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Implementation of the Logistic Growth Model for Projecting the Population of Kuningan Regency in 2026–2035

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Abstract
Differential equations a branch of mathematics that is widely used to solve various problems in real life. In the context of population, differential equations are used to model and project the population of a region in a certain period. This study aims to analyze population growth in Kuningan Regency using a logistic growth model and project the population of Kuningan Regency for the years 2026–2035. The data used is the population data in Kuningan Regency from 2015-2024, obtained from the Central Statistics Agency of Kuningan Regency. Based on the calculation results, nine logistic models were obtained, with an environmental carrying capacity of 1,266,373 people. Model IX was selected as the best model, with a relative growth rate of 17.02% per year, a MAPE value of 1.34%, a MAE value of 14,633 people, and a RMSE value of 23,938 people. The model projects that the population of Kuningan Regency will continue to increase from 1,228,607 people in 2026 to around 1,258,015 people in 2035.

Keywords: *differential equations, logistic growth model, MAPE, MAE, RMSE, population projections.*

1. INTRODUCTION

Indonesia is among the most populous countries in the world, so it requires careful attention and appropriate policies from the government and related institutions so that its population can become a productive resource for national development. Population growth is defined as the increase in the number of people in a certain area and time which is influenced by the number of births minus the number of deaths in all age groups. In demography, population growth is generally classified into two types: natural growth and total growth. Natural population growth is driven only by births and deaths, while total population growth is influenced by births, deaths, immigration and emigration [10].

Continuous population growth resulting from natural increase and urbanization has led to rapid residential expansion accompanied by uncontrolled land management [3]. According to [4], population issues have long constituted a critical concern for both the Indonesian government and demography experts. Population projections, based on specified assumptions,

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attempt to forecast future trends in population size, birth, migration, and death [11]. Therefore, population projections need to be carried out for a region, including Kuningan Regency.

Kuningan Regency is one of the regencies in West Java Province, covering a total area of 1,194.09 km^2. The population density in Kuningan Regency in 2024 reached 1,017 individuals per km^2 [14]. According to data from the Central Statistics Agency (BPS) of Kuningan Regency, the population has been increasing each year.

Population projections can be carried out through mathematical modeling using differential equations, such as the exponential growth model and the logistic growth model. The exponential model describes unrestricted population growth in which the environment imposes no limiting constraints, so that intraspecific competition for resources is absent. In contrast, the logistic model incorporates a number of environmental limits to prevent the population from growing infinitely [5]. Based on a comparative study of both approaches, Lubis et al. [7] found that the logistic model outperforms the exponential model in long-term projections, particularly when the data exhibit a decelerating growth tendency.

In a study by Mangobi et al. [8], the logistic model was shown to describe population growth rates more realistically than the exponential model. This finding is further corroborated by [6], which concluded that the logistic model is the best model for projecting population numbers in the future.

Based on the foregoing background, the research questions addressed in this study are: (1) how the logistic growth model is implemented to describe population growth in Kuningan Regency, and (2) what population projections for Kuningan Regency over the period 2026–2035 are obtained using the logistic growth model.

2. RESEARCH METHODS

2.1. **Data.** The data used in this study consist of the annual population of Kuningan Regency from 2015 to 2024, obtained from the Central Statistics Agency (BPS) of Kuningan Regency. These data are presented in Table 1.

TABLE 1. Population data of Kuningan Regency, 2015–2024

Year	**Population**
2015	1,055,417
2016	1,061,886
2017	1,068,201
2018	1,074,497
2019	1,170,942
2020	1,167,686
2021	1,180,391
2022	1,196,017
2023	1,201,764
2024	1,213,927

Source: Kuningan Regency in Figures, 2015–2024 (BPS Kuningan).

2.2. **Methods and Research Procedures.** The method used in this research is the literature study method, namely by studying theoretical studies, references, and scientific literature related to the research topic[15]. In addition, a case study method was used by implementing a logistic growth model on population data in Kuningan Regency.

2.3. **Parameter Estimation of the Logistic Growth Model.** Parameter estimation for the logistic growth model was carried out in two main stages. First, the environmental carrying capacity was estimated from the first three data points using an analytical approach derived from the logistic model. Subsequently, the growth rate was estimated using the Nonlinear

Least Squares (NLS) method based on the Levenberg–Marquardt algorithm, which minimizes the sum of squared residuals between observed and projected values.

