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EVALUATION OF THE SUCCESS OF THE TOFU INDUSTRIAL WASTEWATER TREATMENT PLANT USING STRUCTURAL EQUATION MODELING

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ABSTRACT: This paper is a case study in Ledok Kulon Village, Bojonegoro Regency. Ledok Kulon Village is known as the center of the tofu industry in Bojonegoro Regency, Indonesia. The number of tofu industries in Ledok Kulon Village is 64 companies. The existence of the tofu industry is considered disturbing to the community because the wastewater produced by the tofu industry causes an unpleasant odor and many disease vectors, such as rats, flies, and other insects. Another problem is the pollution that occurs in the Bengawan Solo River, where this wastewater is disposed of. In 2018, a wastewater treatment plant (WWTP) was built by the Bojonegoro Regency Government at this location, but the above problems have not been resolved. Therefore, this research needs to be carried out to find facts about the factors that influence the successful management and sustainability of WWTP in Ledok Kulon Village using Structural Equation Modeling (SEM). SEM is a multivariate method for examining complex relationships between variables. In this study, there are three exogenous variables, namely *technical* (*X1*), *institutional* (*X2*), and *community participation* (*X3*), and two endogenous variables, namely *WWTP management success* (*Y1*) and *WWTP sustainability* (*Y2*). The results of the SEM analysis show that the three exogenous variables above have a significant and positive effect on *WWTP management success* (*Y1*). The *WWTP management success* (*Y1*) also has a significant and positive effect on *WWTP sustainability* (*Y2*).

Keywords: Bojonegoro Regency, Sustainability, Tofu industrial waste, WWTP management

1. INTRODUCTION

Tofu is a very popular traditional food in Indonesia [1]. Tofu is made from soybean seeds through a long process, including soaking, grinding, boiling, filtering, coagulating, wrapping, and printing [2]. In the production process, wastewater is produced with a high pollution load [3]. In general, high pollution load wastewater can cause water to smell bad, become cloudy, and kill aquatic organisms. The general characteristics of tofu wastewater contain high pollutant parameters, such as BOD, COD, TOC, and TSS [4]. According to Kesari et al. [5], disposal of wastewater directly into the rivers or reuse of wastewater for irrigation purposes can have short-term impacts, such as heavy metal and microbial contamination and pathogen interactions in soil and plants. Wastewater contains major amounts of organic matter and pathogenic and infectious microorganisms. This can spread various diseases, such as typhoid, diarrhea, dysentery, vomiting, and malabsorption.

Therefore, tofu industrial wastewater must be treated so that the pollutant content is low and may be disposed of in the environment without causing pollution. Wastewater treatment can improve water quality. According to Englande Jr et al. [6], wastewater treatment can reduce the content of organic matter, nutrients, and pathogens in wastewater, thereby improving water quality and preventing the spread of disease. Wastewater treatment can also improve human health. According to López-Pila et al. [7], wastewater treatment can prevent the spread of diseases caused by pathogens in wastewater, thereby improving human health. Also, wastewater treatment can increase environmental sustainability [8]. The wastewater treatment can reduce groundwater use and increase the availability of clean water [9] so that it can help maintain environmental sustainability. This paper will discuss the evaluation of the successful operation of a wastewater treatment plant (WWTP) in the tofu industry in Ledok Kulon Village, Bojonegoro Regency, Indonesia. The analytical tool used in this study is Structural Equation Modeling (SEM). This SEM has been used by Masduqi et al. [10] to analyze the sustainability of pipeline water supply in rural areas. SEM is widely used in operations management research [11].

Ledok Kulon Village is located to the north of Bojonegoro District, Bojonegoro Regency, East Java Province, at a geographical position of 7.14150° S and 111.8690° E. Ledok Kulon Village in 2019 has a population of 10,728 people with livelihoods in the trade, livestock, services, and home industry sectors. This village is known as the center of the tofu industry. The number of tofu industries in Ledok Kulon Village is 64 companies, and the number of Tempe industries is 42 companies [12]. In 2018, a WWTP to reduce the negative impact of tofu waste on the community was built. However, this effort has not been able to solve the problems caused by tofu wastewater, namely the unpleasant odor, many disease vectors, and the occurrence of pollution in the Bengawan Solo River, the disposal site for wastewater from WWTP effluent.

