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A QUANTITATIVE DYNAMIC MODEL FOR MANAGING LITTER ABUNDANCE IN THE TRASH TRAP OF AN URBAN LAKE IN INDONESIA

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Abstract
In Indonesia, urban litter is threatening the role of urban lakes as a part of green infrastructures in cities. To overcome this issue, Kenanga Lake—an urban lake with a surface area of 2.8 ha located within the Universitas Indonesia Campus—has been equipped with a trash trap unit on its inlet. However, the large amount of litter and its unpredictable pattern have made trash trap management difficult. The previous study illustrated the conceptual diagram of this problem. As a continuation in terms of looking further for sustainable solutions to this problem, this study aimed to establish its quantitative dynamic model, which is expressed as the mathematical equations of the interrelations among elements. We developed the model using the system dynamics modeling method with the Powersim Studio 10 software and validated it using the Average Mean Error (AME) method. To help calibrate the model, several supporting methods, i.e., field observation, load–weight analysis continuous sampling, and Theory of Planned Behavior (TPB)-based questionnaire survey, were used. Results showed that, on a sunny day, the maximum inlet lake litter load is 33 $g/m^3/h$. Meanwhile, if rain falls, the maximum inlet lake litter load increases tenfold and reaches 346 $g/m^3/h$. Then, the survey found that 22% of the citizens living in the location have a strong intention to dump their waste into the waterway. Moreover, the model has been validated, with the AME value of 0.1079 or confidence level of 89.21%. Finally, we conclude that the TPB-based questionnaire survey method can be combined with the system dynamics modeling method to capture the human sociocultural aspect of the system quantitatively. The applied methods can be used to solve the typical litter abundance problem in other urban lakes.

Keywords: littering; sustainability; system dynamics; theory of planned behavior; urban lake

1. Introduction

Urban lake is an inland body of surface water, which is surrounded by an urban environment and meets several criteria of a lake, i.e., area more than 1 ha, constant water depth, and low ratio between inflow and total volume (Mikos, 2012; Persson, 2012). As the natural hydrologic cycle is disrupted by traditional urbanization in a city, it plays an important role in water resource management (Soeryantono, 2016) and urban stormwater control (Sutjiningsih & Anggraheni, 2011). Moreover, recent studies reported its role in mitigating global climate change (Kavehei, Jenkins, Adame, & Lemckert, 2018) and maintaining the microclimate of a city (Zhu & Zheng, 2018). In the "Blue–Green Infrastructure" concept developed by city planners, ecologists, landscape architects, and civil engineers, they combined urban lakes—regarded as blue infrastructure—with other green infrastructures to maximize the benefits that humans can obtain from the natural environment in urban areas (Chenoweth et al., 2018; Persson, 2012; Versini et al., 2018). However, in spite of its essential roles and potential benefits, the future existence of urban lakes is challenged by the urbanization phenomenon, particularly in developing countries, e.g., China (Chen, Wang, Li, & Li, 2015) and Indonesia (Henny & Meutia, 2014).

Urban litter is one of the urban development side effects that has become a serious threat to the freshwater ecosystem in urban settings (Eerkes-Medrano, Thompson, & Aldridge, 2015; Green, Putschew, & Nehls, 2014; Hoellein, Rojas, Pink, Gasior, & Kelly, 2014; Horton, Waltona, Spurgeon, Lahive, & Svendsen, 2017; Yin et al., 2019). Moreover, several studies confirmed the contamination of urban lake ecosystems by anthropogenic litter (Vincent & Hoellein, 2017), e.g., plastic litter (Driedger, Dürr, Mitchell, & Cappellen, 2015) and microplastic litter (Vaughan, Turner, & Rose, 2017; Yin et al., 2019). In the case of developing countries, Henny & Meutia (2014) also confirmed this threat to urban lakes in the megacity of Jakarta and proposed that it should be managed on the basis of its surrounding characteristics, conditions, and functional contexts. Motivated by the previously mentioned studies, we conducted a study presenting a systems thinking approach to illustrate the relationships among key factors contributing to the issue of litter abundance in the urban lake environment (Muhsin, Karuniasa, & Soeryantono, 2018). However, relevant research addressing this issue in a quantitative manner is still scarce. Zheng, Jiao, Zhang, & Sun (2017) tried to apply a quantitative modeling approach to solve the extensive water pollution issue in urban lakes in China. However, quantitative modeling approach studies that focus on urban lake litter abundance, which has become a serious threat to urban lakes in Indonesia, are still lacking.

Kenanga Lake at the Universitas Indonesia (UI) Campus, Depok City is one of the case studies that represents this problem. Covering a surface area of 2.8 ha, Kenanga Lake is one of several urban lakes at the campus whose purpose is for water management and education (Soeryantono, 2016). Moreover, this lake is important for the campus image because of its strategic location surrounded by the UI library, university administrative building, Ukhuwah Islamiyah Mosque, and great hall of UI. Muhsin et al. (2018) showed that lake cleanness contributes to the campus image, which has a certain influence on the economic and population growth of the city. However, the lake has been polluted by the activities of citizens living in its catchment area for decades. Litter abundance in Kenanga Lake is a challenge that campus management needs to solve. A trash trap unit was installed on the inlet of Kenanga Lake to address the problem. However, the large amount of litter and its unpredictable pattern have made trash trap management difficult. Moreover, the capacity of the trash trap unit has been exceeded by the high load of urban litter. Thus, the lake is still polluted. In addition, the costs increase, which becomes another problem for campus management. Several actions have been made, but it is more reactive in nature than long-term solutions. Therefore, in terms of looking further for sustainable solutions to this problem, there is a need to establish a quantitative model that considers preventive and holistic approaches. This research is the next step in long-term efforts to find sustainable solutions to this issue.

This study is a continuation of the previous study of the urban lake litter abundance problem, which has taken Kenanga Lake and the adjacent area of East Cisadane Empang Irrigation Channel in Depok City, Indonesia as a pilot project location (Muhsin et al., 2018). It aims to further advance the research—that has already described the conceptual diagram of the problem—by establishing its quantitative dynamic model, which is expressed as the mathematical equations of the interrelations among elements. The system dynamics modeling method is used as the main method combined with field observation, load–weight analysis continuous sampling, and Theory of Planned Behavior (TPB)-based questionnaire survey as supporting methods to adjust the equations of the model. These mathematical equations need to be determined because it provides technical support for the decision-maker and the environmental analyst/modeler to analyze alternative solutions to this problem, which has the complexity of coupled human socioeconomic and natural environment systems.

2. Methods

This work is regarded as a model formulation step (Sawah, McLucas, & Ryan, 2010) and is operated using the system dynamics modeling cycle (Soesilo & Karuniasa, 2014). We also conducted field observation of the pilot project location, which will be described further in this section. In light of previous studies that successfully combined the system dynamics modeling method with the TPB-based questionnaire survey (Ding, Yi, Tamb, & Huang, 2016; Guo, Hobbs, Lasater, Parker, & Winch, 2016), this research also conducted a TPB-based questionnaire survey of the littering intention of citizens, so that the sociocultural aspect can be presented in this quantitative model. Moreover, load–weight analysis continuous sampling was used to quantify the urban litter entering the trash trap and to capture its pattern. Afterward, the results were synthesized to find the relevant equations of the model, which is in the form of a Stock-Flow Diagram (SFD). The overview of the methods is illustrated in Figure 1.