2.4. **Goodness-of-Fit Measures.** Three error metrics were employed to assess the degree of fit between the model outputs and the observed data: MAPE, MAE, and RMSE. The model yielding the smallest error values is regarded as the best-fitting model.

2.4.1. *Mean Absolute Percentage Error (MAPE).* MAPE measures the average absolute percentage deviation of projected values from actual values. MAPE was chosen in this study because it expresses prediction error as a percentage, thus facilitating relative comparisons of accuracy levels between the resulting logistic models. According to [13], MAPE is suitable for comparing the relative error levels of competing models and selecting the best one. The formula for MAPE is:

$$MAPE = \frac{1}{n}\sum_{t=1}^{n}\frac{|Y_t - \hat{Y}_t|}{Y_t} \times 100\%,$$

where Y_t denotes the actual population, $\hat{Y}_t$ denotes the projected population, and n is the number of data points.

2.4.2. *Mean Absolute Error (MAE).* MAE represents the average absolute deviation between the projected and actual values [16]. The formula is:

$$\text{MAE} = \frac{1}{n}\sum_{t=1}^{n}|Y_t - \hat{Y}_t|,$$

with the same information as in the previous formula.

2.4.3. *Root Mean Squared Error (RMSE).* RMSE measures the square root of the average squared deviation between projected and actual values. In [17], RMSE was used to quantify the discrepancy between observed data and processed model outputs. The formula is:

$$\text{RMSE} = \sqrt{\frac{1}{n}\sum_{t=1}^{n}(Y_t - \hat{Y}_t)^2},$$

with the same information as in the previous formula.

2.5. **Research Procedure.** After collecting the data, the following analytical steps were carried out:

(1) Determine the environmental carrying capacity.
(2) Construct the logistic growth models and estimate the growth rate .
(3) Compare actual population data with projected results.
(4) Compute the MAPE, MAE, and RMSE.
(5) Select the best logistic growth model based on the smallest error values.
(6) Project the population of Kuningan Regency for the years 2026–2035 using the selected model.
(7) Present the projection results in a population growth curve.

3. RESULTS AND DISCUSSION

3.1. **Mathematical Model.** A mathematical model is a representation of a real-world system, process, or phenomenon expressed in terms of symbols, equations, functions, or mathematical structures [1]. Mathematical modeling is a process of translating complex real-world problems into a mathematical formulation [9]. As stated in [5], mathematical modeling is designed to provide a physical description of a system through equations, or more generally through logical and computational structures. Accordingly, mathematical models serve as a means to represent a real system in a more tractable and quantifiable mathematical framework.

3.2. **The Logistic Growth Model.** The logistic growth model was first introduced by Verhulst (1804–1849). This model describes population growth subject to density-dependent constraints, which reflect the influence of intraspecific competition among individuals [12]. In the logistic growth model, it is assumed that the average total growth depends on the population (linear model) or is equal to the per capita growth rate [2]. The simplest form satisfying this assumption for the relative growth rate is:

$$\frac{1}{N}\frac{dN}{dt} = k\left(1 - \frac{N}{K}\right), \tag{1}$$

where N is the population size at time t, t denotes time in years, dN/dt is the rate of change of the population, k is the growth rate, and K is the environmental carrying capacity.

Multiplying both sides of equation (1) by N yields the logistic differential equation:

$$\frac{dN}{dt} = kN\left(1 - \frac{N}{K}\right).$$

Replacing the constant k by r (the more standard notation for the intrinsic growth rate in the logistic model literature), we obtain:

$$\frac{dN}{dt} = rN\left(1 - \frac{N}{K}\right), \tag{2}$$

where all notation is as in equation (1), with k replaced by r.

After that, solve equation (2) explicitly by finding the general solution of the equation using the following steps.

$$\begin{aligned} \frac{dN}{dt} &= rN\left(1 - \frac{N}{K}\right) \\ \frac{dN}{N\left(1 - \frac{N}{K}\right)} &= r\,dt, \\ \int \frac{K\,dN}{N(K-N)} &= \int r\,dt. \end{aligned}$$

Use partial fractions to find A, B from $\frac{K}{N(K-N)}$, so:

$$\begin{aligned} \frac{K\ dN}{N(K-N)} &= \frac{A}{N} + \frac{B}{K-N}, \\ K &= \frac{A(K-N) + BN}{N(K-N)} \end{aligned}$$

