The 4th International Seminar of Science and Technology
ISST 2024 Vol 4 (2025) 001
Innovations in Science and Technology to Realize Sustainable Development Goals
Faculty of Science and Technology
Universitas Terbuka

Population Projection in Bantul Regency with Malthusian Growth Model and Verhulst Growth

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Abstract - Population growth has positive and negative impacts in Indonesia. One of the negative impacts of high population growth is that the government will need help with regional needs related to food, housing, facilities, infrastructure, etc., if it is not balanced with quality human resources. This impact can be minimized by projecting the population and analyzing population growth trends in that region so that the government can anticipate by developing strategies to prepare for needs in that region in the next few years. In this paper, we use the Malthusian and Verhulst Growth Models to model population data. This paper aims to estimate the population of Bantul Regency using the Malthusian and Verhulst Growth Models and compare the two models. The results show that the Malthusian Model is more accurate than Verhulst Model.

Keywords: Bantul Regency, Malthus, Population Growth Model, Population Projection, Verhulst

1 Introduction

Population growth can be defined as the change in the total number of people in a population using units of measurement per time or describing population changes over time [1]. Population growth is influenced by migration, death rates, and birth rates. Bantul Regency experienced the second-fastest population growth rate after Sleman Regency. In the Special Region of Yogyakarta Province, Bantul Regency is one of four regencies and one city. The area of Bantul Regency is 506,85 km² with 17 sub-districts and is divided into 75 villages and 933 hamlets. Based on information collected by the Central Statistics Agency (BPS) of Bantul Regency, the population in this area was 955.015 people in 2013 and increased to 1.036.489 people in 2020 [2]. Along with the increasing population density in Bantul Regency, there is an uneven distribution of public facilities, including health facilities and other facilities.

The positive impacts of high population growth include an increase in economic growth, market expansion, and its potential use as a target development. While the negative impacts of high population growth, if not accompanied by quality human resources, can make it difficult for the government to meet the needs of food, clothing, housing, facilities and infrastructure in its region [3, 4]. Therefore, the government needs to anticipate things that might happen including the impact on sustainable environmental life. The development of technology and innovation in natural sciences, including mathematics, can contribute to anticipating population growth. One way that can be done is by conducting population projection.

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This is in line with Pandu [5] belief that population prediction is an efficient strategy to mitigate the negative impacts of population growth. Population projection is a calculation of the population in the future (in terms of age and orientation synthesis) in accordance with the direction of increasing birth rates, graduation rates and accepted movements.

To calculate the estimated population, a mathematical model is needed that can reflect the actual situation, especially gradually. According to [6], the application of mathematical models is an important tool for predicting future population growth. The Malthusian growth model and the Verhulst growth model are mathematical models used to predict the population of Bantul Regency. Malthus's first exponential model [7] was published in 1978. Later, this exponential model was developed into a logistic growth model [8]. Verhulst, a biologist from Bel Air, first used this logistic model (Wei et al., 2015).

By utilizing the factors considered, such as food and living space, the strategic development model can show that society will move towards harmony if the number of births and deaths are equal. The carrying capacity of an area, the initial population and the growth rate affect the population in this model. Because the growth rate is limited by the availability of food, shelter, and other living resources, the population is always limited to a certain value [9].

Previous researchers have used both of these models. Anggreini used it to estimate the population of East Java in 2030 [10]. She also used Verhoust model to estimate the population growth of Tulungagung Regency in 2025 [11]. The models also used to estimate the population of Indonesia between 2000 and 2014 [12]. In [13], the models used to apply the logistic growth model to estimate population of Sumenep Regency. Comparison of the two models in estimating the population of Ngada Regency also studied [14]. And the application of Exponential applied the Exponential and Logistic Models in Population Prediction with a Case Study of Palembang City [6] .

The purpose of this study is to find out based on the description which growth model is more accurate in predicting the population of Bantul Regency in 2030 by utilizing the Malthusian growth model and the Verhulst growth model.

2 Materials and methods

The research method begins with a Literature Review. The Malthusian Growth Model and the Verhulst Growth Model are two continuous differential equations used in this study to predict the population of Bantul Regency.

The steps taken to obtain the population projection results for Bantul Regency [15] are as follows.

a. constructing the Malthusian and Verhulst growth models,
b. find the solution of $\frac{dP}{dt} = kP$ and $\frac{dP}{dt} = kP\left(1 - \frac{P}{K}\right)$,
c. find the time at t,
d. determine the initial population as well as the population that will be known annually,
e. calculate the carrying capacity,
f. calculate the growth rate that occurs,
g. calculating the population using the Malthusian and Verhulst growth models,
h. utilizing the Malthusian and Verhulst growth models to project the population of Bantul regency in 2030, and
i. compare which growth model is more accurate in projecting population numbers.