2.1 Study Area

This research observed Kenanga Lake and the adjacent area of East Cisadane Empang Irrigation Channel as the pilot project location (Figure 2). Kenanga Lake is an artificial lake made in 1992, located within the UI Campus, Depok City, and situated between the latitude of 6°21′55.96″S to 6°22′4.78″S and longitude of 106°49′53.50″E to 106°49′44.64″E. Its location is strategic because it is surrounded by buildings that have become icons for the campus, i.e., UI library, university administrative building, Ukhuwah Islamiyah Mosque, and great hall of UI. The lake covers an area of 2.8 ha, with a water depth of approximately 1 m (Soeryantono, 2016). The water source of Kenanga Lake is the East Cisadane Empang Irrigation Channel.

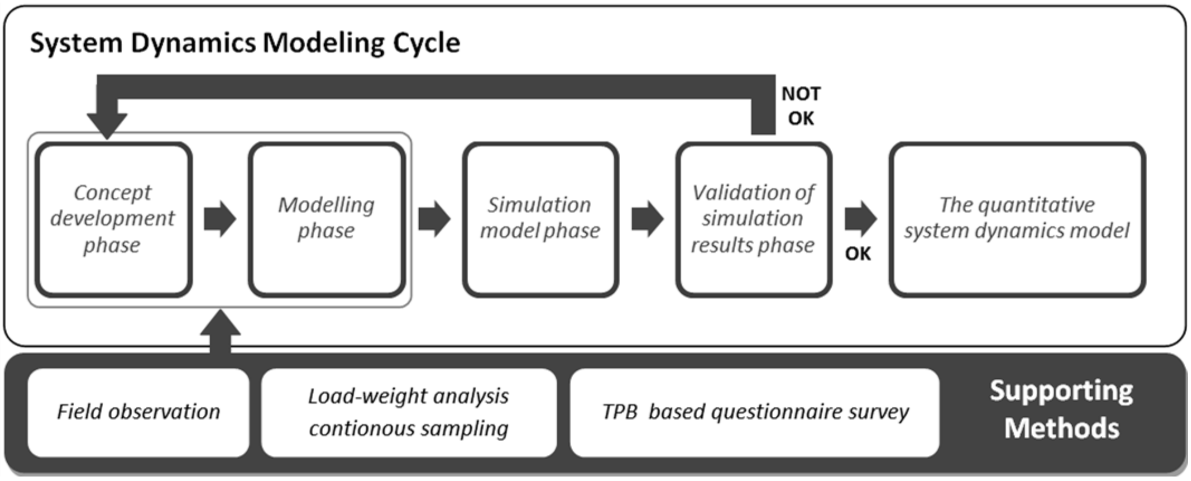


Figure 1. Overview of the model development process undertaken in this study

The characteristics of the surrounding area adjacent to the channel affect its water quality directly. The area consists of dense settlement area, Depok City government office area, integrated bus terminal, train station, and business districts, i.e., Kemiri Muka traditional market, D-Mall, ITC Depok, and Depok Town Square. Statistic of Depok City (2016) recorded that the density of Kemiri Muka settlement area reached 19,671 people/km^2. Harnita (2017) determined that the average waste generation of Depok City was approximately 0.51 kg/person/day. However, the coverage area of the waste collection service provided by the city government was only 91.82%. Moreover, although the municipal government tried to clean up the channel regularly, people in the Kemiri Muka traditional market area littering or dumping their waste directly into the channel contributed a significant amount of litter to the channel (Muhsin et al., 2018).

2.2 System Dynamics

2.2.1 Concept Development Phase

A ballpark figure of the problem has been illustrated in previous work (Muhsin et al., 2018) which has identified that there are unique inter-relationship among three major stakeholders in the systems, e.g. citizen, municipal government and campus management. In this study, we continued the work by extracting and elaborating several elements of the systems to draft a hypothetical Causal Loop Diagram (CLD), especially related to the trash trap management activity. We tried to define the feedback loops of the litter abundance problem considering the field observation, load-weight analysis continuous sampling, and TPB based questionnaire survey results. In addition, on the basis of the system dynamics modeling cycle illustrated previously, if the simulation results are invalid, then we will reevaluate the concept and try to adjust the CLD. Thus, the iteration process continued until the simulation results become valid.

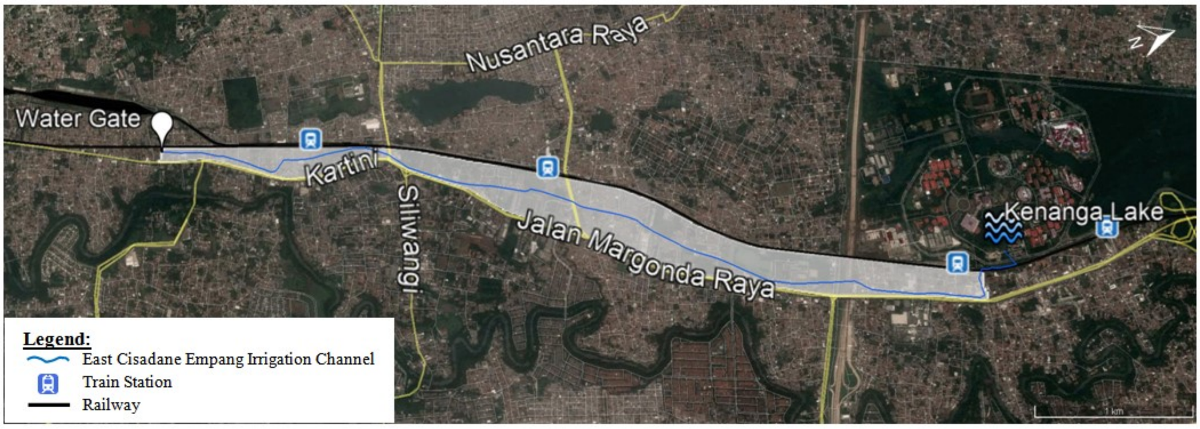


Figure 2. Observed pilot project location—surrounding area adjacent to East Cisadane Empang Irrigation Channel, Depok City, West Java, Indonesia
(Source: Muhsin et al., 2018)

2.2.2 Modeling Phase

In this phase, we built the SFD on the basis of previous hypothetical CLD. First, we identified which variables of the systems will serve as variable stock, variable flow, variable auxiliary, and variable constant. Then, we tried to derive the mathematical equations of the relationships among variables by conducting field observation, sampling, and survey. Several equations were obtained through regression analysis of the sampling and survey results data. We also added several variables to the SFD to complete the relationship equation.

2.2.3 Simulation Model Phase

The Powersim Studio 10 software was utilized in the model simulation phase. All relevant data were inputted into the built SFD in the software. Here, we used several initial datasets obtained from literature review (e.g. rainfall, waste generation, waste collection service, and population growth), stakeholder interview (e.g. personal wage unit cost and transport unit cost), field sampling (e.g. litter density), and questionnaire survey (e.g. citizen waterway-littering intention). The rainfall data were obtained from the Rainfall Measurement Station in the UI Engineering Faculty. When it was necessary, several assumptions were used to simplify the systems. Then, it was simulated to obtain the simulation results, so that it can be assigned in the next phase.

