A Comparative Study of Fundamental Population Growth Models Applied to Kaski District of Nepal [1]

Bhadra Raj Tripathi & Iswar Mani Adhikari

Abstract

Exponential, Logistic, and Gompertz are three classical population growth models. These are also known as fundamental population growth models for measuring the population growth rate and estimating the population. Using census datasets from five decades for the Kaski district, we aim to produce a comparative study of these models and their mathematical formulations, including some of the interesting properties. Here, we present the differential equations and their respective solutions related to these models. Various computational tools are also used for their evaluations. These are compared with respect to their calibration, projections, and mathematical perspectives. Their estimation errors and the best fit are also analyzed with respect to the population of Kaski District. Finally, we recommend the better model for population forecasting.

Keywords: population growth, population dynamics, carrying capacity, growth models, Kaski district population

Introduction

Exponential, Logistic, and Gompertz are three fundamental population growth models used to measure the population growth rate and estimate population size. Modern research contains population models with their interconnections with machine learning, big data, complex networks, climate science, genetics, fractal geometry, simulations, quantum computing, artificial intelligence, etc. Kaski District, Gandaki Province, covers an area of 2017 square km with an elevation range of 450-8,091 m that includes the beautiful tourist hub, Pokhara Valley, and the Annapurna range. It drives significant

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rural-urban migration, complicating local demographic projections and planning. Population growth modeling and its analytical study are essential for such planning, resource allocation, and infrastructural development Lee, 2011; Pokharel & Baral, 2023.

In the five decades from 1981, the population of Kaski District grew from 110,007 to 600,051, with an annual growth rate of approximately 3.5 percent, compounded annually. The intercensal growth rates for 1971 to 1981 and 2011 to 2021 were computed as 7.24 percent and 2.04 percent, respectively. This indicates a demographic shift from rapid growth to gradual slowdown. This shows that linear or exponential extrapolations may not be suitable for long-term prediction. Exponential, Logistic, and Gompertz are three classical models that have influenced literature on population growth. The exponential model, contributed by Malthus (1798), assumes unlimited resources and constant per capita growth. The logistic model, proposed by Verhulst, incorporates the concept of carrying capacity (K), producing an S-shaped growth curve that approaches a maximum sustainable population (Bacaer, 2011). The Gompertz model, created by Gompertz (1825), presents an asymmetric growth curve with a gradually declining growth rate over time.

The economics of agrarian change under population pressure and the mathematical modeling to predict the current change in the human population growth rate are also presented in Boserup (1965) and Mondol et al. (2018), respectively. The Laplace decomposition method, the fractional differential equation approach, and certain partial fractional differential equations are also presented to advance population growth models (Jain et al., 2025). Their impact on economic growth, on different consumable goods, on climate change, and vice versa are also explored by Ferdinand et al. (2025), Ayuba et al. (2025), and Struck & Trinborn (2026), respectively.

Tsoularis & Wallace (2002) have extensively compared these models in theoretical and ecological contexts. Terano (2018) studied the population growth models: Exponential, Hyperbolic, Logistic, Gompertz, Coalition, and Regression for the population growth, taking the datasets from 1960 to 2015, and concluded that the Logistic model and Regression model were best for the prediction of the population growth in the Philippines. Nonetheless, few studies have applied all three models to district-level data in Nepal. This study aimed to address this gap by conducting a comparative analysis of five census datasets to identify a suitable growth model for the Kaski District.

Significance of the study

It provides empirical guidance for selecting a model for district-level population prediction in Nepal and helps the local government formulate policies and plans. It explores the mathematics of such models and compares them to highlight the strengths and weaknesses of each approach in real-world settings.

Research objectives

Our focus is on: to explore three of the fundamental models for population growth from their mathematical perspectives; and to identify the best-fit population growth model for Kaski within the given calibration period and to project the population.

Methodology

This study adopted a quantitative approach and longitudinal research design to compare three classical and fundamental population growth models: Exponential, Logistic, and Gompertz, using decennial census data from Kaski district, Nepal. Population data for the years 1981, 1991, 2001, 2011, and 2021 were obtained from the Central Bureau of Statistics (CBS), Nepal. The 1971 census was excluded from the calibration process due to its abnormal growth rate of 7.24%. The high rate in one census would affect the overall population trend.

Study area

Kaski District (28^{0}15’N84^{0}00’E) borders Tanahun to the east, Lamjung to the north, Parbat to the west, and Syanja to the south. Its diversity in climate, cultures, and geography includes the Phewalake basin and the Annapurna Conservation Area.

