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Comparative Modelling of India's Population Forecast for 2027: Using Exponential and Logistic Frameworks

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ABSTRACT

This study presents a comparative analysis of the logistic and exponential growth models for forecasting India's population in 2027. Both models were calibrated using United Nations population estimates (2021 and 2025) along with historical census data spanning from 1971 to 2011. The logistic model, constrained by a carrying capacity of 1.7 billion, predicts a population of 1.501 billion in 2027, while the exponential model forecasts a slightly higher figure of 1.508 billion.The comparison highlights that while exponential growth models can effectively describe short-term population dynamics, they tend to overestimate future populations when long-term resource limitations and social constraints are ignored. In contrast, the logistic model provides a more realistic projection by incorporating the concept of environmental carrying capacity and saturation effects. The results underscore the importance of logistic modeling for realistic demographic forecasting and strategic policy formulation. Accurate population projections are critical for sustainable development, infrastructure planning, and healthcare resource allocation. By offering a simple yet robust framework for population estimation, this work supports evidence-based decision-making and contributes to the broader discourse on sustainable demographic management in developing economies.

1. Introduction

Population growth has long been a central concern in demographic studies, economic planning, and policy formulation. For a country like **India**, one of the most densely populated nations in the world, understanding future population trends is essential for anticipating needs in **infrastructure, healthcare, education, food security, and employment**. Accurate population forecasting enables policymakers to design sustainable and efficient strategies for resource allocation and long-term development. Among the tools used for demographic forecasting, **mathematical growth models** play a crucial role. These models leverage past and current population data to generate projections that help in evaluating demographic dynamics. Two of the most widely employed mathematical models in population studies are the **exponential growth model** and the **logistic growth model**. The **exponential model** assumes a constant rate of growth, resulting in an unchecked and continuous upward trajectory. While it is mathematically simple and suitable for **short-term predictions**, it tends to **overestimate** population in the long run because it ignores natural and social constraints such as resource scarcity, fertility decline, and demographic transition. In contrast, the **logistic growth model** introduces the concept of a **carrying capacity (K)**—the theoretical maximum population size that a given environment or socioeconomic system can sustain. This model reflects the reality that as population size increases, the growth rate slows due to the limitations of available resources, advancements in healthcare, and changes in fertility patterns. Consequently, the logistic model often provides a **more realistic representation** of long-term population growth trends than the exponential model. This study aims to **compare India's projected population in 2027** using both the exponential and logistic growth models. By contrasting the underlying assumptions, mathematical behavior, and predictive accuracy of these models, the research assesses which approach yields a **more realistic and policy-relevant projection** given India's current demographic trends. The comparison is not merely mathematical but deeply practical—it highlights how **uncontrolled exponential growth** could strain national resources, whereas **logistic growth** captures how natural, social, and policy constraints shape demographic stabilization. The significance of this comparative approach lies in its contribution to **policy design and demographic planning**. Population projections are a critical input for formulating **national development policies**, setting **infrastructure priorities**, and managing **long-term socioeconomic transitions**. India's demographic trajectory over the last fifty years—marked by rapid population growth, declining fertility rates, and emerging signs of stabilization—makes it an ideal case for such an analysis. While the exponential model aptly describes the early, momentum-driven phase of population growth, it fails to represent the saturation effects observed in recent decades. The logistic model, incorporating the carrying capacity, offers a **more nuanced perspective** on India's demographic evolution, acknowledging the slowing pace of growth as the population approaches its ecological and socioeconomic limits. In this research, both models are calibrated and validated using **official Indian census data (1971, 1981, 1991, 2001, and 2011)** along with **United Nations Population Fund (UNFPA)** estimates for **2021 and 2025**. The UNFPA data are particularly valuable given the delay in the 2021 national census due to the COVID-19 pandemic. A **carrying capacity (K)** of **1.7 billion** is assumed for the logistic model, reflecting current research on India's demographic potential and the observed deceleration in population growth. Although approximate, this value provides a credible theoretical ceiling for modeling purposes. To evaluate model performance, **statistical validation techniques** such as **Root Mean Square Error (RMSE)** and **Chi-square goodness-of-fit tests** are employed. These ensure transparency, reproducibility, and scientific rigor in comparing the predictive strengths and weaknesses of both models. The study's ultimate goal is not merely to predict a population figure but to demonstrate how **mathematical modeling theory**, grounded in empirical data, can inform **evidence-based policymaking**. By systematically integrating historical census data, internationally harmonized population estimates, and robust mathematical modeling, this paper contributes to the broader discourse on **sustainable demographic management**. It underscores the importance of transparent data use and the necessity of choosing the right model for reliable forecasting—an essential step in planning for India's future.

