A dynamic model for managing urban waste in Bogor City, West Java Province

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Abstract. Urban waste is threatening the natural environment and sustainability of Bogor City, West Java Province, Indonesia. To overcome this issue, the government have tried several short-term approaches and implemented several long-term policies as a countermeasure. However, the large amount of daily waste and its unpredictable pattern have made trash management difficult. As a continuation in terms of looking further for sustainable solutions to this problem, this study aimed to establish its dynamic model, which is expressed as a system approach study of the interrelations among the related elements. The study method used consisted of a simulation model using a dynamic system. The system model was created with the help of the Powersim Studio 10 Express software. Causal Loops Diagram and Stock-Flow Diagram are used to study the system. A cause circumference diagram is created by determining the significant variables in the system and connecting them depending on the interaction. The simulation result can be seen as table and line graph. A validation system needs to be done on the system model. This research is expected to be useful for various parties related to urban waste management.

1. Introduction

Waste is a problem faced most of the urban areas in Indonesia. Urban waste management no good other than can cause the city being dirty and rundown also causes floods, environmental pollution and disease [1]. Waste is the residual of people's daily activities and/or natural processes in solid form. According to the Republic of Indonesia Law Number 18 of 2008 about waste management, waste is divided to 3 main classifications which are household waste, household-like waste, and specific waste. Household waste is waste originating from daily activities in the household, excluding feces and specific waste [2]. In fact, almost every country has their own system to classify their own waste in order to manage effectively and efficiently. For instance, Law on Waste (LoW) in Armenia is the main legal instrument governing the waste management sector. Both industrial waste and household waste are regarded as waste. Besides that, there are also lists of waste that are very specific which involves hazardous waste, forbidden hazardous waste, hazardous waste classes, specific indicators of the generation of main types of industrial and household waste, and the waste generated within different technological processes [3].

Same as another city in Indonesia, Bogor City also faces many challenges in its waste management. Based on data from the 2015 to 2020 Bogor City Sanitation Strategy (SSK), the total waste produced per day is 1,756 m$^3$ with the average percentage of waste transported to the landfill and 3R is around 70% [4]. This does not indicate an increase in the percentage of services compared to 2009 when the
number of households that could be served in transporting waste by Public Works and Spatial Planning Agency of Bogor City was still 70% [5].

The process of urban waste management can be complex and involves many stakeholders. Hence, a method which may help conceptually analyze and explore this complex system is necessary. Based on a case study in Bogor City, this paper raises the following questions; 1) what are the important variables in the current urban waste management? 2) what possible solution and strategy can be taken by stakeholders for a better urban waste management?

This research studied the impacts and changes resulted from the current management practices on the urban waste in Bogor City, West Java Province, Indonesia from 2015 to 2020. This paper presents the methods, results and discussion, as well as conclusions.

2. Materials and methods

2.1. Materials
For the purpose of modelling, several types of data are necessary. Data related to the average amount of household organic waste output were acquired through observations on several households in Bogor City for 43 days from July to August. Meanwhile, the projected population data of 2015 to 2020 and the data on the average number of households in Bogor were obtained from references from the Bogor City government. Data regarding the capacity of waste landfill and the daily transported urban waste were given by the Environment Agency of Bogor City.

2.2. Area of study
Geographically Bogor City is located between 106° 48’ east longitude and 6° 26’ south latitude. Geographic position of Bogor City in the middle of Bogor District and its very close location to the State Capital of DKI Jakarta is a strategic potential for development and economic growth and services, the center of national activities for industry, trade, transportation, communication, and tourism. The area of Bogor City in the form of a land area of 11,850 ha is divided into 6 Sub-districts. The land area of each Sub-district is Bogor Selatan Sub-district (30.81 km²), Bogor Timur Sub-district (10.15 km²), Bogor Utara Sub-district (17.72 km²), Bogor Tengah Sub-district (8.13 km²), Bogor Barat Sub-district (32.85 km²) and Tanah Sareal Sub-district (18.84 km²).

2.3. System dynamics
A system is called dynamic if its current output depends on past input, if current output depends only on current input, the system is called static. Dynamic systems are represented by differential equations [6]. Dynamic system model is the simplified real phenomena using equation to solve any problem. It can be implemented in various cases such as mechanical, electrical, electronic, electromechanical, fluid and thermal systems. According to other source, dynamic system is a system where the current output variables depend on initial condition of the system and/or the previous input variables. The dynamic variables of the system vary with time [7]. A system dynamics analysis usually consists of concept of development phase, modelling phase, simulation model phase, and validation of simulation results phase.

