BAREKENG: Journal of Mathematics and Its Applications
September 2024 Volume 18 Issue 3 Page 1595–1606
P-ISSN: 1978-7227 E-ISSN: 2615-3017
https://doi.org/10.30598/barekengvol18iss3pp1595-1606

APPLICATION OF DIFFERENTIAL EQUATIONS IN POPULATION GROWTH ESTIMATION OF KEDIRI CITY AS THE IMPLEMENTATION OF THE 2030 SDGS TARGET

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ABSTRACT

Article History:

Received: 21st December 2023
Revised: 18th March 2024
Accepted: 25th June 2024
Published: 1st September 2024

Keywords:

Differential Equation;
Population Estimation;
Logistics Model.

This study focuses on analyzing the application of differential equations in modeling the population growth of Kediri City through a logistic growth model, and aims to predict the city's population for the years 2021-2030. Employing a literature study approach, this research utilizes secondary data sourced from the official website of the BPS (Central Statistics Agency) of Kediri City. The data encompasses population figures from 2005 to 2020. To ensure the accuracy of the population predictions made by the logistic growth model, a comparison with the official data from the Central Statistics Agency is necessary. A critical aspect of this research involves estimating the carrying capacity of Kediri City's population, which is identified as 295,672 individuals in the year 2030. The findings indicate a significant growth trend in the population, characterized by a specific growth rate. To validate the accuracy of the logistic growth model, the Mean Absolute Percentage Error (MAPE) method was applied, resulting in an error percentage that falls within the highly accurate category, thus affirming the reliability of the model in predicting population growth trends.

How to cite this article:

N. Andini, D. Hamidah and A. M. Surur., "APPLICATION OF DIFFERENTIAL EQUATIONS IN POPULATION GROWTH ESTIMATION OF KEDIRI CITY AS THE IMPLEMENTATION OF THE 2030 SDGS TARGET," *BAREKENG: J. Math. & App.*, vol. 18, iss. 3, pp. 1595-1606, September, 2024.

Journal homepage: *https://ojs3.unpatti.ac.id/index.php/barekeng/*
Journal e-mail: *barekeng.math@yahoo.com; barekeng.journal@mail.unpatti.ac.id*
Research Article · Open Access

1. INTRODUCTION

The concept of sustainable development has evolved in modern society or several developed countries and international institutions who believed to be applicable by developing countries through local wisdom like Indonesia [1]. The Sustainable Development Goals (SDGs) were born after the end of the Millennium Development Goals (MDGs). It accommodates all changes and adds several new goals, which are arranged based on social, economic, environmental and institutional dimensions [2]. According to Aziz, sustainable development changes the short-term perspective into the long term and places the dominant economic aspects together with social and environmental development. This is motivated by the increase in population, which has raised issues of social development that have become obstacles to obtaining the benefits of economic growth [3]. So, SDGs exist as an effort of carried out to meet human needs in short term and long term to achieve a high level of quality of life and growth balanced with social and environmental aspects [4].

In balancing these aspects, the SDGs bring 5 basic principles, namely people, planet, prosperity, peace, and partnership that cannot be separated from each other [5]. One of the things that become a problem in sustainable development is population or people, which is why development cannot happen without residents [6]. The population is the actor and the ultimate goal of development itself, so that a large population, especially in Indonesia, can be a potential or challenge in the economic growth of a country [7]. The linkages between people, resources, environment and development in implementing sustainable development goals need to be considered and managed properly to create a dynamic balance [8]. This balance can be realized if a country's equitable development distribution is also carried out properly.

According to Roziika & Nurwati, one of the influences in equitable development is the large population associated with environmental destruction due to the misalignment between production and consumption which is increasing rapidly [8]. If the population growth rate of a developing country such as Indonesia is higher, it will worsen the per capita income growth and labor productivity [9]. One solution to reducing the negative impact of population growth is population projection. According to Khakim, population projection is a process of calculating the quantity or number of residents in the future based on the assumption of factors influencing population growth in a particular area [10]. One of the concepts that can be used to estimate the total population (population) of an area and a certain time is the differential equation [11].