3 Results and discussion

The data used in this study is population data for the Regency Bantul period 2013-2020 obtained from BPS Bantul Regency.

Table 1. Total Population of Bantul Regency Period 2013-2020

Year	Total Population
2013	955,015
2014	968,632
2015	971,511
2016	983,527
2017	995,264
2018	1,006,692
2019	1,022,788
2020	1,036,489

Table 1 shows that the population of Bantul Regency has increased from year to year.

3.1 Analysis of the Population of Bantul Regency based on the Malthusian Growth Model

According to [10], to determine the population size using the Malthusian Growth Model, it is assumed that there must be at least 1.000.000 births per 100.000 individuals, or the death rate does not change. Population growth based on the exponential growth model can be expressed as follows using equation (1).

$$\frac{dP}{dt} = kP \quad (1)$$

Separate variable technique is used

$$\frac{dP}{P} = kdt \quad (2)$$

The solution of equation (2) is

$$\int \frac{dP}{P} = \int kdt$$

obtained

$\ln|P| = t + c_1$ (c_1 : integrating settings)

$P = e^{t+c_1}$

$P = e^{c_1} \cdot e^t = Ce^t$ (here $C = e^{c_1}$)

can be written as

$$P(t) = Ce^t \quad (3)$$

After that, using the initial condition $P(t_0) = P_0$. Substitusing $t = t_0$ to equation (3) retrieved $P_0 = Ce^{t_0}$, so that $C = P_0 e^{-t_0}$. Then obtained

$$P(t) = P_0 e^{k(t-t_0)} \quad (4)$$

If $t_0 = 0$ is the starting point, then

$$P(t) = P_0 e^{kt} \tag{5}$$

3.1.1 The Relationship between the Exponential Growth Model and the Malthusian Growth Model

The Malthusian growth model is a discrete approach to exponential growth (continuous approach). Because a discrete approach is used, the way it is written can be distinguished, namely $P(t)$ is replaced with P_t. It is known that

P_0: population size in year 0 (initial population)

P_t: population size in year t.

Using a discrete approach, the growth rate is the difference in the population size in year $(t + 1)$ and in year t (two consecutive time periods). Furthermore, the basic assumption in the exponential growth model (5) can be considered the same as the assumption that

$$P_{t+1} - P_1 \sim P_t$$

which gives

$$P_{t+1} - P_1 = K \cdot P_t \text{ or } P_{t+1} = (1 + K)P_t \tag{6}$$

From the recursive relationship (6) the form can be derived

$$P_t = (1 + K)^t \cdot P_0 \tag{7}$$

and can be expressed as

$$P_t = P_0 \alpha^t\,, \quad \alpha = 1 + K \tag{8}$$

Based on equation (8), the growth rate value (a) is obtained as follows: $\alpha = 1 + K$. The population growth model that can be formed using the Malthus growth model is:

a. Malthusian Growth Model I with the equation form $P(t) = 955{,}015 \cdot (1.014258415)^t$ and a relative population growth rate of 1.42%.

b. Malthusian Growth Model II with the equation form $P(t) = 955{,}015 \cdot (1.008599538)^t$ and the relative population growth rate is 0.86%.

c. Malthusian Growth Model III with the equation form$P(t) = 955{,}015 \cdot (1.009854251)^t$ and a relative population growth rate of 0.98%.

d. Malthusian Growth Model IV with the equation form $P(t) = 955{,}015 \cdot (1.010373683)^t$ and a relative population growth rate of 1.03%.

Table 2. Results of the Malthusian Growth Model Calculation

Year	Amount Residents (BPS DIY)	Malthusian Growth Model Calculation Results			
		I	II	III	IV
2013	955,015	955,015	955,015	955,015	955,015
2014	968,632	968,632	963,228	964,426	964,922
2015	971,511	982,443	971,511	973,930	974,932
2016	983,527	996,451	979,866	983,527	985,045

Year	Amount Residents (BPS DIY)	Malthusian Growth Model Calculation Results			
		I	II	III	IV
2017	995,264	1,010,659	988,292	993,218	995,264
2018	1,006,692	1,025,069	996,791	1,003,006	1,005,589
2019	1,022,788	1,039,685	1,005,363	1,012,890	1,016,020
2020	1,036,489	1,054,510	1,014,008	1,022,872	1,026,560

Based on Table 2, the Malthus I to Malthus IV models are used to model population growth, and the results show that there is an estimated increase in population every year. The best model is the model with the smallest error value [14]. The best model of the four Malthus models is shown in Table 3.