3. Results and discussion

3.1. Causes and effects of urban waste problems
A lot of aspects can cause urban waste problem. Booming economy, increasing population levels, rapid urbanization and also rise in community living standards have greatly accelerated the urban waste, especially solid waste generation rate in developing countries [8]. For example, in India as one of developing country, urbanization can directly contribute to waste generation, and unscientific waste handling causes health hazards and urban environment degradation [9]. Not only urbanization, but also problems associated with SWM, mixed waste, rapidly increasing population [10] and waste
respectively, lack of planning, lack of resources, oil equipment and technology, and societal apathy make this condition worse.

One of the serious effects from this problem is health risk. Another study was conducted in 2016 in the City of Kolkata, India. The study result clearly indicates that failure of the existing facilities, inadequate collection space facility, high amount of waste generation, and the presence of open-dump sites which generates serious health risks [11]. Another serious effect is air pollution. Air pollution is a major threat to human health as well as environment, particularly pollution from unknown disposal sites which creates danger health problems to the surroundings habitants [12]. Particles that are inhaled continuously consist of dust, fume, mist and smoke causing lung damage and respiratory problems [13]. At a high level, all air pollutants will be bad for humans and the environment. The accumulation of pollutants in the human body through inhalation is an important route [14]. The results of this study reveal health risks. Dust released from various sources can produce a spectrum of diseases ranging from the common cold to deadly diseases such as cancer [15].

3.2. Urban waste in Bogor city in the period of 2015 to 2020
Solid waste management problems in Bogor City arise from various aspects, namely technical operational, financial, management, and socio-cultural aspects. For the purpose of making model simulations, the average amount of organic waste output data is multiplied by the household. From 2015 until 2020, the number of population and households in Bogor city is increasing with time [16]. The number of populations, households, organic urban waste output of Bogor City can be seen on table 1.

| Year | Population | Number of Households | Organic Urban Waste Output (kg) | Percentage Change of Organic Waste Output (%) |
|------|------------|----------------------|---------------------------------|---------------------------------------------|
| 2015 | 1,047,922  | 258,288              | 448,377                         | 1.67                                        |
| 2016 | 1,064,687  | 261,898              | 455,551                         | 1.60                                        |
| 2017 | 1,081,009  | 264,305              | 462,534                         | 1.53                                        |
| 2018 | 1,096,828  | 268,173              | 469,303                         | 1.46                                        |
| 2019 | 1,112,081  | 271,902              | 475,829                         | 1.39                                        |
| 2020 | 1,126,927* | 275,532              | 482,181                         | 1.33                                        |

*projected number

Based on a conducted research, there are five main factors that influence residential waste management systems in Bogor City, namely infrastructure, community behavior, waste processing technology, funds, and stakeholder participation [17]. A review of the prediction model for waste generation shows that the overall household size, household income level, and education level are the most common attributes affecting waste generation [18]. There was a study about future prediction of waste production and its correlation with related total customer expenditure or RTCE. Correlation allows very accurate predictions of the total Municipal Solid Waste or MSW count [19].

3.3. Dynamic system model

3.3.1. Concept development phase. Since a model has to be a simplification of reality, it is important to recognize that no system can be modelled precisely and that every competent system designer needs to have a procedure for constructing a variety of system models of varying complexity so as to find the simplest model capable of answering questions about the system under study [20]. Concept Development Phase or subcomponent is one of the project phases terms which generally used and indicated the type of work done in that phase [21]. This phase is important in order to evaluate the
feasibility of alternatives and to define the project scope, including the system, important activities, and results [22].

The concept of causal loop diagram or CLD was first discussed in the sixties by Jay Forester in 1961 and was further elaborated by researchers such as Rosnay in 1979, Richardson and Puch in 1981, Senge in 1990 [23] and Sterman in 2000 [24]. The function of CLD is to map the structure and feedback of a system to understand its feedback mechanism. CLD is used to understand how a specific behavior has manifested itself in a system so as to develop strategies for working with, or against, the other behavior [24].