The application of differential equations, especially in the estimation of population growth, has been carried out quite a lot, one of which is Kurniawan who applies differential equations to population growth in the city of Surabaya [12]. From his research, two models of population growth were obtained, namely the exponential and logistical population growth models. The two models are then analyzed using graphs to show the right model in estimating the population of the city of Surabaya, and the more accurate model is the logistic growth model. Mathematical modeling using differential equations on population growth is then used in forecasting the population in Trenggalek Regency [13]. This research is motivated by population growth that is not well controlled, which can affect various aspects of economic and social life, especially in the development aspect. The data used in the calculation of the differential equation modeling concluded that the projected population in Trenggalek Regency in 2025 is more appropriate to use the logistic growth model because the value is close to the census results.

From the explanation of several studies that have been carried out, it can be concluded that the differential equation of the logistic growth model is considered more appropriate to be used in projecting population numbers in the future. The logistic growth model is a more accurate population growth estimation model than the exponential model, because the logistic growth model is closer to the total population based on actual census data [11]. The population growth rate of Kediri city in the last 3 years to 2019 was recorded at 0.73% with a population of 287,410 people and 63,404 km^2 of area, the population density level in the city of Kediri will certainly increase in line with the rate of population growth [14].

To avoid a population explosion that might occur, it is necessary to plan to control the population of the city of Kediri using the differential equation application approach of the logistic growth model. This mathematical model can be applied if the data is used accountable and complete [15]. So, the population projection can be a preference for the city government in planning for sustainable development today and in the future.

Given this context, this research aims to apply the logistic growth model using differential equations to estimate the population of Kediri City by 2030, aligning with the SDGs 2030 targets. The study is titled

"Application of Differential Equations in Population Growth Estimation of Kediri City as the Implementation of the 2030 SDGs Target".

2. RESEARCH METHODS

The type of research that will be used is literature study. Library research or literature study is a series of related activities using library data collection methods, reading and taking notes as well processing research materials [16]. In this study, the library data used by the researcher came from books or e-books, journal articles and government documents (BPS and Kediri City Government). Some of the literature related to the research was then studied to be applied in the estimation of population growth in the City of Kediri. The object of research is the population in the City of Kediri and the researchers took data collecting from the official website of the Central Statistics Agency (BPS) of the City of Kediri which can be accessed through the official address, namely https://kedirikota.bps.go.id/ on March 2, 2021. The data used in this research is secondary data. The secondary data in this study is data on the population of Kediri City from 2010-2020 which researchers took from the official website of BPS Kediri City.

Population data in 2010-2020 is data that will be used to obtain a population growth model for the City of Kediri in the next few years, while population data in 2005-2009 is used to test the validity of the resulting growth model. Population data in 2010 and 2020 was taken based on Population Census data, which shows that every 10 years, BPS conducts a Population Survey or Census. For population data other than census data, namely in addition to 2010 and 2020, namely 2005-2009 and 2011-2019, the data is obtained from the results of population projections conducted by BPS which is based on assumptions from the components of population change, such as births, deaths and migration. using the population base data from SP2010 [14].

After obtaining the data, the next thing to do is analyze the data. The steps in analyzing the data in this study include find solutions from the logistics growth model, estimating the value of carrying capacity and the rate of population growth based on the desired time-taking interval, calculating the results of the estimated population of the city of Kediri in 2010-2020, comparing the accuracy of the population estimation results calculated using the logistic growth model with the original data on the population of the city of Kediri in 2010-2020, testing the validity of the population growth model generated using population data for the years 2005-2009, calculate the estimated population in the following year, namely 2021-2030 using the logistic growth model that has been obtained previously, and the last step is draw conclusions based on the results obtained in the study.

