An evaluation of the sustainability of domestic wastewater management in DKI Jakarta, Indonesia

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Abstract. Wastewater management in Jakarta has been a longstanding issue that should be immediately resolved. The level of water pollution shows an increasing trend nowadays. Central of domestic wastewater service has been started since 1972, but the development effort of this is running slowly. This study was through the direct observation and the comprehensive interview to the 26 selected experts from central government, provincial government, academics, private-own business, professional organizations and community. The selection was based on their experience and competence, reputation/related occupation, credibility, commitment, neutrality, willingness to be asked and received opinion, understanding, and whether be in the research location. This study was aimed to evaluate the sustainability of domestic wastewater management in DKI Jakarta. The method was using a multidimensional scaling method (MDS) to determine object position based on the similarity assessment. The result showed that in the multidimensional context, the sustainability of domestic wastewater management in DKI Jakarta has the index value of 39.23, or it is in a "less sustainable" status. The index value of sustainability for each aspect as follow: the social aspect is the lowest with 34.42, economic aspect 34.75, institutional aspect 37.29, ecological aspect 44.13 and technological aspect 45.56.
Key Words: domestic wastewater, sustainability, water pollution, Multi-dimensional Scaling (MDS).

Introduction. Jakarta as the largest city and the capital city of Indonesia faces many complex issues. One of them is the bad handling of water pollution derived from domestic wastewater. A review by JICA et al (2012) mentioned that the average of domestic waste in Jakarta in 2010 was 147 liters person^{-1} day^{-1}. It means, with a population of 9 million the total waste volume was 1,316,113 m^3 day^{-1}. The waste consist of domestic wastewater with 1,038,205 m^3 day^{-1} (74%), wastewater from the offices and commercial area with 448,933 m^3 day^{-1} (18%), and industrial wastewater with 105,437 m^3 day^{-1} (8%). The type of organic pollutant from domestic wastewater contributed up to 70%, while 14% from the offices and 16% from the industrial activities. It showed that domestic wastewater has the largest contribution to water pollution in DKI Jakarta. Jakarta has a central domestic wastewater service, but it is in a low coverage. The result of a previous review also showed that as many as 9.27% of slum area disposed their domestic wastewater directly into the rivers, 64.03% absorbed into the soil through conventional septic tanks without any adequate treatment, 25,00% processed their wastewater through Wastewater Treatment Plant (WWTP), and only 1.26% of the residence have used WWTP piping system with better technology.

This poor handling will have a massive impact on water quality, both to the surface water and groundwater. It is signified by the high concentration of *Escherichia coli* as an indicator of water contamination by domestic waste, especially those containing feces (BPLHD 2016). The presence of *E. coli* in the waters indicated the feces-contaminated and highly possible of other enteric pathogenic microorganisms.

Annual report by BPLHD 2016 mentioned that in almost water samples from the river, lake and well in five municipal areas indicated the presence of *E. coli* with multiple exceeding the quality standard. It showed that quality of surface and groundwater in Jakarta is terrible and not safe to be a source of drinking water. This condition is potential to cause an adverse impact on people's health. The poor management of domestic wastewater in developing countries caused 85 to 90% of diarrheal disease and 1.6 million of children death under 5^{th} age annually (Prüss-Üstün et al 2004).

The comprehensive study to evaluate the sustainability of domestic wastewater management system in Jakarta through ecological, economic, social, technological and institutional approach has not been conducted. Therefore the study needs to be conducted to find out the low sustainability aspect and the attributes that need to be addressed immediately.

Material and Method

Location. This study was conducted from October to December 2017 in five administrative areas of Central Jakarta, North Jakarta, West Jakarta, South Jakarta and East Jakarta (not including Seribu Island Administrative Area).

Methodology. This study has used multidimensional scaling (MDS) approach with the modification program of Rap-Wastman (Rapid Appraisal-Wastewater Management) technique (Kavanagh 2001; Pitcher & Preikshot 2001; Fauzi & Anna 2005). MDS model used in this study was a computer-based statistical analysis technique on Ms. Excel by transforming each aspects and multidimensional sustainability of domestic wastewater management. Dataset was obtained through the interview and questionnaires to the experts of stakeholders, both central government and local government, academia, professional organizations and communities.

MDS is one of the type of multiple variable techniques that can be used to determine the position of the object based on its similarity assessment. Referring the development of Rapfish approach that be used to assess the sustainability status, Roy (1982) stated that MDS model can be used for the designing model, analyzing, and planning the sustainable operational management.

MDS approach provides more stable result than the other double-variable analysis method and moreover simplifies the multiple aspects (Pitcher & Preikshot 2001). All datasets from the attributes which were considered in this study then would be multidimensionally analyzed to determine the position of sustainability point to the two references of "good" and "bad". According to Fauzi & Anna (2005), MDS on Rapfish is applied by calculating the closest distance of euclidean distance in the equation:

$$d_{12} = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2 + \ldots}$$

in which: d_{12} is the distance; $x_{1,2}$ is the data value of the row; and $y_{1,2}$ is the data value of the column.

