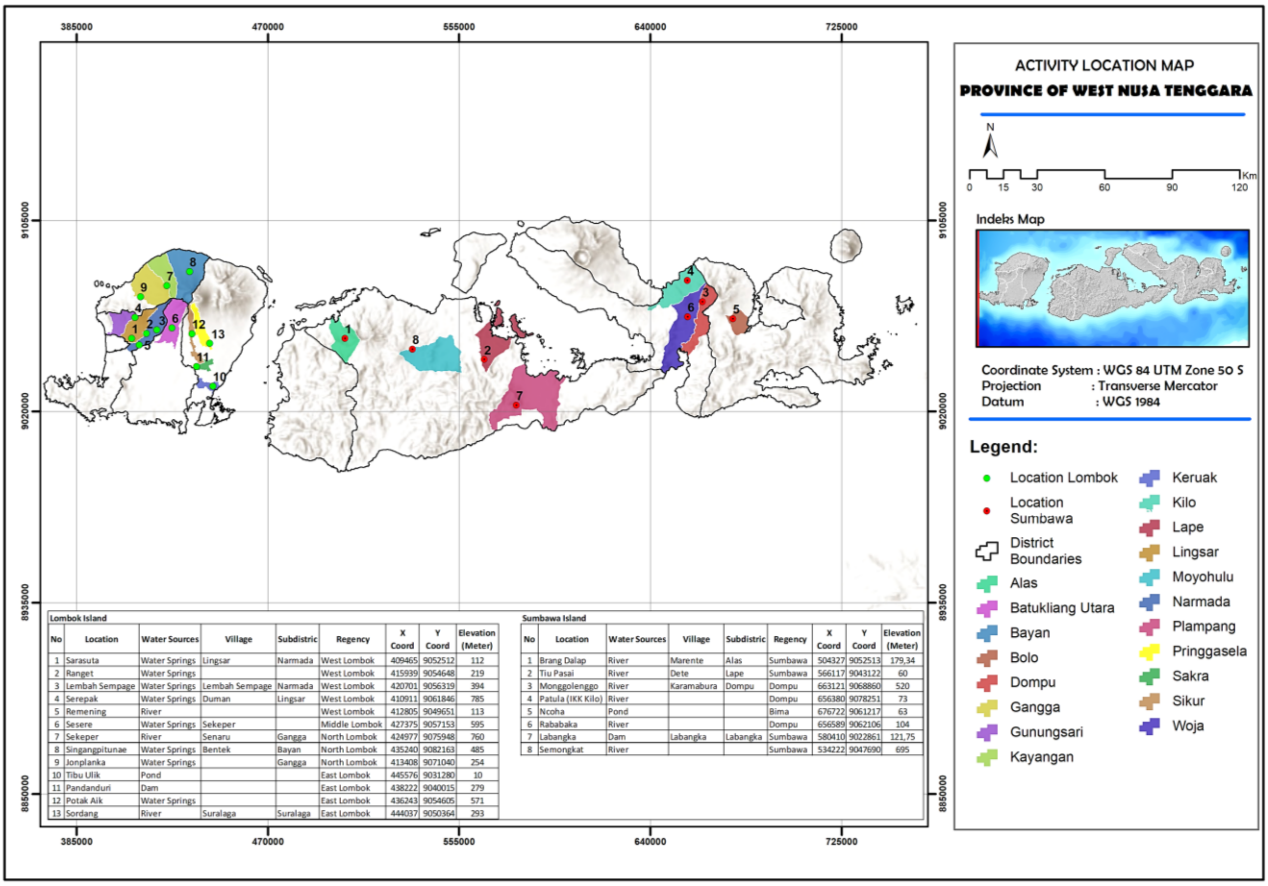

Figure 1. Research Location in Nusa Tenggara Barat Province

2.3. Data Collecting

The method of data collection in this research uses the collecting methods of field data and quantitative data. The data that is used in this research analysis is field data from the survey results on 21 raw water infrastructures in two islands and questionaries' data that are divided among 160 respondents. The distribution of secondary data on the questionnaire consists of:

- Technical variables consist of a) water source quantity; and b) the physical condition of raw water infrastructure;
- Non-technical variables that consist of a) socio-economic and culture; b) policy/regulation; c) personal organization; d) management institution; e) documentation; f) human resources; asset of raw water infrastructure;
- Environmental variables that consist of environment at the surrounding water source and b) sustainability of the water source.

2.4. Scheme of Research Concept

The scheme of the research concept can be seen in Figure 2.