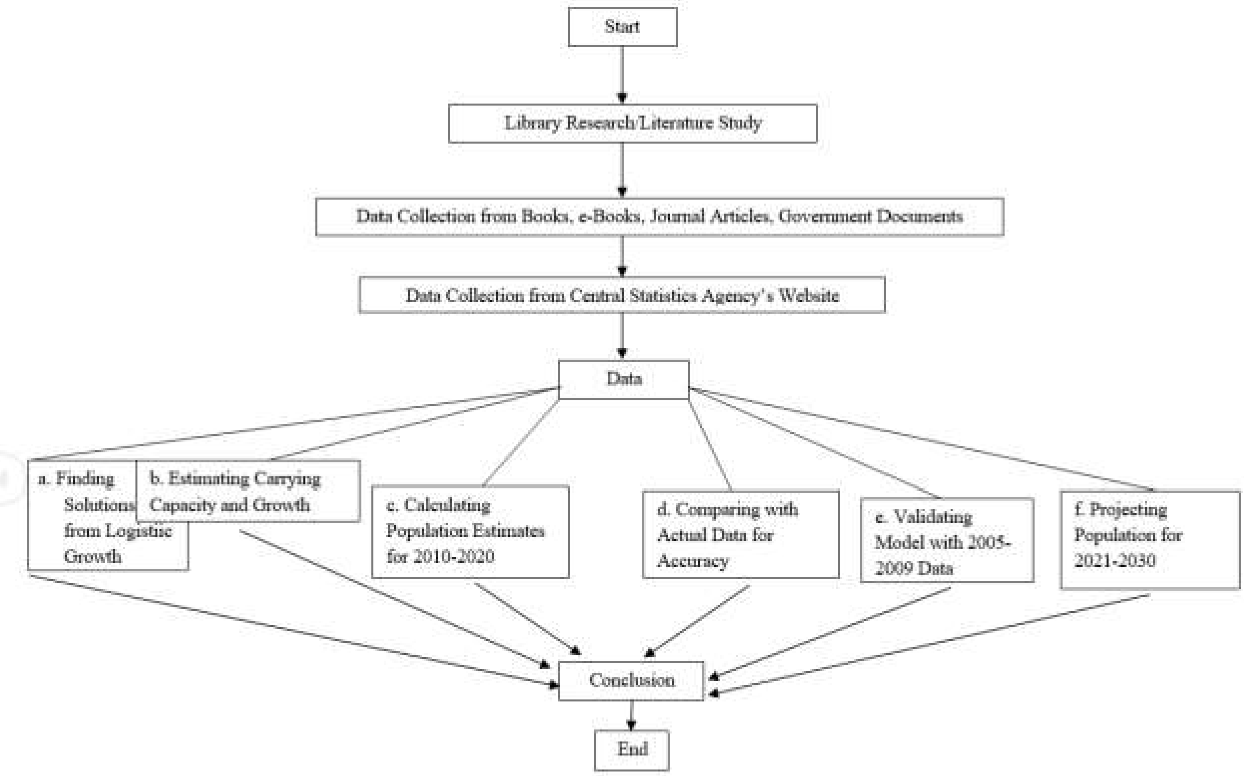

Figure 1. **The Flowchart of Research Study on Population Growth Estimation**

3. RESULTS AND DISCUSSION

Writing the results and discussion can be separated into different subs or combined into one sub. The summary of results can be presented in the form of graphs and figures. The results and discussion sections must be free from multiple interpretations. The discussion must answer research problems, support, and defend answers with results, compare with relevant research results, state the study's limitations, and find novelty.

3.1 Solution of the Logistics Growth Model

The logistics growth model is a refinement of the previous model, namely the exponential growth model. The refinement of the model is done because in reality a population cannot grow indefinitely. In addition, some of the assumptions previously mentioned, the simplest form of equation for the logistic growth model is as follows:

$$\frac{dP}{dt} = rP\left(1 - \frac{P}{K}\right) \tag{1}$$

Equation (1) is a separate differential equation, so it can be solved explicitly by finding a solution as below.

Solution:

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

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

$$\int \frac{dP}{P - \frac{P^2}{K}} = \int r\,dt$$

$$\int \frac{dP}{\frac{KP - P^2}{K}} = \int r\ dt \tag{2}$$

To simplify the equation, multiply both sides by $\frac{1}{k}$ to get:

$$\int \frac{dP}{KP - P^2} = \frac{1}{K}\int r\ dt$$
$$P = \frac{Ke^{rt+c}}{1 + e^{rt+c}} \tag{3}$$

If the initial value $t = 0$ and $P(0) = P_0$ is given, the value of c or the constant of integration will be obtained as follows:

$$c = \ln\left(\frac{P_0}{K - P_0}\right)$$

Next, substituting the value of c back into equation P, then we get:

$$P = \frac{Ke^{rt+\ln\frac{P_0}{K-P_0}}}{1 + e^{rt+\ln\frac{P_0}{K-P_0}}}$$

Based on the nature of the exponential on the natural logarithm, the following equation will be obtained:

$$P = \frac{KP_0}{P_0 + (K - P_0)e^{-rt}}$$

By multiplying $\frac{P_0}{P_0}$ in the above equation, we get a special solution to the equation of the logistic growth model:

$$P = \frac{K}{1 + \left(\frac{K - P_0}{P_0}\right)e^{-rt}} \tag{4}$$

If P_0 represents the population at $t = 0$, P_T is the population $t = T$ and P_{2T} is the population at $t = 2T$, then from **Equation (4)** we get:

$$r = -\frac{1}{T}\ln\frac{P_0(P_{2T} - P_T)}{P_{2T}(P_T - P_0)} \tag{5}$$

$$K = \frac{a}{b} = \frac{P_T(P_0P_T - 2P_0P_{2T} + P_TP_{2T})}{{P_T}^2 - P_0P_{2T}} \tag{6}$$

Equation (5) shows the population growth rate at the time interval t years and **Equation (6)** shows the carrying capacity.