Multidimension of euclidean distance between those two points (d_{12}) is then projected into the euclidean distance of two dimensions (D_{12}) with the regression formula:

$$d_{12} = a + b\, D_{12} + e$$

in which: e = error

The regression applies ALSCAL algorithm with an iteration or repetition to get the smallest error value. According to Kavanagh (2001), ALSCAL algorithm forces the intercept to be value of 0 (a = 0). The regression would change to the following equation:

$$d_{12} = b\, D_{12} + e$$

Similar object (presented in dots) in MDS are mapped in adjacent distance, whereas different object appears in far distance on each. The dots will also be very useful in the regression analysis to calculate the stress value which is also a part of the MDS method. The value of each attribute will form the matrix of X (n x p), where n is the number of region and their reference point, while p is the number of attribute. Then the score value of each attribute was being standardized so that would be equal in total for each attribute and the differences between measurement scales could be eliminated.

The iteration stops when the stress value is less than 0.25 (Fauzi & Anna 2005), as defined in the equation:

$$Stress = \sqrt{\frac{1}{m}\sum_{k=1}^{m}\left[\frac{\sum_i \sum_j (D_{ijk} - d_{ijk})^2}{\sum_i \sum_j d_{ijk}^2}\right]}$$

in which: k and m is the number of data matrices; D_{ijk}= dissimilarity matrix; d_{ijk}= euclidean distance; d^2_{ijk}= squared Euclidean distance between points i and j for participant k.

ALSCAL also gives the Stress measure for the last iteration, as well as the R - squared (R2), which represents the level of variance in data. Stress value also can be obtained with the following formula:

$$Strees = \frac{MSS\ e_{ijk}}{MSS\ d_{ijk}}$$

in which: MSS = mean sum square

A good model is reflected by a small stress value (less than 0.25) and R^2 approaching 1. The sustainability index scales have a value of 0-100. In this study, four categories of sustainability status were shown in Table 1.

Table 1

Sustainability index (Kavanagh 2001)

Range	*Category*
0-25	Bad (not sustainable)
25-50	Poor (less sustainable)
51-74	Fair (quite sustainable)
75-100	Good (sustainable)

Leverage analysis was used to find out the sensitive attributes of sustainability. This will help management activities plan in future. Leverage analysis aims to see the difference value of error in determining the value of sustainability if one of the attributes is taken from the analysis. According to Pitcher (1999), leverage analysis or sensitivity analysis is performed on all attributes of each aspect. The calculation is stepwise by removing each attribute in sequence then calculating the error value or root mean square (RMS). The result is then compared to the RMS value from all attributes. This is known as the jackknife method (Kavanagh 2001). The error effect on estimating process of ordination analysis is evaluated by using Monte Carlo simulation.

This study used the MDS with Rap-Wastman which is a Rapfish modification from University of Columbia to assess the sustainability of marine fisheries. Rap-Wastman ordination procedure is as follow: (1) attribute determination; (2) assessment of each attribute on an ordinal scale; (3) Rap-Wastman ordination analysis using MDS method on excel to determine the ordination and stress value; (4) assessing the index and sustainability status; (5) leverage analysis to determine the sensitive variables which affecting the sustainability, where the dominant attributes will exceed the average value; and (6) Monte Carlo analysis to calculate the uncertain aspects (Kavanagh 2001; Pitcher & Preikshot 2001).

Data collection. The dataset is the primary data from comprehensive interviews and the answering the questionnaire with the judgment knowledge of the experts/respondents by considering: (a) the experience and competence in their professional; (b) reputation/position; (c) credibility; (d) commitment to the problem under study; (e) neutrality and willingness to accept the opinions from other respondents; (f) willingness to have a discuss; and (g) comprehension and whether be in the research location (Ramadhan et al 2014). Based on the mentioned criteria, a total of 26 experts or respondents were selected and represent on each: central government of National Development Planning Agency (Bappenas) and Ministry of Public Works and People's Housing (5 persons or 19.23%); local government of DKI Jakarta Provincial Government from Regional Development Planning Agency (Bappeda), Water Management Service and Environmental Service (9 persons or 34.61%); academics (3 persons or 11.54%); private-own business (3 persons or 11.54%); professional organizations (2 persons or 7.69%); and community (4 persons or 15.38%). The educational background of the experts above is postgraduate (9 persons or 34.61%) and doctoral (17 persons or 65.38%).

Identification aspect and attributes of sustainability. A study on domestic wastewater management in Jakarta with a case in Setiabudi and Tebet sub-districts shows that the sustainability is dominantly and significantly influenced by technological, economic/financial, environmental, institutional and socio-cultural aspects (Setiawati et al 2013). From those aspects, the attribute indicators are described as follows:

- technology, a variable measured by four indicators of system endurance, availability of spare parts, operational ease, and adaptability (Balkema et al 2002; Nhapi & Gijzen 2004; UNESCO/IHP 2006; UNESCO/IHP & GTZ 2006; Flores et al 2008; Paramita 2009; Peter-Varbanets et al 2009; Werner 2009; Gaulke et al 2010);
- economic/finance, a variable measured by three indicators of investment costs, maintenance and operational costs, and regional development (Mukherjee & Van Wijk 2003; De Carvalho et al 2008; Flores et al 2008; Paramita 2009; Werner 2009);
- ecological, a variable measured by three indicators of not polluting the water sources, raw material efficiency and wastewater minimization (Balkema et al 1998; Balkema et al 2002; Bradley et al 2002; Mukherjee & Van Wijk 2003; De Carvalho 2008; Werner 2009);
- institutional, a variable measured by two indicators of regulations of wastewater, and regulations of environmental protection (Balkema et al 2002; Bradley et al 2002; Pushpangadan & Murugan 2008; Werner 2009);
- socio-cultural, a variable measured by four indicators of willingness to pay (Kaliba et al 2009; Ifabiyi 2011), local capacity, community acceptance, and suitability with local culture (Balkema et al 1998; Carter et al 1999; UNESCO/IHP & GTZ 2006; Flores et al 2008; Werner 2009).

By considering the result of previous studies (Van der Wulp et al 2016; Pangestu et al 2017) and opinions from the experts, sustainability index of domestic wastewater management in DKI Jakarta is determined on the aspect of ecological, economic, social, technological and institutional attributes (Table 2).

Table 2

The attributes and aspect of sustainability

Sustainability	*Attributes*
Ecology	1. Well water turbidity; 2. Well water smell; 3. Water canal turbidity; 4. Water canal smell; 5. Well water usage for drinking; 6. Well water usage for washing; 7. River water usage for drinking; 8. River water usage for washing; 9. Diseases caused by water contamination; 10. Quality decline of aquatic biota life.
Economy	1. Development cost; 2. Operational and maintenance cost; 3. Household outcome for wastewater treatment; 4. Ability to pay; 5. State Budget of Indonesia (APBN) allocation; 6. Regional Budget (APBD) allocation; 7. Mud/biogas utilization; 8. Economic impact due to water pollution; 9. Private willingness to invest; 10. Financial institution willingness to carry out the financing.
Social	1. People understanding; 2. People willingness to pay; 3. Community participation; 4. The quality of environmental education for the community; 5. Community resistance; 6. The difficulty in land acquisition; 7. Availability of government-owned land; 8. Combined payment for wastewater and clean water; 9. Service coverage; 10. Service quality.
Technology	1. Capacity of septic tank system; 2. The power of WWTP system; 3. Energy consumption for septic tank operation and maintenance (O & M) ; 4. Energy consumption of OM WWTP; 5. OM difficulty of septic tank; 6. OM difficulty of WWTP; 7. Suitability of technology adaptation in septic tanks; 8. Suitability of technology adaptation in WWTP; 9. Wastewater quality from processing in septic tank; 10. Wastewater quality from processing in WWTP.
Institutional	1. Applicable regulations; 2. Competence of regulator and operator human resources; 3. Central government's role; 4. Local government's role; 5. Commitment for APBN budget from Central government; 6. Commitment for APBD budget from Local government; 7. Central government's support; 8. Involvement of private-owned business; 9. Government supervision and monitoring; 10. Law enforcement.

Results and Discussion. The analysis of Rap-Wastman showed that the sustainability index of domestic wastewater management in DKI Jakarta on the attribute assessment of those 5 dimensions of sustainability resulted in a stress value of less than 0.25. While the value of coefficient of determination (R^2) on each dimension approaching 1. It can be said that all aspects of mentioned attributes were able to describe the sustainability of domestic wastewater management in DKI as shown in Table 3.

Table 3

Statistical parameter of sustainability aspects

Parameter	*Sustainability aspect*				
	Ecology	*Economy*	*Social*	*Technology*	*Institutional*
Stress	0.20	0.22	0.22	0.24	0.24
R^2	0.88	0.89	0.89	0.88	0.90

Multidimensionality of sustainability. Multidimensionality of sustainability of wastewater management in DKI Jakarta showed an index value of 39.23, or they were in "less sustainable" status. Monte Carlo analysis results at confidence interval of 95% showed a small difference than MDS sustainability index, which less than 5% as shown in Table 4. This condition indicates as follow: (1) scoring error in each attribute is relatively small; (2) scoring variation due to the different opinion is relatively small; (3) the repetition of MDS analysis is relatively stable; and (4) errors in data entry and lost data can be avoided. This small difference also indicates that the results have a high degree of confidence (Dzikrillah et al 2017).

Table 4

Statistical parameters of sustainability aspect

Dimension of sustainability	*Sustainability index*			*Sustainability status*
	MDS	*Monte Carlo*	*Deviation*	
Ecology	44.13	44.54	0.41 (0.94%)	Less sustainable
Economy	34.75	35.22	0.47 (1.35%)	Less sustainable
Social	34.42	34.90	0.48 (1.38%)	Less sustainable
Technology	45.56	45.71	0.15 (0.33%)	Less sustainable
Institutional	37.29	37.68	0.38 (1.03%)	Less sustainable
Multidimensional	39.23	39.61	0.38 (0.96%)	Less sustainable

Analysis result on Table 3 showed that Rap-Wastman method is suitable to be used to quantitatively evaluate the sustainability of domestic wastewater management in DKI Jakarta. The multidimensional figures on ecological, economic, social, technological and institutional can be seen in Figure 1.