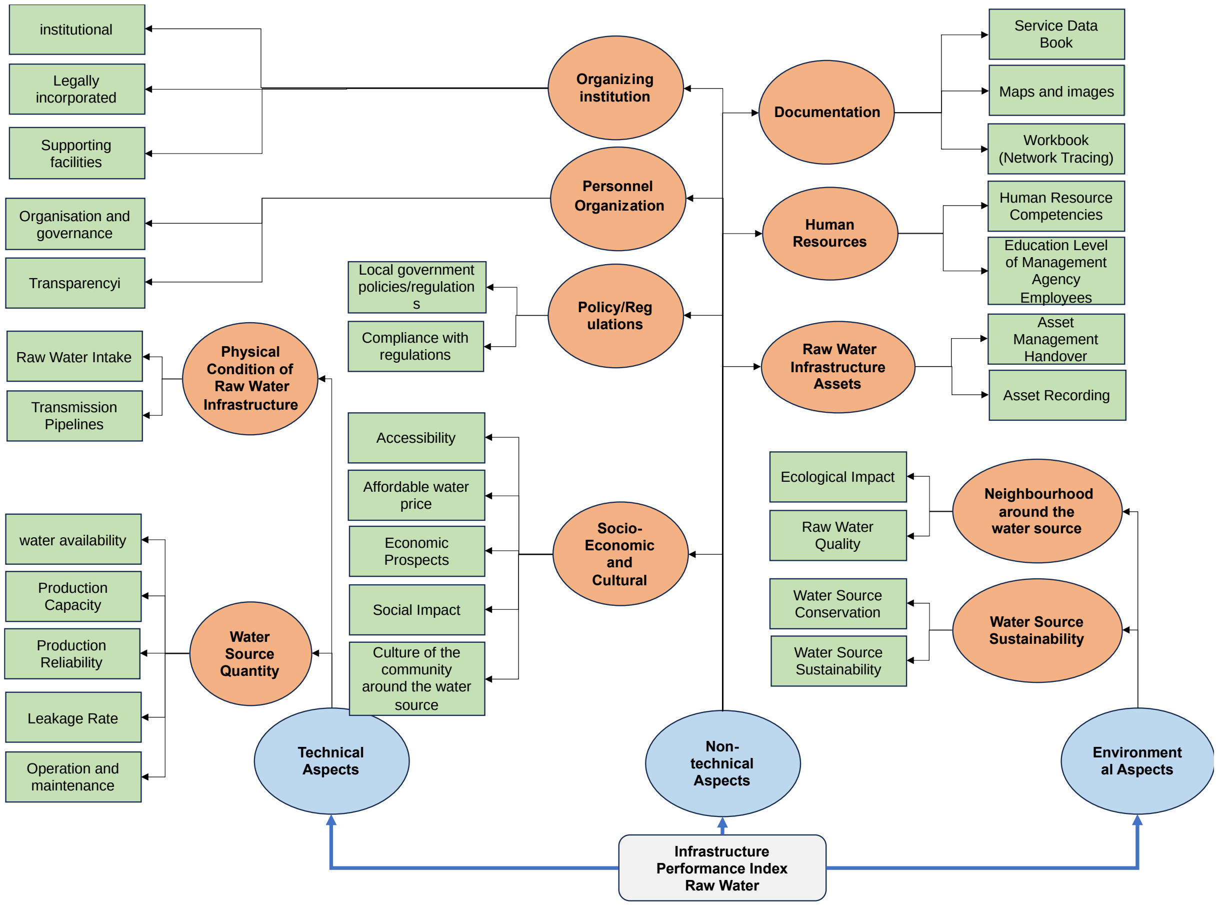

Figure 2. Concept Chart of Raw Water Infrastructure Performance Index Model

2.5. Methodology

2.5.1. Method of Analysis

The steps to carry out performance index analysis of raw water infrastructure are as follows:

- To collect secondary data and field observation (survey of research location).
- To arrange the questionnaire for the water source and the variables that will be tested.
- To select the technical, non-technical, and environmental variables, including the indicator that has the most influence.
- Evaluation of the technical, non-technical, and environmental performance index models.
- Based on point 4, the performance index model of raw water is obtained, and then the validation is carried out due to the SE Dirjen SDA (Circular Letter, Directorate General of Water Resources) No. 03/2021.

2.5.2. Qualitative and Quantitative Analysis

The qualitative analysis in this study is integrated with quantitative analysis, using data from observation results and literature reviews, categorized into dimensions and indicators. The selection of dimensions and indicators is derived from qualitative analysis, and then quantitative analysis is conducted by distributing questionnaires to respondents. This research involves 160 respondents, including related stakeholders, water users, and field staff. The quantitative analysis technique involves testing hypotheses through mathematical and statistical analysis. This research integrates qualitative and quantitative analyses, where the model produced from quantitative analysis is verified using qualitative analysis to compare the model results and test the goodness of fit between the model and field conditions.

The technical aspect consists of water source quantity and the physical condition of raw water. The non-technical aspect includes socio-cultural and economic factors, policies/regulations, organizational structure, management institutions, documentation, human resources, and raw water infrastructure assets. The environmental aspect comprises the surrounding environment and sustainable water sources. Quantitative evaluations and questionnaire distribution results for these three aspects are carried out using a Likert scale. The scale results are then used as input in the application of SEM-PLS, followed by quantitative analysis using regression analysis within SEM-PLS. The result of the SEM-PLS analysis forms the performance index model for each aspect. This model is then run again to develop the overall performance index model for raw water infrastructure.

2.5.3. SEM-PLS

According to Cameron, the Partial Least Squares (SEM-PLS) method is a statistical technique used for analyzing regression and modeling when there are predictor variables and one or more response variables. This technique aims to find the linear relationship between predictor and response variables by minimizing the number of residual squares [15]. It is particularly useful in situations where there are more predictors than observations because it creates latent variables that capture the maximum variance in predictors while relating to the response variables. These latent variables, or components, are constructed to be uncorrelated, resulting in a more efficient and accurate regression model. Based on this, the research conducted to obtain a mathematical model for the performance index of raw water infrastructure utilizes SEM-PLS. There are many dimensions and indicators that influence the technical, non-technical, and environmental aspects, necessitating the selection of the most influential indicators. The evaluation of these influential indicators is conducted using the Generalized Reduced Gradient (GRG) method. GRG is a numerical optimization algorithm used to find the local minimum or maximum of a non-linear function subject to constraints. The GRG method iteratively adjusts the function variables to minimize or maximize the value while meeting boundary conditions. In each iteration, the method analyzes the gradient reduced from the objective function concerning the variables. The reduced gradient is then used to update the variable values, moving towards the optimal solution.

3. Results and Discussion

The performance index assessment of raw water infrastructure with the research location in the province of Nusa Tenggara Barat is based on the three variables above. The three variables above have a weighted value based on the statistical analysis of questionnaire results and secondary data (field data).

3.1. Analysis of variables

In this research, there are 3 variables, 11 dimensions, and 30 indicators that are interrelated, as presented in Table 2.

Table 2. Variable, Dimension, and Indicator of Raw Water Infrastructure Performance Assessment- own study, 2023

Variable	Dimension	Indicator
Technical (A)	Quantity of Water Source (A_1)	Water availability ($A_{1.1}$)
		Production capacity ($A_{1.2}$)
		Production reliability ($A_{1.3}$)
		Leakage level ($A_{1.4}$)
		Maintenance and improvement ($A_{1.5}$)
	Physical condition of raw water infrastructure (A_2)	Raw water intake ($A_{2.1}$)
		Transmission pipe network ($A_{2.2}$)
Non-technical (B)	Socio-economic and culture (B_1)	Accessibility ($B_{1.1}$)
		Achievable water price ($B_{1.2}$)
		Prospect of economy ($B_{1.3}$)
		Social impact ($B_{1.4}$)
		Society culture in surrounding water source ($B_{1.5}$)
	Policy/regulation (B_2)	Policy/ regulation of local government ($B_{2.1}$)
		Obedience to regulation ($B_{2.2}$)
	Personal organization (B_3)	Organization and management ($B_{3.1}$)
		Transparency ($B_{3.2}$)
	Management institution (B_4)	Institution ($B_{4.1}$)
		Legal entity ($B_{4.2}$)
		Supporting facility ($B_{4.3}$)
	Documentation (B_5)	Service data book ($B_{5.1}$)
		Map and figure ($B_{5.2}$)
		Workbook (network rooting) ($B_{5.3}$)
	Human resources (B_6)	Competence of human resources ($B_{6.1}$)
		Staff educational degree of management institution ($B_{6.2}$)
	Asset of raw water infrastructure (B_7)	Handover asset management ($B_{7.1}$)
		Recording of asset ($B_{7.2}$)
Environment (C)	Environment surrounding water source (C_1)	Ecology impact ($C_{1.1}$)
		Raw water quality ($C_{1.2}$)
	Sustainability of water source (C_2)	Water source conservation ($C_{2.1}$)
		Water source sustainability ($C_{2.2}$)

Table 2 shows the division of each variable, including dimension and indicator, that will become the initial data in the running process by using SEM-PLS. Table 3 shows the data demand based on the variable that will be tested and the number of data points that are obtained.