2.2.4 Validation of Simulation Results Phase

The model validation phase is used to determine whether the results of the model represent actual system performance or still need more adjustments. The average mean error (AME) method was used for statistical validation in this study. This process was done by comparing the AME value of the simulation results with that of the reference data. The formula for AME validation is expressed in formula (1):

$$AME = \frac{|Si - Ai|}{Ai} \times 100\% \tag{1}$$

where A refers to the actual value, S is the value of the simulation, and i indicates the time interval of the field observation. In this issue, certain variables cannot be controlled; thus, the

AME limit value of 30% is considered sufficient to express the valid model (Soesilo & Karuniasa, 2014).

2.3 Load–Weight Analysis Continuous Sampling

Load–weight analysis is one of the three common methods used to quantify the amount of generated or collected waste in a particular time or place (Gawaikar & Deshpande, 2006). Here, we conducted load–weight analysis continuous sampling. We implemented this method for approximately 48 h and recorded the weight of urban litter collected in the trash trap as the object of measurement every hour. Sampling was conducted on 27–28 April 2018. Moreover, to determine the hydrodynamics of the irrigation channel, we measured the channel water flow using a propeller-type digital current meter. Both the collected urban litter weight data and channel water flow data from this sampling activity were used to calculate the density and maximum load of the collected urban litter. Moreover, these data were analyzed using regression analysis to derive the required formula for model development.

2.4 Theory of Planned Behavior-Based Questionnaire Survey

The TPB proposed by Ajzen (2006) has been used in previous studies to describe the contribution of humans to the litter abundance issue in Indonesia (Ghassani & Yusuf, 2015; Rahmadin et al., 2015). Here, we reutilized the questionnaire survey method employed by Ghassani (2015). In the field observation, Google Earth exploration, and literature review conducted, we designated the households in the pilot project location as the research population. As a result, approximately 1,633 households in the research location were included in the survey. Then, we defined the sample size using the probability sampling formula (Trobia, 2008) expressed in formula (2).

$$n = \frac{z^2 pqN}{E^2 (N-1) + z^2 pq} \tag{2}$$

where n refers to the sample size, z is the confidence level of the estimate, pq is the variance, N is the size of the population, and E is the sampling error. With several adjustments to the formula, i.e., confidence level of 90%, z value of 1.645, pq value of 0.25, and E value of 10%, the minimum sample size is 65 samples. Thus, in this work, we managed to survey 68 respondents, with each of them representing their own household. Afterward, all responses were analyzed using successive interval methods as described by Ghassani (2015). These data can be used to calculate the potential waterway litter generation (WLG) in the research area.

3. Results and Discussion

3.1 Abundance of Litter in Kenanga Lake

Boundary judgment of the system is required to extend the qualitative systems thinking approach to the quantitative system dynamics modeling practice (Nabavi et al., 2017). In the case of litter abundance in Kenanga Lake, our research findings play an important role in guiding the overall process of model development. To set the system boundary, this section will explain the essential results of the sampling, observation, and survey.

From three supporting methods implemented in this study, several interesting findings became the main considerations for the next steps. First, on a sunny day, the maximum inlet lake litter load is 33 g/m^3/h. Second, if rain falls, the maximum inlet lake litter load increases tenfold and reaches 346 g/m^3/h. Third, the density of collected urban litter on the trash trap is 303.67 kg/m^3. Fourth, the TPB-based questionnaire survey showed that 22% of the citizens living in the location have a strong intention to dump their waste into the waterway. This finding is consistent with those of Ghassani & Yusuf (2015) and Rahmaddin, Hidayat, Yanuwiadi, & Suyadi (2015), which showed that waterways are still the preferred place for the society to dump its waste. Fifth, potential WLG based on the survey results and literature reviews is 1,147 kg/day or 3.78 m^3/day.

Meanwhile, the results of our sampling activity, as illustrated in Figure 3, highlighted the pattern of litter abundance in the trash trap unit of Kenanga Lake. Combining this result with the field observation result, this pattern can be explained, as follows: On the first hour, the high load value indicated that a channel-cleaning activity was conducted by the municipal water resource officers. When they cleaned the channel using traditional manual methods, some of the litter passed through and flowed with the water, so that eventually they reached the trash trap. Then, the low load values between 16:00 PM and 22:00 PM on the first day of sampling corresponded to low water flow. This low water flow indicated water gate adjustment at the opening of the East Cisadane Empang Irrigation Channel. It was confirmed by the gate officer's explanation of his role to close half of the gate when heavy rains come. As the officer predicted, at approximately 22:00 PM, heavy rains fell, followed by the extremely high load of urban litter for approximately 3 hours in the trap. Armitage (2007) described this extremely high load phenomenon as a first flush. Subsequently, the mid-high load values between 22:00 PM and 06:00 AM coincided with the peak time of Kemiri Muka traditional market activities, strengthening the argument about the contribution of market litter to the litter abundance issue. Otherwise, the mid-low load values on the last 24 h expressed the litter pattern on a sunny day when no channel water flow alterations occurred and the flows were relatively low.

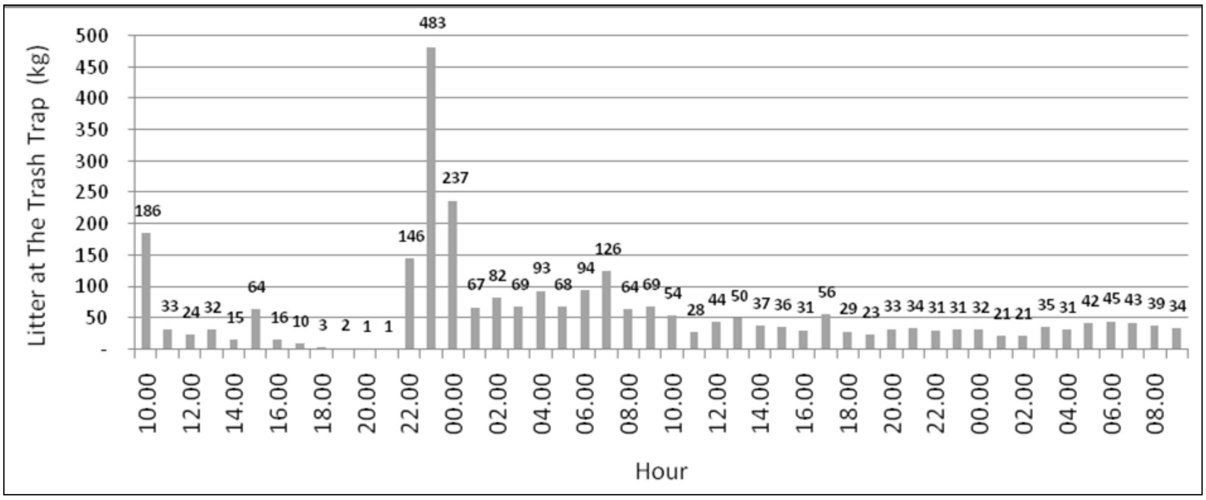


Figure 3. Weight of litter abundance in the trash trap on the inlet of Kenanga Lake on 27–28 April 2018