3.2. Population Data of Kediri City

Data on the population of the city of Kediri is presented in the form of tables and graphs of growth as follows:

Table 1. Population Data of Kediri City in 2010-2020

No.	Years	Total Population
0	2010	268,507
1	2011	271,511
2	2012	260,297
3	2013	267,310
4	2014	278,072
5	2015	280,004
6	2016	281,978
7	2017	284,003

8	2018	285,570
9	2019	287,409
10	2020	286,796

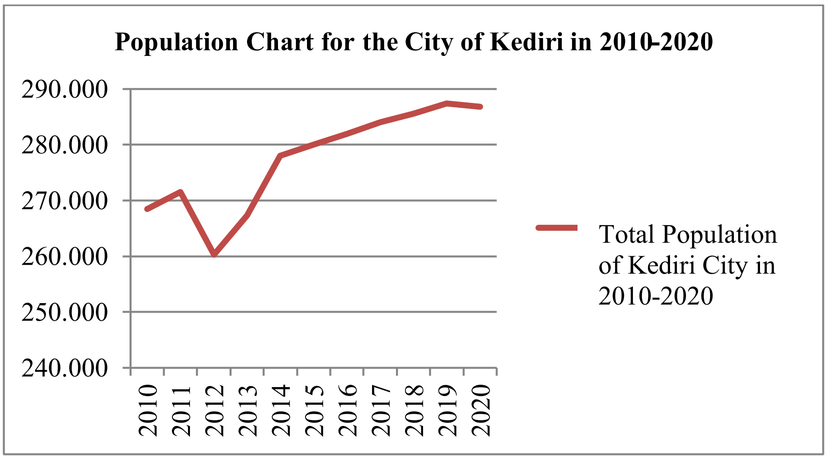

Figure 2. Population Chart of Kediri City in 2010-2020

Based on the graph above, it can be concluded that the highest population increase in the last 10 years occurred in 2019 with a population of 287,409 people. In 2012, it can be seen that the population growth chart in the city of Kediri decreased quite a bit, with a population of 260,297 people. To find out whether the population growth of Kediri city in the following years has increased or not, a population projection of the city of Kediri is carried out based on population data in previous years.

3.3. Kediri City Population Logistics Growth Model

Before estimating or projecting the population in the city of Kediri, the first step that needs to be done is to determine the logistics growth model based on data on the population of Kediri city in 2010-2020. The growth model is based on **Equation (4)** which has been analyzed previously. Therefore, the next step that needs to be done is to determine the value of K or carrying capacity and the value of r (rate of population growth).

In determining the capacity, the sampling time interval used needs to be considered. In this study, the time interval used is $\Delta t = 5$ with 3 different times taken in the last 10 years and the estimated capacity must be greater than the highest population. The following table presents the data on the population of the city of Kediri based on the time interval $t = 0$ and so on.

Table 2. Population Data of Kediri City in 2010-2020

No	Years	Year-	Number of Population to-
1.	2010	$t = 0$	$P_0 = 268{,}507$
2.	2011	$t = 1$	$P_1 = 271{,}511$
3.	2012	$t = 2$	$P_2 = 260{,}297$
4.	2013	$t = 3$	$P_3 = 267{,}310$
5.	2014	$t = 4$	$P_4 = 278{,}072$
6.	2015	$t = 5$	$P_5 = 280{,}004$
7.	2016	$t = 6$	$P_6 = 281{,}978$
8.	2017	$t = 7$	$P_7 = 284{,}003$
9.	2018	$t = 8$	$P_8 = 285{,}570$
10.	2019	$t = 9$	$P_9 = 287{,}409$
11.	2020	$t = 10$	$P_{10} = 286{,}796$