Table 3. Data Demand of Each Variable

Demand of data	Classification of Data
Technical variable	Quantity data of water source and condition of raw water infrastructure that is obtained from the filling of field survey form in 21 water sources.
Non-technical variable	Questionnaire data by 160 respondents in two islands that are Lombok and Sumbawa
Environmental variable	Data of spatial map and questionnaire data by 60 respondents in two islands: Lombok and Sumbawa

3.2. Performance Index Model of Raw Water Infrastructure

The performance index assessment of raw water infrastructure is a unified system of raw water supply that serves as the basis for evaluation parameters. The functional and management value becomes an important factor by considering the condition of the developed infrastructure. The management and sustainability of raw water supply depend on the operation and maintenance patterns of the raw water infrastructure. In this research, infrastructure management is conducted by the river region institution of Nusa Tenggara I (BWS NT I) and the local government. The performance of raw water infrastructure is also influenced by the condition of water availability, the environment surrounding the water source, and the condition of the management institution. The data used in this research includes secondary data from BWS NT I and the local drinking water supply management institution. The filtering process for the three variables is carried out using SEM-PLS, followed by analysis using the GRG method to solve non-linear equations with objective and constraint assumptions.

3.2.1. Analysis Statistic by using PLS-SEM

In this research, technical, non-technical, and environmental variables are analyzed using the Partial Least Square (PLS) model with the SMART-PLS program. This program identifies the most influential variable among several variables and is also referred to as soft modeling. This method can eliminate the assumptions required in the Ordinary Least Square (OLS) technique and does not require a large number of samples. The same model can be used for categorical, interval, and ordinal measurement scales. The developed model is presented in Figure 2. Figure 2 shows the developed model with the technical variable consisting of 2 dimensions: A_1 with 7 indicators and A_2 with 4 indicators. The non-technical variables consist of 7 dimensions: B_1 with 7 indicators, B_2 with 4 indicators, B_3 with 2 indicators, B_4 with 3 indicators, B_5 with 2 indicators, B_6 with 2 indicators, and B_7 with 3 indicators. The environmental variable consists of 2 dimensions: C_1 with 6 indicators and C_2 with 3 indicators.

Cross loading is an evaluation method that compares the loading value between an indicator and one latent variable with the loading values between the indicator and other latent variables. The loading value between indicators $A_{1.1}$ to $A_{1.7}$ and the water source quantity variable is greater than the loading values between these indicators and any other latent variables. Therefore, indicators $A_{1.1}$ to $A_{1.7}$ are correctly associated with the latent variable of water source quantity. The loading values for other indicators are presented in Table 4 and Figure 3, showing that all indicators are accurately assigned to their respective latent variables.

After obtaining the cross-loading value, it is seen that each indicator enters a variable, which will be evaluated for reliability and validity with the Alfa Cronbach, and Composite Resilience Size (CR) is used for checking the reliability. The two sizes must show the value is ≥ 0.70 and AVE (Average Variance Extracted) [16]. AVE (Average Variance Extracted) is a value on average that informs how much a latent or construct variable can explain the variance of indicators [17, 18]. The parameters of AVE are as follows:

- The higher the AVE, the better a latent or constructed variable is at explaining the variance of indicators.
- AVE ≥ 0.50; however, the loading factor shows that the values are ≥ 0.70.

The minimum boundary of AVE is 0.5; that is, AVE > 0.5 can be accepted.

Table 5 shows the analysis result of AVE on the three variables and dimensions. The result of AVE > 0.5 means that the latent variable of performance index has absorbed the variance of each indicator by about 50%.

Table 4. Result of Cross Loading for Each Dimension- own study, 2024

	A_1	A_2	B_1	B_2	B_3	B_4	B_5	B_6	B_7	C_1	C_2
$A_{1.1}$	0.920	0.866	0.882	0.883	0.854	0.890	0.844	0.830	0.880	0.887	0.866
$A_{1.2}$	0.912	0.896	0.889	0.875	0.844	0.879	0.846	0.838	0.869	0.877	0.886
$A_{1.3}$	0.910	0.881	0.903	0.890	0.862	0.889	0.852	0.857	0.879	0.892	0.897
$A_{1.4}$	0.935	0.896	0.894	0.901	0.851	0.886	0.859	0.877	0.877	0.905	0.903
$A_{1.5}$	0.950	0.910	0.911	0.940	0.873	0.892	0.870	0.887	0.903	0.914	0.913
$A_{1.6}$	0.900	0.867	0.856	0.882	0.836	0.860	0.797	0.818	0.887	0.868	0.865
$A_{1.7}$	0.940	0.882	0.909	0.901	0.910	0.890	0.873	0.887	0.898	0.900	0.896
$A_{2.1}$	0.881	0.913	0.870	0.859	0.837	0.890	0.813	0.816	0.860	0.875	0.865
$A_{2.2}$	0.879	0.917	0.899	0.878	0.848	0.898	0.871	0.870	0.879	0.901	0.890
$A_{2.3}$	0.875	0.915	0.886	0.873	0.838	0.847	0.848	0.857	0.867	0.878	0.870
$A_{2.4}$	0.882	0.926	0.882	0.889	0.849	0.857	0.826	0.878	0.845	0.880	0.861
$B_{1.1}$	0.894	0.882	0.931	0.897	0.870	0.889	0.906	0.841	0.885	0.902	0.883
$B_{1.2}$	0.911	0.902	0.929	0.906	0.842	0.879	0.877	0.875	0.901	0.914	0.891
$B_{1.3}$	0.898	0.895	0.917	0.867	0.870	0.905	0.856	0.861	0.861	0.900	0.881
$B_{1.4}$	0.869	0.870	0.893	0.869	0.819	0.849	0.837	0.870	0.833	0.872	0.847
$B_{1.5}$	0.873	0.864	0.906	0.888	0.839	0.867	0.830	0.833	0.854	0.889	0.862
$B_{1.6}$	0.874	0.888	0.918	0.862	0.856	0.852	0.853	0.862	0.856	0.870	0.872
$B_{1.7}$	0.857	0.861	0.900	0.849	0.845	0.855	0.846	0.860	0.824	0.868	0.852
$B_{2.1}$	0.882	0.876	0.889	0.932	0.839	0.870	0.827	0.860	0.879	0.899	0.859
$B_{2.2}$	0.911	0.886	0.906	0.940	0.871	0.886	0.844	0.848	0.884	0.904	0.873
$B_{2.3}$	0.898	0.882	0.886	0.925	0.868	0.872	0.848	0.857	0.866	0.896	0.892
$B_{2.4}$	0.936	0.921	0.911	0.943	0.884	0.907	0.880	0.871	0.922	0.925	0.937
$B_{3.1}$	0.913	0.891	0.923	0.898	0.959	0.881	0.898	0.905	0.893	0.905	0.912
$B_{3.2}$	0.870	0.867	0.853	0.872	0.954	0.869	0.838	0.837	0.845	0.869	0.852
$B_{4.1}$	0.885	0.879	0.891	0.867	0.858	0.926	0.839	0.852	0.888	0.898	0.882
$B_{4.2}$	0.879	0.877	0.872	0.880	0.857	0.925	0.806	0.828	0.874	0.872	0.849
$B_{4.3}$	0.887	0.880	0.880	0.875	0.821	0.922	0.846	0.841	0.854	0.894	0.869
$B_{5.1}$	0.870	0.870	0.889	0.859	0.888	0.854	0.941	0.836	0.849	0.869	0.859
$B_{5.2}$	0.857	0.849	0.876	0.849	0.819	0.835	0.939	0.831	0.846	0.868	0.844
$B_{6.1}$	0.879	0.886	0.885	0.876	0.858	0.857	0.840	0.957	0.855	0.887	0.875
$B_{6.2}$	0.897	0.899	0.912	0.884	0.888	0.884	0.859	0.959	0.869	0.898	0.902
$B_{7.1}$	0.897	0.898	0.889	0.902	0.868	0.889	0.860	0.845	0.954	0.895	0.892
$B_{7.2}$	0.921	0.895	0.888	0.907	0.863	0.893	0.846	0.851	0.957	0.890	0.903
$B_{7.3}$	0.911	0.887	0.904	0.898	0.861	0.909	0.864	0.869	0.940	0.911	0.885
$C_{1.1}$	0.886	0.894	0.874	0.877	0.834	0.867	0.840	0.848	0.855	0.913	0.894
$C_{1.2}$	0.913	0.881	0.902	0.896	0.841	0.874	0.868	0.850	0.866	0.912	0.885
$C_{1.3}$	0.844	0.865	0.857	0.861	0.850	0.875	0.826	0.863	0.828	0.898	0.859
$C_{1.4}$	0.877	0.891	0.904	0.894	0.865	0.878	0.861	0.854	0.874	0.919	0.878
$C_{1.5}$	0.873	0.886	0.894	0.892	0.832	0.899	0.826	0.829	0.870	0.925	0.869
$C_{1.6}$	0.900	0.864	0.900	0.894	0.866	0.880	0.849	0.868	0.892	0.917	0.892
$C_{2.1}$	0.899	0.878	0.892	0.883	0.874	0.870	0.855	0.867	0.876	0.891	0.931
$C_{2.2}$	0.910	0.889	0.887	0.908	0.866	0.876	0.842	0.860	0.892	0.903	0.941
$C_{2.3}$	0.881	0.886	0.882	0.870	0.839	0.875	0.835	0.864	0.859	0.894	0.921