With the dependence on conventional waste management, especially the limited waste landfill, citizens do not receive adequate education and training on the importance of reducing and utilizing household organic waste as a sustainable lifestyle. Included in this sustainable lifestyle are separating waste types, composting organic waste, urban gardening, and 3R (Reduce, Reuse, Recycle). Based on figure 1, every day the burden of urban waste always increases, as a result of dependence on conventional waste management and the increasing ignorance of the community and the minimization of waste through a sustainable lifestyle.

**Figure 1.** Causal Loop Diagram (CLD) of the model for managing urban waste in Bogor City

The CLD shown in figure 1 has all the basic elements of a CLD. There are 4 variables, 3 loops, and 6 links between the variables. This model uses the assumptions that the sources of organic waste other than the household waste from Bogor City are ignored.

3.3.2. **Modelling phase.** Modelling is the process of applying the appropriate fundamental physical laws in order to derive mathematical equations that adequately describe the physics of engineering system [19]. Example of case studies in dynamic model applied to environment is a modeling approach and developed a model called the Quantitative Water Air Sediment Interaction (QWASI) model in which rivers are treated as a series of connected lakes or ranges, each of which is considered well mixed. [25]. Well-connected and mixed sequences have been applied as a simplification for the diffusion-advection model. For example, CSTRs (Completely Stirred Tank Reactors) are systems that can be used to model natural water bodies [26]. This simple conceptual approach, also known as the mobile segment model, or the cell-in-sequence model, has been successfully applied to modelling [27-31].
The brief explanation of the flow chart that can be seen in figure 2 is that urban waste load increases due to the increase of urban waste rate and decreases due to the implementation sustainable lifestyle and short-term waste processing (landfill dependent). Furthermore, urban waste rate is influenced by the initial urban waste. Meanwhile, sustainable lifestyle is affected by the citizen ignorance and sustainable lifestyle factor. The short-term waste processing rate is influenced by waste processing factor and the waste processing efficiency. To complete the SFD and to prepare for the simulation model phase, the Powersim model equation was inputted. As for the Powersim model equation can be seen in table 2.

**Table 2. Powersim model equation**

| Variable                          | Equation                                                                 |
|----------------------------------|--------------------------------------------------------------------------|
| init Urban_Waste_Load =          | 448.37                                                                   |
| flow Urban_Waste_Load            | +dt*Urban_Waste_Rate-dt*Sustainable_Lifestyle-dt*Waste_Processing_Rate   |
| aux Urban_Waste_Rate             | DELAYMTR(Sustainable_Lifestyle;5;1;0)+Urban_Waste                       |
| aux Waste_Processing_Rate        | Waste_Processing_Efficency*Waste_Processing_Factor                       |
| aux Sustainable_Lifestyle        | Citizen_Ignorance*Sustainable_Lifestyle_Factor                           |
| aux Waste_Processing_Factor      | GRAPHCURVE(Urban_Waste_Load;100;10;{10;11;12;13;14;15;16;17;18;19;20}) |
| aux Citizen_Ignorance           | GRAPHCURVE(Waste_Processing_Rate;100;10;{200;180;160;140;120;100;80;60;40;20;10}) |
| const Waste_Processing_Efficency | 10%                                                                      |
| const Sustainable_Lifestyle_Factor | 10%                                                                    |
| const Urban_Waste                | 448.37                                                                   |

3.3.3. Validation phase. Validation is a process to test the models to establish the confidence which can be placed in them [33]. Verification is usually carried out by the model author and refers to a computer program. In other words, it is the process of checking whether a program is free from formal, ‘technical’ errors, while validation is a more complex issue - it results in determining whether and how well the model represents reality [34]. It is important to select a validation method that is...
adequate for the purposes of the model. Depending on the reference point for the system-generated data or modelling objectives, various authors recommend descriptive, predictive or structural validity testing [35]. Note that it is not necessary to test all three conditions. Therefore, if, for example, the aim of the model is to find out why productivity in a firm has fallen, then there is no need to check whether the data provided by the model will match the value, the firm will generate in the future [36].

\[
AME = \frac{\sum_{t=1}^{T} |Ps - \sum_{t=1}^{T} Pi|}{\sum_{t=1}^{T} Pi}
\] (1)