Based on the table, it can be concluded that the highest population is in 2019. So, for taking three different times in the time range $t = 5$, P_0, P_5 and P_{10} are taken. P_0 is represents the total population in 2010, P_5 represent the total population in 2015, and P_{10} represent the total population in 2020. So, based on **Equation (5)** the value of K (capacity) is obtained as follows:

$$K = \frac{P_T(P_0P_T - 2P_0P_{2T} + P_TP_{2T})}{{P_T}^2 - P_0P_{2T}}$$
$$= \frac{P_5(P_5P_0 - 2P_0P_{10} + P_5P_{10})}{{P_5}^2 - P_0P_{10}} = 295.672$$

If the resulting P_0 and K values are substituted into **Equation (4)**, the equation will be obtained:

$$P_t = \frac{295,672}{1 + (0.10117)e^{-rt}} \tag{7}$$

After obtaining the value of the capacity (K), the next step is to find the rate of population growth in the Kediri city in a predetermined time interval. Based on **Equation (6)**, the value of the population growth rate of the Kediri city in an interval of 5 years is as follows:

$$r = -\frac{1}{T}\ln\frac{P_0(P_{2T} - P_T)}{P_{2T}(P_T - P_0)}$$
$$= -\frac{1}{5}\ln\frac{P_0(P_{10} - P_5)}{P_{10}(P_5 - P_0)} = 0.11845$$

Data regarding the population growth rate in Kediri each year can be seen in the table below.

Table 3. Kediri City Population Growth Rate From Year to Year

t	Years	Total Population	*r*
0	2010	268,507	-
1	2011	271,511	0.12832
2	2012	260,297	-0.29513
3	2013	267,310	-0.04759
4	2014	278,072	0.46903
5	2015	280,004	0.59224
6	2016	281,978	0.73393
7	2017	284,003	0.90110
8	2018	285,570	1.05081
9	2019	287,409	1.25817
10	2020	286,796	1.18447

Due to the value of the population growth rate used to project the population of Kediri city in 2010-2020 is 0.11845, it will be substituted into **Equation (7)**. The form of the resulting logistic growth model equation is as follows:

$$P_t = \frac{295,672}{1 + (0.10117)e^{-(0.11845)t}} \tag{8}$$

The results of the obtained equations will then be compared with the original population data from the Central Bureau of Statistics, Kediri. The resulting logistic growth model will then also look for the smallest error or error value based on actual data to conclude whether the model is valid and can be used to project the population of Kediri in the following years. The comparison of population data in the city of Kediri with projections using the logistic growth model is presented in the following table.

Table 4. Calculation Result of Population of Kediri City Based on Logistics Model

Year	Total Population	Prediction
2010	268,507	268,507
2011	271,511	271,291
2012	260,297	273,813
2013	267,310	276,093
2014	278,072	278,151
2015	280,004	280,004

2016	281,978	281,671
2017	284,003	283,169
2018	285,570	284,513
2019	287,409	285,717
2020	286,796	286,796

The prediction results based on the logistic growth model in the table above show that the population according to the Kediri BPS and the model results have quite a small difference. For more details, see the graphic image below.

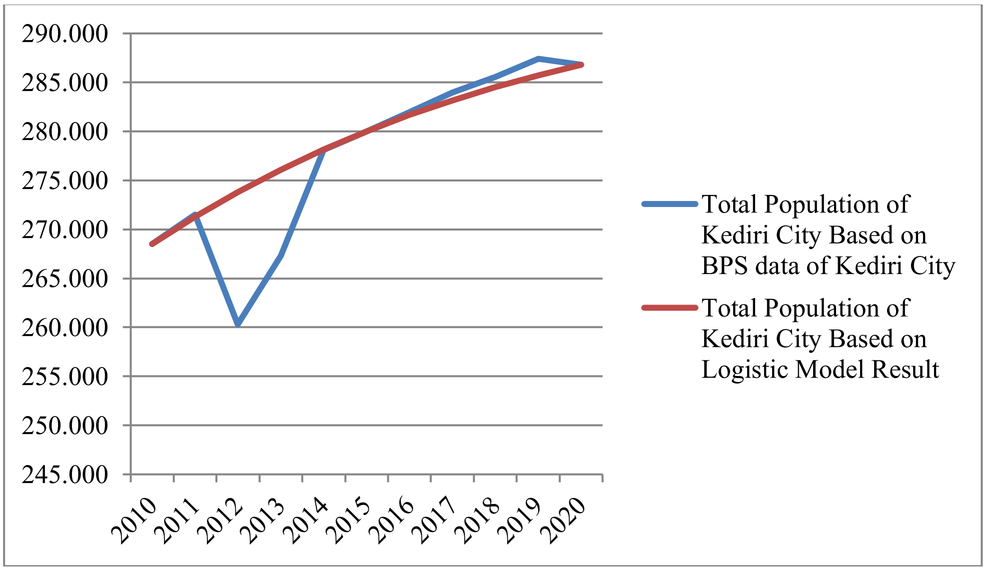

Figure 3. Graph Population of Kediri City based on BPS data and Logistics Growth Model in 2010-2020