Compare the coefficients, we get $A = B = 1$. Then, continue the general solution of the equation above.

$$\begin{aligned} \int \left(\frac{1}{N} + \frac{1}{K-N}\right) dN &= \int r\ dt \\ \ln\left(\frac{N}{K-N}\right) &= rt + C \\ N &= (K-N)e^{rt+C} \\ N\left(1 + e^{rt+C}\right) &= Ke^{rt+C} \\ N(t) &= \frac{K\,e^{rt+C}}{1 + e^{rt+C}}, \end{aligned} \tag{3}$$

where N is the total population, K is the carrying capacity, e is Euler's number, r is the growth rate, t is time, and C is the integration constant.

Applying the initial condition $N(0) = N_0$ to equation (3):

$$\begin{aligned}
N(0) &= \frac{Ke^{r(0)+C}}{1+e^{r(0)+C}} \\
N_0 &= \frac{Ke^{C}}{1+e^{C}}, \\
N_0(1+e^{C}) &= Ke^{C}, \\
e^{C}(K-N_0) &= N_0, \\
C &= \ln\left(\frac{N_0}{K-N_0}\right).
\end{aligned}$$

Substituting $C = \ln\left(\dfrac{N_0}{K-N_0}\right)$ into equation (3) and simplifying yields the particular solution:

$$\begin{aligned}
N(t) &= \frac{Ke^{rt+\ln\left(\frac{N_0}{K-N_0}\right)}}{1+e^{rt+\ln\left(\frac{N_0}{K-N_0}\right)}} \\
&= \frac{K\,e^{rt}\left(\dfrac{N_0}{K-N_0}\right)}{1+e^{rt}\left(\dfrac{N_0}{K-N_0}\right)} \\
&= \frac{K\,e^{rt}N_0}{K-N_0+e^{rt}N_0} \\
&= \frac{K}{\left(\dfrac{K}{N_0}e^{-rt}-e^{-rt}+1\right)}.
\end{aligned}$$

Therefore, the explicit solution of the logistic growth model is:

$$N(t) = \frac{K}{e^{-rt}\left(\dfrac{K}{N_0}-1\right)+1}, \tag{4}$$

where N_0 is the initial population at $t = 0$, and all other notation is as previously defined.

The carrying capacity K is obtained when $t \to \infty$. This means that the value of K is the largest population when $t \to \infty$, then:

$$N(t)_{\max} = \lim_{t\to\infty} N(t) = \frac{a}{b} = K,$$

where a is the relative population growth rate and b reflects the influence of increasing population density.

In this study, the carrying capacity is estimated from the first three time steps $t = 0, 1, 2$, corresponding to the years 2015, 2016, and 2017, with respective populations N_0, N_1, and N_2.

From equation (4), then obtains:

$$\begin{aligned}
N &= \frac{\frac{a}{b}}{e^{-rt}\left(\frac{\frac{a}{b}}{N_0}-1\right)+1} \\
\frac{1}{N} &= \frac{b}{a}\left(e^{-rt}\left(\frac{a}{bN_0}-1\right)+1\right) \\
\frac{1}{N} &= \frac{b}{a}\left(1-e^{-rt}\right)+\frac{e^{-rt}}{N_0}
\end{aligned}$$

$$\frac{b}{a}\big(1-e^{-rt}\big) = \frac{1}{N}-\frac{e^{-rt}}{N_0}, \tag{5}$$

with the same description as in the previous equation. Substituting $t = 1$ and $t = 2$ into equation (5):

$$N_1 = \frac{b}{a}\big(1-e^{-r}\big) = \frac{1}{N_1}-\frac{e^{-r}}{N_0}, \tag{6}$$

$$N_2 = \frac{b}{a}\big(1-e^{-2r}\big) = \frac{1}{N_2}-\frac{e^{-2r}}{N_0}., \tag{7}$$

with the same information as in the previous equation, and N1 and N2 are the population in the first year and the second year after the initial year. Next, perform division on equations (6) and (7) to eliminate the value $\frac{a}{b}$, then obtained:

$$\frac{\frac{b}{a}(1-e^{-2r}) = \frac{1}{N_2}-\frac{e^{-2r}}{N_0}}{\frac{b}{a}(1-e^{-r}) = \frac{1}{N_1}-\frac{e^{-r}}{N_0}}$$

