Structural equation modeling for assessing of the sustainability of rural water supply systems

A. Masduqi, N. Endah, E. S. Soedjono and W. Hadi

ABSTRACT

As one of the basic human needs, water services should be sustainable. Researches related to the sustainability of water services have been conducted in several developing countries. However, there are no identical researches in Indonesia. This paper discusses the analysis of factors that contribute to sustainability of rural water supply systems in East Java, Indonesia. Data is collected by observing rural water supply facilities, interviewing water committees and water users, and taking documentation. The data is used to build a model, which was developed from theoretical or conceptual model. The model's development uses structural equation modeling (SEM). This model can show the factors that contribute to sustainability of rural water supply systems. The sustainability is influenced significantly by nine variables; they are selection of technology, water sources, investment cost, capability of operator, availability of spare parts, operation cost, technical operation, community participation, and institutional management.

Key words | Brantas River Basin, rural water supply system, structural equation modeling, sustainability

A. Masduqi (corresponding author)
E. S. Soedjono
W. Hadi
Department of Environmental Engineering,
Institut Teknologi Sepuluh Nopember,
Surabaya,
Indonesia
E-mail: *masduqi@its.ac.id*

N. Endah
Department of Civil Engineering,
Institut Teknologi Sepuluh Nopember,
Surabaya,
Indonesia

INTRODUCTION

Some developing countries have faced serious problem on water supply and sanitation. UNICEF & WHO (2008) reported that about 884 million people of the third world did not use an improved source of drinking water (746 million in rural and 137 million in urban areas). In Indonesia, coverage of water services by pipeline and non-pipeline was 18.4 and 57.2%, respectively (report of MDGs implementation in Indonesia 2007). It is difficult to improve the water and sanitation services in this country. Before year 2000, the government of Indonesia had built many water and sanitation facilities in many villages over the country; however, many programs was fail. Many water supply and sanitation facilities at those villages have not operated anymore. In other words, those water and sanitation facilities are not sustainable. The same problems happen in many developing countries.

Researches related to the sustainability of water services have been conducted in several developing countries. The failure of sustainability was mostly caused by lacks of community participation and public acceptance to new technology (Carter *et al.* 1999; Brikké & Bredero 2003). Lenton & Wright (2004) identified that the political factor (water and sanitation has not been a priority), financial factor (poverty), institutional factor (lack of appropriate institutions which could manage the systems and the available institutions were impotent), and technical factor (unevenly spread of the location of settlements and climate factors, i.e. floods always happen in the rainy season and droughts always happen during the dry season) were common problems that caused the failure of water supply systems.

Sustainability is influenced by many factors – technical and non-technical (Choguill 1996; Bhandari & Grant 2007; Pushpangadan & Murugan 2008; Rietveld *et al.* 2009). Lockwood (2004), Satterthwaite *et al.* (2005) and Hoko & Hertle (2006) in their research found that sustainability was

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related, strongly, to community participation. Moreover, Kaliba (2002) showed that a strong correlation between community participation and management to the sustainability was obvious. Effective community organizations, ability of the community to operate and maintain facilities, ability of the community to raise adequate user fees for purchasing spare parts, and strong backup support from external parties at the district level to solve major breakdowns were revealed by Musonda (2004) as factors that contribute to the sustainability of water supply systems. The research related to sustainability of water supply for rural areas has not been conducted in Indonesia, yet. Therefore, it is essential to conduct this research with the case in rural areas of Indonesia since this country has different characteristics with those ones.

This paper discusses the analysis of factors that contribute to sustainability of rural water supply systems in Brantas River Basin, East Java, Indonesia. A structural equation modeling (SEM), which is a statistical method of multivariate analysis, is utilized. SEM with latent variables is routinely used in social science research and biomedical applications (Dunson *et al.* 2005). Muthen (1983), Anderson & Gerbing (1988), Bentler & Yuan (1999), Gefen *et al.* (2000), and Krishnakumar & Ballon (2008) have developed theory and practice of SEM in different fields.

