

The Dynamic Concept for Waste Pile Prediction in Bogor City

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Abstract

Areas with high population density have the potential to degrade environmental quality. This is because an increase in population leads to a higher amount of waste accumulation. Bogor City is known for its dense population. In 2018, the Galuga Bogor Landfill received 650 tons of waste per day. With the population growing each year, accompanied by an increase in waste generation, there is a need for effective and sustainable waste management efforts. However, several obstacles are often encountered in waste management, such as the lack of understanding among the population. If left unaddressed, this situation can have serious implications for the environment, leading to natural disasters and public health issues. The aim of this research is to predict the amount of waste accumulation in Bogor City, with the hope of assisting the government and the community in enhancing waste management practices. The research methodology involves the analysis of Causal Loop Diagram (CLD) and Stock Flow Diagram (SFD), which will be simulated using Time Graph and Time Table, and processed through the Powersim Studio 10 Express application. Simulation results indicate that waste accumulation in Bogor City is expected to continue increasing from 2018 to 2025. The difference in waste accumulation between 2018 and 2025 is estimated to be 87,783 tons, with the Bogor City Landfill projected to receive 890 tons of waste per day by 2025.

Keywords: Waste Pile, Simulation Model, Causal Loop Diagram, Stock Flow Diagram

INTRODUCTION

Indonesia ranks fourth as the country with the largest population in the world (Ministry of Foreign Affairs, 2023). Based on population data from the Directorate General of Population and Civil Registration (Dukcapil) of the Ministry of Home Affairs, Indonesia's population reached 280.73 million in 2023, with a population density of 153.2 people/km². In contrast, in 2022, Indonesia's population was 275.5 million (Central Statistics Agency, 2023). These data indicate that Indonesia's population increased by 1.13% in 2023 compared to 2022.

High population density is one of the factors that potentially increases the risk of disasters in a region (City of Surakarta Regional Disaster Management Agency, 2022). Areas with high population density have the potential to degrade environmental quality. With the increasing population, there is a corresponding increase in waste accumulation (Mustikasari, 2021: 6). According to Rizal (in Fitriansyah, et al., 2020: 73), increasing waste accumulation can lead to a decline in environmental quality and public health. In such conditions, if waste piles are left unattended for a long period without proper waste management efforts, it can potentially lead to disasters.

According to the Republic of Indonesia Law Number 18 of 2008 concerning Waste Management, waste is the residue of human daily activities and/or natural processes that are in solid form. Indonesia is the second-largest waste producer in the world (Yogyakarta Special Region Health Office, 2023). Based on data from 2023, Indonesia had a waste accumulation of 19,071,915 tons/year, with 67.49% of waste managed annually and 32.51% of waste unmanaged annually. The majority of this waste is plastic waste (Ministry of Environment and Forestry, 2023).

Bogor City is known for its dense population, with a population of 1,126,927 in 2020 (Central Statistics Agency, 2024). The city covers an area of 11,850 hectares or 0.27% of the total area of West Java province. It consists of six districts: South Bogor, North Bogor, East Bogor, West Bogor, Central Bogor, and Tanah Sareal. Bogor City is located at 106°48' E and 6°36' S and has an average elevation of 190 meters, with slopes ranging from 0-3%, 4-15%, 16-30%, and above 40%. Several rivers flow through Bogor City, including the Ciliwung, Cisadane, Cipakancilan, Cidepit, Ciparigi, and Cibalok rivers. Additionally, Bogor City is surrounded by Mount Salak, Mount Pangrango, and Mount Gede. Bogor City is also known as the Rain City due to its high rainfall, which ranges from 3,500 to 4,000 millimeters per year (Bogor City Government, 2021).

In terms of waste management efforts, the Bogor City and Bogor Regency Governments have established the Galuga Landfill, covering an area of 38 hectares. The Galuga Landfill has been operational since 1986 (Khija, et al., 2020: 1). According to data from 2020, the Galuga Landfill receives an average of 650 tons of waste per day (Kholisdinuka, 2021). Additionally, based on Bogor City BPS data for 2020, the waste generated per person is 2.5 liters per day, totaling approximately 2,742 m³ of waste per day in Bogor City (Ristiano, et al., 2022: 8). With this situation, Bogor City ranks as the second-largest waste contributor in West Java province, producing 245.92 thousand tons of waste annually (Rizaty, 2022).