The purpose of this study is to find facts about the factors that influence the successful management and sustainability of the WWTP in Ledok Kulon Village using the SEM method. The results of this study are expected to provide references and suggestions for tofu industry entrepreneurs in general and local communities in Ledok Kulon Village in terms of:

- Efforts to solve problems caused by tofu industrial wastewater.
- Increasing the reliability of the tofu industrial WWTP that has been built so that it can be successful and sustainable in treating wastewater.

2. RESEARCH SIGNIFICANCE

In general, small industries that are managed by the community do not have the financial capacity and expertise to manage their wastewater. Therefore, they really hope for government assistance to support the success of their wastewater management. This research is important to do to determine the factors that influence the success and sustainability of wastewater management so that government assistance will be more appropriate for them, whether technical assistance, institutional development, or increased community participation. Factors that influence the success and sustainability of wastewater management can be determined using structural equation modeling.

3. METHODS

This study was conducted based on SEM theory supported by data collected at the study locations, both survey and institutional data. Data collection was carried out through interviews and filling out questionnaires by respondents, observation, documentation, wastewater sampling, and laboratory examination. Interviews and questionnaires were conducted with tofu industry owners and communities affected by tofu industry wastewater. Furthermore, the data that has been collected and analyzed by SEM. This SEM is used to confirm the study hypothesis that has been prepared, namely the *WWTP management success* is influenced by *technical* aspects, *institutional* aspects, and *community participation*. The success of subsequent management will affect sustainability. Each variable is indicated by several indicators (see Table 1). The relationship between variables can be seen in Fig. 1. SEM analysis using AMOS software from SPSS. To obtain reliable analysis results, various tests were carried out on the collected data. The tests performed are normality test, outlier test, singularity test, validity test, and reliability test.

A normality test is carried out to ensure that the data obtained is normally distributed. This is one of the requirements of the SEM method. To see this normality, the critical ratio must be calculated. Data is considered normally distributed, both univariately and multivariate, if -1.96 ≤ critical ratio ≤ 1.96, at a significance level of 5 percent [13].

The outlier test is to assess the emergence of extreme values in a univariate or multivariate manner. This study uses Mahalanobis distance or Mahalanobis d-squared [14]. Mahalanobis values that are greater than the Chi-square table or *p-values* < 0.001 are considered outlier data. The singularity test is carried out through the determinants of the covariance matrix. A determinant value that is approximately zero indicates that there is a singularity problem that causes the data to not be used for research.

Validity and reliability tests were carried out with Product Moment and Cronbach Alpha. At this step, the composite variable consisting of several indicators is calculated for its total score and tested for validity and reliability using Product Moment correlation and Cronbach Alpha. In the next step, latent variables are tested for validity and reliability through CFA (confirmatory factor analysis) and construct reliability (CR). The CR value is calculated by the equation [15] [16] [17]:

$$\boldsymbol{CR} = \frac{(\sum \boldsymbol{\lambda_i})^2}{(\sum \boldsymbol{\lambda_i})^2 + \sum(\boldsymbol{1} - \boldsymbol{\lambda_i^2})} \quad (1)$$

Where, λ_i is the *component loading* to indicator.

Another method is to assess discriminant validity, which is to compare the root value of the average variance extracted (AVE) of each construct with the correlation between constructs and other constructs in the model [17] [18]. The equation for calculating AVE is:

$$\boldsymbol{AVE} = \frac{\sum \boldsymbol{\lambda_i^2}}{\sum \boldsymbol{\lambda_i^2} + \sum \boldsymbol{Var(e_i)}} \quad (2)$$

with $\boldsymbol{Var(e_i)} = \boldsymbol{1} - \boldsymbol{\lambda_i^2}$.