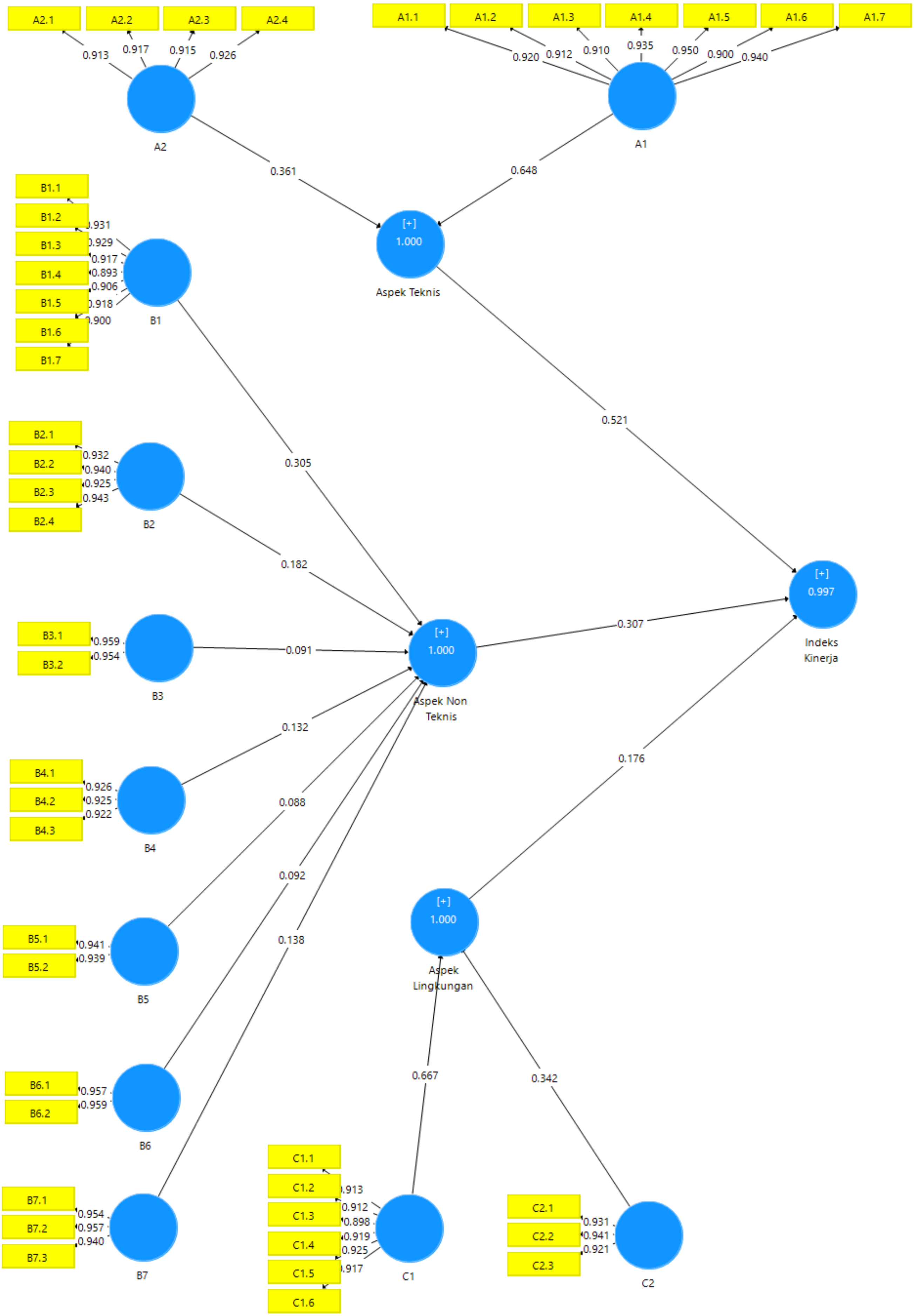

Figure 3. Relation Curve between Variable and Indicator

Table 5. Result of AVE Value- own study, 2024

	Cronbach's Alpha	Rho/ ρ A	Composite Reliability	Average Variance Extracted (AVE)
A_1	0.971	0.972	0.976	0.854
A_2	0.937	0.938	0.955	0.842
B_1	0.967	0.967	0.972	0.835
B_2	0.952	0.952	0.965	0.874
B_3	0.907	0.909	0.956	0.915
B_4	0.914	0.914	0.946	0.854
B_5	0.868	0.868	0.938	0.883
B_6	0.910	0.910	0.957	0.917
B_7	0.946	0.946	0.965	0.903
C_1	0.961	0.961	0.968	0.836
C_2	0.924	0.924	0.952	0.867
Environmental aspect	0.975	0.975	0.978	0.832
Non-technical aspect	0.990	0.990	0.991	0.823
Technical aspect	0.980	0.980	0.982	0.833
Performance index	0.990	0.991	0.991	0.827