Table 3. Malthusian Growth Model Errors

Year	Malthusian Growth Model Error			
	I	II	III	IV
2013	0.000%	0.000%	0.000%	0.000%
2014	0.000%	0.558%	0.434%	0.383%
2015	1.125%	0.000%	0.249%	0.352%
2016	1.314%	0.372%	0.000%	0.154%
2017	1.547%	0.701%	0.206%	0.000%
2018	1.825%	0.984%	0.366%	0.110%
2019	1.652%	1.704%	0.968%	0.662%
2020	1.739%	2.169%	1.314%	0.958%
$\sum$	1.022%	0.721%	0.393%	0.291%

Table 3 shows that the Malthusian Growth Model IV has the smallest error of 0.291%. Therefore, the best Malthusian Growth Model is the Malthusian Growth Model IV with the equation form $P(t) = 955{,}015 \cdot (1.010373683)^t$ and population growth rate $a = 1.010373683$. And if presented in graphical form, it can be seen in Fig. 1.

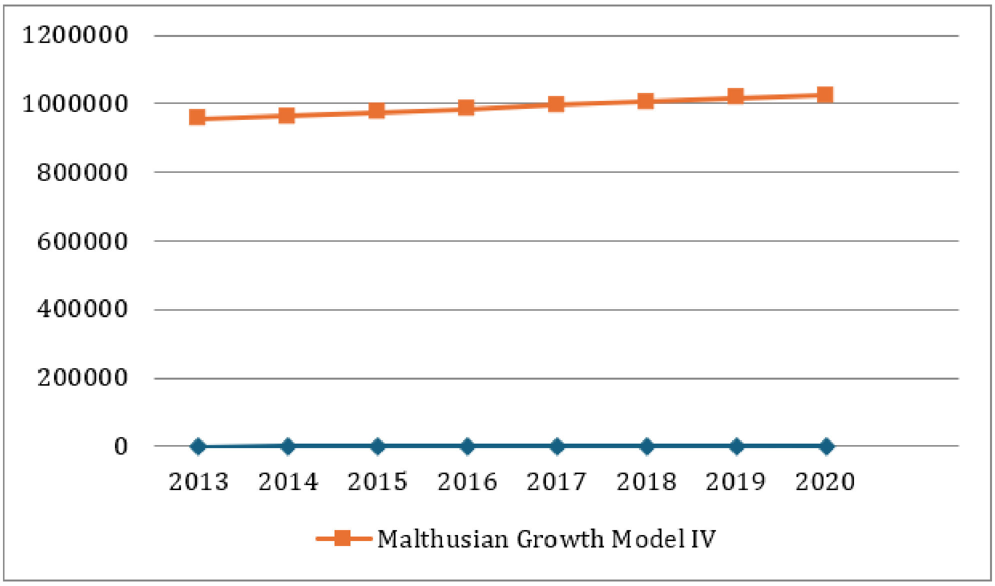

Fig. 1. Projection of the population of Bantul Regency using the Malthusian Growth Model IV

3.2 Analysis of the Population of Bantul Regency Based on the Verhulst Growth Model

Belgian mathematician Pierre Francois Verhulst (1804-1849) introduced the logistic model as a model developed from the Malthusian growth model. Population limits are also taken into account in the calculation of the logistic model so that the population does not increase to infinity. The Verhulst Growth Model can be started as follows

$$\frac{dP}{dt} = kP\left(1 - \frac{P}{K}\right), \quad k, K > 0 \tag{9}$$

with K is the carrying capacity, k is the growth rate, t is time and P is the population at time t. The solution to equation (9) can be solved using the following method.

$$\int \frac{1}{P\left(1 - \frac{P}{K}\right)} dP = \int k dt\,. \tag{10}$$

The $\frac{1}{P\left(1-\frac{P}{K}\right)}$ form in equation (10) is integrated using the partial fractional integration method, so that we obtain

$$\int \left(\frac{1}{P} + \frac{1}{K - P}\right) dP = \int kdt$$

$$\ln|P| - \ln|K - P| = kt + c_1$$

$$\ln\left|\frac{P}{K - P}\right| = kt + c_1$$

$$\left|\frac{P}{K - P}\right| = e^{kt + c_1}$$

$$\frac{P}{K-P} = -Ce^{kt}$$
$$\frac{K-P}{P} = Ce^{-kt}$$
$$K = (1 + Ce^{-kt})P$$
$$P(t) = \frac{K}{1 + Ce^{-kt}}. \tag{11}$$

Substitusing $t = 0$ and $P(0) = P_0$ into equation (11) we obtain

$$C = \frac{K}{P_0} - 1.$$

The particular solution of the Verhulst Growth Model equation is

$$P(t) = \frac{K}{1 + \left(\frac{K}{P_0} - 1\right) e^{-kt}}. \tag{12}$$

The largest value of $P(t)$ can be obtained by exploring the constraints of equation (12) with $t \to \infty$.

$$\lim_{t\to\infty} \frac{K}{1 + \left(\frac{K}{P_0} - 1\right) e^{-kt}} = K.$$

By using the population numbers at three different times and the same time for data collection, researchers can estimate the values of k and K.