$$\begin{aligned}
1+e^{-r} &= \frac{N_0N_1 - N_1N_2e^{-2r}}{N_0N_2 - N_1N_2e^{-r}} \\
e^{-r}(N_0N_2 - N_1N_2e^{-r}) &= N_0(N_1-N_2) + N_1N_2e^{-r} - N_1N_2e^{-2r}
\end{aligned}$$

$$e^{-r} = \frac{N_0N_2 - N_1^2}{N_1(N_1-N_0)}. \tag{8}$$

with the same information as in the previous equation, substituting equation (8) back into equation (6), obtained:

$$\frac{b}{a}\left(1-\frac{N_0(N_2-N_1)}{N_2(N_1-N_0)}\right) = \frac{1}{N_1} - \frac{\frac{N_0(N_2-N_1)}{N_2(N_1-N_0)}}{N_0}$$

$$\frac{b}{a} = \frac{\frac{N_1^2 - N_0N_2}{N_1N_2(N_1-N_0)}}{\frac{N_1N_2 - 2N_0N_2 + N_0N_1}{N_2(N_1-N_0)}}$$

$$\frac{a}{b} = \frac{N_1(2N_0N_2 - N_1N_2 - N_0N_1)}{N_0N_2 - N_1^2}$$

Based on the calculation results above, the environmental carrying capacity equation can be written as:

$$K = \frac{N_1(2N_0N_2 - N_1N_2 - N_0N_1)}{N_0N_2 - N_1^2}. \tag{9}$$

3.3. **Solution of the Logistic Growth Model.** To solve the logistic growth model using the population data of Kuningan Regency from Table 1, let $t = 0, 1, 2$ represent the years 2015, 2016, and 2017, with $N_0 = 1{,}055{,}417$, $N_1 = 1{,}061{,}886$, and $N_2 = 1{,}068{,}201$. Substituting these values into equation (9):

$$\begin{aligned} K &= \frac{N_1(2N_0N_2 - N_1N_2 - N_0N_1)}{N_0N_2 - N_1^2} \\ &= \frac{1{,}061{,}886(2(1{,}055{,}417)(1{,}068{,}201) - (1{,}061{,}886)(1{,}068{,}201) - (1{,}055{,}417)(1{,}061{,}886))}{(1{,}055{,}417)(1{,}068{,}201) - (1{,}061{,}886)^2} \\ &= 1{,}266{,}372.847. \end{aligned}$$

Accordingly, the logistic solution takes the form:

$$N(t) = \frac{K}{e^{-rt}\left(\frac{K}{N_0} - 1\right) + 1}$$

$$N(t) = \frac{1{,}266{,}372.847}{(0.199879)\,e^{-rt} + 1}. \tag{10}$$

Next, we will look for a logistics model that can represent the population growth rate in Kuningan Regency. Let $t = 1$ (year 2016), then $N_1 = 1{,}061{,}886$. From (10), it is obtained:

$$\begin{aligned} 1{,}061{,}886 &= \frac{1{,}266{,}372.847}{(0.199879)\,e^{-r} + 1}, \\ (0.199879)\,e^{-r} &= \frac{1{,}266{,}372.847 - 1{,}061{,}886}{1{,}061{,}886} \\ (0.199879)\,e^{-r} &= 0.192569, \\ -r &= \ln(0.96343), \\ r &= 0.03725. \end{aligned}$$

Then, substitute the value of r into equation (10) so that:

$$N(t) = \frac{1{,}266{,}372.847}{0.199879\,e^{-0.03725\,t} + 1}. \tag{Model I}$$

Subsequently, the $N(t)$ value for the following year is calculated by substituting the t value into equation (10) in the same manner as in the previous calculation. The results of the $N(t)$ value calculation for $t = 1$ to $t = 9$ are presented in the following Table 2:.