3.2 Causal Loop Diagram

After the iteration process, the CLD of the issue is shown in Figure 4. The CLD was built on the basis of the results of the previous study (Muhsin et al., 2018) which has already enlisted the inter-relationships among the elements among citizen (i.e. population, waste generation, waterway litter, and citizen littering intention), municipal government (i.e. municipal waste collection services and waterway cleaning), and campus management (i.e. inlet lake litter load, urban lake litter, urban lake cleaness, and trash trap management elements, e.g. cleaning personnel and cost). In the CLD development process, those results were strengthened by the results of the supporting methods mentioned previously which provide quantitative data for the modeling phase. These inputs improve our understanding about the problem of litter abundance in the Kenanga Lake, i.e. the sampling results help us understand about the role of waterway flow in the litter abundance at the trash trap inlet and the TPB based survey ensure us that the citizen littering behavior is an everyday phenomenon, e.g. 22% of the citizens. As illustrated in Figure 4, the two subsystems of the system are distinguished by the color of the boxes, which will be explained as follows.

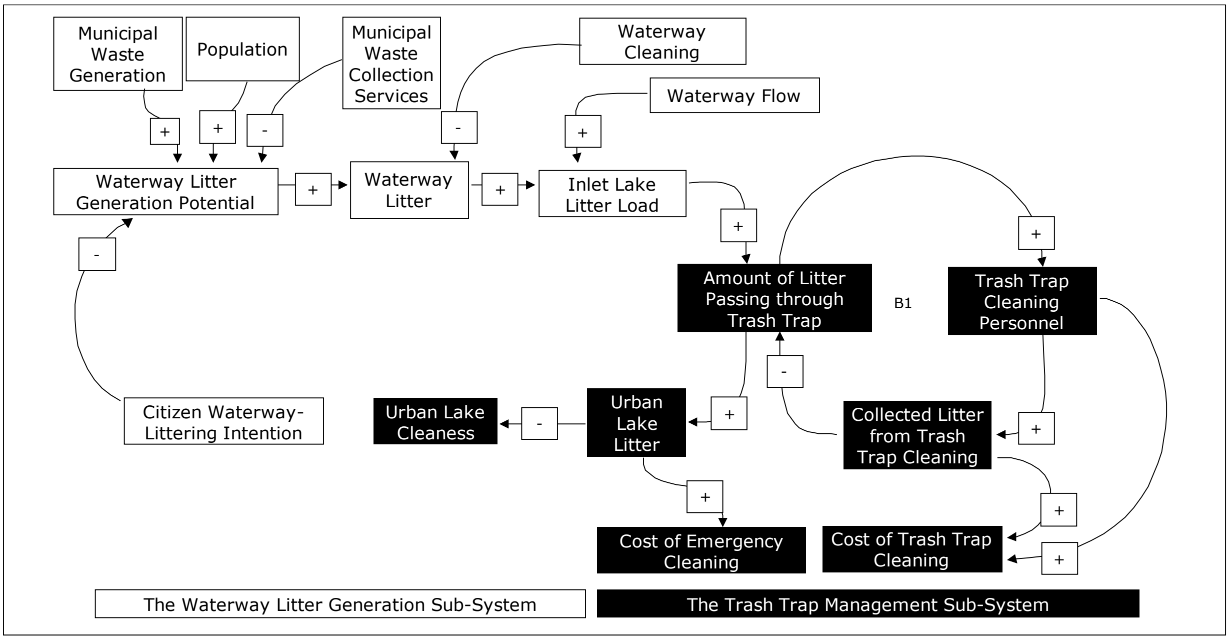


Figure 4. Causal loop diagram of Kenanga Lake litter abundance

First, the subsystem indicated by the white box is the WLG subsystem. Given the local scale of this study, the subsystem was illustrated as having no feedback loop and only consisting of several arrows toward a single end—the variable "amount of litter passing through the trash trap to the lake." the variables "municipal waste generation" and "population," indicated by positive signs, seem to support the growth trend. However, three variables, i.e., "municipal waste collection services," "waterway cleaning," and "citizen waterway-littering intention," indicated by the negative signs, could prevent this subsystem from undergoing absolute growth.

Second, the subsystem indicated by the black box is the trash trap management subsystem conducted by the UI Campus management. The "amount of litter passing through the trash trap," which is influenced directly by "inlet lake litter load," affects "urban lake litter" and "urban lake cleanness." Notably, this subsystem has a balancing feedback loop, which illustrates the effort of the system, i.e., campus management, to control the abundance of litter. The increase in the "amount of litter passing through the trash trap" influences the addition of "trash trap cleaning personnel," so that it will increase the "collected litter from trash trap cleaning" and decrease the "amount of litter passing through the trash trap." However, when the input of "inlet lake litter load" increases, the cleaning cost tends to increase, as illustrated by both the lake and trash-trap-cleaning costs that have positive signs. This financial matter is a burden for campus management.

3.3 Stock Flow Diagram

The SFD of Kenanga Lake litter abundance is illustrated in Figure 5. It is developed from the previous CLD so that it also distinguishes the WLG subsystem (white diagram) and trash trap management subsystem (gray diagram). The SFD elaborates each element on CLD into its quantitative variables and divided it into variable stock, variable flow, variable auxiliary, and variable constant. Population, litter, personnel, and cost are variables served as stock in this SFD, while other variables either served as flow, auxiliary or constant influencing the dynamics of the stock variables. As described in CLD, this SFD also has balancing feedback loop highlighted by the orange arrows.