In the graphic above, it can be seen that the prediction results of the population of the city of Kediri in 2010-2020 using the logistic growth model show a graph that is almost close to the original data from BPS. The graph does not show a sudden increase or decrease with a significant difference. Although in 2012 it showed a fairly large difference in the figure, the resulting error value was still included in a relatively small number with the indicator still below 10%.

3.4. Validity Test of Population Growth Model

The number of natives based on data from the BPS of Kediri City every year is compared with the predicted population data using a logistic model through the calculation of the value of error or error. The following is a table that shows that the error or error value of the two data is quite small.

Table 5. Comparison of Kediri City Population Based on BPS Data and Logistics Growth Model 2010-2020

Year	Total Population	Prediction with Logistics Model	Error	Error (%)
2010	268,507	268,507	0	0.000%
2011	271,511	271,291	0.00081	0.081%
2012	260,297	273,813	0.051926	5.193%
2013	267,310	276,093	0.032858	3.286%
2014	278,072	278,151	0.000282	0.028%
2015	280,004	280,004	0	0.000%
2016	281,978	281,671	0.001088	0.109%
2017	284,003	283,169	0.002936	0.294%
2018	285,570	284,513	0.003702	0.370%
2019	287,409	285,717	0.005886	0.589%
2020	286,796	286,796	0	0.000%

Table 5 presents a comparative analysis between the actual population figures of Kediri City from the Central Statistics Agency (BPS) and the predictions made using a logistic growth model from 2010 to 2020.

The inclusion of both actual and predicted numbers allows for an evaluation of the model's precision. Notably, the model achieves perfect accuracy with zero error in several years like 2010, 2015, and 2020. However, in other years, such as 2012 and 2013, the model shows a more significant deviation from the actual data, with errors around 5% and 3% respectively. This variation in accuracy highlights the model's effectiveness in certain years and potential areas for refinement in others.

The comparison of population data through BPS with population data based on the logistic growth model of Kediri City in 2005-2009 is presented in the following table.

Table 6. Comparison of Kediri City Population Based on BPS Data and Logistics Growth Model for 2005-2009

Year	Total Population (X_t)	Prediction with Logistics Model $(\breve{X}_t)$	Error	Error (%)
2005	256,563	249,951	0.02577	2.577%
2006	259,042	254,344	0.01813	1.813%
2007	261,545	258,378	0.01211	1.211%
2008	264,072	262,071	0.00758	0.758%
2009	266,623	265,440	0.00444	0.444%

Similar to Table 5, Table 6 compares the actual population data of Kediri City with the logistic model's predictions, but for the years 2005-2009. The table shows a consistent decrease in error percentage over these years, starting from a 2.577% error in 2005 and decreasing to a 0.444% error in 2009. This trend suggests that the logistic growth model's predictions became increasingly accurate over this period. The decreasing error percentage over these years indicates an improving reliability of the model for predicting the population

The comparison of population data between BPS and the logistic growth model for the City of Kediri in 2005-2009 can be seen in the graph below.