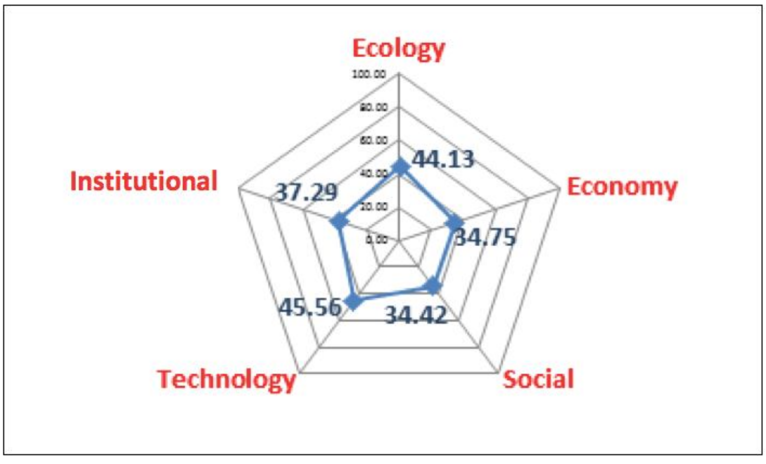

Figure 1. Multidimensional of sustainability.

Sustainability based on ecological dimension. Referring to the Table 4 above, the sustainability for ecological dimension of domestic wastewater management in Jakarta has an index value of 44.13, or it can be said that they are in "less sustainable" status (Figure 2).

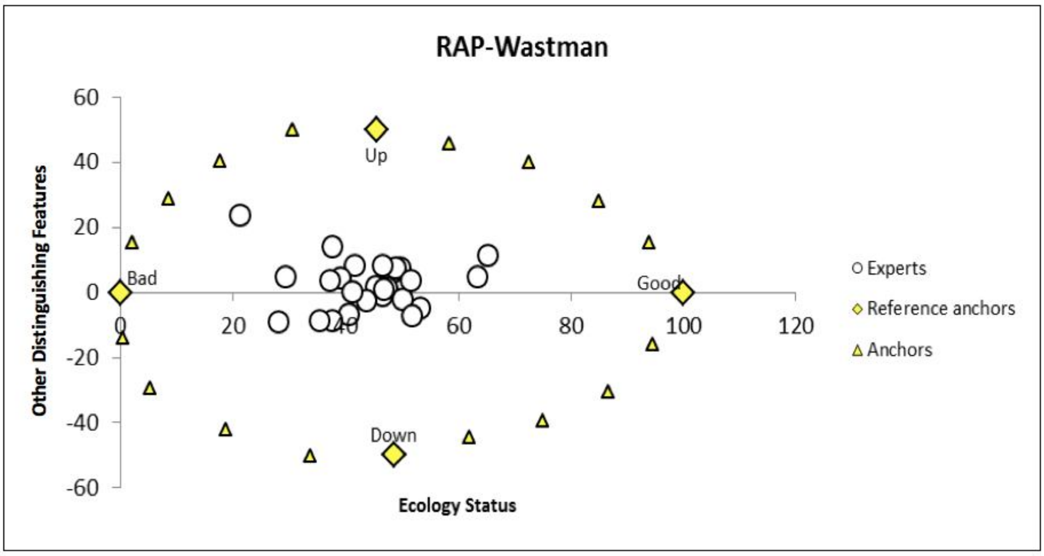

Figure 2. Sustainability index for ecological dimension.

Leverage analysis showed the five dominant attributes (value in red ink) that influence the domestic wastewater management as follow: (1) well water usage for drinking; (2) well water usage for washing; (3) water canal smell; (4) water canal turbidity; and (5) river water usage for drinking. This is in line with the previous studies by Balkema et al (1998), Balkema et al (2002), Bradley et al (2002), Mukherjee & Van Wijk (2003), De Carvalho (2008), and Werner (2009). Leverage analysis for ecological dimension in detail can be seen in Figure 3.