Suppose P_0: population at $t = 0$, and P_T: population at $t = T$ and P_{2T}: population at $t = 2T$ with $T \in N$ then

$$\frac{1}{K}[1 - e^{-kT}] = \frac{1}{P_T} - \frac{e^{-kT}}{P_0} \tag{13}$$
$$\frac{1}{K}[1 - e^{-k2T}] = \frac{1}{P_{2T}} - \frac{e^{-k2T}}{P_0} \tag{14}$$

By dividing equations (13) and (14) we obtain

$$\frac{\frac{1}{K}[1 - e^{-k2T}]}{\frac{1}{K}[1 - e^{-kT}]} = \frac{\frac{1}{P_{2T}} - \frac{e^{-k2T}}{P_0}}{\frac{1}{P_T} - \frac{e^{-kT}}{P_0}}$$
$$e^{-kT} = \frac{P_0(P_{2T} - P_T)}{P_{2T}(P_T - P_0)}$$

So k is obtained by the formula $k = -\frac{1}{T}\ln\left(\frac{P_0(P_{2T}-P_T)}{P_{2T}(P_T-P_0)}\right)$.

If the value of k is substituted into equation (5) the result is

$$K = \frac{P_T(P_TP_0 - 2P_0P_{2T} + P_TP_{2T})}{{P_T}^2 - P_0P_{2T}}$$

Then the value of K (carrying cappacity) is obtained as:

$$K = 972{,}269$$

Population growth model that can be formed using the Verhulst growth model is

a. Verhulst Growth Model I

$$P(1) = 968{,}632 = \frac{972{,}269}{1 + \left(\frac{972{,}269}{955{,}015} - 1\right)e^{-k}}$$

$$968.632 = \frac{972{,}269}{1 + (0.0180667319361)e^{-k}}$$

$$e^{-k} = \frac{972{,}269 - 968{,}632}{17{,}500.014688774} = 0.207828 \ldots$$

$$-k = -1.571043 \ldots$$

Verhulst growth model I with its equation form $P(t) = \frac{972{,}269}{1+\left(\frac{972{,}269}{955{,}015}-1\right)e^{-1.571043\ldots\times t}}$ and a relative growth rate of 157.10%.

b. Verhulst Growth Model II

$$P(2) = 971{,}511 = \frac{972{,}269}{1 + \left(\frac{972{,}269}{955{,}015} - 1\right)e^{-2k}}$$

$$971{,}511 = \frac{972{,}269}{1 + (0.0180667319361)e^{-2k}}$$

$$e^{-2k} = \frac{972{,}269 - 971{,}511}{17{,}552.028810018} = 0.0431858 \ldots$$

$$-k = -1.571120 \ldots$$

Verhulst growth model II with its equation form $P(t) = \frac{972{,}269}{1+\left(\frac{972{,}269}{955{,}015}-1\right)e^{-1.571120..\times t}}$ and a relative growth rate of 157.11%.

c. Verhulst Growth Model III

$$P(3) = 983{,}527 = \frac{972{,}269}{1 + (0.0180667319361)e^{-3k}}$$

$$e^{-3k} = \frac{972{,}269 - 983{,}527}{17{,}769.118660916} = -0.6335711 \ldots$$

$$-3k = \ln(-0.6335711 \ldots)$$

undefined.

Therefore, the Verhulst Growth Model III cannot be used in calculating the population of Bantul Regency. So that the calculation of the Verhulst Growth Model is only used from the Verhulst Growth Model I to II.

The results of calculating the population of Bantul Regency using two Verhulst models are presented in Table 4.

Table 4. Results of the Verhulst Growth Model Calculation

Year	Amount Residents (BPS Special Region of Yogyakarta)	Verhulst Growth Model	
		I	II
2013	955,015	955,015	955,015
2014	968,632	968,632	968,632
2015	971,511	971,511	971,511
2016	983,527	972,111	972,111
2017	995,264	972,236	972,236
2018	1,006,692	972,262	972,262
2019	1,022,788	972,268	972,268
2020	1,036,489	972,269	972,269

Based on the Verhulst I to II growth models, Table 4 shows that the population is expected to increase every year. The best model of the two Verhulst growth models is shown in Table 5.

Table 5. Results of the Verhulst Growth Model Calculation

Year	Verhulst Growth Model Errors	
	I	II
2013	0.000%	0.000%
2014	0.001%	0.000%
2015	0.000%	0.000%
2016	1.161%	1.161%
2017	2.313%	2.313%
2018	3.420%	3.420%
2019	4.939%	4.939%
2020	6.196%	6.196%
∑	18.030%	18.029%

Table 5 shows that the Verhulst Growth Model either I or II has the smallest error. Therefore, the Verhulst growth model used is Verhulst I growth model with the form of the equation $P(t) = \frac{972{,}269}{1+\left(\frac{972{,}269}{955{,}015}-1\right)e^{-1.5721t}}$ and a relative growth rate of 157.11%.

