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PREDICTION OF WASTE GENERATION USING A LOGISTIC GROWTH MODEL IN DELI SERDANG

Rika Hanifah Tanjung[1], Mutiara Salsabila[2]

[1]Department of Mathematics, State Islamic Univesity of North Sumatra, Medan, Indonesia
[2]Faculty of Public Health, State Islamic University of North Sumatra, Medan, Indonesia

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ABSTRACT

The increase in population growth in a country has a negative impact on environmental pollution, especially the emergence of waste production with human activities to meet their needs. The application of the logistic method is a non-human object, namely waste generation which has a different concept in terms of its growth by using differential equation calculations. This research aims to predict the amount of waste generation in Deli Serdang Regency in the upcoming period of 2024 to 2028. The data used is secondary data from the National Waste Management Information System (SIPSN) analyzed to understand the pattern of waste growth. The analysis results show that the logistic I model has the best prediction accuracy with a Mean Absolute Percentage Error (MAPE) value of 3.18%, indicating a low error rate. The amount of waste generation in Deli Serdang Regency is projected to continue to increase every year until it approaches maximum capacity. In 2024, the amount of waste generation is estimated to reach 439,363.19 tons. In addition, in 2025 it was 447,529.07, in 2026 it was 455,846.2 tons, in 2027 it was 464,318.50 tons, and 472,948.002 in 2028. These projections provide a realistic picture of growth dynamics.

Corresponding Author:

Rika Hanifah Tanjung,
Department Of Mathematic,
State Islamic University of North Sumatra

Email: rika0703222038@uinsu.ac.id

1. INTRODUCTION

An increase in the percentage of population growth in a country has a negative impact on environmental pollution, especially the emergence of waste production with human activities to meet their needs. Indonesia is a country with the largest population that ranks 10th in the world. Based on SIPN data in 2024, the source of the most waste shows a percentage of 51.99% coming from

households with a composition based on the type of food waste of 40.14%. Every year shows an increase in the amount of waste generation in Indonesia with 368 districts, as much as 38,437,064.87 tons per year. With a waste reduction of only 13.61% or around 5,229,621.15 tons (SIPN, 2024). Deli Serdang Regency is one of the areas with a total waste generation of 411,211.01 tons during the last decade (SIPN, 2024). The problem of accumulating waste is often an environmental issue that has great attention that must be handled properly, it is possible that it will greatly affect health (Tiosiarno Hadisbroto et al., 2021).

The government makes efforts to process waste through the 3R system, namely reduse, reuse and recycle. With the main target in realizing the implementation of operational planning for all landfills, for sanitary landfills through the utilization of methane gas in 2025. However, planning alone is not enough if it is not accompanied by predicting waste generation in the following year. Predicting the level of waste generation is very important because the results of the prediction can be used to take proactive measures in solving future waste problems by the authorities, including by providing adequate TPS, officers, transportation facilities and infrastructure (Simbolon et al., 2023). One of the measurement tools that can make predictions in the coming year is applying logistic models in the use of differential equations.

The logistic model is a density-related population growth model. The model developed by Pierre-Francois Verhulst is used to assume the growth of waste generation that is influenced by resource availability and environmental capacity (Sugandha et al., 2022). In context, the logistic differential equation describes how the growth rate will be fast in small populations and slow down as it approaches maximum capacity (Sari et al., 2024). Previous research conducted focuses more on human population growth, the application of logistic models to predict the growth of waste generation is rarely found. In general, logistic models are used to predict population or things related to human growth (Anggreini, 2018). However, in this study, the logistic model is applied to a non-human object, namely waste generation, which has a different concept in terms of its growth. This was reaffirmed in a study in Jekan Raya sub-district, which showed that the prediction of waste generation can be done by calculating population growth and using a logistic model for the next five years of projection. The results show a significant increase in the amount that needs to be managed (Tiosiarno Hadisbroto et al., 2021). Thus, this research can enrich the literature related to the use of logistic models on non-human population objects and provide a new approach in waste management planning. Therefore, the use of logistic models in this context provides an innovative and useful approach to environmental planning in the North Sumatra region. This study aims to predict the amount of waste generation that occurs in Deli Serdang district from 2024 to 2028 using a logistic model. With this approach, it is expected that an overview of landfill processing can be obtained.