Data sources

Population data were obtained from six national censuses conducted by Nepal's CBS. The census year, population, and respective growth rate are as in Table 1.

Table 1

Population data of Kaski district

Census Year	Population	Intercensal growth rate (%)
1971	110,007	-
1981	221,272	7.24
1991	292,945	2.85
2001	380,527	2.65
2011	492,098	2.60
2021	600,051	2.04

Source: CBS, Nepal; Compiled from City population (2023).

Analysis of the Models

Several population growth models exist: Exponential, Logistic, Gompertz, Lotka-Volterra, Metapopulation, Leslie Matrix, Network population, Discrete Logistic, Allee Effect, Stochastic, age-structured, Spatial diffusion, Reaction-diffusion, Delayed population, Cellular automata, Harvesting, etc. Among them, the researcher selected only three models: Exponential, Logistic, and Gompertz models to identify the best model in the context of the Kaski District for the prediction of the population in the forthcoming years.

Fundamental growth models

Among several population growth models, our focus is on the mathematics of three fundamental classical models: the Exponential, Logistic, and Gompertz models.

Exponential Growth Model

The exponential growth model states that the rate of change of a population is proportional to its current size. If P is the present population at time t, then mathematically it can be expressed as $\frac{dP}{dt} \propto P$. Then

$$\frac{dP}{dt} = rP \tag{1}$$

Then, from the solution of the first-order differential equation, we get,

$$P(t) = P_0 e^{rt} \tag{2}$$

Where, $P(t)$= population at any time t, P_0= initial population, and r = intrinsic population growth rate. Here, r>0 represents exponential growth, and r<0 represents exponential decay. The growth rate of this model is geometric, and the curve is J-shaped. This model was developed by Thomas R. Malthus in 1798. So, it is also known as the Malthusian growth model. **Example 1:** Suppose a bacterial culture initially contains P_0=100 bacteria and the intrinsic bacterial growth rate r=0.5 per hour. Estimate the population after 5 hours by using the Exponential growth model. **Solution:** From the exponential growth model, $P(t) = P_0 e^{rt}$, we get, $P(5) = 100\, e^{2.5} \approx 1218.25$ Here, the growth rate is unrestricted, and the population increases very rapidly. The growth itself keeps increasing. The population in different hours can be discretized as in Table 2.

Table 2

Bacterial population at different hours

Time (Hrs): t	0	1	2	3	4	5
Population: P(t)	100	165	272	448	739	1218

Logistic growth model

The logistic growth model is an improved form of an exponential growth model. No population can increase indefinitely in a limited environment, and population growth is self-limiting due to environmental constraints. Mathematically, it is given by,

$$\frac{dP}{dt} = \left(1 - \frac{P}{K}\right) rP \qquad (3)$$

Where K = carrying capacity and $1 - \frac{P}{K}$ = environmental resistance factor.

For its solution, we can rewrite it as, $rdt = \frac{K\,dP}{P(K-P)} = \left(\frac{1}{P} + \frac{1}{K-P}\right)\, dP$

On integration, $ln\, ln\, |P| - ln\, ln\, |K-P| = rt + c$. It gives, $\frac{P}{K\_P}\, | = rt + c$. Then, $\frac{P}{K-P} = C\, e^{rt}$. Then, $P + PCe^{rt} = KC\, e^{rt}$. Hence, the population after time t becomes,

$$P(t) = \frac{K}{1 + A\, e^{-rt}} \qquad (4)$$

As for t=0, the initial population $P_0 = \frac{K}{!+A}$, where $A = \frac{K-P_0}{P_0}$. At equilibrium points, $\frac{dP}{dt} = 0$. It gives P=0 and P+K. Where P=0 gives the unstable equilibrium, and P=K gives the stable equilibrium. But if $= \frac{K}{2}$, it gives the inflection point at which the growth rate is fastest. This model was developed by Belgian Mathematical biologist Pierre Verhulst and is known as the Verhulst growth model (Bacaer, 2011). It gives a sigmoid curve, i.e., an S-shaped curve.

Example 2: Let the initial population of deer in a forest be P_0= 50, with carrying capacity K = 500. Estimate the deer population after 6 years using the Logistic model, assuming a growth rate r = 0.6. **Solution:** For the logistic growth model, $A = \frac{K-P_0}{P_0} = \frac{500-50}{50} = 9$. Then from the model, $P(t) = \frac{K}{1+A\, e^{-rt}}$, we get, $P(6) = \frac{500}{1+9\, e^{-0.5}} \approx 401$.