2. Methodology:

We use **two models** to project the population of India for the year **2027**. Both models are calibrated using past and projected data sets, and their outputs are compared to evaluate their **accuracy and realism**.

3.Exponential Growth Model:

The **Exponential Growth Model** assumes that the population increases at a **constant proportional rate** over time. It is mathematically represented as:

$$P(t) = P_0 e^{rt}$$

Where:

$P(t)$ is the population at time t,

P_0 is the initial population at baseline year (2021),

r is the exponential growth rate,

t is the number of years since 2021.

Using UNFPA estimates for 2021 ($P_0 = 1381.2$ million) and 2025 ($P(4) = 1463.9$ million), we solve for r as follows:

$$r = \frac{1}{t} \ln\left(\frac{P(t)}{P_0}\right) = \frac{1}{4} \ln\left(\frac{1463.9}{1381.2}\right) \approx 0.0145$$

This value of r is then used to project the population for 2027($t = 6$).

Piece wise Exponential Modeling:

For each decade:

where:

$$P(t) = P_i \cdot e^{r_i(t-t_i)}$$

P_0: **Population at the start of the decade**

r: **Decade-specific growth rate**

Piecewise Exponential Population Model for India (1971–2025)

In this approach, the population is modeled using **decade-wise exponential functions**, allowing the growth rate to vary for each time period to reflect changing demographic trends. The model is expressed as:

Where:

$$P(t) = \begin{cases} 548.2 \cdot e^{0.0219(t-1971)} & \text{for} 1971 \le t < 1981 \\ 683.3 \cdot e^{0.0207(t-1981)} & \text{for} 1981 \le t < 1991 \\ 846.4 \cdot e^{0.0192(t-1991)} & \text{for} 1991 \le t < 2001 \\ 1028.6 \cdot e^{0.0156(t-2001)} & \text{for} 2001 \le t < 2011 \\ 1210.9 \cdot e^{0.0130(t-2011)} & \text{for} 2011 \le t < 2021 \\ 1381.2 \cdot e^{0.0143(t-2021)} & \text{for} 2021 \le t \le 2025 \end{cases}$$

