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POPULATION PREDICTION OF SIMALUNGUN DISTRICT USING THE LOGISTIC MODEL IN 2025-2030

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ABSTRACT

Population growth prediction is an important aspect in regional development planning, including in Simalungun Regency, which has complex demographic dynamics. Based on data from BPS, the population in Simalungun Regency is increasing every year, so a solution is needed to reduce the negative impact so that there is no population explosion. The solution that can be used to project the population in Simalungun Regency is to use a logistic growth model. This model is used to calculate the value of the growth rate and environmental carrying capacity (Carrying Capacity) using population data in Simalungun Regency in 2019-2023. The results obtained show that the environmental carrying capacity that limits the population in Simalungun Regency is 1,005,168.408 people. With the relative growth rate per year of the population in Simalungun Regency using the logistic model I is 3.46%. This model also projects the population in Simalungun Regency from 2025-2030. The population in 2025 amounted to 1,374,983 people until the year 2030 is estimated to amount to 1,476,292 people.

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1. INTRODUCTION

Population issues are a serious problem that must be faced by every country, especially countries that are classified as developing or underdeveloped countries. Indonesia is categorized as a developing country and has a relatively large population. Population growth in the region is important because it can affect the progress and welfare of the region. (Pandu, 2020).

Basically, population growth continues to occur every year and can have an impact on various regions. Population growth is one of the social problems that need attention. This is from the seriousness of the government in establishing institutions that specifically deal with population issues through programs such as BPS (Central Statistics Agency) which organizes population censuses and BKKBN (National Population and Family Planning Agency) which organizes family planning programs. The establishment of these institutions shows the importance of population issues including population growth.

The government routinely conducts a census conducted by BPS (Central Statistics Agency) and family data collection activities conducted by BKKBN (National Population and Family Planning Agency) to map the population. Data collection activities are carried out by appointing several members of the community as implementers of regional data collection. However, the number of census takers often does not match the number of communities, so the implementation of data collection is not in accordance with the planned schedule. Therefore, if projecting population growth in the next year, it can be estimated that up to households will experience mismatch problems every day. Due to the short time limit, almost all data collection officers faced a similar problem, namely the delay in completing the data collection in their area in accordance with the time given. (Romadhon et al., 2022).

In general, there are three things that affect growth in Indonesia that are difficult to avoid, namely births (natalitas), deaths (mortality), and population movements (migration). Population growth is a dynamic balance between forces that increase and forces that decrease the population. The number of people born is still affected by the amount, but at the same time the number of deaths is equal and occurs in all age groups. (Sa'adah et al., 2023).

Statistical indicators of regional development in Simalungun Regency in 2023 show that population growth plays an important role in the formulation of development plans by the government. Understanding the demographic landscape of government agencies, the business community, research institutions and the general public is essential. Population growth rates can also be a factor for companies to consider in their business strategies. Of course, as the population grows, opportunities for home-based entrepreneurship and various ventures in other areas may continue to be considered. Social issues such as welfare levels, population density, and average life expectancy, as well as demographic issues such as working-age dependency and the number of people of childbearing age, are also closely related to the impact of population growth.

In the research of Population Prediction of Simalungun Regency using the Logistic Model in 2025-2030 that the logistic population model is appropriate for predicting in Simalungun Regency. In research conducted. (Iswanto, 2012) also found that the accuracy of the logistic model compared to the exponential model is higher because the exponential model ignores factors that inhibit population growth, while the logistic model ignores factors that inhibit population growth closer to reality in the field. This model takes into account factors that inhibit population growth such as war, famine, and disease outbreaks.

Therefore, this study of the population of Simalungun Regency in 2024 aims to predict the population of Simalungun Regency in 2025-2030. The growth model used to predict population growth in Simalungun Regency is the logistic model. Meanwhile, the population data of Simalungun Regency used in this study comes from the 2019-2023 census of the population of Simalungun Regency from BPS North Sumatra Province.

Then in research (Andika, 2024) applying two methods in predicting population, it was concluded that the exponential model is very good, but its ability to predict long-term population growth is limited because this model assumes constant growth. The Logistic model is more realistic in predicting long-term population growth because it takes into account the maximum capacity of the population. While in previous research (Sugandha et al., 2022), it was concluded that the Logistic method of model completion was more accurate to be used.

The logistic method has a major advantage in predicting population growth as it is able to take into account limiting factors, such as carrying capacity, that limit population growth over time. This approach is realistic for long-term projections, especially in resource-constrained regions, as the logistic model assumes that initial growth is exponential but slows down as it approaches environmental limits.