In water management, SEM had been implemented to build models. Arhonditsis *et al.* (2006) applied SEM to analize ecological pattern. He tried to assess the relative role of several ecological processes (e.g. vertical mixing, intrusion of the hypolimnetic nutrient stocks, and herbivory) and to determine the level of water quality variables related to management interest (e.g. water clarity and cyanobacteria). Hurlimann *et al.* (2008) developed a model using SEM and tested it to explain and predict components of community satisfaction to recycled water use (for non-potable use) that was delivered to the community through a dual water supply system. The results indicated that the components of community satisfaction to recycled water use were (i) positive perception of communities to the Water Authority, (ii) trust to the Water Authority, (iii) fairness in the implementation of recycled water system, (iv) good quality of the recycled water that was accepted by the communities, (v) financial value of the recycled water, and (vi) low risk to communities when using recycled water. Porter *et al.* (2005) utilized SEM to build a model of community acceptability of an urban water supply system. He concluded that acceptability was affected directly by perceived outcomes, community trust, perception to equity and fairness, and subjective assessment (benefit or risk of the proposed water supply system). However, the acceptability was affected by perception to risk, indirectly. All those studies showed that SEM is a powerful method for modeling related to these types of problem.

Table 1 | Rural water systems by pipeline in Brantas river basin and their condition

			Rural water supply systems by pipeline						
					Condition of systems				
Regency	Amount of villages	Amount of rural population	Amount of serviced villages	Amount of systems	Good	Minor damaged	Major damaged	Amount of serviced population	Coverages
Malang	285	1,526,285	109	115	41	71	3	226,979	14.87
Blitar	196	855,212	54	58	27	31	–	72,688	8.50
Tulungagung	185	592,331	29	29	–	29	–	39,229	6.62
Trenggalek	132	560,567	23	23	11	4	8	27,315	4.87
Kediri	249	950,385	38	40	21	19	–	73,714	7.76
Nganjuk	202	692,257	22	22	6	8	8	33,144	4.79
Jombang	164	541,152	5	5	–	5	–	6,796	1.26
Mojokerto	212	598,640	54	63	25	34	4	80,828	13.50
Sidoarjo	91	261,465	5	5	2	1	2	5,040	1.93
Total	1,716	6,578,294	339	360	133	202	25	565,733	8.60

MATERIALS AND METHODS

Geographic location and sample

The study is conducted in the Brantas River Basin, East Java, Indonesia. In this area, there are 360 pipelined rural water supply systems (Masduqi *et al.* 2007) that are spread in nine regencies (Table 1). The water supply systems were built by local or central government and operated by appointed persons from local communities. Samples for the study are taken from 24 villages in which 364 households are involved as respondents. Survey was carried out in March–June 2008.

The method for survey and variable measurement

Data is collected by observing rural water supply facilities, interviewing water committees and water users, and taking documentation. The data consists of physical condition of the study area (topography and water sources), socioeconomic of the communities (number of poor households, level of participation, willingness to pay, and satisfaction to water supply services), water supply management (particularly in financial and institutional management and technology), and water quality. All data was quantified and grouped into six variables, i.e. planning, management, community, support, reliability of system, and sustainability of system.

Development of theoretical model

The model is developed based on the hypothesis: factors that affecting sustainability of rural water supply services are the reliability of water supply system and the characteristics of the community. The reliability of the system is influenced by technical planning and management of the system. The hypothesis is defined based on the information from many literatures (previous researches and projects that used cases in Indonesia and other third countries) and the relationship among variables. This relationship is formulated based on logical framework.