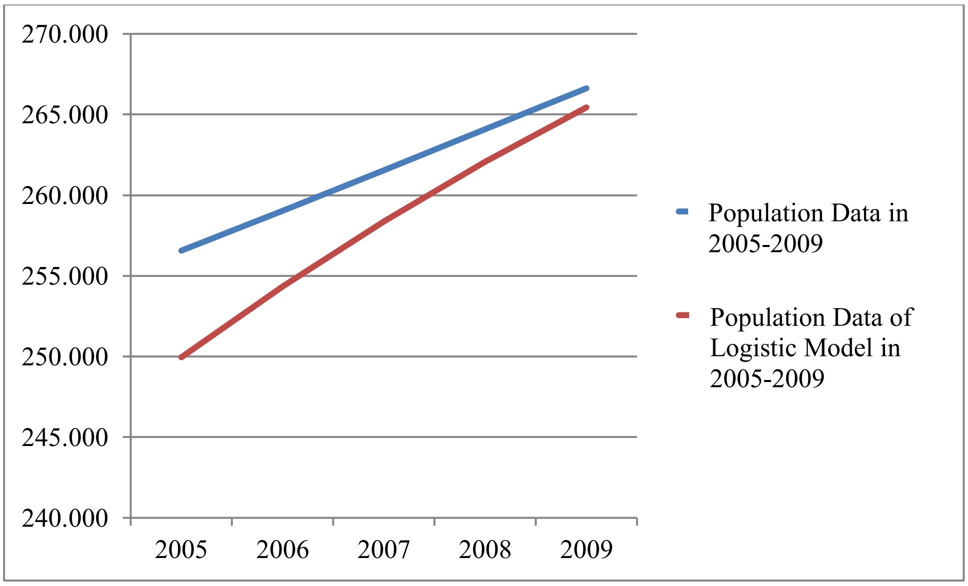

Figure 4. Graph of Population of Kediri City based on BPS data and Logistic Growth Model for 2005-2009

Figure 4 graphically represents the data in Table 6, plotting the actual BPS population data and the logistic model's predictions for 2005-2009. The visual representation is crucial for quickly grasping the relationship between the predicted and actual values. If the lines representing the BPS data and model predictions are close together or overlapping, it signifies high accuracy of the model. This graphical analysis is instrumental in visually validating the logistic growth model's effectiveness in estimating the population growth of Kediri City.

Furthermore, the total error value for prediction using the logistic growth model with population data according to BPS Kediri City is as follows:

$$MAPE = \frac{1}{5}\sum_{t=1}^{11}\left|\frac{X_t - \breve{X}_t}{X_t}\right| \times 100 = 1.3605\%$$

Based on the table above, it can be concluded that the logistic growth model used to estimate the population of the city of Kediri in the following years is in the Equation (8).

3.5. Kediri City Population Projection Results

Population estimation is carried out as a step in dealing with the demographic bonus as Affandi stated that Indonesia will experience a demographic bonus period in 2030-2040 [17]. During this period, the number of people in the productive age is estimated to be greater than the non-productive age. Therefore, it is necessary to estimate the population. Based on the model equation obtained, in this case the estimated population to be predicted starts at time $t = 11$ to $t = 20$, $t = 11$ represents the year 2021 and so on, until $t = 20$ which represents the year 2030 which is then substituted into the **Equation (8)**. The estimated population of Kediri city in 2021-2030 is presented in the following table:

Table 7. Population of Kediri City in 2021-2030 Based on Estimation Using Logistic Growth Model

No	Year	Time (t)	Total Population	Population Growth Rate (r)
1.	2021	11	287,761	-
2.	2022	12	288,624	0.11845
3.	2023	13	289,394	0.23689
4.	2024	14	290,082	0.35534
5.	2025	15	290,696	0.47379
6.	2026	16	291,243	0.59223
7.	2027	17	291,732	0.71068
8.	2028	18	292,167	0.82913
9.	2029	19	292,554	0.94758
10.	2030	20	292,899	1.06602

Table 7 provides a detailed projection of Kediri City's population from 2021 to 2030, utilizing a logistic growth model. This model is crucial for urban planning, especially considering Indonesia's impending demographic bonus period. The table lists the years alongside 'Time (t)', which is a variable in the model representing each year from 2021 ($t = 11$) to 2030 ($t = 20$). The 'Total Population' column shows a gradual increase in population each year, while the 'Population Growth Rate (r)' column reflects the rate at which the population is expected to grow annually. Such detailed projections are vital for preparing adequate resources and infrastructure to accommodate the growing population.

The increase in the estimated population of the city of Kediri in 2021-2030 can be seen in the graph below.