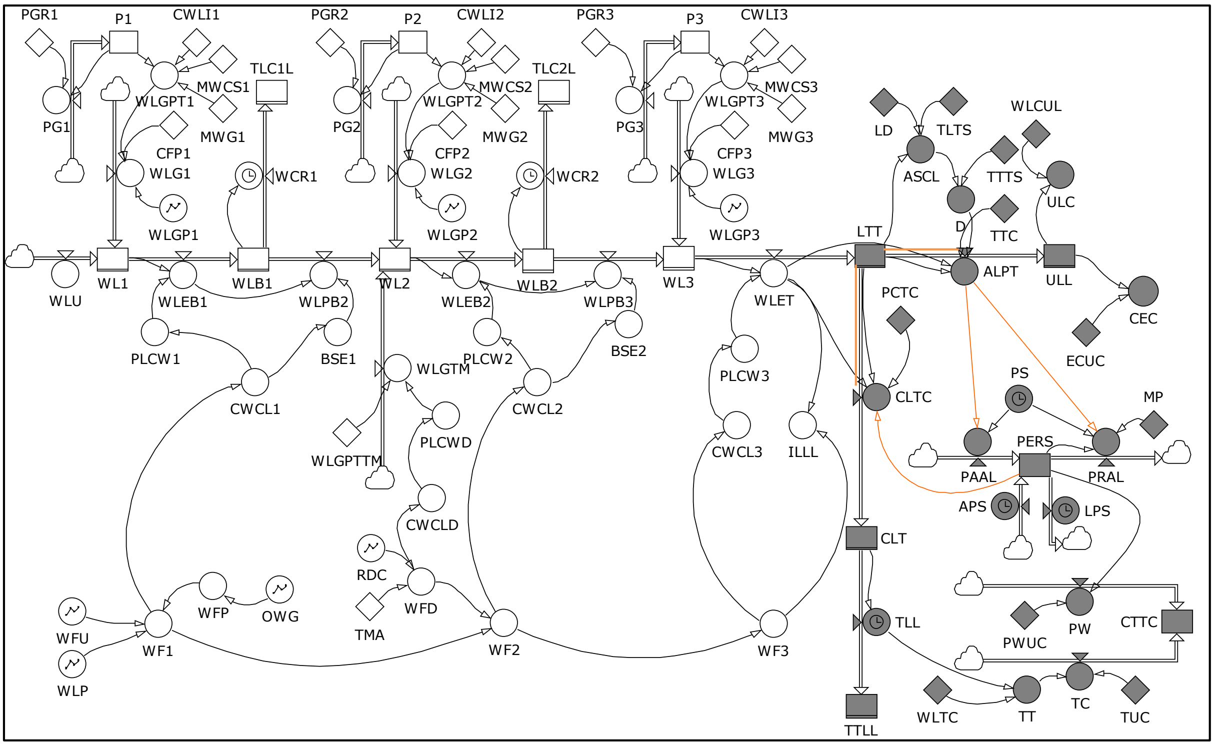


Figure 5. Stock-flow diagram of Kenanga Lake litter abundance

The white diagram illustrates the flow of waterway litter in the East Cisadane Empang Irrigation Channel. It considers the "waterway litter from upstream" (WLU), "waterway litter generation" (WLG), "waterway cleaning rate" (WCR) conducted by the city government, and "waterway flow". In the SFD development process, based on the field observations results, this channel was divided into three section, e.g. channel on Depok Sub-District (Area 1), Kemiri Muka Sub-District (Area 2), and Pondok Cina Sub-District (Area 3). Each district has it owns waterway litter generation variables derived from its waterway litter potential. This study utilized the results of the TPB-based questionnaire survey on "Citizen Waterway-Littering Intention" to determine the WLG. In line with the studies of Guo et al. (2016) and Ding et al. (2016), this study successfully captured the human sociocultural aspect of the system quantitatively. In addition, the SFD also consider the waterway litter generation from Kemiri Muka traditional market (WLGTM) identified by Muhsin et al. (2018) as an area that contribute a significant amount of litter. As for the waterway cleaning, this diagram depicts several bar screen installations cleaned by city government regularly which located on Depok Sub-District (Area 1) and Kemiri Muka Sub-District (Area 2).

Besides, the "waterway flow" was included on the lower left area of the diagram. It flows from the upstream and get increase because of the drainage water from the traditional market. The contribution of upstream flow to waterway flow is calculated using the proxy of "open water gate" (OWG) adjustment obtained from stakeholder interview and "waterway flow from upstream" using data from the Public Works Ministry's Ciliwung-Cisadane Flood Control Office (*Balai Besar Wilayah Sungai Ciliwung-Cisadane*/BBWSCC). As for the drainage contribution, it uses the proxy of rainfall data collected by Universitas Indonesia Faculty of Engineering and traditional market area in the calculation process. Then, the regression analysis was employed in order to find the relationship between waterway flow and the amount of waterway litter. It expresses as the "capability of water to carry a portion of litter" (CWCL) illustrated in Figure 6.

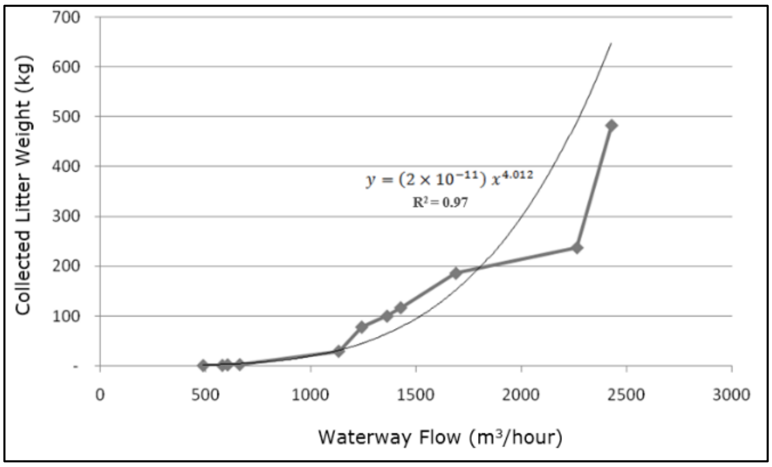


Figure 6. Regression analyses of the "capability of water to carry a portion of litter" (CWCL)

Meanwhile, the gray diagram illustrates the continuation of waterway litter flow and its interrelationship with essential aspects of managing litter abundance in the trash trap of an urban lake, i.e., human resource and financial aspects. The model can depict the amounts of "litter at the trash trap" (LTT), "urban lake litter" (ULL), and "total transported litter to landfill" (TTLL), which can provide useful insights into managing trash trap cleaning. The number of personnel (PERS) in this model considers current campus management approaches to manage "Personnel Shift" (PS) in the trash-trap-cleaning activity. In terms of the financial aspects, the model considers the "Personnel Wage" (PW) and "Transport Cost" (TC) of the collected trash. Thus, with these aspects considered, the model can be used by the decision-maker and environmental analyst/modeler to reevaluate the management of litter abundance in the trash trap on the inlet of Kenanga Lake.

In a nutshell, the final SFD is generated on the basis of several adjustments. The first adjustment is the addition of several technical variables of the system expressed by the white-colored structures. For example, to simplify the mathematical equations of the model, this model separated the irrigation channel into three sections on the basis of its local administrative boundaries. Table 1 provides a list of these variables.