However, some of the drawbacks of the logistic method in predicting population growth are that the basic assumptions of the model require the carrying capacity of the environment, which is often difficult to determine accurately. Environmental capacity is dynamic and influenced by factors such as technological changes, policies, and social shifts, which are not always captured in the model. In addition, logistic methods tend to be ineffective in modeling areas with very small or unstable populations, where population growth does not follow the initial exponential pattern that the model assumes. The calculation process is also more complex than simple methods such as linear or exponential regression, requiring more detailed data and more in-depth analysis. This can be challenging in areas with limited data or low data quality.

Another advantage of the model is that it provides a more accurate picture of population dynamics, especially in urban or densely populated areas, where the influence of resources, infrastructure, and government policies are significant (Irma Suryani & Nur Khasanah, 2022). By considering non-linear relationships in population data, this method helps in making better decisions for development planning and demographic policies.

We identified the Logistic method as a method for predicting population growth based on its ability to more realistically model population dynamics than other methods, especially since it considers carrying capacity, which is important for long-term projections.

Based on several aspects that have been explained, the author took the title "Population Prediction of Simalungun Regency Using the Logistic Model in 2025 - 2030".

2. RESEARCH METHODE

The approach used in making this research is a quantitative approach, which is a method that relies heavily on numbers, from collecting data, processing data, analyzing the data, to presenting the results. The type of writing is a literature study, which is writing by studying various references and relating them to the calculation results in the research. In calculating population estimates, several general theories are applied.

This study uses data, namely secondary data regarding population information in Simalungun Regency for the 2019-2023 period obtained from the Central Bureau of Statistics. Secondary data is an approach used in research to analyze and interpret data or information that has been collected.

In this study, the data used in the study were sourced from the Central Statistics Agency (BPS) through Simalungun Regency publications. The data used are the results of surveys and official BPS publications published in 2019-2023.

Table 1 below is the sample used is data on the total population in Simalungun Regency in 2019-2023 based on BPS (Central Statistics Agency) data (BPS, 2022).

Table 1. Population data of Simalungun Regency

No.	Tahun	Hasil Sensus
1.	2019	867.922 jiwa
2.	2020	990.246 jiwa
3.	2021	1.003.727 jiwa
4.	2022	1.021.615 jiwa
5.	2023	1.035.920 jiwa

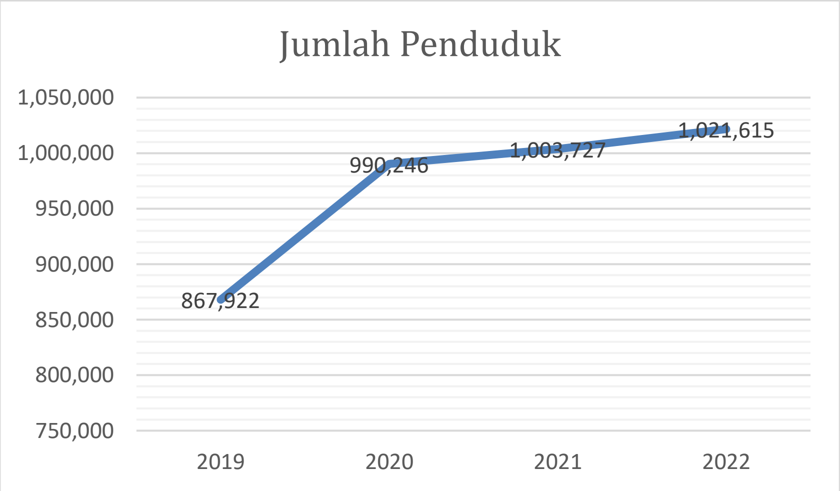

Figure 1. Graph of population in Simalungun Regency based on census results and Logistic model results.

3. RESULT AND ANALYSIS

Ecologists define carrying capacity as the maximum population that can be sustained by a particular environment without experiencing an increase or decrease in population size over a relatively long period of time. Carrying capacity denoted by $\frac{p}{k}$ m is a property of the environment, therefore carrying capacity varies over time (t) and space as finite resources are abundant. Population growth is limited by the availability of food, shelter, and other living resources. The growth rate is represented by p (Abraham, 2024). The specific solution of the logistic model at time t is

$$\frac{dp}{dt} = kP\left(1 - \frac{p}{k}\right) \quad (1)$$

Considering equation (1), the equation can be solved by finding the solution of the generalized logistic equation

