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SERVICE INDEX MODELING OF URBAN DRAINAGE NETWORK

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ABSTRACT: This research develops a formula for determining the condition of infrastructure service of urban drainage network based on the technical and non-technical aspect. This formula works by elaborating the variable and indicator which gives the values to each aspect both the technical and non-technical one. The three variables that give the important aspect to the technical aspect namely system capacity, puddle problems and drainage patterns, each indicated by an indicator. Non-technical aspects influenced by five variables are institutional management, legal and regulatory aspects, socio-cultural and economic, public and private roles and flood losses. The research conducts in the Citepus drainage network that has 16 primary channels. Collecting data from the technical aspects is carried out by the direct site visit measurements as well as the secondary data collection. The non-technical aspects use the questionnaire as the qualitative data that converted to the quantitative one. Furthermore, an analysis using the GRG-Generalized Reduced Gradient method is used by allowing the nation-linear constraints and arbitrary bounds on the variables. The result of this research is the “Suprayogi” index model, with regard of the urban drainage index model that is developed using the technical and non-technical aspects involving the variables and indicators affecting the service level of the drainage network. The result shows, for the technical aspect: the capacity system has the largest influence with the determinant coefficient of 0.853, followed by the puddle problems (0.127), and the drainage patterns (0.07). For the non-technical aspects: socio-cultural and economic aspect has the greatest influence with the determinant coefficient of 0.47, followed by flood losses (0.604), legal and regulatory aspect (0.306), the institutional management (0.087), the public and private roles (0.0026)..

Keywords: capacity system, Generalized Reduced Gradient (GRG) Methods, optimal, service index, technical and non-technical aspect, urban drainage.

1.INTRODUCTION

The rapid urban sprawl brings the significant landscape modifications, of which the most pervasive hallmark is considered to be the transformation from the natural lands to the imperviousness [1]-[2]. This alteration leads to the negative hydrologic impacts that result in the enhanced hydraulic efficiency and thus it can increase the stormwater runoff volumes, the flow rates and the peak flows and the flow-time reductions in the urban catchments [3]-[4]. While the climate change predictions are inherently uncertain, the predictions of the future changes in the precipitation patterns seem fairly robust [5]. The anticipated climate change will affect and increase the extremes precipitation, leading to an increase in the design intensities of at least 20 % [6]-[7]. This poses a challenge to the urban drainage design as the future drainage systems will have to deal with the increased frequency and the volume of the storm water flows. As a result, the urban drainage capacity needs to be significantly increased in many parts [8], including the case area in Indonesia addressed in this study. However, there are the increased concerns that expanding the underground pipe system is not a sustainable solution for the climate adaptation in the long term or that the attractive alternatives exist [9]-[11].

Due to the global climate change and intensive urban construction, although the increasing efforts have been made in the urban infrastructure construction including the drainage system, the problem of the urban waterlogging is still serious. Therefore, an accurate assessment of the service performance of drainage system and simulation of its operation status has become an urgent problem [12]. To date, there has not been a service assessment system of the urban drainage that can be become as a reference. In addition, there has not been a network service index of the urban drainage too by considering the technical as well as the non-technical indicator that can be become as a reference in determining the priority of the handling as well as the maintenance. However, the condition of drainage network can also influence the water quality in the river [13]. It is unfortunate, remembering that the Indonesian government has made the reference of the irrigation network assessment in the General Work Ministry Rule No 01/PRT/M/2014 which is useful in the development and maintenance of irrigation network although it is not based on the scientific approach; however it is based on the agreement. The technical, as well as the non-technical aspect, has the important role. Both aspects integrate each other to support the water resources management in the future [14].

The technical aspect can be used to show the areas which are not underserved by the drainage network. Dewi et al. [15] have shown the channel capacity analysis in handling flood. However, Mefri [16] has studied the relation between the drainage system damage and the flood and found that both of them are very related. The presence of the unsure on the technical aspect (for example: legal and regulatory, society) in determining the index, will show the continuity of an urban drainage network. Andayani and Yuwono [17] try to see the influence of the two aspects without carrying out the detail discussion; however, the assessment is only based on the questionnaire that less can represent the actual condition, so it cannot apply directly. Even though the research shows that there is the significant relation between the two aspects of the drainage service level.