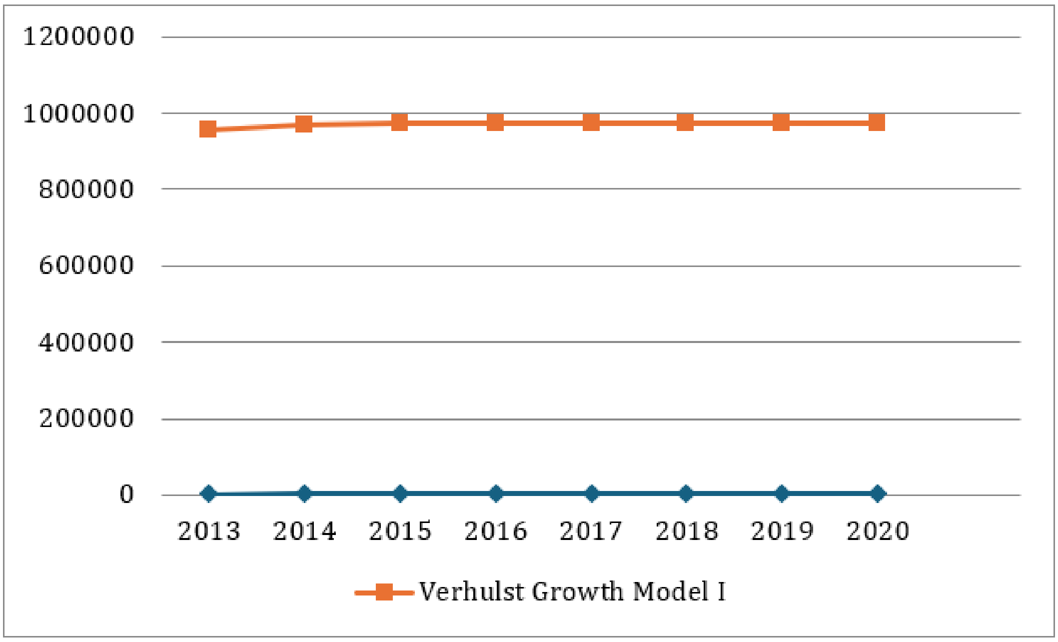

Fig. 2. Projection of the population of Bantul Regency using the Verhulst Growth Model I

3.3 Projection of Population of Bantul Regency

3.3.1 Projection of the population of Bantul Regency in 2030

Based on the calculation of the population analysis of Bantul Regency with the Malthusian Growth Model, the Malthusian IV Growth Model was obtained with the smallest error. Therefore, the Malthusian IV Growth Model is used to estimate how many people will live in Bantul Regency in 2030. Thus, for $t = 17$ it will be obtained:

$$P(17) = 955{,}015 \cdot (1.010373683)^{17} = 1{,}138{,}163.4372 \approx 1{,}138{,}163$$

Using the Malthusian Growth Model IV, the population census value of Bantul Regency in 2030 was 1,138,163 people as presented in Fig. 3.