$$\frac{dp}{dt} = kP\left(1 - \frac{p}{k}\right),$$

$$\frac{dP}{p\left(1-\frac{p}{k}\right)} = k\ dt,$$

$$\frac{dP}{P\left(1-\frac{P}{K}\right)} = \int k\ dt,$$

$$\int \frac{dP}{P-\frac{P^2}{K}} = \int k\ dt,$$
$$\int \frac{KdP}{KP-P^2} = \int k\ dt,$$
$$\ln P - \ln(K-P) = kt + c,$$
$$\frac{P}{K-P} = e^{kt+c},$$
$$P = e^{kt+c}(K-P),$$
$$P = Ke^{kt+c} - Pe^{kt+c},$$
$$P(1+e^{kt+c}) = Ke^{kt+c},$$
$$P(t) = \frac{Ke^{kt+c}}{1+e^{kt+c}} \quad (2)$$

Based on equation (1) that has been obtained, t = 0 when given a value as the initial value. Next, enter the value of $= \frac{a}{b}$.
K is obtained as follows

$$K = \frac{P_1(P_1P_2-2P_0P_2+P_0P_1)}{{P_1}^2-P_0P_2} \quad (3)$$

Further details

$$P(t) = \frac{Ke^{kt+\ln\left(\frac{P_0}{K-P_0}\right)}}{1+e^{kt+\ln\left(\frac{P_0}{K-P_0}\right)}},$$
$$P(t) = \frac{Ke^{kt\left(\frac{P_0}{K-P_0}\right)}}{1+e^{kt\left(\frac{P_0}{K-P_0}\right)}},$$
$$P(t) = \frac{\frac{Ke^{kt}P_0}{K-P_0}}{\frac{K-P_0+e^{kt}P_0}{K-P_n}},$$
$$P(t) = \frac{Ke^{kt}P_0}{K-P_0+e^{kt}P_0},$$
$$P(t) = \frac{KP_0}{(K-P_n+e^{kt}P_0)},$$
$$P(t) = \frac{KP_0}{(K-P_n+e^{kt}P_0)e^{-kt}},$$
$$P(t) = \frac{KP_0}{(Ke^{-kt}-P_ne^{kt}+P_n)},$$
$$P(t) = \frac{KP_0}{(\frac{K}{P_0}e^{-kt}-e^{-kt}+1)},$$
$$P(t) = \frac{K}{e^{-kt}-\left(\frac{K}{P_0}1\right)+1},$$
$$P(t) = \frac{K}{e^{-pt}\left(\frac{K}{N_0}-1\right)+1}$$
(4)

The K value is obtained when $t \to \infty$. In other words, the value of K is the total population especially When $t \to \infty$. Therefore

$$N_{max} = lim_{t\to\infty}K = \frac{p}{q} = \frac{P_1(P_1P_2-2P_0P_2+P_0P_1)}{{P_1}^2-P_0P_2} \quad (5)$$

Where,
K: capacity (soul)
$P(t)$: population at time t = 0 (people)
p_n: the population at point n at a given time, where 1, 2, 3 is n
k : growth rate (soul)
t : year (time)
To estimate the total population in Simalungun Regency with a logistic model, the measured time (t) measured in years is assumed first and then it is postulated that $t = 0$ in 2019 then the initial condition is $P_0 = 867.922$. Next is to determine the value of environmental carrying capacity with equation (3).
From Table 1 obtained $t = 0, 1, 2$ namely 2019, 2020, 2021 with values P_0, P_1, P_2, P_3, P_4 with each value being $P_0 = 867.922$, $P_1 = 990.246$, $P_2 = 1.003.727, P_3 = 1.021.615, P_4$ =1.035.920. To find the Carrying Capacity value, it can be calculated using equation (3).

$$K = \frac{990.246(2(867.922)(1.003.727) - (1.003.727)(990.246) - (867.922)(990.246)}{(867.922)(1.003.727) - (990.246)^2}$$
$$K = 1.005.168{,}408$$