2. RESEARCH METHOD

This research was conducted using primary data from the SIPSN website and was conducted in November. This type of research uses quantitative research methods. The research object in the study is the amount of waste generation in North Sumatra Province, Deli Serdang Regency which includes data from various types of waste (food waste, wood or twigs, paper or cardboard, plastic, metal, cloth, rubber or leather, glass, and others) during the period 2019 to 2023. This data is obtained from the annual publication of SIPSN (National Waste Management Information System). The focus of this research is to analyze the growth pattern of waste generation in the Deli Serdang region, by predicting the amount of waste growth from the period 2024 to 2028 using a logistic model approach.

3. RESULT AND ANALYSIS

The calculation results using logistic model 1 show that the amount of waste generation in 2024 is predicted to reach 439,363.19 tons. Using the same method, the predicted amount for the years 2025 to 2028 can also be calculated. The predicted amount of waste generation for the period 2024-2028 is presented in Table 5, namely:

Table 1. Results of Predicted Waste Generation 2025-2028

Years	n	Result of prediction (tons)
2024	6	439.363,19
2025	7	447.529,07
2026	8	455.846,20
2027	9	464.318,50
2028	10	472.948,00

Historical data from 2019 to 2023 shows a consistent upward trend in the amount of generation, from 393,401.56 in 2019 to 411,211.01 in 2023. However, this can be explained by the nature of the logistics growth model, which includes an assumed maximum capacity of 4,182,794,107 tons. As the amount of waste approaches this capacity, the growth rate will slow down, and may even show a decline as the system dynamics adjust. In addition, external factors such as government policies that encourage large-scale waste reduction may also affect the results of this prediction. While these predictions differ from historical trends, they provide insight into future scenarios, especially if external conditions are favorable.

To project the amount of waste generation in Deli Serdang Regency, it is necessary to analyze the historical data of the number of vehicles in the region. This step aims to understand the patterns and trends contained in the data, so that the resulting projections can be more accurate. The amount of data analyzed also plays an important role in determining the accuracy of the prediction model to the overall condition of the number of vehicles. In this case, the data used is real or original data obtained from the National Waste Management Information System, in the period 2018 to 2023. The following is table I which displays the amount of waste generation in that period:

Table 2. Waste Generation Period 2018-2023

Years	n	Total Waste Generation (tons)
2019	1	393401,56
2020	2	400716,89
2021	3	408129,89
2022	4	411211,01
2023	5	411211,01

Based on Table I, the amount of waste generation in Deli Serdang Regency continues to increase from 2019 to 2023. To build a logistics model based on the data in table I, it is necessary to determine the maximum capacity (carrying capacity). Where using the following formula:

$$K = \frac{x_1\left(x_0x_1 - 2x_0x_2 + x_1x_2\right)}{x_1^{\,2} - x_0x_2} \tag{1}$$

with $x_0 = 393.401{,}56,\ x_1 = 400.716{,}89,\ x_2 = 408.129{,}89$

$$K = \frac{400.716{,}89((393.401{,}56 \cdot 400.716{,}89) - (2 \cdot 393.401{,}56 \cdot 408.129{,}89) + (400.716{,}89 \cdot 408.129{,}89))}{400.716{,}89^2 - 393.401{,}56 \cdot 408.129{,}89}$$

Thus, the maximum capacity for waste generation is obtained:

$K = 4.182.794.107{,}52$

Then the prediction test is carried out using the following formula:

$$P = \frac{K}{e^{-an}\left(\frac{K}{x_0} - 1\right) + 1} \quad (2)$$

$$P = \frac{4.182.794.107{,}52}{e^{-an}(10631{,}3) + 1}$$

Find the value a in 2020 with values $n = 1\ and\ x_1 = 400{,}716{,}89$

$$400.716{,}89 = \frac{4.182.794.107{,}52}{e^{-an}(10631{,}3) + 1}$$

$$e^{-a}(10631{,}1) = \frac{4.182.794.107{,}52 - 400.716{,}89}{400.716{,}89}$$

$$e^{-a}(10631{,}1) = 10437{,}3$$

$$e^{-a} = \frac{10437{,}3}{10631{,}3} = 0{,}981752$$

$$-a = \ln(0{,}981752)$$

$$a = -\ln 0{,}981752 = 0{,}01814165$$

The value in is substituted into (2) to produce a logistic model 1, namely,

$$P(n) = \frac{4.182.794.107{,}52}{e^{-0{,}01814165t}(10631{,}1) + 1} \quad (3)$$