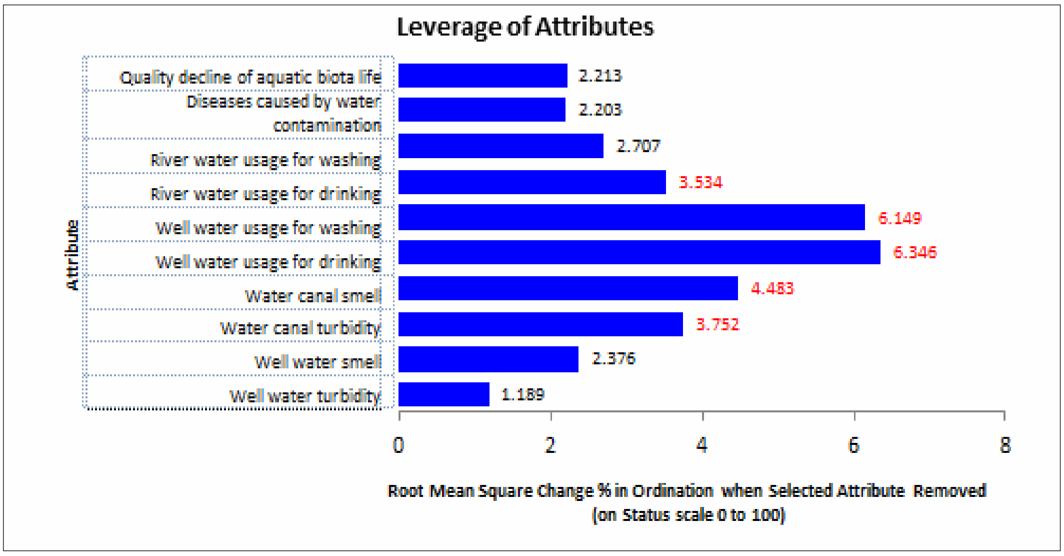

Figure 3. Leverage of ecological dimension.

Sustainability based on economic dimension. The sustainability index for economic dimension of domestic wastewater management in Jakarta was 34.75 or they were in "less sustainable" status as shown in Figure 4.

Leverage analysis of economic dimension showed the six dominant attributes that influence the domestic wastewater management as follow: (1) ability to pay; (2) household outcome for wastewater treatment; (3) mud/biogas utilization; (4) APBD allocation; (5) APBN allocation; and (6) economic impact due to water pollution. These results are in line with the studies by Mukherjee & Van Wijk (2003), De Carvalho et al (2008), Flores et al (2008), Paramita (2009), and Werner (2009). Leverage analysis of economic in detail could be seen in Figure 5.

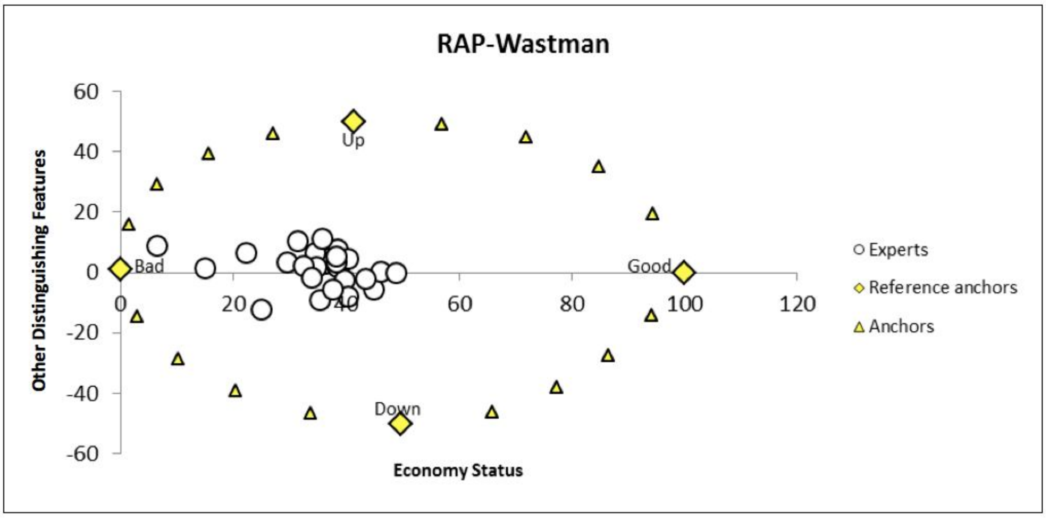

Figure 4. Sustainability for economic dimension.

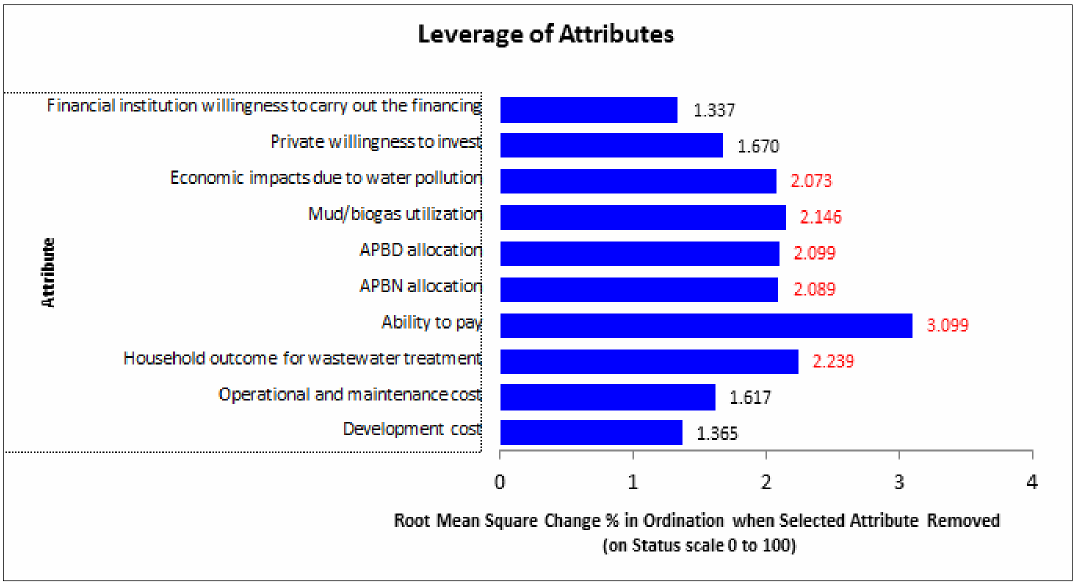

Figure 5. Leverage of economic dimension.