Table 2. Logistic growth models and their estimated growth rates

Model	Equation	Growth Rate (%)
I	$N(t) = \dfrac{1{,}266{,}372.847}{(0.199879)\, e^{-(0.03725)\,t} + 1}$	3.73
II	$N(t) = \dfrac{1{,}266{,}372.847}{(0.199879)\, e^{-(0.037277)\,t} + 1}$	3.73
III	$N(t) = \dfrac{1{,}266{,}372.847}{(0.199879)\, e^{-(0.037573)\,t} + 1}$	3.76
IV	$N(t) = \dfrac{1{,}266{,}372.847}{(0.199879)\, e^{-(0.22428)\,t} + 1}$	22.43
V	$N(t) = \dfrac{1{,}266{,}372.847}{(0.199879)\, e^{-(0.172157)\,t} + 1}$	17.22
VI	$N(t) = \dfrac{1{,}266{,}372.847}{(0.199879)\, e^{-(0.168237)\,t} + 1}$	16.82
VII	$N(t) = \dfrac{1{,}266{,}372.847}{(0.199879)\, e^{-(0.17474)\,t} + 1}$	17.47
VIII	$N(t) = \dfrac{1{,}266{,}372.847}{(0.199879)\, e^{-(0.16414)\,t} + 1}$	16.41
IX	$N(t) = \dfrac{1{,}266{,}372.847}{(0.199879)\, e^{-(0.1702)\,t} + 1}$	17.02

Table 3 and Table 4 present the comparison between actual population data and the projected values obtained from all nine logistic models for Kuningan Regency over the period 2015–2024.

Table 3. Comparison of actual population and projected values (Models I–V)

Year	Actual	Model I	Model II	Model III	Model IV	Model V
2015	1,055,417	1,055,417	1,055,417	1,055,417	1,055,417	1,055,417
2016	1,061,886	1,061,885	1,061,890	1,061,941	1,091,963	1,083,975
2017	1,068,201	1,068,192	1,068,201	1,068,300	1,123,037	1,109,243
2018	1,074,497	1,074,340	1,074,353	1,074,497	1,149,169	1,131,445
2019	1,170,942	1,080,330	1,080,347	1,080,535	1,170,942	1,150,838
2020	1,167,686	1,086,164	1,086,185	1,086,414	1,188,943	1,167,686
2021	1,180,391	1,091,845	1,091,870	1,092,137	1,203,730	1,182,257
2022	1,196,017	1,097,375	1,097,403	1,097,706	1,215,813	1,194,808
2023	1,201,764	1,102,756	1,102,787	1,103,124	1,225,644	1,205,583
2024	1,213,927	1,107,991	1,108,024	1,108,393	1,233,615	1,214,806

Table 4. Comparison of actual population and projected values (Models VI–IX)

Year	Actual	Model VI	Model VII	Model VIII	Model IX
2015	1,055,417	1,055,417	1,055,417	1,055,417	1,055,417
2016	1,061,886	1,083,362	1,084,378	1,082,720	1,083,669
2017	1,068,201	1,108,160	1,109,952	1,107,022	1,108,703
2018	1,074,497	1,130,021	1,132,377	1,128,518	1,130,736
2019	1,170,942	1,149,181	1,151,918	1,147,426	1,150,013
2020	1,167,686	1,165,888	1,168,855	1,163,976	1,166,792
2021	1,180,391	1,180,391	1,183,466	1,178,400	1,181,330
2022	1,196,017	1,192,933	1,196,019	1,190,924	1,193,878
2023	1,201,764	1,203,742	1,206,768	1,201,762	1,204,671
2024	1,213,927	1,213,032	1,215,944	1,211,116	1,213,927

The MAPE, MAE, and RMSE values for all nine models are presented in Table 5.

Table 5. MAPE, MAE, and RMSE values for each logistic model

Model	MAPE (%)	MAE (individuals)	RMSE (individuals)
Model I	4.74	56,443	73,111
Model II	4.74	56,426	73,091
Model III	4.73	56,257	72,870
Model IV	2.40	26,754	34,400
Model V	1.36	14,796	24,166
Model VI	1.34	14,648	23,732
Model VII	1.40	15,241	24,497
Model VIII	1.38	15,080	23,375
Model IX	1.34	14,633	23,938

The results in Table 5 show that Models VI and IX share the lowest MAPE value of 1.34%, indicating equivalent relative accuracy. Since model selection should not rely solely on a single error measure, further evaluation was performed using MAE and RMSE. Based on the MAE criterion, Model IX yields a smaller value (14,633 individuals) than Model VI (14,648 individuals). The difference in RMSE between the two models is relatively small so overall, Model IX is selected as the best model overall on account of its lowest combined error. Furthermore, since the MAPE of Model IX is less than 10%, the logistic growth model is classified as highly accurate for population projection purposes, in accordance with the criterion proposed by [18].