Based on the description as above, there is needed to develop the service index of drainage network in the urban area in order to be able to help the determination of handling and operational priority. The index has to be able to represent the technical as well as the non-technical aspect to guarantee the integrity and the continuity of a drainage network (specific) and measurable for determining the handling and operational priority (achievable) regarding to the drainage service level policy that is applicable (relevant) which is carried out in the certain period and it can be updated regarding the demand (timely).

2. MATERIALS AND METHODS

The Bandung city topographically is as highland and lowland on the Bandung basin area and has the slope in the range of 0-30%, Based on the altitude, the study location is a highland with the height of 791 m over the sea level. Basically, the slope in the Bandung city is divided into two as follow: 1) the area with the relatively steep slope and it is on the northern side with the height of 1,050 m over the sea level; and 2) the area with the shallow slope and it is on the southern side with the height of 675 m over the sea level. Therefore, the drainage flow pattern in the Bandung area is divided into two flow patterns due to the slope condition. However, this condition often causes the stacking of rainfall in the southern of Bandung due to the change of flow velocity such as from very fast to slow so there is happened the water stagnant before it enters to the acceptant water body such as the Citarum river.

2.1 The performance assessment of drainage network

Performance of the drainage network system is a success level of a drainage system which has been developed for fulfilling the flood problem. Based on the master plan of the urban drainage network system preparation, the aspects which have to be attended in the design of the drainage network system are the technical, operational, and management aspects [18]. Vadlon [19] suggested the assessment component of the drainage network physical condition and the weighting value based on the assessment guidance of irrigation network condition which is issued by the Directorate General of Water (Jakarta, 1999). The assessment of drainage network physical condition overall is obtained by analyzing the condition of outlet or estuary building (%), complementary building (%), facility building (%), and drainage channel (%) by using the formula as follow [19]:

$$KJD = Kbom + Kbp + Kbf + Ksd \quad (1)$$

Where:

KJD : the condition of drainage network (%),
Kbom : condition of outlet/ estuary building (%),
Kbp : the condition of the complementary building (%),
Kbf : the condition of facility building (%)
Ksd : the condition of drainage channel (%)

2.2 Indicator on the service level of urban drainage

The service level of urban drainage is a latent variable or a variable that cannot be measured directly (unobserved variable). The variable consists of 6 dimensions of level-1 which is contributed to the service level of drainage [17]. The six variables are as follow: 1) water management of urban drainage, 2) software, 3) participation of stakeholder, 4) infrastructure, 5) operation and maintenance, and 6) natural disturbance. Then, the six dimensions of level-1can are described into the dimension of level-2 and more detail into 45 indicators which can be measured (observed indicator). Furthermore, the indicator is analyzed by using the Structural Equation Model (SEM) with the help of Analysis of Momen Structure (AMOS). The result of simulation model produces the weight factor of every indicator.

2.3 Technical aspect

The technical aspects are as follow: 1) The system capacity: the assessment is carried out to the condition of water building and the channel in the system. The hydraulic condition will influence the capacity of a drainage system; 2) The puddle problem: the assessment is carried out to the flood scale that consists of the area or the height and duration. The puddle problem which is happened in the location will give the illustration on the drainage service of a system; 3) The drainage pattern: the assessment is carried out to the flow parameter that influences the hydrograph of the drainage system. The flow parameter consists of the land cover and the time of flow.

2.4. Non-technical aspect

The non-technical aspects are as follow: 1) The institutional management: the presence of active institutional management with supporting the adequate human resources, will give support to the system drainage service; 2) The public and private roles: the public and private roles can follow to play an active role in maintaining and increasing the drainage service by forming the independent forum which can help the legal institution to increase the drainage service; 3) The aspects of legal and regulatory: the presence of law enforcement, the clear rule and it is obeyed, will increase and maintain the drainage service; 4) Socio-culture and economy: the socio-cultural condition of Indonesian will have the influence to the drainage service. For example, the garbage problem and the wild house are as the drainage problem which is generally appearing from the socio-cultural and economic factor; 5) Flood losses: the flood will give the different losses. It is depended on the location of the flood. The good drainage service will minimize the losses due to the flood in an area which in turn will give the feedback to the drainage network performance.