4. RESULTS AND DISCUSSION

4.1 Data Description

In the early steps, data testing was carried out, i.e. the normality test, outlier test, singularity test, validity test, and reliability test. In the normality test, the multivariate critical ratio value was equal to 1.948, so it was concluded that the data had a normal multivariate distribution. The calculation of the Mahalanobis and Chi-square values in the outler test shows that there is no *p-value* <0.001, which means that there are no outliers. In the Singularity test, the determinant value of the sample covariance matrix is 0.513 (considered not approximate to zero), which means that there is no singularity problem in the data being analyzed. Confirmatory Factor Analysis (CFA) was carried out using AMOS software, which obtained loading factor and regression weight values. CFA results will be obtained from each simulation discussed in each measurement model.

The next step is the respondent's assessment of all latent variables. In the assessment of the *technical* variables (*X1*), *institutional* (*X2*), *community participation* (*X3*), *WWTP management success* (*Y1*), and *WWTP sustainability* (*Y2*), the average values were respectively 3.341 (standard deviation 0.936), 3.394 (standard deviation 0.918), 3.388 (standard deviation 0.966), 3.390 (standard deviation 1.015), and 3.336 (standard deviation 0.943). The meaning of all these values is that respondents tend to agree with the statements of the indicators for all latent variables.

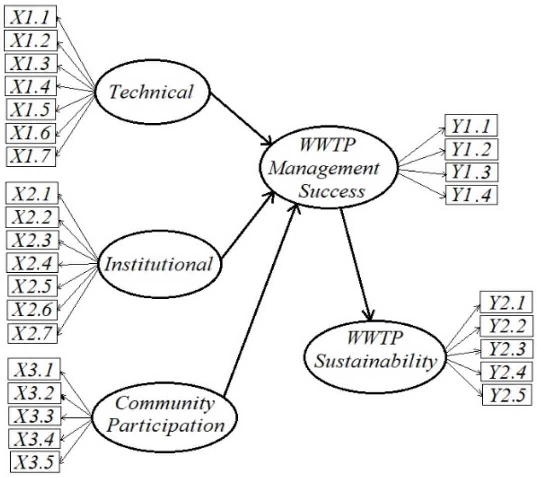

Fig. 1 The relationship between latent variables is hypothesized in this study.

Table 1 Variable and Indicator of Each Latent Variable

Latent variables		Type of variable	Indicators	
Code	Name		Code	Name
X1	*Technical*	exogenous	*X1.1*	*Selection of technology*
			X1.2	*Availability of materials*
			X1.3	*Physical condition of infrastructure*
			X1.4	*WWTP performance*
			X1.5	*Implementation of SOP*
			X1.6	*Ease of operation*
			X1.7	*Possibility of system expansion*
X2	*Institutional*	exogenous	*X2.1*	*Organization and management*
			X2.2	*Mechanism for electing administrators*
			X2.3	*Institutional management capability*
			X2.4	*Financial management capability*
			X2.5	*Operator performance*
			X2.6	*Board and user meetings*
			X2.7	*External support*
X3	*Community participation*	exogenous	*X3.1*	*Demand Response*
			X3.2	*In-kind support*
			X3.3	*Community understanding level*
			X3.4	*Willingness to pay*
			X3.5	*Social interaction*
Y1	*WWTP management success*	endogenous	*Y1.1*	*Ease of access*
			Y1.2	*Cleanliness and comfort*
			Y1.3	*WWTP management agency*
			Y1.4	*Appropriate quality*
Y2	*WWTP sustainability*	endogenous	*Y2.1*	*System quality*
			Y2.2	*Human capacity development*
			Y2.3	*Local agency capability*
			Y2.4	*Unit cost sharing*
			Y2.5	*Inter-organizational collaboration*

4.2 Variable Testing

After testing each latent variable, several prerequisites that must be met in structural modeling are the normal multivariate assumption, the assumption that there is no multicollinearity or singularity, and outliers. This test uses the AMOS software to obtain the loading factor of each latent variable for all indicators (Table 2). The loading factor value of all latent variables on the indicators is greater than 0.50, which means that all indicators can indicate latent variables.