With the increasing population and corresponding increase in waste generation each year, there is a need for effective and sustainable waste management efforts. According to Republic of Indonesia Law Number 18 of 2008, waste management involves systematic, comprehensive, and sustainable activities, including waste reduction and handling. Waste management encompasses waste collection, transportation, treatment, and disposal, accompanied by monitoring and waste management regulations (Rijulvita, 2023: 3200). However, in efforts to reduce and manage waste, various obstacles are often encountered, such as the lack of understanding among the population. This lack of understanding can have serious implications for the environment, leading to natural disasters and disrupting public health (Saifuddin, 2018).

Based on the background provided, this research aims to depict a dynamic conceptual model in the form of Causal Loop Diagrams (CLDs) and Stock Flow Diagrams (SFDs) to predict waste accumulation in Bogor City, aiming to mitigate the potential disaster risks.

RESEARCH METHODS

The required data to construct the model are obtained from interviews and secondary data from relevant government agencies, digital sources, as well as previous research findings. The collected data include population data and waste data obtained from the Badan Pusat Statistik (Central Statistics Agency) and the Bogor City Government. Other data concerning waste management conditions, such as waste generation, waste sources, waste composition, and historical waste data managed at waste treatment facilities and landfills, are obtained from the Dinas Lingkungan Hidup (DLH). In this study, simulations will be used to predict data from three years prior, namely 2018, 2019, and 2020. Meanwhile, the simulated data to be displayed as waste predictions will cover seven years, detailing from 2017 to 2024.

This research employs a quantitative method with analysis using Causal Loop Diagram (CLD) and Stock-Flow Diagram (SFD) models processed through the Powersim Studio 10 application. The model development begins with conceptualizing the model, which is translated into CLD form and then structured into SFDs. The model's validity is tested using the average deviation test, specifically the Absolute Means Error (AME) test. According to Muhammadi (in

Rahadiati, 2018: 143), if the AME value is less than 10%, the model is considered valid, with the formula:

$$AME = \frac{[Mean\ Simulation\ Data - Mean\ Reference\ Data]}{Mean\ Reference} \times 100\%$$

RESULT AND DISCUSSION

Causal Loop Diagram (CLD) Model

In general, the term "*model*" is interpreted as a conceptual framework used as a guide in carrying out an activity. According to Good and Travers (in Tibahary, et al., 2018), a model is an abstraction of the real world or a representation of complex events or systems, in the form of narrative, mathematical, graphical, or other symbols. Models function to mimic, represent, estimate, or introduce something.

Systems thinking is a comprehensive depiction of something and has interconnections among variables. From systems thinking, a model called the Causal Loop Diagram (CLD) is generated (Trilestari, 2004: 55). CLD is useful for identifying and analyzing cause-and-effect relationships among the elements involved. Models in CLD that take the form of loops are designated with an R (reinforcing) or a B (balancing) sign (Abdullah, 2018).

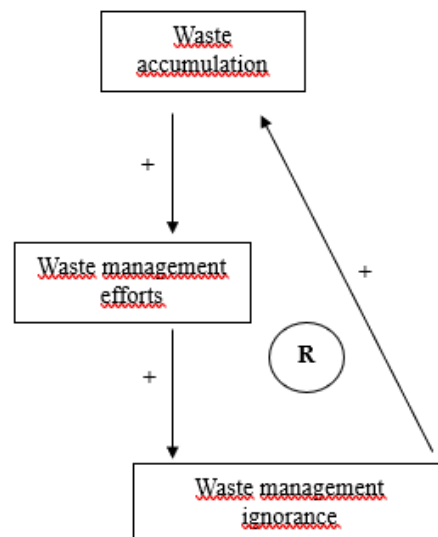


Figure 1 CLD Model of "Waste Accumulation Issues in Bogor City"
(Source: Author's Compilation, 2024)

Figure 1 depicts a CLD model illustrating the relationship between waste accumulation, waste management efforts, and waste management ignorance in Bogor City. Data used as a reference for constructing the CLD model were collected from the years 2018, 2019, and 2020. Each component of the CLD model has operational definitions (DOVs), namely:

- "Waste accumulation" refers to the pile-up of waste resulting from the population density in Bogor City. The volume of waste (in tons) disposed of daily at the Bogor City Landfill is recorded over the period spanning 2018, 2019, and 2020.
- "Waste management efforts" entail the various efforts to manage different types of waste through diverse methods. This encompasses waste management activities conducted at the Bogor City Landfill (TPA).
- "Waste management ignorance" denotes the lack of knowledge and awareness among the residents of Bogor City regarding waste and how to properly manage it.