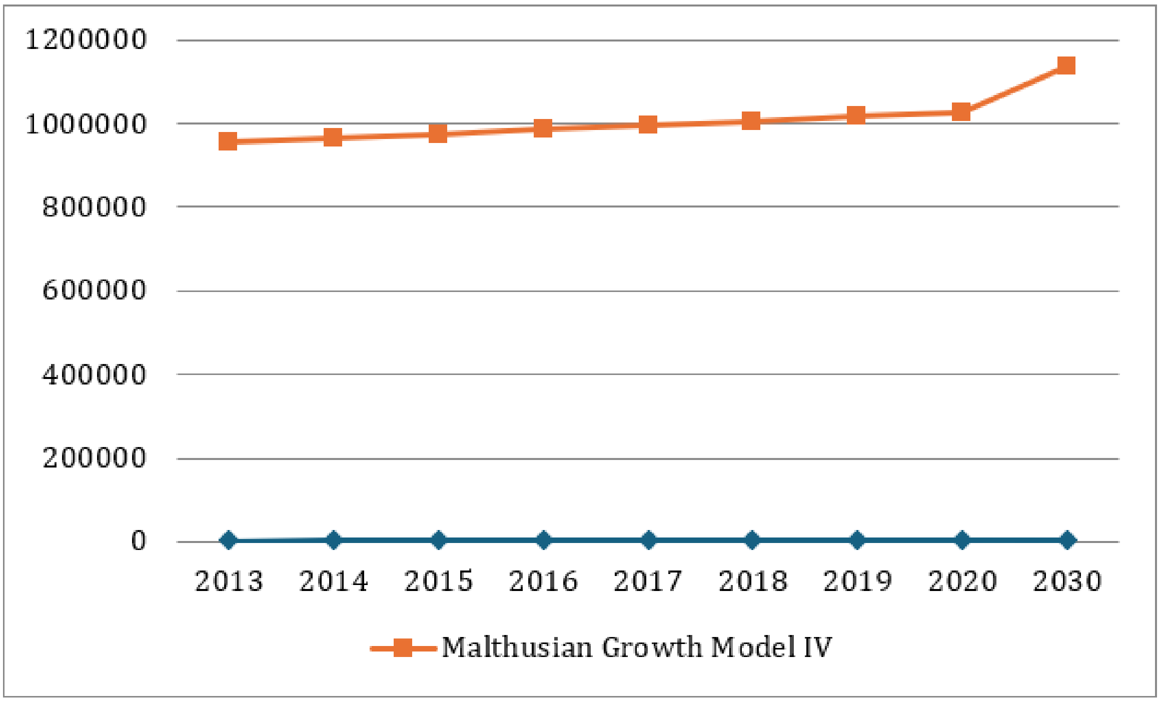

Fig. 3. Projection of the population of Bantul Regency in 2030 using the Malthusian Growth Model IV

3.3.2 Projection of the population of Bantul Regency in 2030

Based on the calculation of the population analysis of Bantul Regency based on the Verhulst Growth Model, it was found that the Verhulst model, either I or II, had the same error. Therefore, in this study, the Verhulst I model will be used to estimate the number of residents who will live in Bantul Regency in 2030. Thus, for $t = 17$ it will be obtained:

$$P(t) = \frac{972{,}269}{1 + \left(\frac{972{,}269}{955{,}015} - 1\right) e^{-1.571043\ldots\times 17}} = 972{,}269$$

By using the Verhulst I growth model, the population census value of Bantul Regency in 2030 was 972,269 people as presented in Fig. 4.

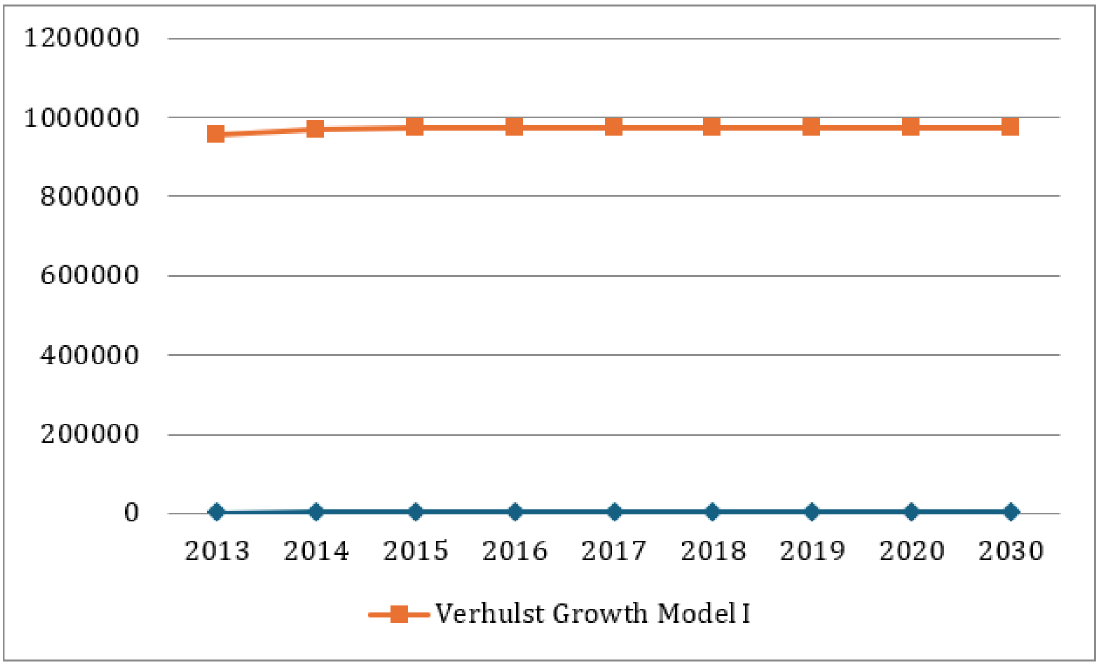

Fig. 4. Projection of the population of Bantul Regency in 2030 using the Verhulst Growth Model I

3.4 Comparison of the Malthusian Growth Model and the Verhulst Growth Model

Based on the solution that has been explained, the population growth model of Bantul Regency with the minimum error value is the Malthus IV growth model with the equation form $P(t) = 955{,}015 \cdot (1.010373683)^t$ and Verhulst I growth model with the equation form $P(t) = \frac{972{,}269}{1+\left(\frac{972{,}269}{955{,}015}-1\right)e^{-1.571043\ldots t}}$.