3.2.2. Analysis of Structural Model

Analysis of Structural Equation Modelling (SEM) with Partial Least Square (PLS) is used to examine the influence relationships between dimensions and indicators [19]. This test evaluates whether the relationships between variables significantly influence the results. The results of the significance test for direct or indirect influences are shown in Table 6. Table 6 displays the path coefficient value (original sample) of the technical variable (A) to the performance index as 0.521, a positive value, indicating that the technical variable positively influences the performance index with a P-value of 0.00, which is less than 0.05. Therefore, it is concluded that the technical aspect significantly influences the performance index. The non-technical variable (B) has a path coefficient value to the performance index of 0.305, also a positive value, indicating that the non-technical variable positively influences the performance index with a P-value of 0.00, which is less than 0.05. It is concluded that the non-technical aspect significantly influences the performance index. The path coefficient value of the environmental variable (C) to the performance index is 0.174, another positive value, indicating that the environmental variable positively influences the performance index with a P-value of 0.00, which is less than 0.05. Therefore, it is concluded that the environment significantly influences the performance index.

Table 6. Evaluation of Structural Model- Analysis of SEM-PLS, 2024

Dimension	Original Sample (O)	Sample Mean (M)	Standard Deviation (STDEV)	T Statistics (|O/STDEV|)	P Values
A_1 → Technical	0.640	0.640	0.004	149.337	0.000
A_2 → Technical	0.360	0.360	0.004	89.533	0.000
B_1 → non-technical	0.300	0.300	0.003	116.145	0.000
B_2 → non-technical	0.180	0.180	0.003	72.167	0.000
B_3 → non-technical	0.090	0.090	0.002	59.729	0.000
B_4 → non-technical	0.130	0.130	0.002	74.462	0.000
B_5 → non-technical	0.080	0.080	0.002	46.044	0.000
B_6 → non-technical	0.090	0.090	0.002	53.569	0.000
B_7 → non-technical	0.130	0.130	0.002	56.367	0.000
C_1 → Environmental	0.660	0.660	0.004	155.923	0.000
C_2 → Environmental	0.340	0.340	0.004	77.802	0.000
Environmental → Performance index	0.174	0.174	0.031	5.606	0.000
Non-technical → Performance index	0.305	0.305	0.041	7.435	0.000
Technical → Performance index	0.521	0.521	0.039	13.489	0.000

Table 7 shows that r-square or determination coefficient from the three variables with r-square is 0.997 (has fulfilled). However, the value of r-square is a value that expressed how big the independent variable can explain the variance of dependent variable.

Table 7. Value of R-Square- own study, 2024

Description	R Square	R Square Adjusted
Performance index	0.997	0.997
Environmental (Li)	1.000	1.000
Technical (Tk)	1.000	1.000
Non-technical (NT)	1.000	1.000

Based on the evaluation result of the structural model and the value of R-square, mathematically, the performance index value of raw water infrastructure is as follows:

$$\text{IK Technical} = 0.640\ A_1 + 0.360\ A_2 \tag{1}$$

$$\text{IK non-technical} = 0.300\ B_1 + 0.180\ B_2 + 0.09\ B_3 + 0.130\ B_4 + 0.080\ B_5 + 0.09\ B_6 + 0.130\ B_7 \tag{2}$$

$$\text{IK Environmental} = 0.660\ C_1 + 0.340\ C_2 \tag{3}$$

$$\text{IK Infrastructure Raw Water} = 0.521\ IK_{Tk} + 0.305\ IK_{NT} + 0174\ IK_{Li} \tag{4}$$

3.2.3. Generalized Reduced Gradient (GRG)

This method is combined with the Microsoft Excel Solver tool to determine the weights of each variable, dimension, and indicator. In iterative modeling, it is crucial to establish boundaries, and in this research, field data is utilized for this purpose. Evaluation in GRG involves using Microsoft Excel, which includes regression analysis metrics such as Sum of Squared Residuals (SSR) to gauge how well the regression model fits the given data. The goal is to minimize the SSR to enhance the model's performance [19].

Root Mean Square Error (RMSE) assesses linear regression by quantifying the accuracy of model estimations. RMSE is calculated by squaring the prediction error (prediction - observation), dividing by the number of data points on average, and then taking the square root, yielding a unitless measure. RMSE ranges from 0 to ∞ and is negatively oriented; lower values indicate better accuracy. A smaller RMSE signifies closer predicted values to observed values [20].

Mean Square Error (MSE) is a statistical and machine learning metric used to evaluate how accurately a regression model predicts numerical values. MSE measures the squared differences between predicted and actual values, ensuring all differences are positive. A smaller MSE indicates a more accurate regression model for prediction purposes. MSE is particularly useful for selecting the most accurate regression model [21]. The constraints of the performance index model are as follows:

Evaluation of Generalized Reduced Gradient by using variable condition is as follow:

- $0 \leq$ IK technical ≤ 4, it shows that for technical performance index has the performance value from 0 until 4.
- $0 \leq$ IK non-technical ≤ 4, the performance index value for non-technical is from 0 until 4.
- $0 \leq$ IK environmental ≤ 4, the performance index value for environmental is from 0 until 4.
- KSA + KFPA = 1, the assessment of technical performance index with total = 1 means that number of dimensions of the water source quantity (KSA) and physical condition of raw water infrastructure (KFPA) that in this application is as mathematical function.
- SEB + K/R + OP + LP + D + AIA + SDM = 1, non-technical performance index total of mathematical function from dimension of socio-economic-culture (SEB) + dimension of policy/ regulation (K/R) + personal organization (OP) + management institution (LP) + documentation (D) + asset of raw water infrastructure (AIA) + human resources (SDM).
- LSA + KSA = 1, environmental performance index total of mathematical function for environment surrounding water source (LSA) + sustainable water source (KSA).
- $0 \leq$ IK raw water infrastructure ≤ 4, performance index value of raw water infrastructure is from 0 until 4.
- $\alpha + \beta + \gamma = 1$, this value is as the function of IK technical (α) + IK non-technical (β) + IK environmental (γ).