Here, the population initially grows rapidly and then slows as food and space becomes limited. Finally, the population gradually approaches the energy capacity of 500. Its population is shown in Table 3.

Table 3

Population estimation of deer in a forest

Time (yrs): t	0	1	2	3	4	5	6
Population:P(t)	50	84	135	201	275	345	401

Gompertz growth model

The Gompertz growth model assumes that the growth rate decays exponentially with time, rather than linearly with population size as in the logistic model. This means the model describes a process in which growth starts rapidly but slows at an everincreasing rate, causing the curve to rise sharply and then approach a carrying capacity asymmetrically, with the slowing phase occurring earlier and more symmetrically on a logarithmic scale. Its central theme is that the growth rate decays exponentially with time. Mathematically,

$$\frac{dP}{dt} = rP\, ln\, ln\left(\frac{K}{P}\right) \qquad (5)$$

Here, K denotes the carrying capacity as the upper asymptote, and r is the growth parameter. For its solution, let $u = ln\, ln\left(\frac{K}{P}\right)$, then, $P = K\, e^{-u}$. Here, Equation (5) becomes, $\frac{dP}{dt} = -K\, e^{-u}\frac{du}{dt} = -P\,\frac{du}{dt}$. We can write the model equation as, $-P\,\frac{du}{dt} = r\,P\,u$. Then, $\frac{du}{u} = -r\,dt$. This, on integration, $ln\, ln\,|u| = -r\,t + c$. Equivalent to, $u = Ce^{-rt}$. Then, $ln\, ln\left(\frac{K}{P}\right) = C\,e^{-rt}$. It gives, $= e^{Ce^{-rt}}$. Hence, the population after time t becomes,

$$P(t) = K\, e^{-Ce^{-rt}} \qquad (6)$$

Initially, for $(t) = P_0$, it gives $P_0 = K\, e^{-C}$ and then $C = ln\, ln\left(\frac{K}{P_0}\right)$. This model was developed by British Mathematician Benjamin Gompertz and is known as the Gompertz growth model. It gives an asymmetric Sigmoid curve.

Example 3: Let the initial tumor cell count, $P_0 = 20$. maximum tumor size, K=1000. The growth parameter is r = 0.5 per month. Then, find the tumor size after 5 months by using the Gompertz model. **Solution:** Here, C=$ln\, ln\left(\frac{K}{P_0}\right)$ =$ln\, ln\left(\frac{1000}{20}\right)$ =ln (50) ≈ *3.912.* Then the population after 5 months is given by, $P(5) = K\, e^{-Ce^{-rt}} = 1000\, e^{-3.912\, e^{-0{,}5(5)}} \approx 725$. Its population is shown in Table 4.

Table 4

Tumor size estimation

Time (Months): t	0	1	2	3	4	5
Tumor size: P(t)	20	70	180	360	560	725

Here, the initial count is fast. The internal biological limitation gradually suppresses the growth, and it becomes increasingly slow near maturity.

Theorem 1: The Logistic and Gompertz models are the non-linear extensions of the exponential model. **Proof:** From Equation (1), the exponential model is given by $\frac{dP}{dt} = rP$. From Equation (3), the Logistic model can be expressed as $\frac{dP}{dt} = \alpha.rP$ where $\alpha = 1 - \frac{P}{K}$, as a nonlinear extension factor. From Equation (5), the Gompertz model can be expressed as $\frac{dP}{dt} = \beta.rP$ where $\beta = ln\ ln \left(\frac{K}{P}\right)$, as a nonlinear extension factor. □

Corollary 1: For a small population, the logistic model coincides with the exponential model near it. **Proof:** For a small population, P <<K, $1 - \frac{P}{K} \approx 1$. Clearly, the Logistic model, $\frac{dP}{dt} = \alpha.rP$ reduces to $\frac{dP}{dt} \propto P$, as the exponential model. □

Corollary 2: The Gompertz model also coincides with the exponential model near the initial state. **Proof:** Consider P is far below K, P <<K, then $ln\ ln \left(\frac{K}{P}\right) \approx constant$. Clearly, the non-linear extension factors $\beta = ln\ ln \left(\frac{K}{P}\right) \approx constant$. Then, the Gompertz model, $\frac{dP}{dt} = \beta.rP$ reduces to $\frac{dP}{dt} \propto P$, as the exponential model. □

Generalization of fundamental population growth models

All of these three fundamental population growth models can be generalized in the form,

$$\frac{dP}{dt} = \zeta.rP \qquad (7)$$

Where, ζ gives the generalizing factor of the population dynamics. As in the generalized form given by Equation (7), it is obvious that $\zeta = 1$ gives the Exponential model, $\zeta = 1 - \frac{P}{K}$ gives the Logistic model, and $\zeta = ln\ ln \left(\frac{K}{P}\right)$ gives the Gompertz model, respectively.