Because K is too close to the value of P_t, we can assume the value of K = 1,500,000, so the next step is to determine the value of r for each t. The values of K and P_0 are substituted into equation (4) of the logistic model solution to obtain:

$$P(t) = \frac{K}{e^{-rt}\left(\frac{K}{P_0} - 1\right) + 1}$$

$$P(t) = \frac{1.500.000}{e^{-rt}\left(\frac{1.500.000}{867.992} - 1\right) + 1}$$

$$P(t) = \frac{1.500.000}{e^{-rt}(0,72812)+1} \qquad (6)$$

Next, we will look for a logistic model that can represent the population growth rate in Karo Regency for the following reasons $t = 1$ in 2020 then $P_1 = 990.246$, then from equation (3) can be obtained:

$$P(t) = \frac{K}{e^{-rt}\left(\frac{K}{P_0} - 1\right) + 1}$$

$$990.246 = \frac{1.500.000}{e^{-r(1)}\left(\frac{1.500.000}{867.992} - 1\right) + 1}$$

$$e^{-r}(0,72812) + 1 = \frac{1.500.000}{990.246}$$

$$e^{-r}(0,72812) = \frac{1.500.000 - 990.246}{990.246}$$

$$-r = \ln(0,706985)$$

$$r = -\ln(0,706985)$$

$$r = 0,3467458297$$

The value of r obtained is substituted into equation (6) and obtained:

Model I

$$P(t) = \frac{1.500.000}{e^{(-0,3467458297)t}\left(\frac{1.500.000}{867.992} - 1\right) + 1}$$

From equation (6) for $t = 2$ in 2021 then $P_2 = 1.003.727$ can be obtained:

$$P(t) = \frac{K}{e^{-rt}\left(\frac{K}{P_0} - 1\right) + 1}$$

$$1.003.727 = \frac{1.500.000}{e^{-r(2)}\left(\frac{1.500.000}{867.992} - 1\right) + 1}$$

$$e^{-2r}(0,72812) + 1 = \frac{1.500.000}{1.003.727}$$

$$e^{-2r}(0,72812) = \frac{1.500.000 - 1.003.727}{1.003.727}$$

$$-2r = \ln(0,67905)$$

$$r = \frac{-ln\ (0,67905)}{2}$$

$$r = 0,1935302582$$

The value of r obtained is substituted into equation (6) and obtained:

Model II

$$P(t) = \frac{1.500.000}{e^{(-0,1935302582)t}\left(\frac{1.500.000}{867.992} - 1\right) + 1}$$

From equation (5) for $t = 3$ in 2022 then $P_3 = 1.021.615$ can be obtained:

$$P(t) = \frac{K}{e^{-rt}\left(\frac{K}{P_0} - 1\right) + 1}$$

$$1.021.615 = \frac{1.500.000}{e^{-r(3)}\left(\frac{1.500.000}{867.992} - 1\right) + 1}$$

$$e^{-3r}(0{,}72812) + 1 = \frac{1.500.000}{1.021.615}$$
$$e^{-3r}(0{,}72812) = \frac{1.500.000 - 1.021.615}{1.021.615}$$
$$-3r = \ln(0{,}64310)$$
$$r = \frac{-ln\ (0{,}64310)}{3}$$
$$r = 0{,}1471516819$$

The value of r obtained is substituted into equation (6) and obtained:

Model III

$$N(t) = \frac{1.500.000}{e^{(-0{,}1471516819)t}\left(\frac{1.500.000}{867.922} - 1\right) + 1}$$

From equation (6) for $t = 4$ in 2023 then $P_4 = 1.035.920$ can be obtained:

$$P(t) = \frac{K}{e^{-rt}\left(\frac{K}{P_0} - 1\right) + 1}$$
$$1.035.920 = \frac{1.500.000}{e^{-r(4)}\left(\frac{1.500.000}{867.992} - 1\right) + 1}$$
$$e^{-4r}(0{,}72812) + 1 = \frac{1.500.000}{1.035.920}$$
$$e^{-4r}(0{,}72812) = \frac{1.500.000 - 1.035.920}{1.035.920}$$
$$-4r = \ln(0{,}61525)$$
$$r = \frac{-ln\ (0{,}61525)}{4}$$
$$r = 0{,}1214316474$$

The value of r obtained is substituted into equation (6) and obtained:

Model IV

$$P(t) = \frac{1.500.000}{e^{(-0{,}1214316474)t}\left(\frac{1.500.000}{867.922} - 1\right) + 1}$$

From the results of the above calculations, the logistic model results are as follows:

1. Logistic Model I equation form $P(t) = \frac{1.500.000}{e^{(-0{,}3467458297)t}\left(\frac{500.000}{867.922} - 1\right) + 1}$ with an annual relative growth rate of about 3.46%.
2. Logistic Model II equation form $P(t) = \frac{1.500.000}{e^{(-0{,}1935302582)t}\left(\frac{1.500.000}{867.922} - 1\right) + 1}$ with an annual relative growth rate of about 1.93 %
3. Logistic Model III equation form $P(t) = \frac{1.500.000}{e^{(-0{,}1471516819)t}\left(\frac{500.000}{867.922} - 1\right) + 1}$ with an annual relative growth rate of about1,47 %.
4. Logistic Model IV equation form $P(t) = \frac{1.500.000}{e^{(-0{,}1214316474)t}\left(\frac{500.000}{867.922} - 1\right) + 1}$ d with an annual relative growth rate of about 1,21%