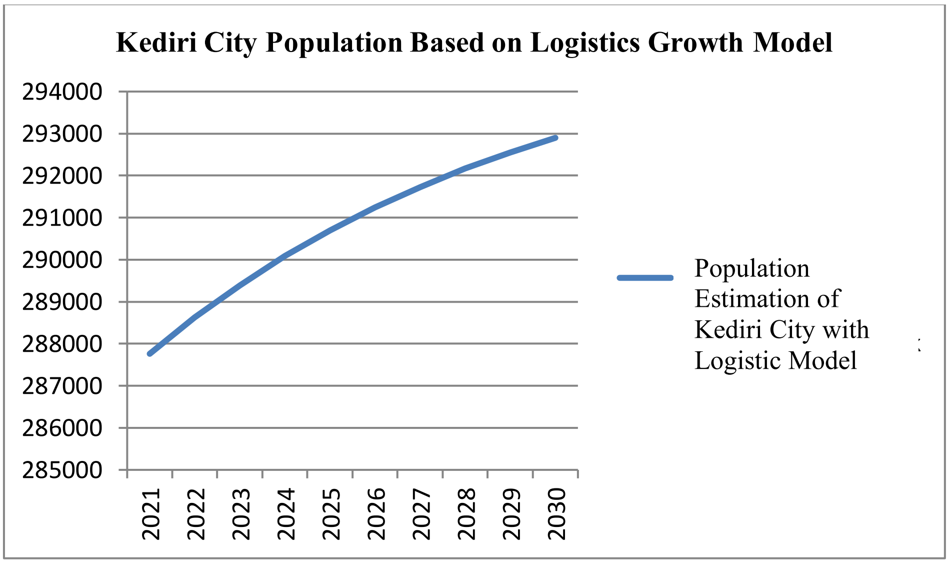

Figure 5. Graph of Population Estimation of Kediri City in 2021-2030 Based on Logistic Growth Model

The **Figure 5** shows the projected population growth of Kediri City from 2021 to 2030 based on a logistic growth model. The x-axis represents the years from 2021 to 2030, while the y-axis indicates the estimated population, increasing from approximately 287,761 in 2021 to around 292,899 in 2030. The smoothly ascending line reflects a steady annual population increase. This projection is crucial for urban planning and resource management, especially as Indonesia approaches the demographic bonus period expected between 2030 and 2040, during which the productive age population is predicted to outnumber the non-productive age population. Utilizing the logistic growth model, this projection aids in preparing adequate infrastructure and resource allocation to support the growing population, thereby ensuring sustainable urban development. Furthermore, this estimation is valuable for formulating appropriate policies and strategies to address future demographic challenges. This projection is crucial for urban planning and resource management, especially as Indonesia approaches the demographic bonus period expected between 2030 and 2040, during which the productive age population is predicted to outnumber the non-productive age population.

Utilizing the logistic growth model, this projection aids in preparing adequate infrastructure and resource allocation to support the growing population, thereby ensuring sustainable urban development. Furthermore, this estimation is valuable for formulating appropriate policies and strategies to address future demographic challenges. It is essential to consider additional social strategies, such as increasing public awareness of zakat, as evidenced by Kediri BAZNAS's initiatives **[18]**. Enhancing human resources, optimizing zakat applications, and innovating the zakat collection and distribution system are crucial strategies that can support the city's sustainable development goals **[19]**, **[20]**.

This approach aligns with the broader Sustainable Development Goals (SDGs), emphasizing the integration of urban dimensions into global sustainability initiatives. The role of cities in tackling complex problems like climate change has become increasingly recognized, necessitating robust, data-driven planning and collaboration among local and global actors **[21]**. As cities like Kediri adapt SDG targets to local contexts, it is vital to maintain holistic, integrated planning approaches to achieve sustainable urban growth **[22]**, **[23]**.

4. CONCLUSIONS

The study on the population growth of Kediri City using a logistic growth model has confirmed the model's accuracy and efficiency in predicting demographic trends. It has successfully projected the city's population to reach approximately 292,899 by 2030, based on a carrying capacity ($K = 295{,}672$) and a growth rate ($r = 0.11845$). The total error value for prediction using the logistic growth model with population data according to BPS Kediri City is 1.3605%. These projections are not only vital for demographic research but also for urban planning and development, especially in support of the Sustainable Development Goals (SDGs). The research findings are instrumental for policymakers and urban planners, providing a robust basis for policy development, resource allocation, and strategic implementation of initiatives aimed at achieving the SDGs by 2030.

Furthermore, the research facilitates future academic exploration in the field of population dynamics. It encourages researchers to delve deeper into the logistic growth model and consider more complex variables and alternative models that account for fluctuations, such as the delayed logistic growth model. This approach could provide a more nuanced understanding of demographic changes. The study not only contributes to the existing body of knowledge but also opens new avenues for research, enhancing our comprehension of demographic trends and their implications for urban environments.

ACKNOWLEDGMENT

Alhamdulillah, and we thank all parties who helped until this research and writing were completed and could be published. Especially to the supervising lecturers and examiners for their input, and also to the Kediri City government, which has provided complete data, making it easy for the community to use. May Allah ease the affairs of the parties involved.

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