In fact, these are not isolated models but are mathematically connected stages in the evolution of population dynamics theory. For a biological interpretation, an exponential growth model fits for early unrestricted growth. In contrast, the logistic model is well-suited to competition-limited populations, and the Gompertz model is well-suited to aging, tumors, and cellular growth. We can compare the fundamental growth models to specific parameters, as in Table 5.

Table 5

Comparison of the fundamental growth models

Mod-els	**Limiting Factor**	**Long-term Behavior**	**Curve Shaped**	**Equili-brium**	**Comp-lexity**	**Realism Level**	**Weakness**
Exp	none	Infinite Growth	J-shaped	None	Simple	low	Unrealistic in infinity
Log	Carrying Capacity (K)	Stabilizes at K	Sigmoid	K	Non-linear	Medium	Fixed K

Gom	Gradual Inhibition	Slowly approaches K	Asymmetric sigmoid	K	Non-linear	high	Parameter Interpretation

Their hierarchical relationship, like Exponential → Logarithmic → Gompertz, represents increasing biological realism. Generally, an exponential model assumes infinite expansion, a logistic model assumes limits and balance, whereas the Gompertz model assumes aging and gradual saturation. Most religions and cultures believe in creation, preservation, and destruction, which is similar to oscillatory ecological systems, and it reflects population dynamics.

Model fitting strategy

The calibration datasets consisted of the first four census points (1981, 1991, 2001, 2011; n = 4). The 2021 census point (n = 1) was reserved exclusively for validation. Models were estimated using nonlinear least squares regression with the Levenberg-Marquardt algorithm as implemented in SciPy's curve fit function in Python 3.10. Initial Parameter Guesses were: P_0 = 221,272, r = 0.025 to 0.03, and k = 700,000. Bounds were set for the logistic and Gompertz models to ensure convergence ($500{,}000 \le K \le 1{,}500{,}000$; $P_0 > 0$; $0 \le r \le 0.1$).

Evaluation Metrics

Model Performance was assessed using standard statistical criteria:

- R^2 (Coefficient of Determination): Values closer to 1 indicate a better fit, given by, $R^2 = 1 - \frac{SSR}{SST}$, where SSR (Sum of Squared Residuals) = $\sum (Y - \hat{y})^2$ and SST (Total Sum of Squares) = $\sum \left(Y - \underline{y}\right)^2$
- RMSE (Root Mean Square Error): Lower values indicate a better fit, given by RMSE = $\sqrt{\frac{SSR}{n}}$, where SSR = $\sum (Y - \hat{y})^2$ and n = No. of observations.
- AIC (Akaike Information Criterion): Lower AIC values indicate a better fit, penalizing model complexity; AIC = $n \ln \ln \left(\frac{SSR}{n}\right) + 2k$, where SSR = $\sum (Y - \hat{y})^2$ for n = No. of observations, and k = No. of parameters.
- BIC (Bayesian Information Criterion): Lower BIC values indicate a better fit with a strong penalty for extra parameters, where BIC = $\left(\frac{SSR}{n}\right) + k\,\ln(n)$, where SSR (Sum of Squared Residuals) = $\sum (Y - \hat{y})^2$ for n = No. of observations, k =No. of parameters.

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Limitations of the fundamental population growth models

Here, we are presenting the major limitations of these models.

Exponential models

The model predicts that $P(t) \rightarrow \infty$ for $t \rightarrow \infty$. But the Earth has finite resources, ecosystems have limits, and there are energy constraints. It contradicts ecological reality. In fact, unlimited growth is physically impossible. It assumes a constant growth rate. But in real life, fertility, mortality, and environmental conditions may change, and such an assumption becomes unrealistic. It ignores predators, disasters, migration, climate effects, and many more. In fact, it is biologically oversimplified.

Logistic models

The model assumes a constant carrying capacity, K. However, due to climate change, technological change, wars, and resource depletion, K has become dynamic. It assumes competition depends only on total population size, but this is not the case in practice due to age structure, species interactions, etc. It assumes instantaneous feedback, but the real population responds with a delay.