Model IX has a relative population growth rate of $r = 17.02\%$ per year. This implies that under initial conditions, the population of Kuningan Regency grows at a rate of approximately 17.02% annually. Equivalently, for every 100 individuals, approximately 17 new individuals are added per year. However, this growth rate decelerates as the population approaches the environmental carrying capacity K.

3.4. **Population Projection for Kuningan Regency, 2026–2035.** The selected model for projecting the population of Kuningan Regency over the period 2026–2035 is Model IX, given by:

$$N(t) = \frac{1{,}266{,}372.847}{(0.199879)\, e^{-(0.1702)\, t} + 1},$$

where $t = 0$ corresponds to the year 2015.

For instance, the projected population in 2026 is obtained by setting $t = 2026 - 2015 = 11$:

$$N(11) = \frac{1{,}266{,}372.847}{(0.199879)\, e^{-(0.1702)\times 11} + 1} = 1{,}228{,}607.$$

The projection calculations for 2027-2035 were performed using the same steps as in the previous calculations. The results of the population projection calculations for Kuningan Regency for 2026-2035 are presented in Table 6 below: .

TABLE 6. Projected population of Kuningan Regency, 2026–2035

Year	**Projected Population**
2026	1,228,607
2027	1,234,369
2028	1,239,270
2029	1,243,435
2030	1,246,970
2031	1,249,967
2032	1,252,507
2033	1,254,657
2034	1,256,476
2035	1,258,015

Based on Table 6, the plot of population projection data in Kuningan Regency for 2026-2035 using Microsoft Excel can be seen in Figure 1 below:

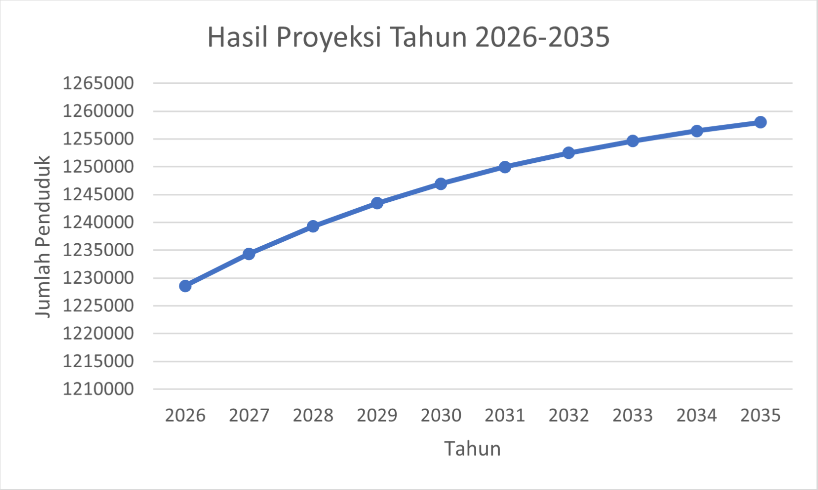

FIGURE 1. Projected population growth of Kuningan Regency, 2026–2035

The graph above shows that Kuningan Regency has a stable population growth trend from year to year. This is evident in the projected data line, which consistently increases without sharp fluctuations.

4. CONCLUSION

Based on data from the Central Statistics Agency (BPS) of Kuningan Regency, this study concludes that the logistic growth model can be effectively employed to project the population of Kuningan Regency for the period 2026–2035. Among the nine logistic models evaluated, Model IX given by

$$N(t) = \frac{1{,}266{,}372.847}{(0.199879)\, e^{-(0.1702)\, t} + 1},$$

achieves the highest accuracy, with an environmental carrying capacity of $K = 1{,}266{,}373$ individuals, a relative growth rate of $r = 17.02\%$ per year, a MAPE of 1.34%, a MAE of 14,633 individuals, and a RMSE of 23,938 individuals. These error metrics confirm that the model is highly accurate for population projection.

The population of Kuningan Regency is projected to increase steadily from 1,228,607 individuals in 2026 to approximately 1,258,015 individuals in 2035. This outcome indicates a stable and sustained population growth trend, provided that no significant inhibiting factors, such as large-scale migration, natural disasters, or major demographic policy shifts, occur during the projection period.

For future research, it is recommended that additional variables such as birth rate, mortality rate, and migration data be incorporated to enhance the accuracy of the projections. Furthermore, the use of a longer time series of population data would allow for a more comprehensive analysis of growth patterns over time.

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