Table 2 Loading Factor Values in the Measurement Model for Each Variable

Latent variables		Indicators	Loading factors
X1	*Technical*	*X1.1*	0.742
		X1.2	0.800
		X1.3	0.680
		X1.4	0.696
		X1.5	0.790
		X1.6	0.724
		X1.7	0.683
X2	*Institutional*	*X2.1*	0.873
		X2.2	0.676
		X2.3	0.680
		X2.4	0.736
		X2.5	0.616
		X2.6	0.746
		X2.7	0.671
X3	*Community participation*	*X3.1*	0.753
		X3.2	0.693
		X3.3	0.748
		X3.4	0.657
		X3.5	0.504
Y1	*WWTP management success*	*Y1.1*	0.793
		Y1.2	0.725
		Y1.3	0.649
		Y1.4	0.559
Y2	*WWTP sustainability*	*Y2.1*	0.709
		Y2.2	0.632
		Y2.3	0.609
		Y2.4	0.845
		Y2.5	0.670

4.3 Structural Equation Testing

After testing the validity and reliability of all latent variables with valid and reliable data results, normal multivariate, no singularities, and no outliers, these latent variables can be continued in the analysis in the form of a path diagram, as shown in Fig. 2. The complete results of model testing with AMOS software can be seen in Table 3.

Table 3 shows that the eight criteria used to assess the feasibility of a model stated "Good" and ”Good enough”. This means that the model is acceptable because it is considered that there is a match between the model and the data. With an appropriate model, each path coefficient inter-variable can be interpreted. The path coefficients are the hypotheses in this study, which can be presented in the following structural equation:

$$Y1 = 0.432\, X1 + 0.232\, X2 + 0.354\, X3 \qquad (3)$$

$$Y2 = 0.982\, Y1 \qquad (4)$$

4.4 Hypothesis Test

The path coefficient test in Figure 2 and the equations (3) and (4) are presented in detail in Table 4. The interpretation of the path coefficients of the variable relationships in Table 4 is as follows:

- *Technical* variable (*X1*) has a significant and positive effect on the *WWTP management success* (*Y1*) at p = 0.027. The increase in technical variables will increase the success variable of WWTP management by 0.432 times.
- *Institutional* variable (*X2*) has a significant and positive effect on the *WWTP management success* (*Y1*) at p = 0.036. Increasing institutional variables will increase the success variable of WWTP management by 0.232 times.
- *Community participation* variable (*X3*) has a significant and positive effect on the *WWTP management success* (*Y1*) at p = 0.023. Increasing the community participation variable will increase the success variable of WWTP management by 0.354 times.
- *WWTP management success* variable (*Y1*) has a significant and positive effect on *WWTP sustainability* (*Y2*) at p = 0.000. Thus, every time there is an increase in the success of WWTP management, the WWTP sustainability will increase by 0.982 times.

4.5 Influence of Inter-variables

In structural equations that involve many variables and paths inter-variables, there are influences of inter-variables, which include direct, indirect, and total effects. For that will be discussed in detail each of these influences.

4.5.1 Direct Effects

A direct relationship occurs between exogenous latent variables (*technical* (*X1*), *institutional* (*X2*), *community participation* (*X3*)) with intervening endogenous latent variables (*WWTP management success* (*Y1*)) and endogenous latent variables (*WWTP sustainability* (*Y2*)). Table 5 presents the direct relationship that occurs between exogenous and endogenous latent variables. This direct inter-variable relationship clarifies the resulting structural equations (equations (1) and (2)).

4.5.2 Indirect Effects

An indirect relationship occurs between exogenous latent variables (*technical* (*X1*), *institutional* (*X2*), *community participation* (*X3*)) with intervening endogenous latent variables (*WWTP management success* (*Y1*)) and endogenous latent variables (*WWTP sustainability* (*Y2*)). Table 6 presents the results of the Indirect effects that occur between exogenous and endogenous latent variables.