Gompertz models

The model is empirically powerful but theoretically less intuitive. Sometimes it underestimates very early growth and has explosive initial expansion. Its parameters are often harder to estimate.

In aggregate, we can conclude that all assume deterministic growth, but in the real world, it is always stochastic and uncertain. They treat all individuals as identical, but in practice, they differ in age, generation, health, behavior, and more. They assume no migration or emigration, which is not the case in practice.

Computational results

Since the population growth rate (7.24%) from 1971 to 1981 was unusually high compared to the growth rates in the remaining censuses, the researcher used the 1981 base population, expecting more stable demographic trends for calibration and carrying capacity. The estimated parameters for each model are presented in Table 6.

Table 6

Parameters for the Three Population Growth Models

Model	P_o (1981)	Growth rate (r)	Annual rate (%)	Carrying capacity (k)
I: Exponential	221, 272	0.0267	2.67	N/A
II: Logistic	221, 272	0.0320	3.20	780,000
III: Gompertz	221, 272	0.0210	2.10	850,000

In comparison, a stable annual growth rate of 2.6 percent is at Model I. It has a higher short-run growth estimate. It is also associated with a higher carrying capacity. But Model III estimated a larger long-term carrying capacity and a slower rate of deceleration. The Goodness-of-Fit metrics are shown in Table 7 for the calibration.

Table 7

Goodness of Fit Metrics for Calibration Period (1981 - 2011)

Model	R^2	RMSE	AIC	BIC
I: Exponential	0.9996	1850	63.93	62.70
II: Logistic	0.9999	720	57.31	55.45
III: Gompertz	0.9998	950	68.94	67.10

Model II has the highest R^2 and lowest RMSE, AIC, and BIC values. It is the best fit for calibration performance. Such a logistic curve closely matched the observed census values. The validation results for the projection of census 2021are:

Table 8

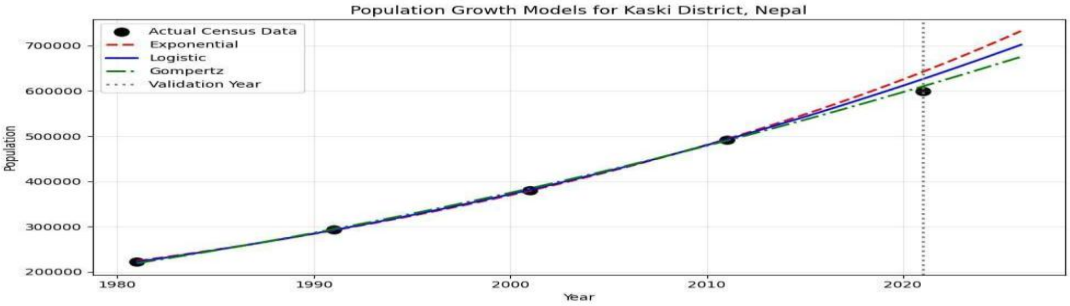
Validation Result for 2021 Population Projection

Model	Predicted 2021	Absolute error	Percent error (%)
I: Exponential	642,900	42,849	7.14
II: Logistic	624,500	24,449	4.07
III: Gompertz	607,800	7,749	1.29

The smallest prediction error is in Model III, and it produced the most accurate forecast for 2021. This model better captured the steady pace of population growth. The population growth comparisons between these models and the observed census data are shown in Figure 1.

Figure 1

Population Growth Models for Kaski District, Nepal



Continued acceleration is on the Exponential model. The Gompertz model has the most realistic representation of recent population dynamics with an asymmetric

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demographic structure. The growth rates decline more gradually than the logistic model assumes, aligning with Kaski's observed intercensal growth rates: 2.85% (1981 – 1991), 2.65% (1991 – 2001), 2.60 % (2001 – 2011), and 2.04% (2011 – 2021). The Gompertz formulation is seen as more consistent.

The Exponential model's insufficient validation performance, having an overestimate, highlights the fundamental limitation of constant-growth assumptions. It fits well, comparatively, for early data, but its extrapolation to 2021 was significantly inaccurate.

The logistic model is an improvement over the exponential model. It estimates the carrying capacity of 780,000, but it is up to 850,000 for Gompertz. The logistic model assumes symmetric deceleration near the carrying capacity, whereas the Gompertz model assumes asymmetric deceleration.