Table 1. List of the variables

No.	Abbr. of Variable	Variable Name	Unit	Initial Value	Data Source*	Function Type
1	ALPT	Amount of Litter Passed through Trash Trap	kg/hour	-	C	IF
2	APS	Added Personnel because of Shift	person/hour	-	A	PULSE
3	ASCL	Area of Screen Covered by Litter	m^2	-	C	-
4	BSE1	Bar Screen Efficiency at Sub-District 1	%/hour	-	A	IF
5	BSE2	Bar Screen Efficiency at Sub-District 2	%/hour	-	A	IF
6	CEC	Cost of Emergency Cleaning	Rupiah	-	C	-
7	CFP1	Correction Factor of Population in Area 1	-	1.1	A	-
8	CFP2	Correction Factor of Population in Area 2	-	1.1	A	-
9	CFP3	Correction Factor of Population in Area 3	-	1.1	A	-
10	CLT	Collected Litter at Trash Trap	kg	0	SIM	-
11	CLTC	Collected Litter from Trash Trap Cleaning	kg/hour	-	C	IF
12	CTTC	Cost of Trash Trap Cleaning	Rupiah	0	SIM	-
13	CWCL1	Capability of Water to Carry the Litter in Irrigation Channel Section 1	kg/hour	-	P, C	-
14	CWCL2	Capability of Water to Carry the Litter in Irrigation Channel Section 2	kg/hour	-	P, C	-
15	CWCL3	Capability of Water to Carry the Litter in Irrigation Channel Section 3	kg/hour	-	P, C	-
16	CWCLD	Capability of Water to Carry the Litter in Drainage Channel	kg/hour	-	P, C	-
17	CWLI1	Citizen Waterway-Littering Intention in Area 1	%	78%	P, C	-
18	CWLI2	Citizen Waterway-Littering Intention in Area 2	%	78%	P, C	-
19	CWLI3	Citizen Waterway-Littering Intention in Area 3	%	78%	P, C	-
20	D	Discrepancy	m^2	-	C	IF
21	ECUC	Emergency Cleaning Unit Cost	Rupiah/kg	1,721	A	-
22	ILLL	Inlet Lake Litter Load	kg/(hour.m^3)	-	C	-
23	LD	Litter Density	kg/m^3	990	P, C	-
24	LPS	Left Personnel because of Shift	person/hour	-	A	PULSE
25	LTT	Litter at The Trash Trap	kg	0	SIM	-
26	MP	Minimum Personnel	person/hour	2	A	-
27	MWCS1	Municipal Waste Collection Services in Area 1	%	91.82	S	-
28	MWCS2	Municipal Waste Collection Services in Area 2	%	91.82	S	-
29	MWCS3	Municipal Waste Collection Services in Area 3	%	91.82	S	-
30	MWG1	Municipal Waste Generation of Area 1	kg/person/day	0.51	S	-
31	MWG2	Municipal Waste Generation of Area 2	kg/person/day	0.51	S	-
32	MWG3	Municipal Waste Generation of Area 3	kg/person/day	0.51	S	-
33	OWG	Opened Water Gate	-	-	A	GRAPH
34	P1	Population of Area 1	person	59,350	SIM	-
35	P2	Population of Area 2	person	46,234	SIM	-
36	P3	Population of Area 3	person	19,427	SIM	-
37	PAAL	Personnel Addition based on Amount of Litter	person/hour	-	A	IF
38	PCTC	Personnel Capability for Trash Trap Cleaning	kg/person/hour	150	A	-
39	PERS	Personnel	person	0	SIM	-
40	PG1	Population Growth in Area 1	person/hour	-	C	-
41	PG2	Population Growth in Area 2	person/hour	-	C	-
42	PG3	Population Growth in Area 3	person/hour	-	C	-
43	PGR1	Population Growth Rate of Area 1	%/hour	0.000403	S	-
44	PGR2	Population Growth Rate of Area 2	%/hour	0.000403	S	-
45	PGR3	Population Growth Rate of Area 3	%/hour	0.000403	S	-
46	PLCW1	Percentage of Litter Carried by Water in Irrigation Channel Section 1	%	-	A	IF

*Notes: A=Assumption; AV=Adjusted Variable Data; C=Calculation Based Data; P=Primary Data; S=Secondary Data; SIM=Simulation Based Data

Table 1. List of the variables (continued)

No.	Abbr. of Variable	Variable Name	Unit	Initial Value	Data Source*	Function Type
47	PLCW2	Percentage of Litter Carried by Water in Irrigation Channel Section 2	%	-	A	IF
48	PLCW3	Percentage of Litter Carried by Water in Irrigation Channel Section 3	%	-	A	IF
49	PLCWD	Percentage of Litter Carried by Water in Drainage Channel	%	-	A	IF
50	PRAL	Personnel Reduction based on Amount of Litter	person/hour	-	A	IF
51	PS	Personnel Shift	-	-	P	IF
52	PW	Personnel Wage per Hour	Rupiah/hour	-	C	-
53	PWUC	Personnel Wage Unit Cost	Rupiah/person/hour	18,000	P	-
54	RDC	Rainfall in Depok City	m	-	S	GRAPH
55	TC	Transport Cost	Rupiah/hour	-	C	-
56	TLC1L	Transported Litter Collected in Sub-District 1 to Landfill	kg	0	SIM	-
57	TLC2L	Transported Litter Collected in Sub-District 2 to Landfill	kg	0	SIM	-
58	TLL	Transported Litter to Landfill per Hour	kg/hour	-	A	PULSE
59	TLTS	Thickness of Litter on Trash Trap Screen	m	0	A	-
60	TMA	Traditional Market Area	m^2	113,553	P	-
61	TT	Total Trips	trip/hour	-	C	IF
62	TTC	Trash Trap Capacity	kg	416	P, C	-
63	TTLL	Total Transported Litter to Landfill	kg	0	SIM	-
64	TTTS	Total Trash Trap Screen	m^2	21	S	-
65	TUC	Transport Unit Cost	Rupiah/trip	72,000	P	-
66	ULC	Urban Lake Cleanness	-	-	C	-
67	ULL	Urban Lake Litter	kg	0	SIM	-
68	WCR1	Waterway Cleaning Rate in Sub-District 1	kg/hour	-	A	-
69	WCR2	Waterway Cleaning Rate in Sub-District 2	kg/hour	-	A	-
70	WF1	Waterway Flow in Irrigation Channel Section 1	m^3/hour	-	C	-
71	WF2	Waterway Flow in Irrigation Channel Section 2	m^3/hour	-	C	-
72	WF3	Waterway Flow in Irrigation Channel Section 3	m^3/hour	-	C	-
73	WFD	Waterway Flow in Drainage Channel	m^3/hour	-	C	-
74	WFP	Waterway Flow Percentage	%	-	C	IF
75	WFU	Waterway Flow from Upstream	m^3/s	-	S	GRAPH
76	WL1	Waterway Litter in Irrigation Channel Section 1	kg	100	SIM	-
77	WL2	Waterway Litter in Irrigation Channel Section 2	kg	100	SIM	-
78	WL3	Waterway Litter in Irrigation Channel Section 3	kg	100	SIM	-
79	WLB1	Waterway Litter at Bar Screen in Sub-District 1	kg	100	SIM	-
80	WLB2	Waterway Litter at Bar Screen in Sub-District 2	kg	100	SIM	-
81	WLCUL	Maximum Weight of Litter Abundance Contained by The Urban Lake	kg	8,502,786	A	-
82	WLEB1	Waterway Litter Entering the Bar Screen at Sub-District 1 per Hour	kg/hour	-	C	IF
83	WLEB2	Waterway Litter Entering the Bar Screen at Sub-District 2 per Hour	kg/hour	-	C	IF
84	WLET	Waterway Litter Entering the Trash Trap	kg/hour	-	C, AV	IF
85	WLG1	Waterway Litter Generation Rate in Area 1	kg/hour	-	C	-
86	WLG2	Waterway Litter Generation Rate in Area 2	kg/hour	-	C	-
87	WLG3	Waterway Litter Generation Rate in Area 3	kg/hour	-	C	-
88	WLGP1	Waterway Litter Generation Patten in Area 1	%/hour	-	A	GRAPH
89	WLGP2	Waterway Litter Generation Patten in Area 2	%/hour	-	A	GRAPH
90	WLGP3	Waterway Litter Generation Patten in Area 3	%/hour	-	A	GRAPH
91	WLGPT1	Waterway Litter Generation Potential from Area1	kg	-	C	-
92	WLGPT2	Waterway Litter Generation Potential from Area 2	kg	-	C	-
93	WLGPT3	Waterway Litter Generation Potential from Area 3	kg	-	C	-
94	WLGPTTM	Waterway Litter Generation Potential from Traditional Market	kg	516	A	-
95	WLGTM	Waterway Litter Generation Rate in Traditional Market	kg/hour	-	C	IF
96	WLP	Waterway Flow Pattern	%	-	A	GRAPH
97	WLPB2	Waterway Litter Passed through Bar Screen into Irrigation Channel Section 2 per Hour	kg/hour	-	C	IF
98	WLPB3	Waterway Litter Passed through Bar Screen into Irrigation Channel Section 3 per Hour	kg/hour	-	C	IF
99	WLTC	Waste Loading Truck Capacity	kg/trip	500	A	-
100	WLU	Waterway Litter from Upstream per Hour	kg/hour	150	A	-