Table 8 presents the performance values used in GRG analysis to obtain the performance index models for technical, non-technical, and environmental aspects. The assessment range is based on a Likert scale, as specified in Circular Letter-Directorate General of Water Resources No. 03-year 2021, which assigns percentage values to each performance result. These values are integral to the field performance index analysis for technical, non-technical, and environmental evaluations.

Table 8. Performance Index Based on Circular Letter- Directorate General of Water Resources No 03-year 2021- SE Dirjen SDA, 2021

Description	Performance Value (%)	Performance Value (Number)
Very good performance	80-100	4
Good performance	70-80	3
Not good performance	55-70	2
Bad performance	<55	1

a). Technical Performance Index

$$\text{IK technical} = 0.640\,A_1 + 0.360\,A_2$$
$$A_1 = 0.920\,A_{1.1}+0.912\,A_{1.2}+0.910\,A_{1.3}+0.935\,A_{1.4}+0.950\,A_{1.5}+0.900\,A_{1.6}+0.940\,A_{1.7} \quad (5)$$
$$A_2 = 0.913\,A_{2.1}+0.917\,A_{2.2}+0.915\,A_{2.3}+0.926\,A_{2.4}$$

The model of IK technical is tested by using the field analysis result data and there is obtained the illustration as presented in the Figure 4.

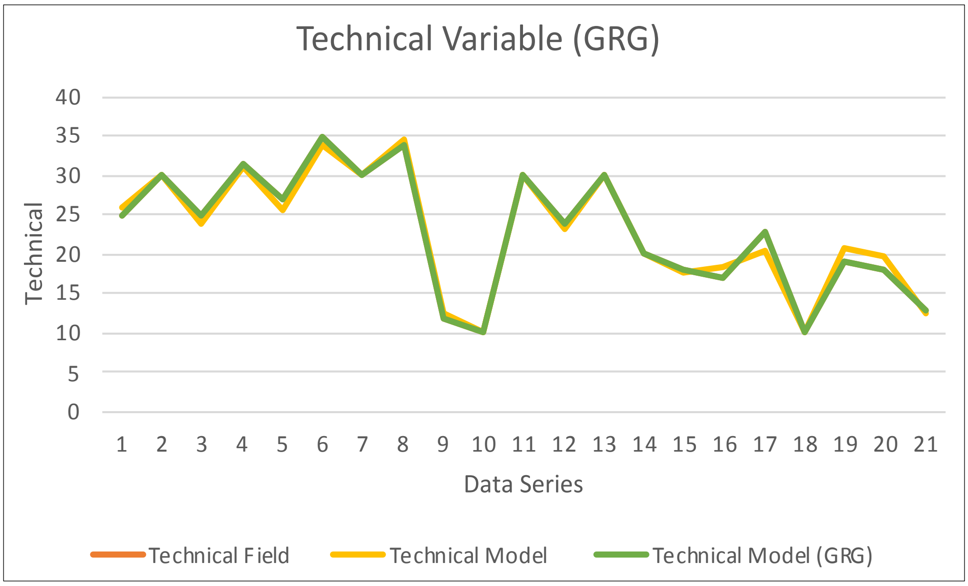

Figure 4. Test Curve of GRG between Model and Field for Technical Variable

Figure 4 shows the test result between field data and the technical performance index model that has been evaluated using GRG, and the values obtained are: A_1=0.500 and A_2=0.500 so the SSR = 21.050, RMSE = 0.105, and MSE = 1.002. The value of RMSE is 0.105, which shows that the predicted value is close to observation. Figure 4 shows that the curve of the field technical variable is close to the curve of the technical model variable before the GRG analysis is carried out; however, the curve of the technical model variable after the GRG is similar to both.

b). Non-technical Performance Index

$$\text{IK non-technical} = 0.300\,B_1+0.180\,B_2+0.09\,B_3+0.130\,B_4+0.080\,B_5+0.09\,B_6+0.130\,B_7$$
$$B_1 = 0.931\,B_{1.1}+0.929\,B_{1.2}+0.917\,B_{1.3}+0.893\,B_{1.4}+0.906\,B_{1.5}+0.918\,B_{1.6}+0.90\,B_{1.7}$$
$$B_2 = 0.932\,B_{2.1}+0.940\,B_{2.2}+0.925\,B_{2.3}+0.943\,B_{2.4}$$
$$B_3 = 0.959\,B_{3.1}+0.954\,B_{3.2}$$
$$B_4 = 0.926\,B_{4.1}+0.925\,B_{4.2}+0.922\,B_{4.3} \quad (6)$$
$$B_5 = 0.941\,B_{5.1}+0.939\,B_{5.2}$$
$$B_6 = 0.957\,B_{6.1}+0.959\,B_{6.2}$$
$$B_7 = 0.954\,B_{7.1}+ 0.957\,B_{7.2}+ 0.940\,B_{7.3}$$

Figure 5 shows the testing result of GRG between the non-technical performance index model and field analysis data, so it produces the value as follows: B_1=0.160, B_2=0.090, B_3=0.120, B_4=0.110, B_5=0.090, B_6=0.180, and B_7=0.250, so the value of SSR = 17.918, RMSE = 0.202, and MSE = 0.853. Figure 5 illustrates that the non-technical performance index model, the model, and GRG are the same, and it indicates that the data that is inputted is the same. However, Figure 4 shows that the line-of-field non-technical variable analysis result with the GRG-tested non-technical variable result is the same; therefore, the model analysis result of the non-technical variable is similar to both.