3. RESULTS AND DISCUSSION

3.1 Assessment of technical and non-technical criteria

The survey is conducted in the 16 primary channels which are located in the Citepus watershed. The survey intends to obtain the value (score) from each variable and index of technical as well as non-technical criteria. The variables (T) and the indicator (t) of technical criteria are as follow: 1) T1 – the system capacity consists of $t_{1.1}$ –channel capacity, $t_{1'2}$ –channel age, $t_{1.3}$ –channel condition, $t_{1.4}$ –complementary building condition, $t_{1.5}$ –drainage density, $t_{1.6}$ –land use change rate; 2) T2 –the flow condition consists of $t_{2.1}$ –time concentration, $t_{2.2}$ –land cover, $t_{2.3}$- drainage system; 3 T3 –the puddle problem consists of $t_{3.1}$ –flood area, $t_{3.2}$ –mean depth of flood, $t_{3.3}$ –mean duration of flood. However, the technical criteria have 3 variables which consist of 12 indicators.

The variables (N) and the indicators (n) of non-technical criteria are as follow: 1) N1 – institutional management consists of $n_{1.1}$ – organization committee, $n_{1.2}$ –human resources, $n_{1.3}$ –supervisor committee, $n_{1.4}$ –standard operational procedure, $n_{1.5}$ –master plan; 2) N2 – public and private roles consists of $n_{2.1}$ –society forum which is involved, $n_{2.2}$ –the involving of society and private; 3) N3 –legal and regulatory consists of: $n_{3.1}$ –monitoring to the rule, $n_{3.2}$ –the effort of law enforcement, $n_{3.3}$ –reward to the society; 4) N4 –socio-culture and economy consist of $n_{4.1}$ –boundary line condition, $n_{4.2}$ – education level, $n_{4.3}$ –operational cost, $n_{4.4}$ – maintenance cost. However, the non-technical criteria have 4 variables which consist of 14 indicators.

This study uses the SEM Partial Least Square (PLS(method for determining which variables and indicators influence the technical or non-technical aspect. Based on the second circle of structural model by using the SEM Partial Least Square (PLS), the relation between the technical variables (system capacity, flow pattern, and puddle problem) and the non-technical variables (institutional management, society and private role, legal aspect and regulatory, socio-culture and economy) has the significant influence to the drainage infrastructure service. It can be seen on the inner model number of technical variable is 4.241 and the non-technical variable is 2.698. Each variable has the value more than 0.5. Based on the result of the SEM-Partial Least Square (PLS), there are 6 indicators are almost not influencing the drainage service index such as 1) technical aspect: $t_{1.2}$ –channel age, $t_{1.4}$ –complementary building condition, $t_{2.3}$ – drainage system, $t_{3.1}$ –area of flood; 2) non-technical aspect: $n_{4.2}$ –education level, $n_{4.4}$ – maintenance cost. Therefore, the 6 indicators are not used in the modeling. The questionnaire result about the selected variables and indicators due to the result of the SEM-Partial Least Square (PLS) is presented as in Table 1 and 2, each for technical and non-technical aspect.

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Table 1. The selected criteria assessment and the coefficient value of the technical aspect

No	Name of primary channel	T_1				T_2		T_3		
		0.853				0.127		0.021		
		t_{11}	t_{13}	t_{15}	t_{16}	t_{21}	t_{22}	t_{32}	t_{33}	tcalc
		0.188	0.429	0.493	0.144	0.246	0.190	0.090	0.389	0.73
1	Cipedes Hilir	5	3	2	5	1	1	1	3	3.437
2	Surjadi	5	4	2	5	1	1	5	4	3.819
3	Cobogo	5	4	1	5	1	1	3	4	3.395
4	Citepus	4	3	2	5	1	1	1	4	3.285
5	Supadio	5	4	2	5	1	2	5	4	3.843
6	Cikakak	5	3	2	4	1	1	1	4	3.322
7	Kopo	5	4	2	4	1	1	1	4	3.688
8	Waringan	4	3	2	4	2	1	5	4	3.200
9	Ciroyom	4	4	2	5	1	1	1	4	3.651
10	Babakan Tarogong	3	4	2	4	3	2	5	5	3.469
11	Arjuna	3	3	2	4	1	2	5	5	3.041
12	Otista	5	2	3	4	2	1	1	4	3.408
13	Leuwisari	3	4	2	4	2	1	5	5	3.414
14	Kurdi	4	3	2	5	2	1	5	5	3,322
15	Muara	4	3	2	5	1	1	5	5	3.300
16	Curug Candung	3	4	2	5	4	1	5	5	3,599

Explanation: There are 3 variables (T) and 8 indicators (t):
1) T_1 – the system capacity consists of: $t_{1.1}$ –channel capacity, $t_{1.3}$ –channel condition, $t_{1.5}$ –drainage density, $t_{1.6}$ –land use change rate; 2) T_2 –the flow condition consists of: $t_{2.1}$ –time concentration, $t_{2.2}$ –land cover; 3) T_3 –the puddle problem consists of: $t_{3.2}$ –mean depth of flood, $t_{3.3}$ –mean duration of flood.