From the three components, relationships between each component can be assumed, namely:

- The relationship between the "Waste Accumulation" component and the "Waste Management Efforts" component: As waste accumulation increases, a higher level of waste management efforts is required. This is because through these efforts, it is expected to reduce the amount of waste accumulation and maximize the benefits obtained from waste.
- The relationship between the "Waste Management Efforts" component and the "Waste Management Ignorance" component: Increasing the need for waste management efforts must be accompanied by adequate knowledge and skills. However, this often leads to a higher level of ignorance regarding waste management due to the increasing quantity and variety of waste.
- The relationship between the "Waste Management Ignorance" component and the "Waste Accumulation" component: The high number of individuals lacking understanding in waste management leads to an increase in waste accumulation.

Based on those assumptions, it is found that in the CLD above, it shows a reinforcing loop (R), which means that the increasing amount of waste accumulation per day in Bogor City is caused by the lack of efforts and the ignorance of the community regarding waste management.

Stock Flow Diagram (SFD) Model

In the field of modeling, there is a term called System Dynamics. System Dynamics is a methodology and mathematical modeling technique for strategy development. It utilizes simulation modeling based on feedback system theory, complementing the systems thinking approach. This system has been developed since 1959 by Jay W. Forrester. System Dynamics has advantages compared to other methods, as it can incorporate external environmental aspects into consideration as causal factors (Trilestari, 2004: 73).

Stock and flow diagram (SFD) is constructed from CLD to observe the relationships between elements and the dynamic behavior of a system. During the SFD creation phase, it will be determined which components will serve as stocks, flows, auxiliaries, and constants from the previously constructed CLD. The following are the components of the SFD model to be developed: 1) Waste Accumulation serves as a stock; 2) Waste Management Efforts serve as a flow; and 3) Waste Management Ignorance serves as a flow. Thus, an SFD model can be constructed as depicted in the figure below:

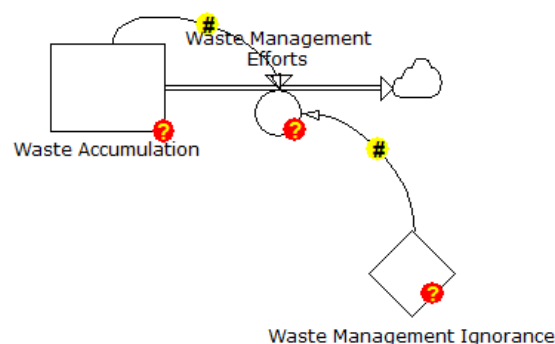


Figure 1 SFD Model Prior to Data Input
(Source: Author's Compliation, 2024)

Figure 2 depicts the SFD model of waste accumulation increasing annually due to the lack of effective and sustainable waste management efforts, attributed to the high level of waste

management ignorance among the community. The simulation within the model is also presented in the form of a Time Graph and Time Table based on the Powersim Studio 10 Express application. The data collected for the SFD model are presented in the table below:

Table 1. Quantity of Waste Received by Bogor City Landfill

	2018	2019	2020
Tons of waste per day	650 ton	680 ton	710 ton
The amount of untreated waste	24,15%	22,96%	22,80%

Source: Bogor City Government and Bogor City Environment Agency (DLH), 2022

Hence, before being executed, the assumptions of the constituent components of the SFD model are as follows:

- Waste Accumulation: in 2018 amounted to 237,250 tons per year.
- Waste Management Efforts: 'Waste Accumulation' x 'Waste Management Ignorance'
- Waste Management Ignorance: 4.6% per year.

Once the data is input into the system, the lines and symbols become interconnected, resulting in a diagram as shown below::

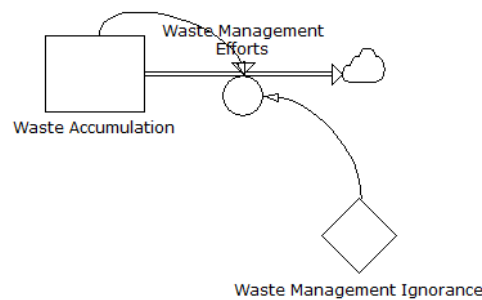


Figure 2 SFD Model After Data Input
(Source: Author's Compliation, 2024)

The data input includes data from the year 2018, followed by simulation using Time Graph and Time Table for a duration of 7 years (2018-2025).