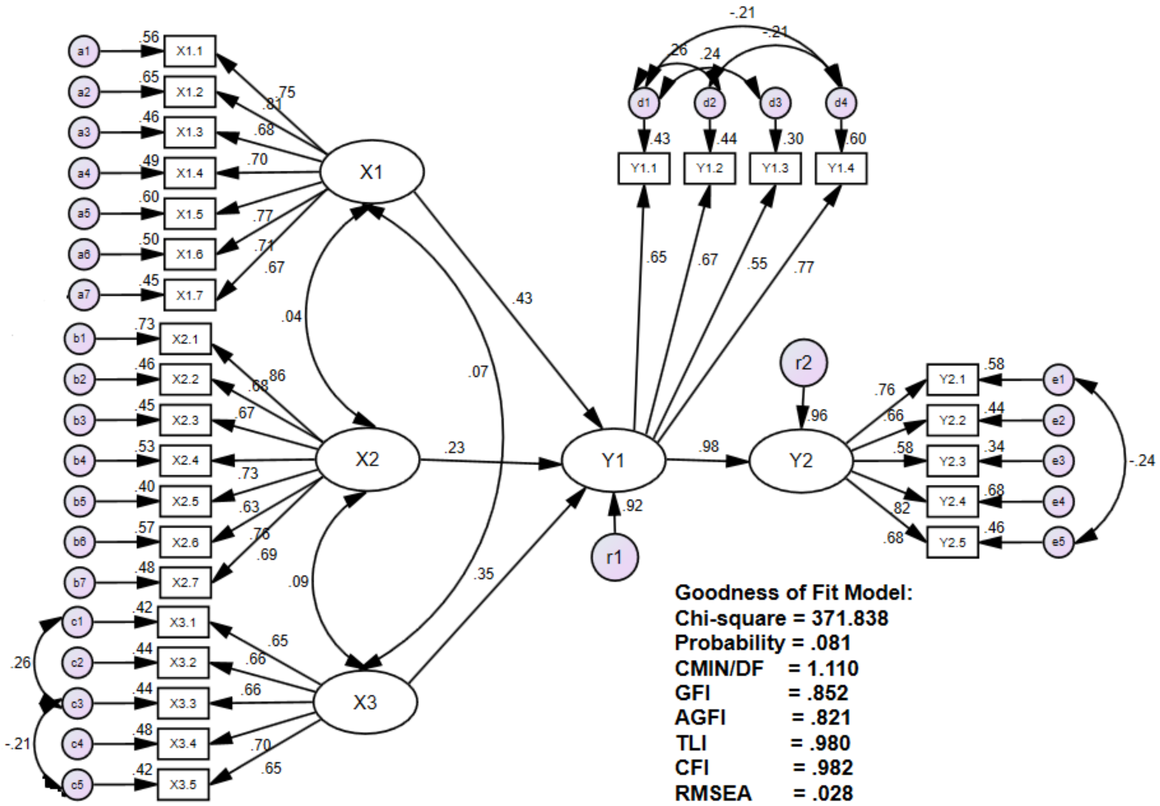

Fig. 2 Structural model which states the influence of exogenous variables (*X1*, *X2*, and *X3*) on endogenous variables (*Y1* and *Y2*)

Table 3 Variable and Indicator of Each Latent Variable

Criteria	Cut–off values	Calculation results	Remarks
Chi-Square	Expected small	371.838	χ^2 at *df* = 335 is 378.682; Good
Significance Probability	> 0.05*	0.081	Good
RMSEA	< 0.08*	0.028	Good
GFI	> 0.90*	0.852	Good enough
AGFI	> 0.90*	0.821	Good enough
CMIN/DF	< 2.00	1.110	Good
TLI	> 0.90*	0.980	Good
CFI	> 0.90*	0.982	Good

*: [19]