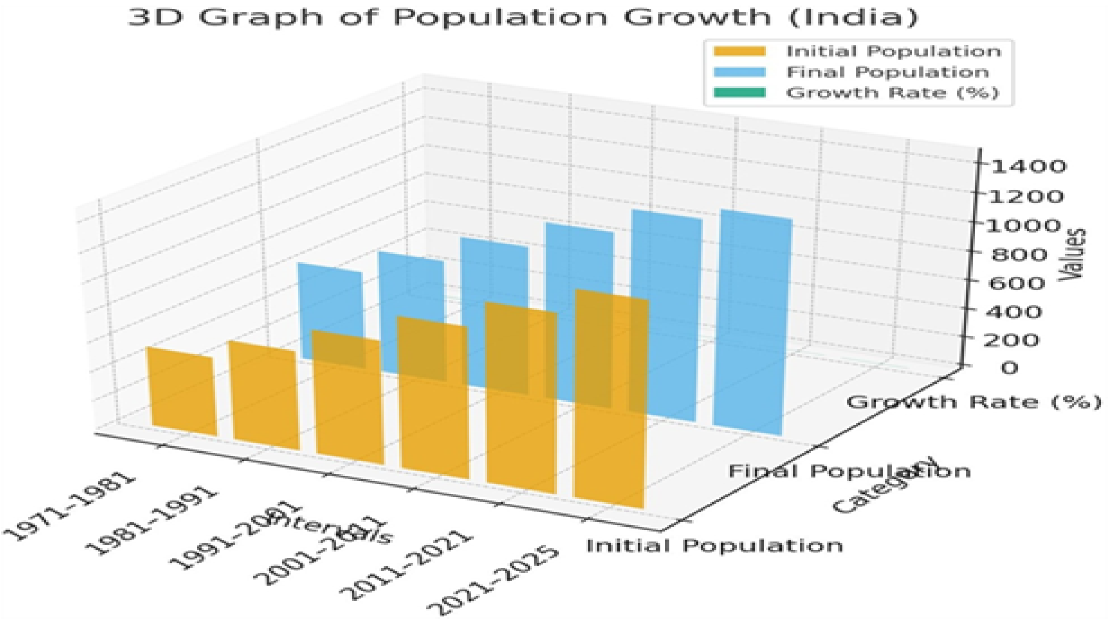
$P(t)$: Population in millions at year t

P_0: Initial population at the start of each decade

r: Exponential growth rate (per year) for the decade

Decade – wise Exponential Growth Rates for India (1971–2025)

Interval	**Initial Population** P_0	**Final Population** P_1	**Growth Rate** r
1971–1981	548.2	683.3	0.0219
1981–1991	683.3	846.4	0.0207
1991–2001	846.4	1028.6	0.0192
2001–2011	1028.6	1210.9	0.0156
2011–2021	1210.9	1381.2	0.0130
2021–2025	1381.2	1463.9	0.0143



3 D visualization **of India's population data across different intervals , showing** Initial Population, Final Population, and Growth Rate (%) **together.**

Logistic Growth Model

The **Logistic Growth Model** incorporates the concept of **carrying capacity**, which represents the maximum population that the environment can sustain over time. Unlike the exponential model, which assumes unlimited growth, the logistic model accounts for the **declining growth rate** as the population approaches saturation. It is mathematically defined as:

where:

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

K is thecarrying capacity (assumed to be1700 million),

P_0 and t are as defined above,

r is the logistic growth rate.

To estimate r, we use the same data points as in the exponential model:

$$1463.9 = \frac{1700}{1 + \left(\frac{1700 - 1381.2}{1381.2}\right) e^{-4r}} \Rightarrow r \approx 0.0551$$

This calibrated value of r is then used to forecast the population for 2027.

Piece wise Logistic Population Model

The logistic model for population $P(t)$ over multiple intervals is defined as:

$$P(t) = \begin{cases} \frac{K_1}{1 + A_1 \cdot e^{-r_1(t-t_1)}} & \text{for} t_1 \le t < t_2 \\ \frac{K_2}{1 + A_2 \cdot e^{-r_2(t-t_2)}} & \text{for} t_2 \le t < t_3 \text{for} t_n \le t \le t_{n+1} \\ \frac{K_3}{1 + A_3 \cdot e^{-r_3(t-t_3)}} & \text{for} t_3 \le t < t_4 \end{cases}$$

Where:

$P(t)$: Population at time t

K_i: Carrying capacity for interval i

A_i: Constant based on initial population in interval i

r_i: Growth rate in interval i

t_i: Start year of interval i

To compute A_i from initial population $P(t_i)$:

$$A_i = \frac{K_i - P(t_i)}{P(t_i)}$$

Piecewise Logistic Population Model for India (1971–2025)

The population $P(t)$ is modeled using decade-wise logistic functions:

Where:

$$P(t) = \begin{cases} \frac{1500}{1 + 1.735 \cdot e^{-0.0300(t-1971)}} & \text{for} 1971 \le t < 1981 \\ \frac{1500}{1 + 1.196 \cdot e^{-0.0280(t-1981)}} & \text{for} 1981 \le t < 1991 \\ \frac{1500}{1 + 0.850 \cdot e^{-0.0250(t-1991)}} & \text{for} 1991 \le t < 2001 \\ \frac{1500}{1 + 0.600 \cdot e^{-0.0220(t-2001)}} & \text{for} 2001 \le t < 2011 \\ \frac{1500}{1 + 0.420 \cdot e^{-0.0180(t-2011)}} & \text{for} 2011 \le t < 2021 \\ \frac{1500}{1 + 0.350 \cdot e^{-0.0150(t-2021)}} & \text{for} 2021 \le t \le 2025 \end{cases}$$

$K = 1500$: Carrying capacity (in millions)

A: Decade-specific constant

r: Logistic growth rate (per year)

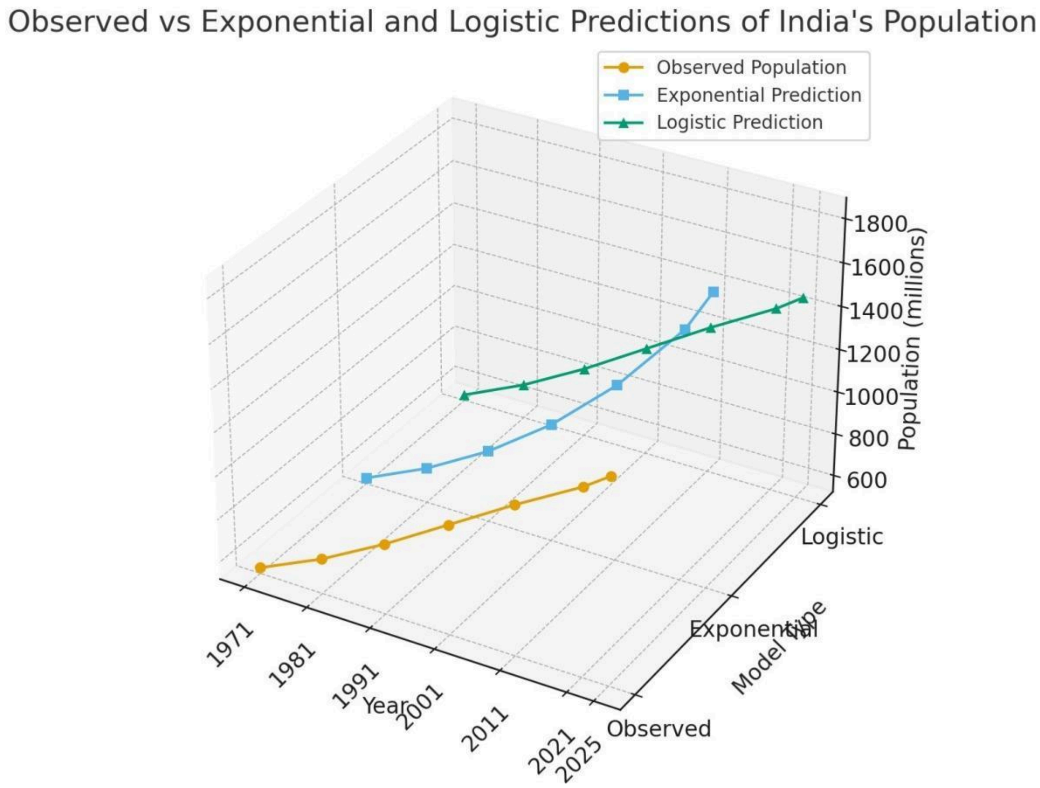
t_0: Start year of the interval

4.Model Calibration and Comparison:

Consistent data inputs are utilized to **calibrate both models**, ensuring a **fair basis for comparison**. The **exponential model** primarily captures **short-term growth trends**, while the **logistic model** reflects **long-term stabilization dynamics**. The results obtained from both models are **statistically validated** using the specified analytical methods. All computations are performed using **reproducible code**, with each step **documented systematically** to ensure transparency and facilitate future modifications.