Table 2 below makes the results of the number of residents in Simalungun Regency in 2025-2030 as follows:

Table 2. Comparison between census results and model results on population in Karo District

Year	Census Results	Model I	Model II	Model III	Model IV
2019	867.922	867.922	867.922	867.992	867.992
2020	990.246	990.246	937.494	921.097	911.928
2021	1.003.727	1.099.756	1.003.724	972.453	954.728
2022	1.021.615	1.193.034	1.065.767	1.021.618	996.135
2023	1.035.920	1.269.136	1.122.968	1.068.236	1.035.926

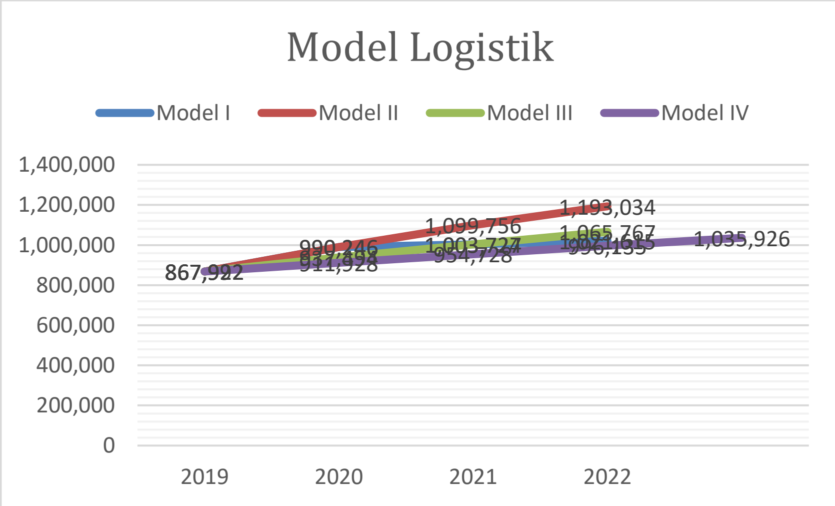

Figure 2. Logistic Model Graph of Simalungun District

Population Prediction in Karo Regency 2025-2030

Because the logistic model I will be used to predict the number of residents in Karo Regency in 2025-2030, the model equation used is

$$P(t) = \frac{1.500.000}{e^{(-0,3467458297)t}\left(\frac{500.000}{867.922} - 1\right) + 1}$$

The relative growth rate of the above model is 3.46% per year. Furthermore, from the logistic model I will first predict the population in 2024 by taking $t = 2024 - 2019 = 5$ then obtained:

$$P(5) = \frac{1.500.000}{e^{(-0,3467458297)t}\left(\frac{500.000}{867.922} - 1\right) + 1}$$

$$P(5) = 1.329.074,389$$

So, the result of calculating the population in Kabupaten Karo in 2024 using the logistic model is 1,329,074 people. In the same way, the population for 2025-2030 can be obtained. The predicted population in Kabupaten Karo for 2025-2030 is shown in table (3).

Table 3. Predicted population in Simalungun Regency

Tahun	Hasil Prediksi
2024	1.329.074 jiwa
2025	1.374.983 jiwa
2026	1.409.403 jiwa
2027	1.434.795 jiwa
2028	1.453.306 jiwa
2029	1.466.684 jiwa
2030	1.476.292 jiwa

Table (3) above is the result of calculations using the logistic growth model which shows that the population in Karo Regency continues to increase.

4. CONCLUSION

The logistic growth model becomes more accurate and can be used as the final model to predict future population. Logistic model I was determined by using the Carrying Capacity value which limits the population of Simalungun Regency to 1,005,168.408 people. Logistic Growth Model to predict population in Simalungun Regency

$$\frac{dN}{dt} = rN_t\left(1 - \frac{N_t}{K}\right)$$

The equation form of Logistic Model I is

$$P(t) = \frac{1.500.000}{e^{(-0,3467458297)t}\left(\frac{500.000}{867.922} - 1\right) + 1}$$

With the relative growth rate per year of the population in Simalungun Regency using the logistic model I is 3.46%.
Based on the Logistic Growth Model I, it can make predictions of the number of people in Simalungun Regency in 2025 totaling 1,374,983 people until 2030 is estimated to be 1,476,292 people.

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