Performance validation can be done with a consistency test procedure, namely by performing statistical tests to see the deviation between the simulation output and the actual data with AME. AME (Absolute Mean Error) is the deviation between the simulation average value and the actual value. On Equation 1, T stands for time, Ps as the simulation result value, and Pi as the factual value. As for the accepted deviation limit is < 5%. As seen in Table 3, after statistical calculations, the AME result is obtained. Because the AME value is below 5%, the mean data is accepted.

| Table 3. Table of simulation model validation results |
| --- | --- | --- |
| Year | Actual Value | Simulation Value |
| 2015 | 448.37 | 448.37 |
| 2016 | 455.55 | 456.19 |
| 2017 | 462.53 | 462.29 |
| 2018 | 469.3 | 467 |
| 2019 | 475.82 | 470.6 |
| 2020 | 482.18 | 473.32 |
| Mean | 465.62 | 462.96 |
| Standard Deviation | 12.65 | 9.39 |
| AME | 0.147 | |

Note: AME > 5% so mean data is valid

3.3.4. Simulation phase. Simulation is a process to get the system's dynamic response by solving modelling equations that govern numerically which can be carried out by digital computers and simulator software [7]. The basic idea is that the model takes a number of simulation steps along the time axis. At the end of each step, several system variables, which indicate the system status, are updated to represent the consequences of the previous simulation step [32]. The system dynamics model consists of dynamic simulation models that explicitly consider information feedback that governs interactions in the system. This capability is very useful in analyzing and recommending policy decisions [33].

| Table 4. Simulation result of the model for managing urban waste in Bogor City |
| --- | --- | --- | --- | --- | --- | --- |
| Unit of time | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
| Waste_Processing_Factor | 44.84 | 85.32 | 126.25 | 167.47 | 208.83 | 250.22 |
| Sustainable_Lifestyle (%) | 310.33 | 3,829.38 | 3,747.50 | 3,665.06 | 3,582.34 | 3,499.57 |
| Citizen_Ignorance | 391.03 | 382.94 | 374.75 | 366.51 | 358.23 | 349.96 |
| Urban_Waste_Rate | 448.37 | 456.19 | 462.29 | 467.00 | 470.60 | 473.32 |
| Waste_Processing_Rate (%) | 338.37 | 853.15 | 1,262.52 | 1,674.70 | 2,088.30 | 2,502.20 |

It can be seen in Table 4, in the management of urban waste, several aspects of the system behavior are the rate of urban waste, the implementation of waste processing (waste processing factor and waste processing rate), sustainable lifestyle, and citizen ignorance.
Figure 3. Timeline graph of the simulation of the model for managing urban waste in Bogor City

Based on the simulation that has been done, it appears in figure 3 that the urban waste rate, is increasing with time. The sustainable lifestyle is decreasing with time. The citizen ignorance is decreasing over time. Lastly, the rate of waste processing rate is increasing with time.

Given that one of the main roots causes of increasing urban waste is the increase in population. So short-term waste processing (landfill dependent) policy can only be a temporary solution to the symptoms of the main problem. In this case, although it takes a longer time, the implementation of sustainable lifestyle (through education, training, and policy) can be said to be the right solution to address the root causes of the increase in urban waste in Bogor City. This interaction between variables is an enactment sign of the standard load transfer model. The standard load transfer model highlights the general tendency to reduce or eliminate symptoms of the problem rather than solving the root cause of the actual problem. This standard model also shows the ease of being addicted to solving the symptoms of a problem and the diminishing desire or ability to do fundamental problem solving.

4. Conclusions
Based on the results and discussions, the waste management in Bogor City can be analyzed and explored using a system dynamics model. The model itself shows that valid behaviors with several aspects of the system behavior are the rate of urban waste, the implementation of waste processing (waste processing factor and waste processing rate), sustainable lifestyle, and citizen ignorance. From the result of dynamic model simulation of 2015 to 2020, the urban waste rate is increasing with time while the sustainable lifestyle is decreasing with time. The result of the model simulation is a sign of the standard load transfer model which highlights the existence and influence of root problem in a system. This paper discusses how sustainable lifestyle implementation can be used to address the urban waste problem, and also to reduce the impact of future environmental problems in Bogor City. Although this paper uses various and sometimes complex methods or techniques, the main reason for this research is not the development of a complex model, but an attempt to utilize a dynamic systems model to gain insights and approaches related to addressing urban waste, particularly those caused by the increase of badly managed organic waste from urban areas. This discourse is essential for explaining and distributing findings, motivating action, and stimulating future research on this issue.

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