Sustainability based on social dimension. The sustainability index for social dimension of domestic waste water management in Jakarta has an index value of 34.42 or in "less sustainable" status. Figure 6 showed the detail result of RAP-Wastman analysis.

Leverage for social dimension showed the seven dominant attributes that influence the domestic wastewater management as follow: (1) community resistance; (2) combined payment for wastewater and clean water; (3) the difficulty in land acquisition; (4) the quality of environmental education for the community; (5) availability of government-owned land; (6) community participation; and (7) people willingness to pay. These results are in line with the studies by Ifabiyi (2011), Kaliba et al (2009), Balkema et al (1998), Carter et al (1999), UNESCO/IHP & GTZ (2006), Flores et al (2008), and Werner (2009). The detail of leverage analysis of social dimension was shown in Figure 7.

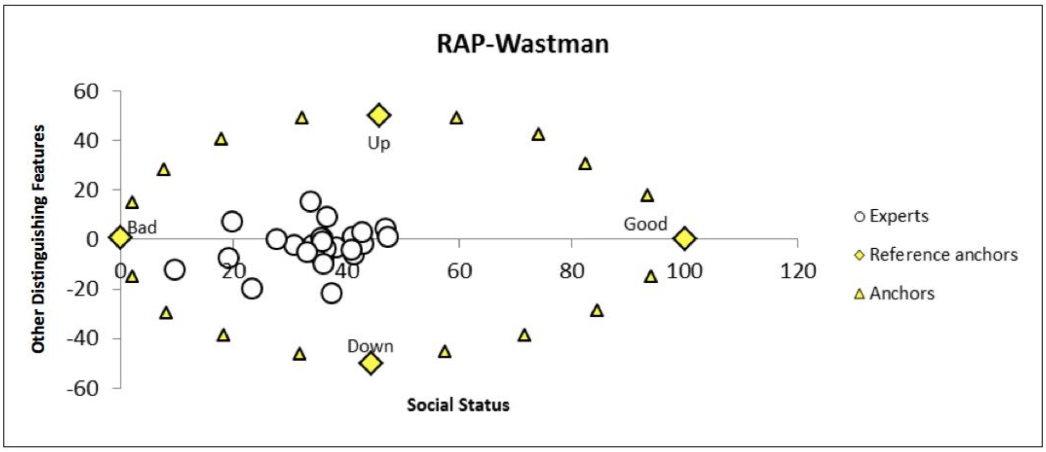

Figure 6. Sustainability for social dimension.

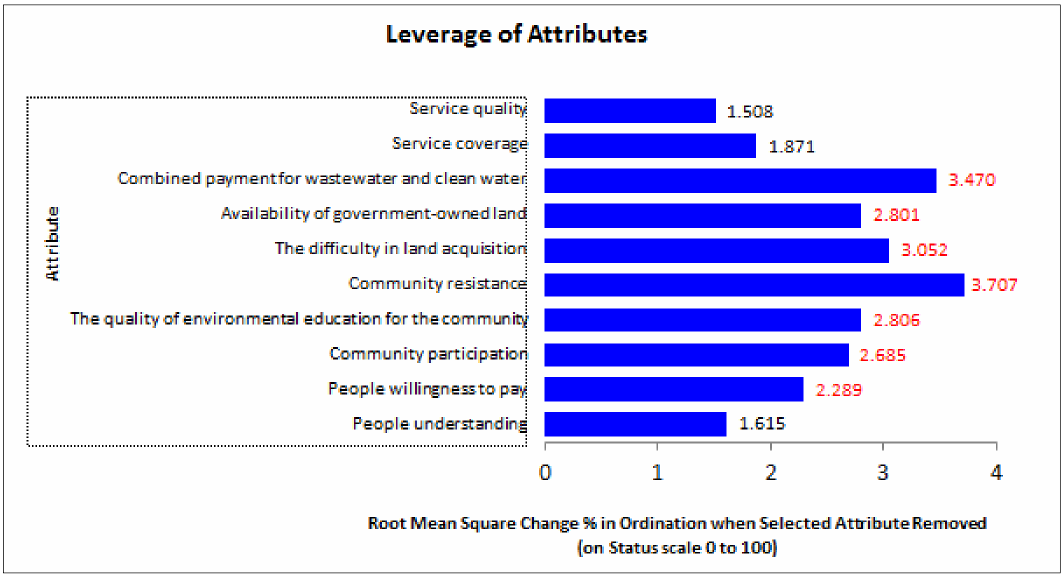

Figure 7. Leverage of social dimension.

Sustainability based on technological dimension. The sustainability of technological dimension of domestic waste water management in Jakarta has an index value of 45.56 or they are in "less sustainable" status. Figure 8 showed the detail result of sustainable index using RAP-Wastman analysis.