Table 4 Test Results for the WWTP Sustainability Model Path Coefficient

Variable relation	Coefficient	Critical ratio	Probability	Remarks
X1→ *Y1*	0.432	2.210	0.027	Significant
X2 → *Y1*	0.232	2.102	0.036	Significant
X3 → *Y1*	0.354	2.267	0.023	Significant
Y1 → *Y2*	0.982	7.708	0.000	Significant

Table 5 Direct Influence of Inter-variables

Direct effects		Intervening variable (*Y1*)	Endogenous variable (*Y2*)
Exogenous Variable	*X1*	0.432	
	X2	0.232	
	X3	0.354	
Intervening Variable	*Y1*		0.982

Table 6 Indirect Effect of Inter-variable

Indirect effects		Intervening variable	Endogenous variable (*Y2*)
Exogenous Variable	*X1*	*Y1*	0.424
	X2	*Y1*	0.228
	X3	*Y1*	0.348

Detecting the effect of mediation can be seen as mediation. If the direct effect of the exogenous variable on the endogenous variable is significant and the indirect effect through the intervening variable is also significant, then it is considered *partial mediation*. Conversely, if the direct effect of the exogenous variable on the endogenous variable is insignificant, while the indirect effect through the intervening variable is significant, then it is considered *complete mediation* or *perfect mediation* [20]. The results of the indirect effect test using the *Sobel* test are presented in Table 7.

Based on Table 7, the results of the indirect effect test can be explained as follows:

1. The direct effect of *technical* (*X1*) on *WWTP sustainability* (*Y2*) is significant, while the indirect effect through the mediation of *WWTP management success* (*Y1*) is known to be significant, with the nature of mediation being *partially mediation*. Thus, the *technical* (*X1*) can increase the *WWTP sustainability* (*Y2*), even without going through the mediation of *WWTP management success* (*Y1*), but if also supported by a strong *WWTP management success* (*Y1*), the *WWTP Sustainability* (*Y2*) will be higher.
2. The direct effect of *institutional* (*X2*) on *WWTP sustainability* (*Y2*) is significant, while the indirect effect through the mediation of the *WWTP management success* (*Y1*) is known to be significant, with the nature of mediation being *partially mediation*. Thus, *institutional* (*X2*) can increase the *WWTP sustainability* (*Y2*), even without going through the mediation of *WWTP management success* (*Y1*), but if also supported by strong *IPAL management success* (*Y1*), then *WWTP sustainability* (*Y2*) will be higher.
3. The direct effect of *community participation* (*X3*) on *WWTP sustainability* (*Y2*) is significant, while the indirect effect is through mediation. The *WWTP management success* (*Y1*) is known to be significant, with the nature of mediation being partially mediation. Thus, *community participation* (*X3*) can increase the *WWTP sustainability* (*Y2*), even without going through the mediation of *WWTP management success* (*Y1*), but if also supported by strong *WWTP management success* (*Y1*), then *WWTP sustainability* (*Y2*) will be higher.

4.5.3 Total Effects

The total effect is the sum of direct and indirect effects between exogenous latent variables (*technical* (*X1*), *institutional* (*X2*), *community participation* (*X3*)) on intervening endogenous latent variables (*WWTP management success* (*Y1*)) and endogenous latent variables (*WWTP sustainability* (*Y2*)). Table 8 presents the total results regarding the direct and indirect relationships that occur between exogenous and endogenous latent variables.

Referring to the analysis of the influence of exogenous variables on endogenous variables, both direct, indirect, and total effects, as well as the relationship between the variables and their indicators (Table 2), it can be obtained the relationship between the indicators of the variables exogenous (as a measured variable) on the sustainability of WWTP (Table 9). The *technical* variables have the greatest influence on sustainability, followed by *community participation* and *institutional* variables. The measurable variables of the *technical* latent variables that have a very large influence (only 4 are taken) are the *availability of materials*, *implementation of SOP*, *selection of technology*, and *ease of operation*. For the latent variable of *community participation*, the most influential indicator is *demand response*, while the largest indicator of *institutional* variables is *organization and management*.