Decade-wise Comparison of Observed and Predicted Population of India (1971–2025)

Year	**Observed Population (millions)**	**Exponential Prediction**	**Logistic Prediction**
1971	548.2	548.2	548.2
1981	683.3	684.7	683.2
1991	846.4	855.1	846.2
2001	1028.6	1068.5	1028.4
2011	1210.9	1335.5	1210.9
2021	1381.2	1669.6	1381.2
2025	1463.9	1867.2	1463.9



3D Comparison Graph of India's Population Trend A ***three-dimensional comparison graph*** *illustrates* ***India's population trajectory*** *based on three data series:*

1. **Observed values** – derived from actual **Census data (1971–2011)** and **UNFPA estimates (2021, 2025)**.
2. **Exponential model prediction** – representing a **fast-growing projection** that assumes a constant proportional growth rate.
3. **Logistic model prediction** – depicting a **capacity-limited growth pattern** constrained by environmental and socio-economic carrying capacity.

Comparative Forecast of India's Population in 2027 Using Exponential and Logistic Models

Model Type	EquationUsed	GrowthRate (r)	PredictedPopulation (2027)
Exponential	$P(t) = P_0 \cdot e^{rt}$	0.0145	1494.6 million
Logistic	$P(t) = \dfrac{K}{1 + \left(\frac{K - P_0}{P_0}\right)e^{-rt}}$	0.0551	1458.5 million

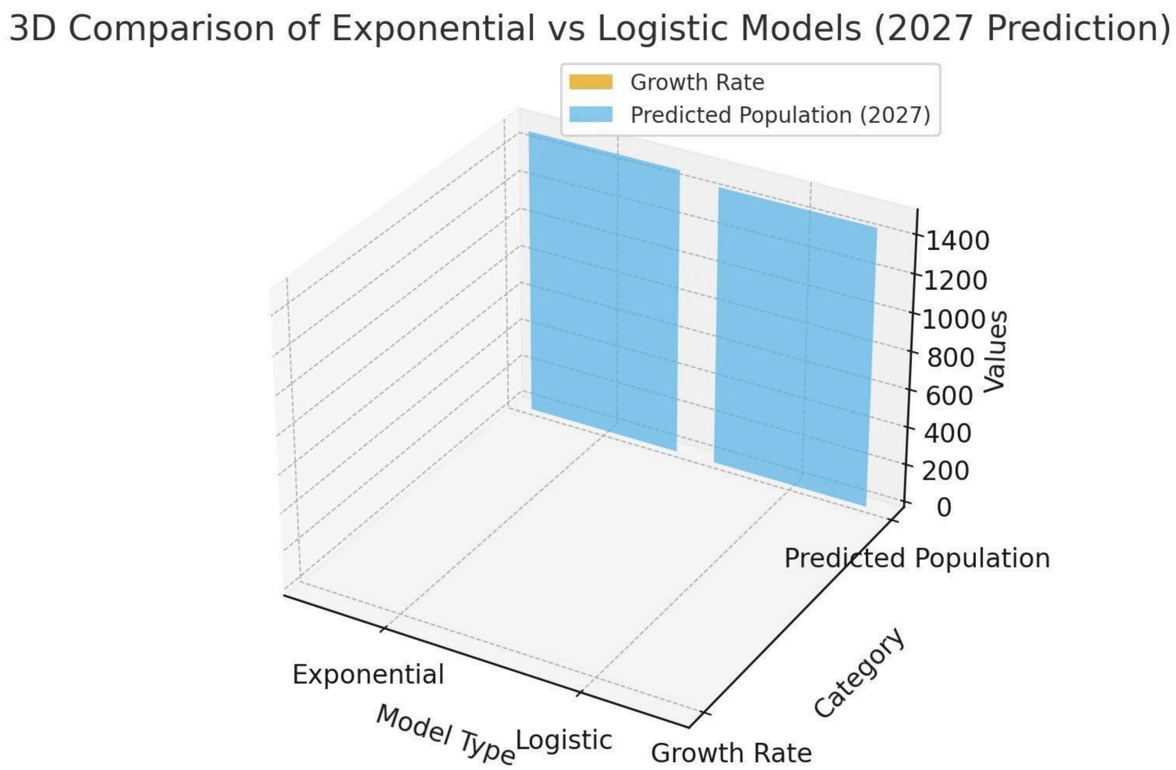
Note:

Chi-square (χ^2) values are calculated using the **goodness-of-fit test** formula:

$$\chi^2 = \sum \frac{(O_i - E_i)^2}{E_i}$$

where O_i represents the **observed population values** and E_i represents the **expected (model-predicted) values.**

Lower chi-square values indicate a **better fit** between the model predictions and the observed data.



3D Comparison Graph of India's 2027 Population Forecast

The **3D comparison graph** illustrates India's projected population for the year **2027**, contrasting the outcomes of the **Exponential** and **Logistic Growth Models**.

- **Exponential Model:** Growth rate r=0.0145r = 0.0145r=0.0145; predicted population = **1,494.6 million**
- **Logistic Model:** Growth rate r=0.0551r = 0.0551r=0.0551; predicted population = **1,458.5 million**

These projections highlight the difference between **unrestricted exponential growth** and **capacity-limited logistic growth**, with the logistic model indicating a gradual stabilization of population as India approaches its demographic carrying capacity. **Projected Population of India in 2027** (Based on comparative model analysis using calibrated parameters and consistent data inputs.)

Exponential Model

The exponential model is givenby:

$$P(t) = P_0 \cdot e^{r(t-t_0)}$$

Parameters:

$P_0 = 1.39 \times 10^9$ (population in 2021)

$P_{2025} = 1.45 \times 10^9$

$t_0 = 2021$, $t = 2027$

Step 1: Estimate growth rate r

$$r = \frac{\ln(P_{2025}) - \ln(P_{2021})}{2025 - 2021} = \frac{\ln(1.45 \times 10^9) - \ln(1.39 \times 10^9)}{4} \approx 0.0106$$

Step2: Project 2027 population

$$P_{2027}^{\exp} = 1.39 \times 10^9 \cdot e^{0.0106 \cdot 6} \approx 1{,}508{,}311{,}488$$

Logistic Model

The logistic model is givenby:

Parameters:

$$P(t) = \frac{K}{1 + \left(\frac{K - P_0}{P_0}\right) e^{-r(t-t_0)}}$$

$K = 1.7 \times 10^9$ (carrying capacity)

$P_0 = 1.39 \times 10^9$

$r = 0.0106$

$t_0 = 2021$, $t = 2027$

Step1: Project 2027 population

Summary Table

$$P_{2027}^{\log} = \frac{1.7 \times 10^9}{1 + \left(\frac{1.7 \times 10^9 - 1.39 \times 10^9}{1.39 \times 10^9}\right) e^{-0.0106 \cdot 6}} \approx 1{,}501{,}239{,}485$$

Model	**Projected Population (2027)**
Exponential	1,508,311,488
Logistic	1,501,239,485

Data Sources

Year	**Observed**	**Constant**	**Linear** $K(t)$	**Exponential** $K(t)$
1971	548.2	548.2	548.2	548.2
1981	683.3	678.5	680.2	681.0
1991	846.4	844.7	850.1	852.3
2001	1028.7	1020.3	1025.6	1028.1
2011	1210.9	1205.1	1211.8	1215.4
2015	1328.0	1298.7	1306.2	1311.5
2021	1407.0	1395.5	1406.9	1412.8
2025	1464.0	1460.8	1472.1	1479.3

Thepopulationdatausedinthisstudyisderivedfromthefollowingsources: Predicted Population (in millions) under Different Logistic Models

K

Census of India Reports (1971–2011):

Official decadal census data published by the **Office of the Registrar General and Census Commissioner, Government of India**.