Development of data-driven model

The model in this research is a qualitative model. It is based on qualitative data and can be applied to predict a phenomenon based on qualitative data (data-driven model). The development of the model begins with a theoretical model that has been tested by an indication test and a causality test. For the development of this model, data of 364 respondents is grouped into three. The first group is 314 respondents (from 20 villages), that are used for training or developing model. The second one is 35 respondents (from 3 villages), that are used for model validation. The third one is 15 respondents (from 1 village), that are used for the application of the model (prediction of sustainability). Tools for confirming the model is Amos *16.0.0* software.

RESULTS AND DISCUSSION

Theoretical model

The scheme of theoretical model that expresses the relationship among variables is shown in Figure 1. Furthermore, this theoretical model is tested to observe logical relationship between latent variables and indicator variables. A latent variable is an unobserved one, while an indicator variable is an observed one. The test used in this step is the indication test and the causality test. These tests are performed to ensure that the indicator(s) really indicate the latent variable. An indicator can be accepted if:

- the indicator is an indication, sign, or the definition of latent variables,
- the indicator should not have a causality relationship with latent variables to be formed.

Data-driven model

Data of rural water supply systems is quantified in range 0 to 1. An example of data quantification of water quality is as follows: (i) for water that meets all parameters of a potable water quality standard, the score is 1; (ii) if there are one to three parameters that do not meet the standard, the score is 0.6; (iii) if there are more than three parameters that do not meet the standard, the score is 0.3; and (iv) if the water contains hazardous matters, the score is 0. All quantitative data is entered to the model as shown in Figure 1. This model is analyzed and confirmed by SEM.

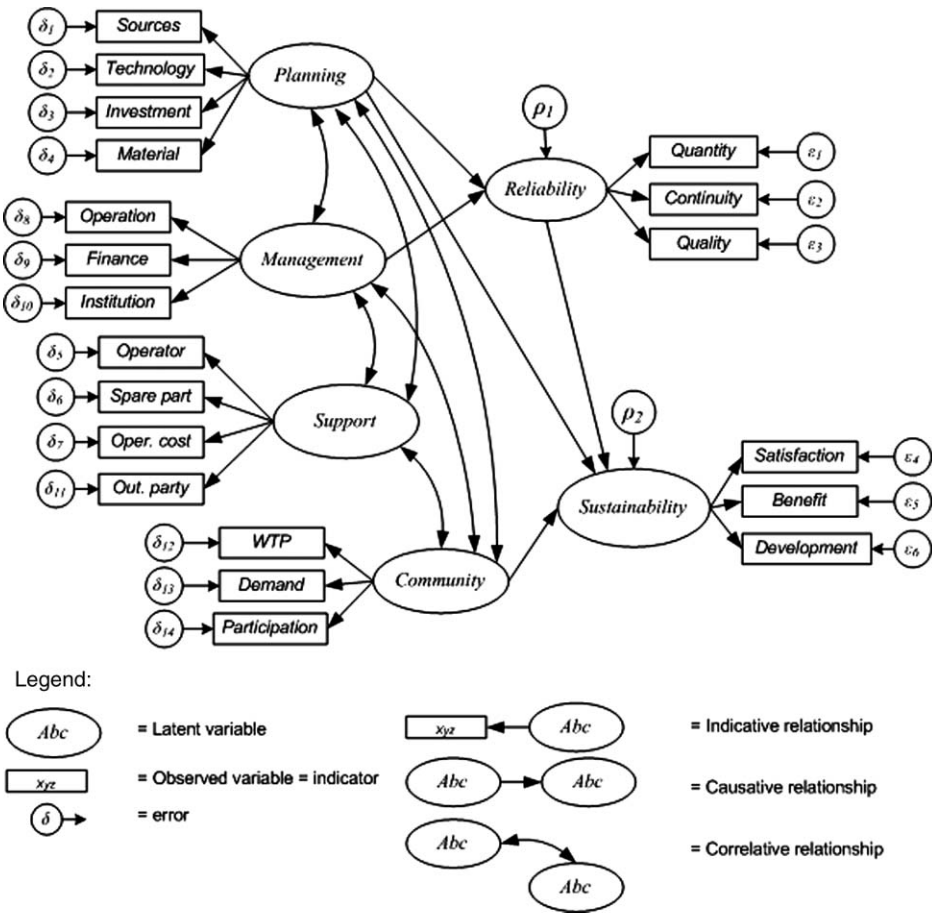

Figure 1 | Model of water supply system sustainability on theoretical-based.