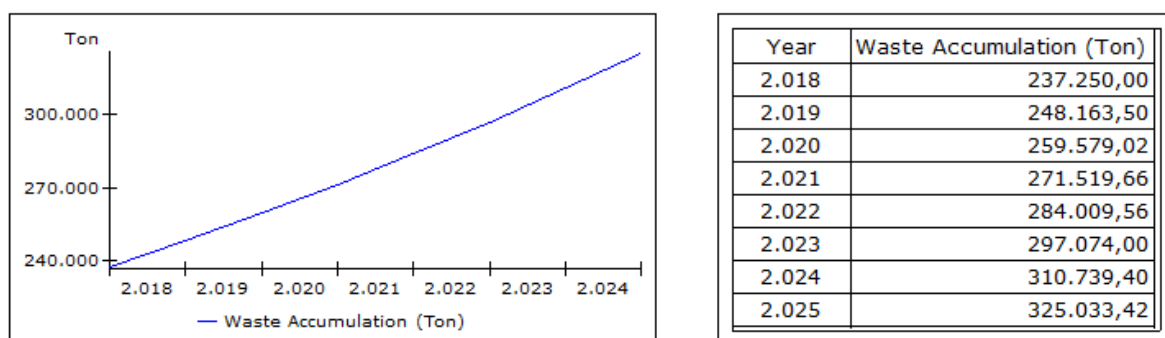


Figure 3 Simulation Results: Time Graph and Time Table
(Source: Author's Compliation, 2024)

Based on the simulation results from Figure 4, it is evident that the amount of waste accumulation is increasing every year. From 2018 to 2025, the difference in waste accumulation is estimated to reach 87,783 tons. This is attributed to more individuals within the community lacking understanding in waste management compared to those who are knowledgeable in waste management efforts. The simulation results above can assist both the government and the community in being more attentive to waste management practices that are more sustainable and environmentally friendly. It is crucial to prevent the potential disasters in the future that may arise from the increasing waste accumulation each year combined with the lack of understanding in waste management.

Model Validation

Model validation is the process of ensuring that the model and data accurately represent important aspects of the system correctly and accurately (Pattiapon, 2015: 3). To conduct model validation, the Absolute Means Error (AME) test is used, with the formula:

$$AME = \frac{[Mean Simulation Data - Mean Reference Data]}{Mean Reference Data} \times 100\%$$

Before conducting the calculation, it is necessary to compare the reference data and the simulation results, namely:

Table 2. Comparison of Reference Results and Simulation Results

Year	Reference	Simulation
2018	237.250 tons	237.250 tons
2019	248.200 tons	248.163 tons
2020	259.150 tons	259.579 tons

Source: Bogor City Government and Bogor City Environment Agency (DLH) (2022) & The researchers processed using Powerism application (2024)

Therefore, it was determined that:

$$\begin{aligned} AME &= \left| \frac{Mean Simulation Data - Mean Reference Data}{Mean Reference Data} \right| \times 100\% \\ &= \frac{248.330 - 248.200}{248.200} \times 100\% \\ &= \frac{130}{248.200} \times 100\% \\ &= 0,05237712\% \text{ (The simulation results are valid and exhibit the same trend)} \end{aligned}$$

Based on the validity test results above, the model is considered valid because the error percentage is only 0.05237712%. Additionally, the trend shown by the simulation data aligns with the reference data, indicating an increasing trend.

CONCLUSION

Based on the results of the Causal Loop Diagram, Stock Flow Diagram, as well as the Time Graph and Time Table simulations, it can be observed that the issue of waste accumulation continues to increase annually. From 2018 to 2025, the difference in waste accumulation is estimated to reach 87,783 tons, and it is projected to continue increasing each year. If this trend persists, by 2025, the Bogor City Landfill will receive 890 tons of waste per day. Therefore, more effective and efficient waste management efforts are needed. This

program should also be supported by enhancing the quality of knowledge and skills among the community in preventing and managing waste accumulation, aiming to reduce the potential disaster risks arising from waste in the future.

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