The Exponential Model assumes unbounded growth and is a poor fit for long-term projections. But with an overestimated population. The Gompertz Model, another sigmoid growth model with an asymmetric curve, is suitable for rapid early growth followed by a prolonged slowing phase, for the Kaski district, corresponding to this calibration period.

Conclusion

This study compared three well-known population models: Exponential, Logistic, and Gompertz for Kaski District, Nepal, using five census datasets from 1981 AD to 2021 AD. Calibration on the 1981 to 2011 datasets and validation against the 2021 population (600,051) showed that the Gompertz model produced the most accurate projection (607,800; 1.29% error). Meanwhile, the Logistic (624,500; 4.07% error) and Exponential (642,900; 7.14% error) models produced less realistic results than the Gompertz Model. The Gompertz Model predicted a carrying capacity of 850,000, and its asymmetric deceleration best matched Kaski's population growth decline scenario from 2.85% to 2.04%. The exponential model was unsuitable for long-term prediction. Therefore, this study recommends that district-level planners in Nepal adopt the Gompertz model for medium-term population projections, recalibrate it after each census, and base infrastructure planning on decelerating growth trajectories rather than linear extrapolations. No single model is universally correct and acceptable. Different models work well at different scales. In general, the exponential model is well-suited to small early growth, the logistic model to resource-limited ecology, and the Gompertz model to aging and tumor systems.

Limitations of the study

This study has the following limitations: Only five census datasets (the first four for calibration and the last for validation) are used. The study was limited to the Kaski District. All three models assume constant carrying capacity, which is unrealistic for a developing district with ongoing infrastructure investment. The models assume deterministic growth and do not incorporate stochastic shocks. Of the several growth models, only three models were compared.

Recommendation

For district-level planners in Nepal, this study recommends: Adopt the Gompertz growth model for medium-term (10–20-year) population projection. Recalibrate models with each new census and update carrying capacity estimates accordingly. Apply these models to other Nepali districts, incorporating factors such as migration, fertility, and mortality rates. The estimation of population during infrastructure planning should be based on a decelerating growth trajectory rather than linear or exponential extrapolations.

References

Ayuba, D. A. D., et al. (2025). Analysis of the impact of population growth on economic growth in Nigeria. *ADSU Intl Jour of Applied Eco, Finance &Mgt*, *10*(3).

Bacaër, N. (2011). Verhulst and the logistic equation. Springer, London. https://doi.org/10.1007/978-0-85729-115-8-6

Boserup, E. (1965). *The conditions of agricultural growth: The economics of agrarian change under population pressure*. Aldine Publishing Company.

CBS, Nepal. (2021). *National population and housing census 2021*. Gov of Nepal.

Citypopulation.de. (2023). *Kaski District popn data*. https://www.citypopulation.de/en/nepal/mun/admin/

Ferdinand, O. I., et al. (2025). Impact of popn growth on the importation of consumable goods in Nigeria. *NAU Eco Journals*, *15*(2), 144-165.

Gompertz, B. (1825). On the nature of function expressive of the law of human mortality, and on a new mode of determining the value of life contingencies. *Philosophical Transactions of the Royal Society of London*, 115, 513–583.

Jain, D., Bhargava, A., & Gupta, S. (2025). A new approach to a pop growth model fractional-order logistic differential equation. *Critical Reviews™ in BiomedicalEngineering*, *53*(2). 10.1615/CritRevBiomedEng.2024055114

Lee, R. (2011). The outlook for population growth. *Science*, 333(6042), 569–573.

Malthus, T. R. (1798). *An essay on the principle of population*. J. Johnson, London.

Mondol, H., et al. (2018). Mathematical modeling and predicting current trends of pop growth in Bangladesh. *MMC D*, 39(1). https://doi.org/10.18280/mmc_d.390101

Pokhrel, B., & Baral, C. (2023). Population growth dynamics of Nepal:. *TGB*, 10(01). https://doi.org/10.3126/tgb.v10i01.71835

Strulik, H., & Trimborn, T. (2026). Climate change and population growth: A reassessment. *JEEM*, 103282. https://doi.org/10.1016/j.jeem.2026.103282

Terano, H. R. (2018). Mathematical models of pop dynamics applied to the Philippine pop growth Analysis. *FJMS*, 103(3). https://doi.org/10.17654/MS103030561

Tsoularis, A., & Wallace, J. (2002). Analysis of logistic growth models. *Mathematical Biosciences*, 179(1), 21–55. https://doi.org/10.1016/S0025-5564(02)00096-2