Table 6. Results of the calculation of the population of Bantul Regency based on Malthusian Growth Model and Verhulst Growth Model

Year	Amount Residents (BPS Special Region of Yogyakarta)	Calculation Results	
		Malthusian	Verhulst
2013	955,015	955,015	955,015
2014	968,632	964,922	968,632
2015	971,511	974,932	971,511
2016	983,527	985,045	972,111
2017	995,264	995,264	972,236
2018	1,006,692	1,005,589	972,262
2019	1,022,788	1,016,020	972,268
2020	1,036,489	1,026,560	972,269

The error values of the Malthusian Growth Model and the Verhulst Growth Model are shown in Table 7.

Table 7. Comparison Error Values of the Malthusian Growth Model and the Verhulst Growth Model

Year	Error	
	Malthusian Growth Model	**Verhulst Growth Model**
2013	0.000%	0.000%
2014	0.383%	0.001%
2015	0.352%	0.000%
2016	0.154%	1.161%
2017	0.000%	2.313%
2018	0.110%	3.420%
2019	0.662%	4.939%
2020	0.968%	6.196%
∑	0.291%	18.030%

The data in Table 6 includes the results of calculations of the Malthusian Growth Model and the Verhulst Growth Model which can be compared with BPS data as shown in Fig. 5.

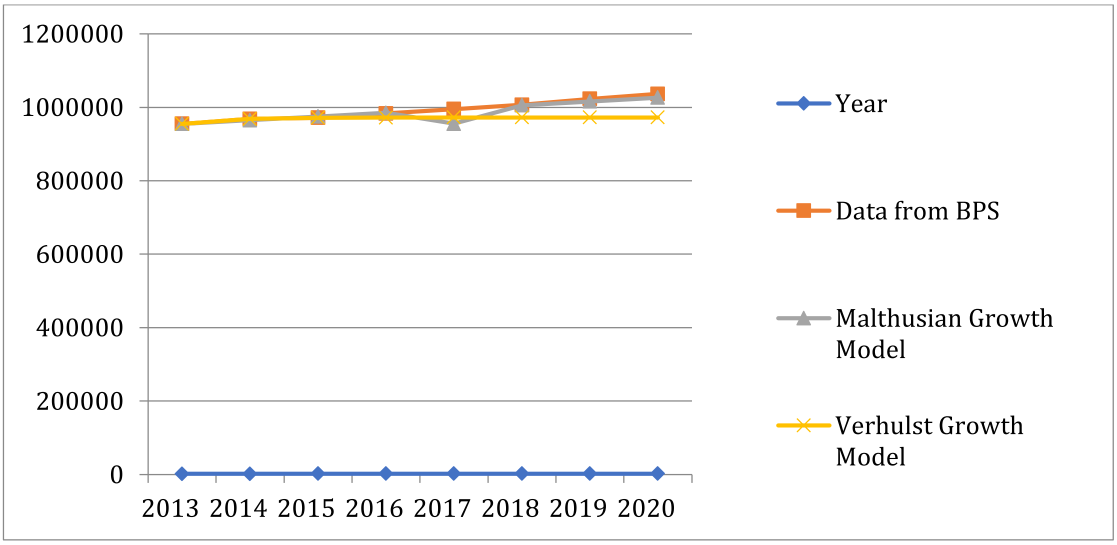

Fig. 5. Comparison between BPS Data, the Malthusian Growth Model, and the Verhulst Growth Model

Fig. 5. shows that the population graph based on the Malthusian growth model is the graph that is closest to the population diagram according to BPS. According to [16], the model that provides the most accurate representation is the model with acceptable data form or the one with the smallest error. Thus, it can be concluded that the Malthusian IV growth model is a more appropriate model to use to predict the population of Bantul Regency in 2030.

4 Conclusion

The first population growth model used is the Malthusian growth model. By utilizing the equation $P(t) = 955{,}015 \cdot (1.010373683)^t$, the Malthusian growth model is used to predict the population of Bantul Regency. The second population growth model is the Verhulst growth model, and the results of the analysis of the predicted population of Bantul Regency are 972,269 formulated with $P(t) = \frac{972{,}269}{1+\left(\frac{972{,}269}{955{,}015}-1\right)e^{-1.571043\ldots t}}$. In projecting the population of Bantul Regency in 2030 using the Malthus growth model, the projection result is 1,138,163 people. And using the Verhulst growth model, the projection result is 972,269 people. Then, compare the two models to find the smallest error. With an error of 0.291%, the Malthusian growth model is considered the most accurate model in predicting the population of Bantul Regency in 2030.