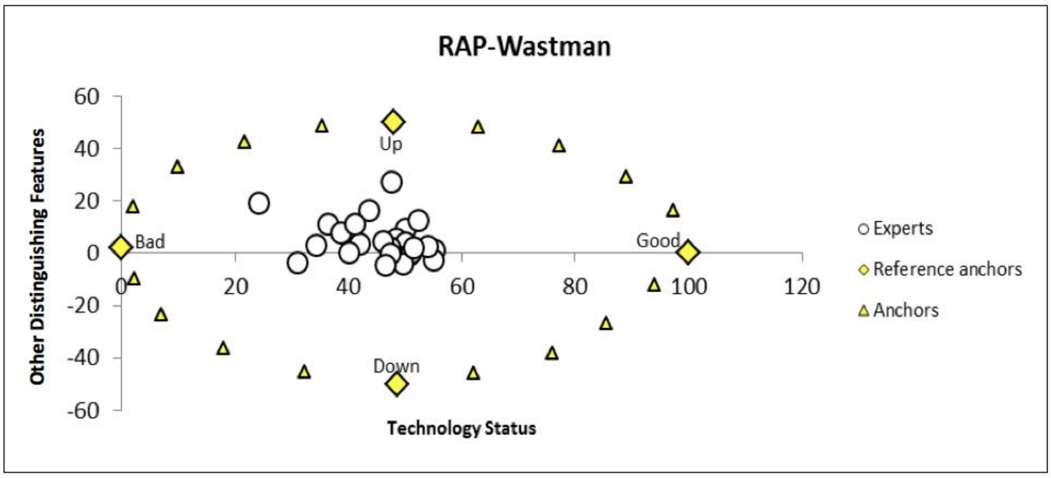

Figure 8. Sustainability for technological dimension.

Leverage analysis of economic dimension showed the five dominant attributes that influence the domestic wastewater management as follow: (1) energy consumption of OM septic tank; (2) OM difficulty of septic tank; (3) OM difficulty of WWTP; (4) energy consumption of OM WWTP; and (5) suitability of technology adaptation in septic tanks. These results are in line with the studies by Balkema et al (2002), Nhapi & Gijzen (2004), UNESCO/IHP (2006), UNESCO/IHP & GTZ (2006), Flores et al (2008), Paramita (2009), Peter-Varbanets et al (2009), Werner (2009), and Gaulke et al (2010). Detailed leverage analysis of technological dimension could be seen in Figure 9.

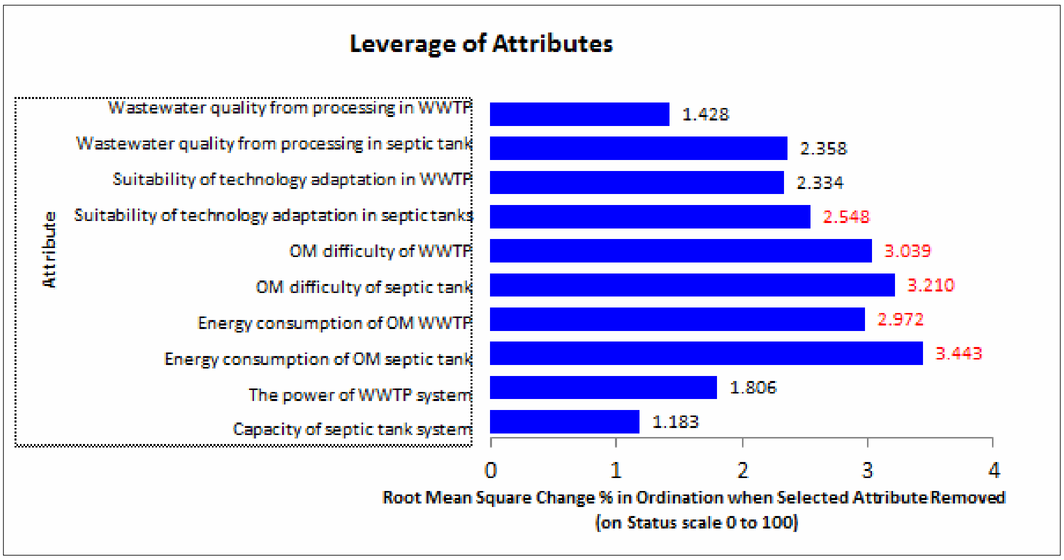

Figure 9. Leverage of technological dimension.