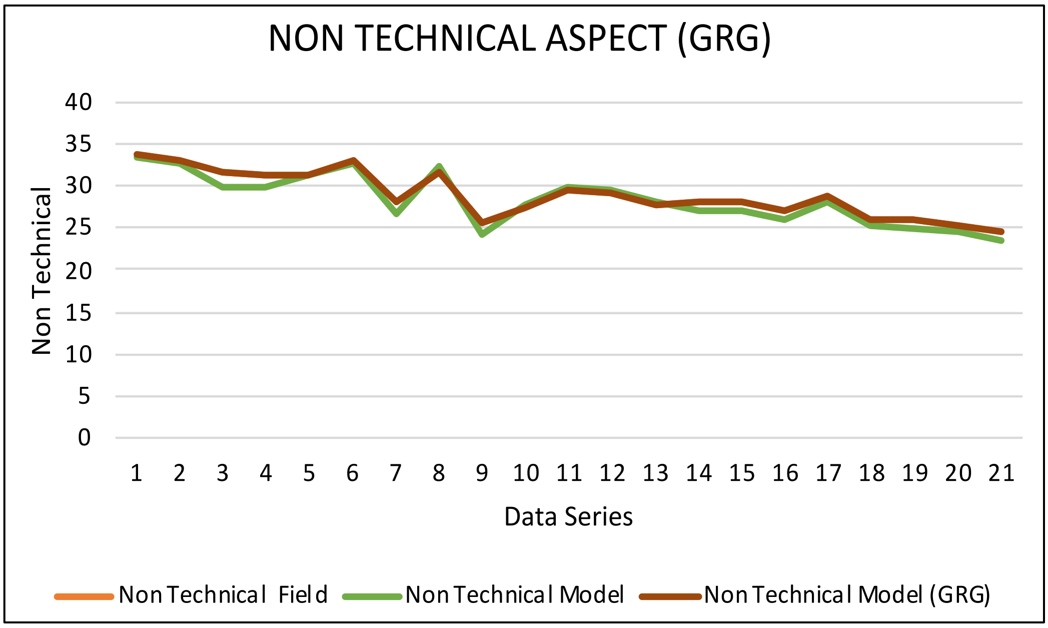

Figure 5. Testing Curve of GRG between Model and Field for Non-technical Variable

c). Environmental Performance Index

$$\text{IK environmental} = 0.660\ C_1 + 0.340\ C_2$$

$$C_1 = 0.913\ C_1.1 + 0.912\ C_{1.2} + 0.898\ C_{1.3} + 0.919\ C_{1.4} + 0.925\ C_{1.5} + 0.917\ C_{1.6} \tag{7}$$

$$C_6 = 0.931\ C_{2.1} + 0.941\ C_{2.2} + 0.921\ C_{2.3}$$

Figure 6 shows the testing results of GRG between the non-technical performance index and field analysis data, so it produces the value as follows: C_1 = 0.470 and C_2 = 0.530, with the values of SSR = 0.285, RMSE = 0.025, and MSE = 0.013. Figure 5 shows that the field value, model value, and GRG value are not far different, but they tend to be similar. It indicates that this model can also be used for environmental variables with field analysis. Figure 6 shows that the curve of the field environmental variable analysis result, the curve of the environmental model variable result, and the curve of the environmental variable GRG test result are almost the same.

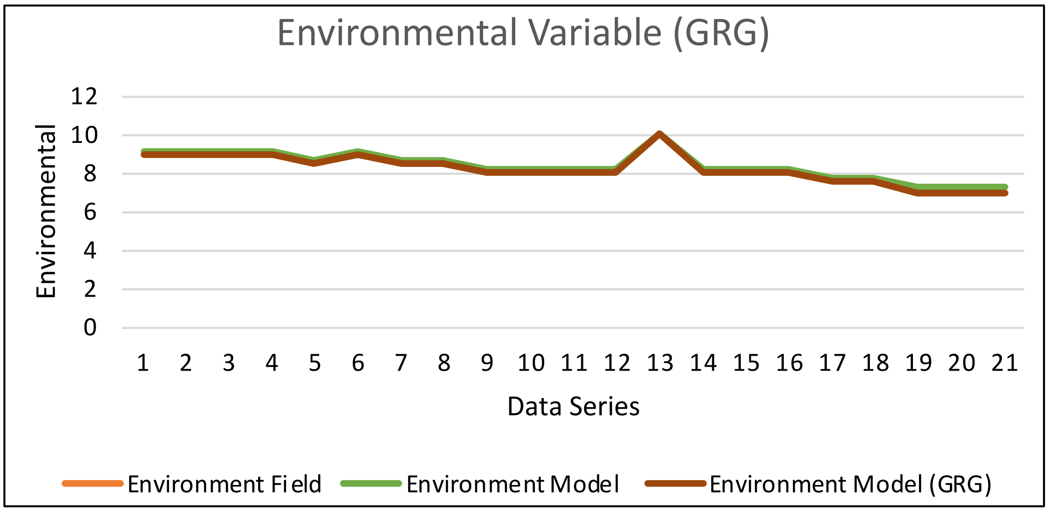

Figure 6. Testing Curve of GRG between Model and Field for Environmental Variable

d). Raw Water Infrastructure Performance Index

IK raw water infrastructure = 0.521 IK $_{Tk}$ + 0.305 IK $_{NT}$ + 0.174 IK $_{Li}$ is a performance index model of raw water infrastructure after being optimized by using GRG. Figure 7 shows the GRG test result of raw water infrastructure performance index with the analysis result of the infrastructure performance index model and the performance index model of field infrastructure, where the coefficient value of the model after being optimized becomes a technical variable of 0.44, a non-technical value of 0.34, and an environmental value of 0.22, with the value of SSR is 83.312, the RMSE is 0.435, and the MSE is 3.967.

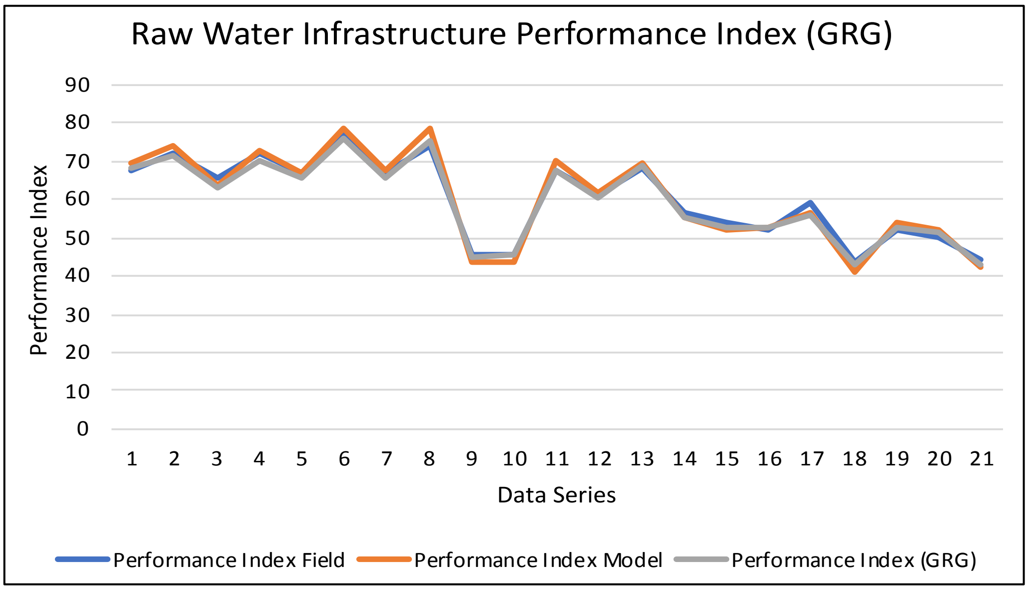

Figure 7. Testing Curve of GRG between Model and Field for Non-technical Variable

Figure 7 shows that the analysis result obtained between field performance index analysis (qualitative analysis result) and the model result of the raw water performance index has almost the same value as the analysis result of the GRG performance index. Table 9 shows the analysis results of the field performance index, model performance index, and performance index of the GRG result. This analysis result is obtained from qualitative analysis in 21 research locations that has produced value based on the technical, non-technical, and environmental variables. Based on the results in Figure 6 and Table 8, it can be concluded that the model can be used in other water locations in Nusa Tenggara Barat Province, mainly in Lombok and the Sumbawa Islands.