Outlier data test

Before the outlier test is performed, a normality test using the Kolmogorov-Smirnov Normality test is carried out. The Outlier test is done using multivariate outlier; the outlier test that combines all variables (20 variables). Criterion used in the outlier test is Mahalanobis distance in p level <0.01. Mahalanobis distance is a statistical term that expresses a distance of one observation to the average of all variables in a multidimensional space. The Mahalanobis distance is evaluated using the Chi-square (χ^2) with the degree of freedom of 20 (same as the number of variables). The obtained value of $\chi^2_{(20,\ 0.01)}$ is 37.6. The data is considered as an outlier if it has a Mahalanobis distance value greater than χ^2. The Mahalanobis distance is calculated using the Amos software. The results of the test shows that there are five multivariate outliers. Therfore, these five data sets are taken out and not to be analyzed, further.

Goodness-of-fit of model

A goodness-of-fit model test is conducted to detect the fitness of the model. The goodness-of-fit test uses some criteria of fitness. The Amos software has an ability to detect the goodness-of-fit of the model. The fitness of the model can be seen from inter-relation among variables and from the whole model. The relation between indicator and latent variable or between two latent variables can be evaluated from the value of standard error (SE), critical ratio (CR), and P-value. A relation is considered as not good, if the value of SE is "extreme great" or "extreme small" (equal to zero). If $\mathrm{CR} > +1.96$ (for $\alpha = 5\%$) or $\mathrm{CR} > 2$ times of SE, the value of RW (regression weight) is not equal to zero.

Table 2 | Modification of model

Trial	Modifications	Results
1	Indicator of *WTP* was eliminated	Influences of *support* on *reliability* was not significant
		Influence of *reliability* and *community* on *sustainability* were not significant
		Indicator of *demand* was not significant
		Goodness-of-fit: insufficient
2	Indicator of *demand* was eliminated	Influences of *support* on *reliability* was not significant
		Indicator of *benefit*, *finance*, *operator*, and *outside party* were not significant
		Goodness-of-fit: insufficient
3	Indicator of *outside party* was eliminated	Influences of *support* on *reliability* was not significant
		Indicator of *benefit*, *finance*, and *operator* were not significant
		Goodness-of-fit: insufficient
4	Indicator of *finance* was eliminated	Influences of *support* on *reliability* was not significant
		Indicator of *benefit*, *operator*, and *spare part* were not significant
		Goodness-of-fit: insufficient
5	Correlative relations among error of indicator in *reliability* was deleted	Influences of *planning, management,* and *support* on *reliability* were not significant
		Indicator of *benefit*, *material*, *spare part*, and *operator* were not significant
		Goodness-of-fit: insufficient
6	Indicator of *material* was eliminated, constraint on indicator of *benefit* was determined	Influence of *support* on *reliability* was not significant
		Influence of *participation* on *sustainability* was not significant
		Indicator of *spare part* and *operator* were not significant
		Covariance was negative
		Variances were not significant
		Goodness-of-fit: insufficient
7	Constraint on correlation inter-variables determined as 0.05	Influences of *planning, management,* and *support* on *reliability* were not significant
		Influence of *participation* on *sustainability* was not significant
		Indicator of *water sources, institution, spare part* and *operator* were not significant
		Goodness-of-fit: insufficient
8	Constraint on error of *quantity*, error of *reliability*, and error of *sustainability* determined as 0.001	Influence of *support* on *reliability* was not significant
		Variances were significant
		Goodness-of-fit: insufficient
9	Correlative relation between error of *participation* and factor of *support* was made	Inter-relation between variables were significant
		Variances were significant
		Goodness-of-fit: accepted (with chi-square correction of 300)