*Notes: A=Assumption; AV=Adjusted Variable Data; C=Calculation Based Data; P=Primary Data; S=Secondary Data; SIM=Simulation Based Data

The second adjustment is the determination of the rigorous formula for the relationships among variables. For example, this study conducted power-type regression analysis to express the "capability of water to carry a portion of litter" (CWCL) away in a particular amount of flow (see Figure 6). The CWCL plays an important role in determining the amount of waterway litter in each section. In addition to linear equations, the developed SFD utilizes other useful functions of the Powersim software, i.e., If Function, Pulse Function, and Graph Function. The final adjustment formulas and functions are determined as listed on Table 2.

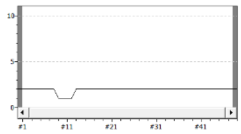
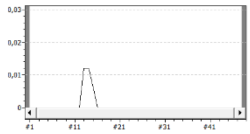
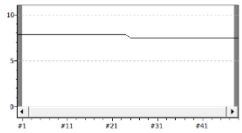
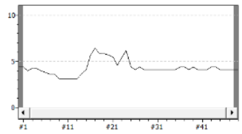
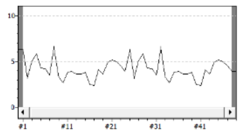
Table 2. List of SFD formulas and functions

No	Formulas and Functions
1	$ASCL = \frac{LTT}{LD/TLTS}$
2	$CEC = ECUC \times ULL$
3	$CWCL_{1,2,3,D} = (2 \times 10^{-11}) \times (WF_{1,2,3,D})^{4,012}$
4	$ILLL = \frac{WLET}{WF_3}$
5	$PG_{1,2,3} = PGR_{1,2,3} \times P_{1,2,3}$
6	$PW = PWUC \times PERS$
7	$TC = TT \times TUC$
8	$ULC = 1 - \left(\frac{ULL}{WLCUL}\right)$
9	$WF_1 = WFU \times WFP \times WLP$
10	$WF_2 = WF_D + WF_1$
11	$WF_3 = WF_2$
12	$WF_D = RDC \times TMA$
13	$WLEB_{1,2} = WL_{1,2} \times PLCW_{1,2}$
14	$WLET = WL_3 \times PLCW_3$
15	$WLPB_{2,3} = WLEB_{1,2} \times (100\% - BSE_{1,2})$
16	$WLG_{1,2,3} = WLGPT_{1,2,3} \times WLGP_{1,2,3} \times CFP_{1,2,3}$
17	$WLGPT_{1,2,3} = P_{1,2,3} \times MWG_{1,2,3} \times (1 - MWCS_{1,2,3}) \times (1 - CWLI_{1,2,3})$
18	$WLGTM = WLGPTTM \times PLCW_D$
	IF Functions
19	$ALPT =$ → Condition : $D > 0\ m^2$ → On True : $0\ kg/hour$ → On False : $WLET + LTT - TTC$
20	$BSE_{1,2} =$ IF — THEN, $CWCL_{1,2} > 300\ kg/hour$ — $BSE_{1,2} = 40\%$ $CWCL_{1,2}$: $100\ kg/hour - 300\ kg/hour$ — $BSE_{1,2} = 50\%$ $CWCL_{1,2} < 100\ kg/hour$ — $BSE_{1,2} = 70\%$
21	$CLTC =$ → Condition : $(WLET + LTT) \geq PCTC \times PERS$ → On True : $PCTC \times PERS$ → On False : $WLET + LTT$
22	$D =$ → Condition : $TTTS - ASCL > 0\ m^2$ → On True : $TTTS - ASCL$ → On False : $0\ m^2$

Table 2. List of SFD formulas and functions (continued)

No	Formulas and Functions
23	$PAAL$= → Condition : $ALPT > 0\ kg/hour$ → On True : $1\ person/hour \times PS$ → On False : $0\ person/hour$
24	$PLCW_{1,2,3}$ = IF — THEN, $CWCL_{1,2,3} > 10\ kg/hour$ — $PLCW_{1,2,3} = 100\%$ $CWCL_{1,2,3}$: $5\ kg/hour - 10\ kg/hour$ — $PLCW_{1,2,3} = 10\%$ $CWCL_{1,2,3} < 5\ kg/hour$ — $PLCW_{1,2,3} = 3\%$
25	$PLCW_D$ = IF — THEN, $CWCL_D > 10\ kg/hour$ — $PLCW_D = 100\%$ $CWCL_D$: $5\ kg/hour - 10\ kg/hour$ — $PLCW_D = 10\%$ $CWCL_D$: $0\ kg/hour - 5\ kg/hour$ — $PLCW_D = 3\%$ $CWCL_D = 0\ kg/hour$ — $PLCW_D = 0\%$
26	$PRAL$ = → Condition : $ALPT = 0\ kg/hour$ and $(PERS - MP) > 0\ person/hour$ → On True : $(PERS - MP) \times PS$ → On False : $0\ person/hour$
27	PS= → Condition : TIMECYCLE (STARTTIME; 24 HOUR; 8 HOUR) = TRUE → Start : $STARTTIME$ → Interval : 24 hour → Duration : 8 hour → On True : 1 → On False : 0
28	TT = IF — THEN, $\left(\frac{TLL}{WLTC}\right) = 0\ trip/hour$ — $TT = 0\ trip/hour$ $\left(\frac{TLL}{WLTC}\right)$: $0\ trip/hour - 1\ trip/hour$ — $TT = 1\ trip/hour$ $\left(\frac{TLL}{WLTC}\right)$: $1\ trip/hour - 2\ trip/hour$ — $TT = 2\ trip/hour$ $\left(\frac{TLL}{WLTC}\right)$: $2\ trip/hour - 3\ trip/hour$ — $TT = 3\ trip/hour$ $\left(\frac{TLL}{WLTC}\right) \geq 3\ trip/hour$ — $TT = 4\ trip/hour$
29	WFP = IF — THEN, $OWG = 0$ — $WFP = 0\ \%$ $OWG = 0.5$ — $WFP = 25\ \%$ $OWG = 1.0$ — $WFP = 50\ \%$ $OWG = 1.5$ — $WFP = 75\ \%$ $OWG = 2.0$ — $WFP = 100\ \%$
	Pulse Functions
30	APS= → Volume : $2\ person$ → Start : $STARTTIME$ → Interval : $24\ hour$
31	LPS = → Volume : $2\ person$ → Start : 8^{th} hour → Interval : $24\ hour$
32	TLL= → Volume : CLT → Start : 5^{th} hour → Interval : $24\ hour$
33	WCR_1 = → Volume : WLB_1 → Start : 96^{th} hour → Interval : $48\ hour$