Table 2. The selected criteria assessment and the coefficient value of the non-technical aspect

No	Name of primary channel	N_1					N_2		N_3			N_4		NT
		0.6046					0.0026		0.0868			0.3060		calc.
		n_{11}	n_{12}	n_{13}	n_{14}	n_{15}	n_{21}	n_{22}	n_{31}	n_{32}	n_{33}	n_{41}	n_{42}	
		0.33	0.29	0.06	0.06	0.26	0,21	0.17	0.16	0.19	0.28	0.34	0.27	0.27
1	Cipedes Hilir	3	2	1	1	1	1	1	3	2	1	4	1	1.719
2	Sarijadi	1	1	1	1	1	2	1	1	2	1	4	1	1.116
3	Cibogo	3	2	1	1	1	1	1	3	2	1	5	1	1.825
4	Citepus	3	2	1	1	1	1	1	3	2	1	5	1	1.825
5	Supadio	3	2	1	1	1	1	2	3	2	1	3	2	1.696
6	Cikakak	3	2	1	1	1	1	2	3	2	1	3	2	1.696
7	Kopo	1	1	1	1	1	1	1	1	2	1	3	2	1.092
8	Waringin	3	2	1	1	1	1	1	1	2	1	3	2	1.668
9	Ciroyon	1	1	1	1	1	1	1	1	2	1	3	1	1.010
10	Babakan Tarogong	2	4	1	1	1	2	1	1	1	4	2	1	1.695
11	Arjuna	3	4	5	5	5	2	2	4	3	1	5	1	2,902
12	Otista	4	2	1	1	3	1	1	4	1	1	5	1	2.340
13	Leuwisari	3	2	1	1	1	1	1	3	2	1	5	1	1.825
14	Kurdi	3	4	5	5	1	2	2	5	5	1	5	1	2.311
15	Muara	3	4	5	5	1	2	2	3	4	1	3	1	2.056
16	Curug Candang	3	2	1	1	1	2	5	4	3	1	3	1	1.647

Explanation: There are 4 variables (N) and 12 indicators (n):
1) N_1 –institutional management consists of $n_{1.1}$ –organization committee, $n_{1.2}$ –human resources, $n_{1.3}$ –supervisor committee, $n_{1.4}$ –standard operational procedure, $n_{1.5}$ –master plan; 2) N_2 –public and private roles consists of $n_{2.1}$ –society forum which is invilved, $n_{2.2}$ –the involving of society and private; 3) N_3 –legal and regulatory consists of: $n_{3.1}$ –monitoring to the rule, $n_{3.2}$ –the effort of law enforcement, $n_{3.3}$ –reward to the society; 4) N_4 –socio-culture and economy consist of $n_{4.1}$ –boundary line condition, $n_{4.3}$ –operational cost.

The formula of technical urban drainage service is as follow:

$$IL_{technical} = a_1.T_1 + a_2.T_2 + a_3.T_3$$

Where: $IL_{technical}$ = technical urban drainage service, T_1 = flow pattern index, T_2 = puddle problem index, T_3 = system capacity index, a_n = weight index

The formula of non-technical urban drainage service is as follow:

$IL_{non\text{-}technical} = b_1.N_1 + b_2.N_2 + b_3.N_3 + b_4.N_4$

Where: $IL_{non\text{-}technical}$ = non-technical urban drainage, N_1 = institutional management index, N_2 = legal aspect and regulatory index, N_3 = socio-cultural and economic index, N_4 = society and private role, N_5 = losses due to the flood index, b_n = weight index.