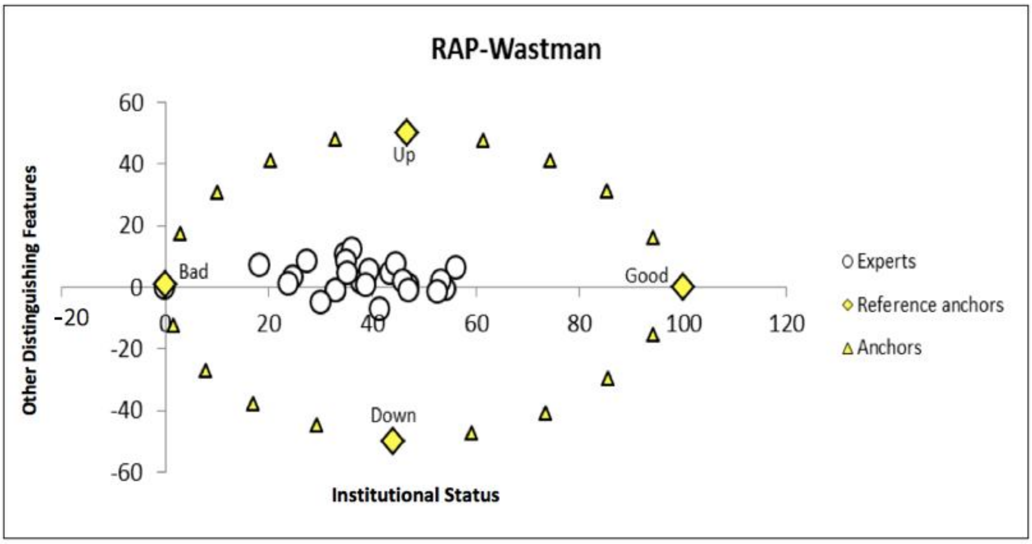

Figure 10. Sustainability for institutional dimension.

Sustainability based on institutional dimension. The sustainability for institutional dimension of domestic waste water management in Jakarta has an index value of 37.29 or they were in "less sustainable" status as shown in detail in Figure 10.

Leverage analysis of institutional dimension showed the six dominant attributes that influence the domestic wastewater management as follow (1) local government's role; (2) central government's role; (3) law enforcement; (4) commitment for APBN budget from Central government; (5) Central government's support; and (6) involvement of private-owned business. These results are in line with the studies by Balkema et al

(2002), Bradley et al (2002), Pushpangadan & Murugan (2008), and Werner (2009). The analysis of leverage of institutional dimension in detail could be seen in Figure 11.

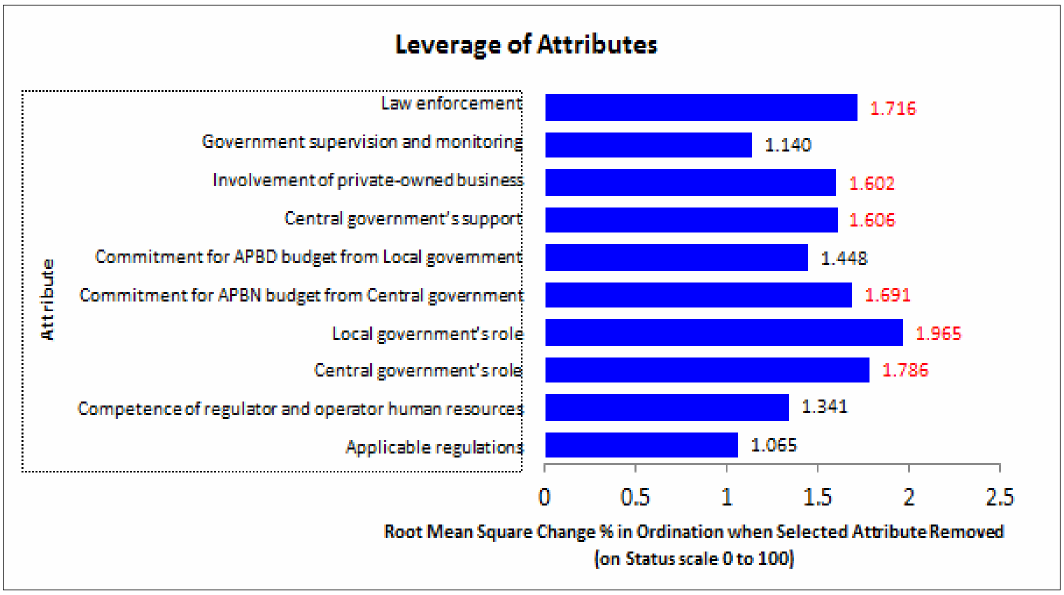

Figure 11. Leverage of intitutional dimension.

Conclusions. MDS models through a Rap-Wastman technique to determine the sustainability of domestic wastewater management in Jakarta in a particular study of the aspect of ecology, economic, social, technological, institutional and multidimensional showed the result of "less sustainable" status.

The dominant attributes in social aspect are community resistance, combined payment for wastewater and clean water, the difficulty in land acquisition, the quality of environmental education for the community, availability of government-owned land, community participation, and people willingness to pay. The dominant attributes in economic aspect are ability to pay, household outcome for wastewater treatment, mud/biogas utilization, APBD allocation, APBN allocation, and economic impact due to water pollution. The dominant attributes in social are community resistance, combined payment for wastewater and clean water, the difficulty in land acquisition, the quality of environmental education for the community, availability of government-owned land, community participation, and people willingness to pay. The dominant attributes in technological aspect are energy consumption of OM septic tank, OM difficulty level of septic tank, OM difficulty level of WWTP, energy consumption of OM WWTP, and suitability of technology adaptation in septic tanks. The dominant attributes in institutional aspect are local government's role, central government's role, law enforcement, commitment for APBN budget from central government, central government's support, and involvement of private-owned business.

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