Table 2. List of SFD formulas and functions (continued)

No	**Formulas and Functions**
34	WCR_2 = →Volume : WLB_2 → Start : 96th hour → Interval : 72 *hour*
	Graph Functions
35	OWG GRAPH(TIME;STARTTIME;1<<hour>>;{2;2;2;2;2;2;2;2;1;1;1;1;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2//Min:0;Max:11//}) 
36	RDC GRAPH(TIME;STARTTIME;1<<hour>>;{0;0;0;0;0;0;0;0;0;0;0;0;0,012;0,012;0,0062;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0 //Min:0;Max:11//} <<m/hour>>) 
37	WFU GRAPH(TIME;STARTTIME;1<<hour>>;{7,876;7,483;7,483//Min:0; Max:11//}<<m^3/s>>) 
38	WLP GRAPH(TIME;STARTTIME;1<<hour>>;{4,4;4;4,3;4,2;4;3,8;3,6;3,6;3,1;3,1;3,1;3,1;3,1;3,7;4,1;5,7;6,4;5,9;5,8;5,7;5,5;4,6;5,4;6,2;4,4;4,1;4,4;4,1;4,1;4,1;4,1;4,1;4,1;4,1;4,1;4,4;4,4;4,1;4,4;4,1;4,1;4,1;4,4;4,4;4,1;4,1;4,1;4,1//Min:0;Max:11//} <<%>>) 
39	$WLGP_{1,2,3}$ GRAPH(TIME;STARTTIME;1<<hour>>;{6,3;3,2;5,1;5,8;4,3;4,2;3,5;6,5;3,3;2,7;3,8;3,9;3,6;3,6;3,8;2,5;2,4;4,1;3,6;4,9;5,2;5;4,5;3,9;6,2;3,2;5,1;5,8;4,3;4,2;3,5;6,5;3,3;2,7;3,8;3,9;3,6;3,6;3,8;2,5;2,4;4,1;3,6;4,9;5,2;5;4,5;3,9//Min:0;Max:11//}<<%/hour>>) 

3.4 Process of Simulation and Model Validation

As the process proceeds further, the collected data were inputted into the model. The initial values of the simulation are presented in Table 1. Given the complexity of real-world problems and the limitation of the model, several assumptions need to be highlighted.

a. Most of the litter captured in the trash trap is household-type and vegetation-type wastes (e.g., small branches, rotten fruits, and leaves). Thus, during model development, large-sized litter (e.g., defective mattress and large trunk) is not considered.
b. Most of the litter that passed through the trash trap is assumed to have ended up in the lake entirely.
c. All the collected litter was assumed to be transported to the landfill.
d. Although the socioeconomic levels of citizens differ, in this study, the waste generation per capita is assumed to be the same for every citizen.
e. Given the high frequency of cleaning activities in the UI Campus, litter generation from the surrounding areas of Kenanga Lake is not considered.
f. Citizen's littering intention quantified from the TPB-based questionnaire survey is assumed to be the same as citizen's littering behavior.

g. The trash trap repairing cost is not considered in the model.
h. The channel-cleaning activity is assumed to be held regularly by the Municipal Resource Water Officer with the same frequency as the field observation.
i. Two gates open is assumed to be the default position of the water gate.
j. The WLG pattern is assumed to follow the sampling results.
k. The rainfall, water gate adjustment, and channel discharge patterns follow the official secondary data collected from the literature review and the officer informal interview.

As the final step, the validity test was conducted. The sampling data shown in Figure 3 were used as the reference data. The comparison of the reference data and the final results shows how the model successfully imitates real-world problems (Figure 5). Similarly, the AME value, which is equal to 0.1079, confirmed the validity of the model. In other words, the confidence level of the model is 89.21%.

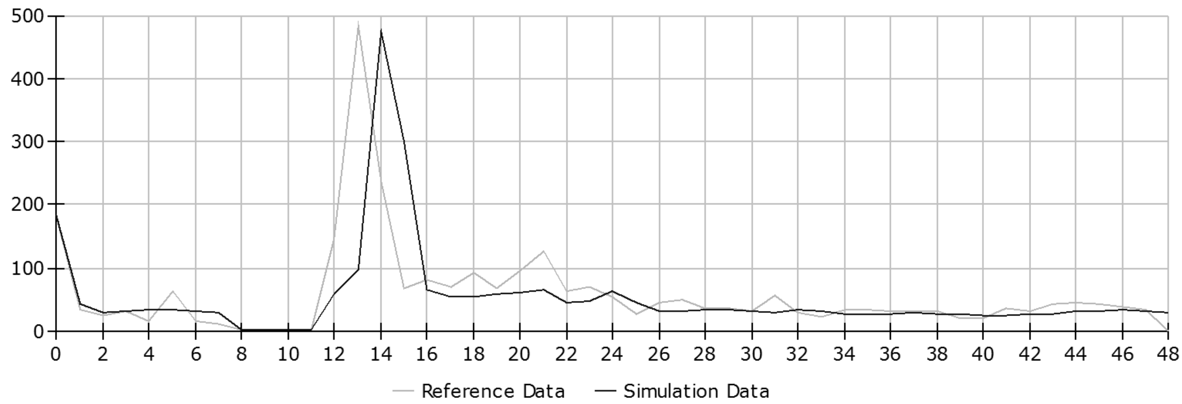


Figure 7. Comparison of the reference data and the final simulation results

Notably, in Figure 7, the results appear to have an hour delay compared with the reference data. This delay is related to the 1 h time difference between data collection. Hence, the reference data have only a 1 h sampling resolution, so that any loading that occurs in between 1 h and the next hour will be accounted for in the next hour and will appear as the 1 h delay. However, the amount of litter tends to correspond to the reference data. In terms of trash trap management, the capability to predict the amount of litter is considered more important than the capability to predict the occurrences that were off by an hour. Thus, in a nutshell, this model has given us a satisfying result for explaining litter abundance in the trash trap quantitatively.

4. Conclusion

This study analyses the quantification of the ULL abundance problem on the basis of scientific knowledge coupled with the appropriate simulation of the complex interaction between the society and the environment using system dynamics modeling approach. As highlighted in previous studies (Ding et al., 2016; Gou et al., 2016), this study also presented how the TPB-based questionnaire survey method can be combined with the system dynamics modeling method to capture the human sociocultural aspect of the system quantitatively. Moreover, the developed model has derived the mathematical formulas and functions required for the decision-maker and environmental analyst/modeler to manage litter abundance in the trash trap on the inlet of Kenanga Lake. The model has been validated, with the AME value of 0.1079 or confidence level of 89.21%. Although the lessons learned in this work are unique to the Kenanga Lake case study, the applied methods can be used to solve the typical litter abundance problem in other urban lakes, particularly in developing countries. Furthermore, concerning future research, this quantitative dynamic model provides useful equations for forecasting litter abundance in an urban lake and evaluating various alternative solutions to this problem in terms of establishing a sustainable waste management model that can prevent the litter abundance phenomenon in the urban lake environment.

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