However, based on the data as presented in the Table 1 and 2, the formula of technical and non-technical urban drainage service is as follow:

$IL_{technical} = 0.853\ T_1 + 0.127\ T_2 + 0.021\ T_3$

$T_1 = 0.188\ t_{11} + 0.429\ t_{13} + 0.493\ t_{15} + 0.144\ t_{16}$

$T_2 = 0.246\ t_{21} + 0.190\ t_{22}$

$T_3 = 0.090\ t_{32} + 0.389\ t_{33}$

$IL_{non\text{-}technical} = 0.6046\ N_1 + 0.0026\ N_2 + 0.0868\ N_3 + 0.3060\ N_4$

$N_1 = 0.33\ n_{11} + 0.29\ n_{12} + 0.06\ n_{13} + 0.06\ n_{14} + 0.26\ n_{15}$

$N_2 = 0.21\ n_{21} + 0.19\ n_{32} + 0.28\ n_{33}$

$N_4 = 0.34\ n_{41} + 0.27\ n_{43}$

The index value of 16 primary drainage channels for technical and non-technical aspect is as follow:

$IL_{technical} = 0.853\ T_1 + 0.127\ T_2 + 0.021\ T_3$

$IL_{non\text{-}technical} = 0.6046\ N_1 + 0.0026\ N_2 + 0.0868\ N_3 + 0.3060\ N_4$

The weighted index is analyzed by using the Generalized Reduced Gradient (GRG), the results are as follow:

$IL = \alpha_{\ technical} + \beta\ IL_{non\text{-}technical}$

$IL = 0.73_{\ technical} + 0.27\ IL_{non\text{-}technical}$

The comparison of urban drainage service index due to the formula (modeling) and the observation is presented as in Table 3.

Table 3. The comparison of $_{modelling}$ and $_{observation}$

No	Name of primary channel	$_{modeling}$	$ILD_{observation}$	Relative error (%)
1	Cipedes hilir	2.975	3	0.05
2	Sarijadi	3.091	3	0.83
3	Cibogo	2.972	3	0.08
4	Citepus	2.892	3	1.17
5	Supadio	3.265	3	7.01
6	Cikakak	2.884	3	1.34
7	Kopo	2.989	3	0.01
8	Waringin	2.788	3	4.51
9	Ciroyom	2.940	3	0.36
10	Babakan Tarogong	2.991	3	0.01
11	Arjuna	3.003	3	0.00
12	Otista	3.120	3	1.44
13	Leuwisari	2.986	3	0.02
14	Kurdi	3.057	3	0.32
15	Muara	2.965	3	0.12
16	Curug Candung	3.073	3	0.54

The maximum standard relative error in this study is determined as 10%, so the analysis as above can be accepted. The maximum error as presented in Table 3 is 7.01% (< 10%) such as in the SP Supadio and the minimum error is 0.02% (< 10%) such as in the SP Leuwisari. It indicates that the indicator coefficient of SP Leuwisari is more suitable than SP Supadio.

4. CONCLUSION

Based on the analysis as above, the conclusion of this study is as follow:

The service means an assessment of an urban drainage network due to the technical aspect is as follow: the system capacity is 3.55 (good), the flow pattern is 1.375 (bad), and the puddle problem is 3.844 (good). However, for the non-technical aspect is as follow: the institutional management is 2 (less), the society and private roles are 1 (bad), the legal aspect and regulatory is 1.95 (less), and the socio-culture and economy are 3 (moderate).

Based on the analysis by using Partial Least Square (PLS)), the 8 technical and non-technical variables which consist of 26 indicators is filtered into as follow: a) The technical aspect: in the beginning has 3 variables which consist of 12 indicators, however, due to the Partial Least Square (PLS) result, becomes into 3 variables which consist of 8 indicator as follow: 1) variable-1: system capacity consists of channel capacity, channel condition, drainage density, and land use change rate; 2) Variable-2: flow pattern consists of time concentration and land cover; and 3) variable-3: puddle problem consist of mean depth of flood and mean duration of flood; b) The non-technical aspect: in the beginning has 5 variables which consist of 14 indicators, however, due to the Partial Least Square (PLS) result, become into 4 variables which consist of 10 indicators as follow: 1) variable-1: institutional management consist of organization committee, human resources, supervisor committee, standard operational procedure, and master plan; 2) variable-2: society and private role consist of society forum which is involved, the involving of society and private; 3) variable-3: legal aspect and regulatory consist of monitoring to the rule, the effort of law enforcement, reward to society; and 4) variable-4: socio-culture and economy consist of boundary line condition and economic activity.

Based on the Generalized Reduced Gradient (GRG), the weighted index for the service index modeling of urban drainage is as follow: $I_L = 0{,}73*I_{teknis} + 0{,}27*I_{non\text{-}tennis}$ and it can be concluded that the technical, as well as non-technical aspect, have a contribution to the service index of urban drainage.

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