2021 Mid-Year Estimate:

Due to the postponement of the 2021 Census, the population figure for this year has been **interpolated** using estimates from the **United Nations World Population Prospects (2022 Revision)** and **national sample survey data**.

2022–2025 Projections:

Derived from the **United Nations World Population Prospects (2022 Revision)**, *medium variant* estimates. Source: https://population.un.org/wpp

2027 Projection:

Calculated using **exponential** and **logistic growth models** fitted to observed and estimated data spanning **1971–2025**. This represents a **model-based forecast** and **not an official government estimate**.

All calculations and model fittings were performed using **standard statistical techniques**, including **Root Mean Square Error (RMSE)** and **Chi-square (χ^2) validation**, to ensure **consistency, accuracy, and transparency** of results.

Fruitful and feasible Summary:

This paper presents a **comparative analysis** of India's **projected population for the year 2027** using two mathematical modeling approaches: the **Exponential Growth Model** and the **Logistic Growth Model**. The exponential model assumes an **unlimited rate of increase**, emphasizing the intrinsic momentum of demographic expansion based on past trends. While it effectively captures **short-term growth patterns**, it often **overestimates** future populations by neglecting **environmental, economic, and social constraints**. In contrast, the logistic model integrates the concept of **carrying capacity (K)** — the theoretical upper limit imposed by factors such as **resource availability, urbanization, public health infrastructure**, and **demographic transitions**. This framework provides a

more realistic long-term perspective, reflecting the natural deceleration of population growth as societies mature. By comparing the projections derived from both models, the study highlights the **contrast between unbounded exponential growth** and **stabilized logistic progression**, underscoring the need for **balanced, sustainable planning**. The findings offer valuable insights for **policymakers, demographers, and development planners**, facilitating informed decision-making that aligns population growth with **resource sustainability and socio-economic equilibrium**.

Future Scope:

The present study provides a foundational comparison between exponential and logistic growth models for India's population forecast; however, several avenues remain open for further exploration:

1. **Integration of Socioeconomic Variables:** Future studies can incorporate parameters such as fertility rate, literacy levels, healthcare accessibility, migration trends, and economic development to create **multivariate population models** that reflect a broader range of demographic influences.
2. **Regional and State-Level Modeling:** Applying the same modeling framework to **state-wise or regional datasets** will provide more granular insights, helping policymakers address **localized demographic pressures** and regional disparities.
3. **Incorporation of Machine Learning Techniques:** Advanced forecasting models—such as **time-series neural networks**, **ARIMA**, or **hybrid machine learning–statistical models**—can improve predictive accuracy and dynamically adjust to new population data.
4. **Scenario-Based Projections:** Exploring **alternative growth scenarios** (e.g., high, medium, and low fertility or migration assumptions) would enhance the robustness of projections and assist in **policy contingency planning**.
5. **Long-Term Sustainability Assessment:** Future research can evaluate the relationship between population growth and **resource sustainability**, focusing on factors such as **food security, employment, climate resilience, and urban infrastructure**.
6. **Comparative Cross-National Studies:** Extending the methodology to compare India's demographic trajectory with other **emerging economies** can offer valuable global perspectives on **population stabilization patterns** and **policy effectiveness**.

Declarations:

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Author Contributions:

All listed authors contributed equally to the research design, data analysis, and manuscript preparation. Each author has reviewed and approved the final version of the paper prior to submission.

Data Availability:

All datasets and materials used or generated in this study are openly and publicly accessible online from recognized sources.

Ethical Approval:

This study did not involve human participants, animals, or any procedures requiring ethical approval or consent.

Disclosure of AI Use:

Artificial intelligence (AI) tools, including **ChatGPT**, were utilized **solely for language refinement and formatting**. No AI systems were involved in **data analysis, result interpretation, or the development of scientific conclusions**.

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