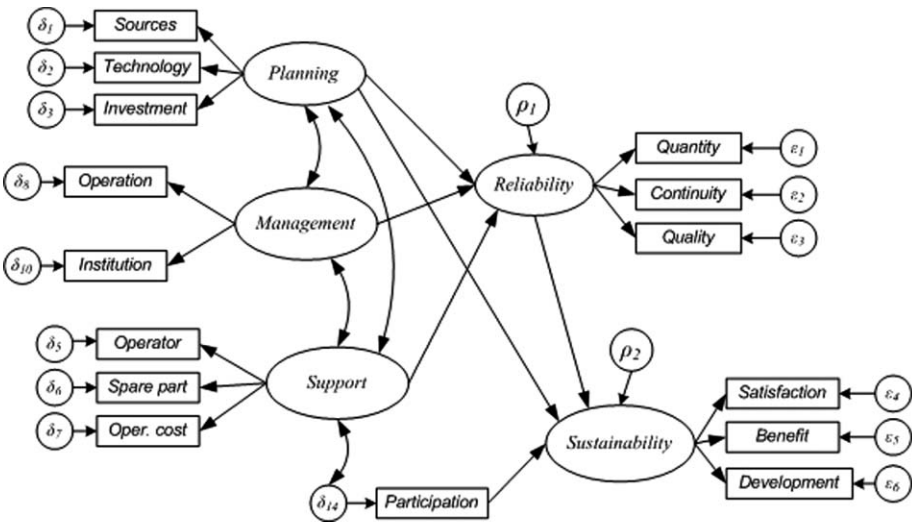

Figure 2 | Data-driven model after modification.

Table 3 | Loading factor and regression weight of the model

Relationship			**Loading factor and regression weight** Estimate	Standardized estimate	S.E.	C.R.	*P*
Reliability	←	Planning	0.198	0.679	0.022	9.022	*
Reliability	←	Management	0.082	0.153	0.036	2.247	0.025
Reliability	←	Support	0.099	0.210	0.037	2.659	0.008
Sustainability	←	Reliability	0.951	0.948	0.087	10.891	*
Sustainability	←	Participation	0.057	0.103	0.027	2.134	0.033
Sources	←	Planning	0.420	0.723	0.028	14.850	*
Technology	←	Planning	1.000	0.863			
Quantity	←	Reliability	2.517	0.993	0.168	14.948	*
Continuity	←	Reliability	1.000	0.582			
Quality	←	Reliability	0.383	0.360	0.062	6.175	*
Satisfaction	←	Sustainability	1.739	0.625	0.166	10.505	*
Benefit	←	Sustainability	1.000	0.407			
Development	←	Sustainability	1.000	0.659			
Operation	←	Management	1.000	0.774			
Institution	←	Management	1.035	0.658	0.068	15.147	*
Spare parts	←	Support	0.457	0.722	0.030	15.166	*
Operator	←	Support	1.328	0.942	0.054	24.548	*
Operation cost	←	Support	1.000	0.653			
Investment	←	Planning	0.118	0.370	0.018	6.508	*

Remarks: $^{*}p < 0.001$.

Table 4 | Value of fitness index

No.	Fitness of model	Index	Value	Standard	Remarks
1.	Absolute fit	Chi-square (χ^2)	97.119; $p = 0.261$	p0.05	Fit
2.	Absolute fit	Normal chi-square (χ^2)/df	1.091	≤ 3	Fit
3.	Absolute fit	Root mean square residual (RMR)	0.031	Approx. 0	Fit
4.	Absolute fit	Root mean square error of approximation (RMSEA)	0.081	< 0.10	Fit
5.	Absolute fit	Goodness of fit index (GFI)	0.623	≥ 0.90	Less fit

RW values are considered significant if P-value $< \alpha$. Based on the values of SE, CR, and P, there are seven relations among the variables that rejected at 5% level of significance ($P > 0.05$) or CR $< 2 \times$ SE.