Table 9. Testing Value of GRG for Raw Water Infrastructure Performance Index- own study, 2024

T	NT	L	IK Field	IK Model	IK GRG
26.00	33.38	9.06	67.60	69.39	68.03
30.00	32.62	9.06	72.00	73.60	71.46
24.00	30.00	9.06	65.50	63.70	63.06
31.20	29.82	9.06	71.90	72.41	70.25
25.60	31.33	8.59	66.90	66.66	65.20
34.00	32.62	9.06	77.00	78.52	75.54
30.00	26.71	8.59	66.50	67.67	65.67
34.40	32.33	8.59	74.00	78.45	75.04
12.40	24.21	8.12	45.50	43.33	44.91
10.00	27.71	8.12	45.50	43.70	45.50
30.00	29.81	8.12	67.50	70.34	67.71
23.20	29.40	8.12	61.00	61.57	60.42
30.00	27.90	10.00	67.80	69.68	68.67
20.00	26.87	8.12	56.20	55.22	54.97
17.60	26.86	8.12	54.20	52.26	52.51
18.40	25.89	8.12	52.00	52.32	52.49
20.40	28.09	7.65	59.10	56.59	55.78
10.00	25.16	7.65	43.60	40.99	42.64
20.80	24.92	7.18	51.80	53.77	52.79
19.60	24.51	7.18	50.30	51.90	51.21
12.40	23.42	7.18	44.50	41.99	42.92

3.2.4. Validation

The analysis result of the raw water infrastructure performance model is validated by using the analysis result due to SE Dirjen SDA 03/2021, which in every research location has carried out the analysis for technical, non-technical, and environmental variables as presented in Table 8 above. In addition, it also uses the GRG application for producing the performance index model of raw water (GRG) that is validated. The validation and verification that have been adjusted with technical, non-technical, and environmental variables in the raw water performance index model are as follows: the accurate value of the validation result is 95.25%, with SSR value is 83.21, RMSE is 0.44, and MSE is 3.97.

Table 10 shows the analysis result of the field raw water infrastructure performance index with the raw water infrastructure performance index due to the validated GRG. The research locations in the number of 21 are in the good performance category. There are four raw water supply systems on Lombok Island; however, the average performance of the raw water supply system on Sumbawa Island is poor.

Table 10. Performance Index of Field and GRG- Analysis Result, 2024

No.	Unit of raw water	Regency	IK Field	IK GRG	Performance Index
Lombok Island					
1	Lembah Sempaga	West Lombok	67.60	68.03	Underperformance
2	Sarasuta	West Lombok	72.00	71.46	Good Performance
3	Remening	West Lombok	65.50	63.06	Underperformance
4	Serepak	West Lombok	71.90	70.25	Good Performance
5	Sesera	Middle Lombok	66.90	65.20	Underperformance
6	Rangat	West Lombok	77.00	75.54	Good Performance
7	Pandanduri	East Lombok	66.50	65.67	Underperformance
8	Sekeper	Northern Lombok	74.00	75.04	Good Performance
9	Tibu Ulik	East Lombok	45.50	44.91	Bad Performance
10	Sordang	East Lombok	45.50	45.50	Bad Performance
11	Singang Pitu Nai	Northern Lombok	67.50	67.71	Underperformance
12	Jonplanka	Northern Lombok	61.00	60.42	Underperformance
13	Otak Aik	West Lombok	67.80	68.67	Underperformance
Sumbawa Island					
1	Semongkat	Sumbawa	56.20	54.97	Underperformance
2	Brangdalap	Sumbawa	54.20	52.51	Bad Performance
3	Tiu Pasai	Sumbawa	52.00	52.49	Bad Performance
4	Labangka	Sumbawa	59.10	55.78	Underperformance
5	Mongglenggo	Dompu	43.60	42.64	Bad Performance
6	Ncoha	Bima	51.80	52.79	Bad Performance
7	Patula	Bima	50.30	51.21	Bad Performance
8	Rababaka	Dompu	44.50	42.92	Bad Performance

4. Conclusion

The sustainability of raw water supply system infrastructure requires comprehensive management of the water source, transmission pipe network, water treatment installation, and distribution system. If any of these components perform poorly, the overall performance will also be poor. This research examines the performance of raw water infrastructure, particularly the intake and transmission pipe network, which are influenced by technical, non-technical, and environmental aspects.

The analysis results indicate that the technical aspect significantly affects the performance of raw water infrastructure, along with non-technical and environmental aspects. The optimization results from GRG show an SSR value of 83.21, an RMSE of 0.44, and an MSE of 3.97. These values suggest that the model meets the criteria for a good fit, as a smaller SSR indicates a better model, and the low RMSE and MSE values further confirm the model's suitability. The model for raw water infrastructure performance is represented by the equation: IK infrastructure raw water = 0.521 IK_{Tk} + 0.305 IK_{NT} + 0.174 IK_{Li}. The mathematical model developed in this research can be applied to other locations with similar characteristics to the research site. For locations with different characteristics, adjustments and further research are necessary, especially in areas with a discharge rate of more than 250 *l/s* and continuous region conditions (non-islands).

The research results reveal the main factors influencing raw water infrastructure performance, based on a coefficient value greater than 0.500. These factors are water availability at the raw water source (0.640 A_1) and the condition of the environment surrounding the raw water source (0.660 C_1). Supporting factors include the physical condition of the raw water infrastructure (0.360 A_2), the sustainability of the water source (0.340 C_2), and the management institution (0.300 B_1). Therefore, if the water source is insufficient, the performance of the raw water supply system is heavily influenced by the environmental conditions around the water source, ensuring the sustainability of water availability.

5. Declarations

5.1. Author Contributions

Conceptualization, S.U.S. and U.A.; methodology, S.U.S.; validation, S.U.S.; formal analysis, S.U.S.; investigation, S.U.S. and S.U.S.; resources, S.U.S. and L.M.L.; data curation, S.U.S. and H.S.; writing—original draft preparation, S.U.S. and U.S.; writing—review and editing, L.M.L. and H.S.; visualization, L.M.L. and H.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.

5.3. Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

5.4. Conflicts of Interest

The authors declare no conflict of interest.

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