Further research can also examine the application of these two models to other regional populations. In addition, the Malthus and Verhulst Growth Model, which is discussed in this article, uses the concept of ordinary derivatives. Researchers can develop this model using fractional derivatives and compare it with models using ordinary derivatives.

References

[1] C. D. Pratiwi, "Aplikasi Persamaan Diferensial Model Populasi Logistik untuk Mengestimasi Penduduk di Kota Balikpapan," *AdMathEdu J. Ilm. Pendidik. Mat. Ilmu Mat. dan Mat. Terap.*, vol. 10, no. 1, pp. 63–76, 2021.

[2] BPS, "Jumlah Penduduk Kabupaten Bantul tahun 2013-2020." https://bantulkab.bps.go.id/subject/12/kependudukan (accessed Apr. 29, 2024).

[3] R. R. Indraswari and R. J. Yuhan, "Faktor-Faktor Yang Memengaruhi Penundaan Kelahiran Anak Pertama di Wilayah Perdesaan Indonesia: Analisis Data SDKI 2012," *J. Kependud. Indones.*, vol. 12, no. 1, pp. 1–12, 2017.

[4] E. Rochaida, "Dampak Pertumbuhan Penduduk Terhadap Pertumbuhan Ekonomi Dan Keluarga Sejahtera Di Provinsi Kalimantan Timur. In Forum Ekonomi: Jurnal Ekonomi, Manajemen Dan Akuntansi," *Forum Ekon. J. Ekon. Manaj. Dan Akunt.*, vol. 18, no. 1, 2016.

[5] Y. K. Pandu, "Prediksi penduduk kabupaten alor dengan menggunakan model pertumbuhan logistik pada beberapa tahun mendatang," *Asimtot J. Kependidikan Mat.*, vol. 2, no. 1, pp. 71–81, 2020.

[6] R. Andika, "Penerapan Model Exponensial Dan Logistik Dalam Prediksi Populasi: Studi Kasus Kota Palembang," *J. Inform. Dan Tek. Elektro Terap.*, vol. 12, no. 2, 2024.

[7] T. . Malthus and D. Winch, *Malthus: "An Essay on the Principle of Population" (Cambridge Texts in the History of Political Thought)*. Cambridge University Press; Revised ed. edition, 1992.

[8] M. Mondol and Biswas, "Mathematical Modeling And Predicting The Current Trends Of Human Population Growth In Bangladesh," *Adv. Model. Anal.*, vol. 55, no. 2, pp. 62–69, 2018.

[9] R. Manafe, Ariyanto, and K. B. Ginting, "Analisis Model Verhults Kaitannya dengan Ketersediaan Dokter Umum di Kabupaten Timor Tengah Selatan (TTS)."

[10]D. Anggreini, "Penerapan Model Populasi Kontinu Pada Perhitungan Proyeksi Penduduk Di Indonesia (Studi Kasus: Provinsi Jawa Timur)," *E-Jurnal Mat.*, vol. 9, no. 4, pp. 229–239, 2020.

[11]D. Anggreini, "Penerapan Persamaan Diferensial Verhulst dalam Menentukan Proyeksi Penduduk di Kabupaten Tulungagung," *J. Fourier*, vol. 7, no. 2, pp. 87–102, 2018.

[12]W. Putri, "PERBANDINGAN MODEL MALTHUS DAN MODEL VERHULST UNTUK ESTIMASI JUMLAH PENDUDUK INDONESIA TAHUN 2000 - 2014," *J. Mat. UNAND*, vol. 4, no. 1, pp. 1–11, 2015.

[13]N. Nurmadhani and F. Faisol, "Penerapan Model Pertumbuhan Logistik Dalam Memproyeksikan Jumlah Penduduk Di Kabupaten Sumenep," *J. Edukasi Dan Sains Mat.*, vol. 8, no. 2, pp. 145–156, 2022.

[14]M. L. W. Misi, O. P. Maure, and D. G. Ludji, "Perbandingan Model Populasi Malthus Dan Model Populasi Verhulst Dalam Mengestimasi Jumlah Penduduk Kabupaten Ngada," *Asimtot J. Kependidikan Mat.*, vol. 5, no. 1, pp. 43–52, 2023.

[15]D. Kerami, *BMP MATA4324 Pemodelan Matematis Ed. 2*. Jakarta: Universitas Terbuka, 2021.

[16]A. Kurniawan, I. Holisin, and F. Kristanti, "Aplikasi persamaan diferensial biasa model eksponensial dan logistik pada pertumbuhan penduduk kota Surabaya," *MUST J. Math. Educ. Sci. Technol.*, vol. 2, no. 1, pp. 129–141, 2017.