To find other values for the following year, the same calculation needs to be done, resulting in Logistic Model 2 in 2021, namely:

$a = 0{,}0183745$ for $P(n) = \frac{4.182.794.107{,}52}{e^{-0{,}0183745\,n}(10631{,}1) + 1}$

Logistic model 3 in 2022, viz:

$a = 0{,}0147604$ for $P(t) = \frac{4.182.794.107{,}52}{e^{-0{,}0147604\,t}(10631{,}1) + 1}$

Logistic model 4 in 2023, viz:

$a = 0{,}0110703$ for $P(t) = \frac{4.182.794.107{,}52}{e^{-0{,}0110703\,t}(10631{,}1) + 1}$

By finding the calculation of the above analysis, the annual growth is obtained, namely, for logistic model 1 by 1,84%, logistic model 2 by 1,83%, logistic model 3 by 1,47%, and logistic model 4 by 1,10%. Then, these logistic models are modified to produce estimates that can be compared with the waste generation data from 2019 to 2023 as follows:

Table 3. Comparison of Actual Value with Predicted Value

Years	Actual Value	Logistics Model (Prediction Value)			
		1	2	3	4
2019	393.401,56	393.401,56	393.401,56	393.401,56	393.401,56
2020	400.716,89	400.716,06	400.699,23	399.253,81	397.783,38
2021	408.129,89	393.537,94	393.537,33	393.490,21	393.452,71
2022	411.211,01	393.406,96	393.406,94	393.405,76	393.405,03
2023	411.211,01	393.404,54	393.404,54	393.404,52	393.404,50

Furthermore, it is necessary to calculate the MAPE value to measure the prediction accuracy of the logistic model so as to enable the selection of the best model that best fits the actual data. MAPE is calculated using the formula in (3), thus the MAPE value obtained for each model is:

Table 4. MAPE Calculation Results

MAPE Value			
1	2	3	4
0,00%	0,00%	0,00%	0,00%
0,00%	0,00%	0,36%	0,73%
3,70%	3,70%	3,72%	3,73%
4,52%	4,52%	4,52%	4,52%
4,52%	4,52%	4,52%	4,52%
3,18%	3,18%	3,28%	3,37%

Table 4 shows that logistic models I and II have the smallest error with the same MAPE value, indicating an optimal level of accuracy. In this case, because the two models have equivalent performance, the researcher uses the logistic model I selected to calculate the predicted value in 2024-2030. By using the logistic model I, the MAPE value in table 4 is 3.18%. The MAPE value is smaller than 10% of the logistic model II. Because the logistic I model will be applied to project the amount of waste generation in Deli Serdang district in the period 2020-2023, the model equation used is:

$$P(t) = \frac{4.182.794.107,52}{e^{-(0,0184165)t}(10631,3) + 1}$$

The relative growth rate of the model is 1.84% per year. Furthermore, logistic model 1 will be used to predict the amount of waste generation in 2024 by taking $t = 2024 - 2019 = 6$so as to produce:

$$P(6) = \frac{4.182.794.107,52}{e^{-0,0184165(6)}(10631,1)+1}$$

$$P(6) = \frac{4.182.794.107,52}{e^{-0,110499}(10631,3) + 1}$$

$$\boldsymbol{P(t) = 439.363,19}$$

4. CONCLUSION

Based on the analysis and implementation of calculations using the Logistics I Model, the amount of waste generation in Deli Serdang Regency is projected to continue to increase every year until it approaches maximum capacity. In 2024, the amount of waste is estimated to reach 439,363.19 tons. In addition, in 2025 it was 447,529.07, in 2026 it was 455,846.2 tons, in 2027 it was 464,318.50 tons, and 472,948.002 in 2028. These projections show that the growth of waste generation continues to increase, providing a realistic picture of the growth dynamics. The model can provide a solid basis for the government to plan more effective and sustainable waste management infrastructure in the future. Based on the results of the discussion about the prediction of waste generation in the next 5 years, it will increasingly fulfill the environment. So it is hoped that the authorities and the community will realize it and make efforts to overcome excessive waste consumption which can cause environmental damage.

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