Table 7 Testing the indirect effect with the Sobel Test

Indirect effect	Coefficient	t-count	p-value	Significance mediating	Mediating properties
X1 → Y1 → Y2	0.424	6.47	0.000	significant	*Partially mediation*
X2 → Y1 → Y2	0.228	2.05	0.042	significant	*Partially mediation*
X3 → Y1 → Y2	0.348	2.87	0.004	significant	*Partially mediation*

Table 8 The total effect of inter-variables

Total effects		Intervening Variable (*Y1*)	Endogenous Variable (*Y2*)
Exogenous Variable	*X1*	0.432	0.424
	X2	0.232	0.228
	X3	0.354	0.348
Intervening Variable	*Y1*		0.982

These results have some similarities and differences with the study of Masduqi *et al*. [10]. The similarities are that sustainability is influenced by a selection of technology, availability of spare parts, technical operations, community participation, and institutional management. Hussain et al. [21] use SEM to determine factors that influence the quality of social infrastructure projects quality. This study determined that better planning and monitoring, and evaluation are important factors that must be considered by environmental infrastructure developers.

The influence of measured variables on *WWTP sustainability* is dominated by measurable variables from *technical* latent variables, followed by *community participation* and, finally, *institution*. This shows that the technical aspects of the WWTPs operation should be a major consideration and should be managed on a community-based rather than an institutional-based. This is in line with the existence of the tofu industry, which is a small industry owned by many residents. In community-based WWTP management, the community should collaborate with NGOs, both from a technical and non-technical aspect [22]. The form of community-based participation is demand response. Using the demand-responsive approach will be able to increase community participation in the water and wastewater infrastructure management [23].

5. CONCLUSIONS

WWTP sustainability is positively influenced by the success of WWTP management, which is expressed by the equation: $Y2 = 0.982\ Y1$, while the success of WWTP management is influenced by *technical*, *institutional*, and *community participation* variables, which are expressed by the equation: $Y1 = 0.432\ X1 + 0.232\ X2 + 0.354\ X3$, with *X1* as a *technical* variable, *X2* is *institutional*, and *X3* as *community participation*. The important technical aspects that must be considered for the sustainability of the WWTP are the availability of materials, implementation of SOPs, selection of technology, and ease of operation. Community participation also plays an important role in supporting the sustainability of the WWTP, namely by using a demand-responsive approach, meaning that the community must be asked for their opinion in the planning and management of the WWTP so that they can find out what the community demands.

6. ACKNOWLEDGMENTS

Acknowledgments and appreciation are given to the managers of the tofu industry in Ledok Kulon Village for the opportunity given to researchers, especially in terms of permits to carry out research at that location, so this research can be well done.

Table 9 Effect of Measured Variables on WWTP Sustainability

Exogenous variables	Total effect on *Y2*	Indicators	Loading factors	Indicator Effect on *Y2*	Weight	Rank
X1	0.424	*X1.1*	0.742	0.315	0.070	3
		X1.2	0.800	0.339	0.076	1
		X1.3	0.680	0.288	0.064	7
		X1.4	0.696	0.295	0.066	5
		X1.5	0.790	0.335	0.075	2
		X1.6	0.724	0.307	0.069	4
		X1.7	0.683	0.290	0.065	6
X2	0.228	*X2.1*	0.873	0.199	0.044	12
		X2.2	0.676	0.154	0.034	17
		X2.3	0.680	0.155	0.035	16
		X2.4	0.736	0.168	0.037	15
		X2.5	0.616	0.140	0.031	19
		X2.6	0.746	0.170	0.038	14
		X2.7	0.671	0.153	0.034	18
X3	0.348	*X3.1*	0.753	0.262	0.059	8
		X3.2	0.693	0.241	0.054	10
		X3.3	0.748	0.260	0.058	9
		X3.4	0.657	0.229	0.051	11
		X3.5	0.504	0.175	0.039	13

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