Furthermore, fitness of the whole model is tested whether the model is able to explain the samples. Fitness of the model is indicated by several parameters, i.e. the Chi-square (χ^2), normal Chi-square (χ^2/df), root mean square residual (RMR), root mean square error of approximation (RMSEA), goodness of fit index (GFI), Tucker-Lewis index (TLI), comparative fit index (CFI), and expected cross validation index (ECVI). The Amos software displays the results of calculation of these parameters. Based on the comparison between the results of the calculation parameters and criteria of fitness, it can be concluded that the model cannot received yet since some of the criteria of the fitness are not met with the model results. Therefore, the model requires a modification.

Modification of model

The model as described in Figure 1 cannot be accepted yet. Consequently, the model should be modified. Modification is done by eliminating indicator(s) that are not significant and/or by changing the path between the variables through trial-error such that the model can be accepted. The changes in each modification are presented in Table 2.

The Amos software provides a guidance to modify the model and the modification index. The modification index provides a description of meaning of the decrease of the Chi-square value when a coefficient is estimated. The modification is done by trial-error. The obtained modified model is illustrated in Figure 2. The model shows the relationship among variables. The relationship between two latent variables is called causative relation while the relationship between a latent variable to its indicators is called indicative relation. Magnitude of the relation is expressed by loading factor and regression weight as listed in Table 3. The fitness indexes of the modified model are provided in Table 4. The fitness indexes of the model shown in Table 4 indicate that the model can be accepted. The model can predict the reliability of systems and sustainability of systems with $R^2 = 0.913$.

Contributor to sustainability

The model shows that sustainability is directly influenced by reliability of water supply systems, technical planning, and community participation. Meanwhile, the reliability of water supply systems is influenced directly by variable of *planning*, *management*, and *technical and non-technical support*. The weight of the direct influences is expressed by loading factors and regression weight values.

Table 5 | Standardized total effect of variables to sustainability

Variables	Weight of effect to sustainability
Water source	0.465
Selection of technology	0.555
Investment cost	0.238
Technical operation	0.112
Institution management	0.095
Operator	0.187
Spare parts	0.144
Operation cost	0.130
Community participation	0.103

The variable of *management* and *support* influence the sustainability indirectly. The influences are shown by standardized total effect value. Total effect is sum of direct effect and indirect effect. Based on the provided total effect value in the *Amos* software, the sustainability – that indicated by user satisfaction, financial benefit, and development possibility – is influenced significantly by variable of *planning*, *management*, *support*, *participation*, and *reliability of system*.

SEM is also able to show indicator variables which influence the sustainability. Sustainability is influenced by nine indicator variables, i.e. *selection of technology*, *water sour*ces, *investment cost*, *capability of operator*, *availability of spare parts*, *operation cost*, *technical operation*, *community participation*, and *institutional management*. Among nine variables, *technology selection* and *water sour*ces are the dominant ones (see Table 5 to compare magnitude of influence of all variables to the sustainability).

Moreover, this study shows that demand responsive does not influence significantly to the sustainability. It means that characteristic of the community in East Java are not same as the community in the other developing countries. Katz & Sara (1998) recommended considering the demand responsive as an important factor to make rural water supply sustainable. It is required to study further. People in some village of East Java generally prefer to choose an individual water supply. However, it does not mean that demand responsive is not important. It may be included in the variable of *participation*, especially participation in planning step.

CONCLUSIONS

The sustainability of rural water supply systems in Brantas River Basin, Indonesia, is influenced significantly by nine variables that dominated by two indicator variables, i.e. *selection of technology* and *availability of water sources*. Seven other variables that also influence the sustainability are *investment cost*, *capability of operator*, *availability of spare parts*, *operation cost*, *technical operation*, *community participation*, and *institutional management*. Good condition of all these variables will support the achievement of the sustainability.

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