The scale **Journal Website:** https://thescalejournal.com.ng/
An Interdisciplinary Journal of
The ACADEMIC STAFF UNION OF POLYTECHNICS - ZONE D
ISSN: 2992-3727 Published 30th November, 2025

MODELING AND FORECASTING NIGERIA'S POPULATION GROWTH USING EXPONENTIAL AND LOGISTIC MODELS: A COMPARATIVE APPROACH (1981–2023)

Samuel O. Adeyemo [1]; Prisca Duruojinkeya PhD [2]
Department of Statistics, Federal Polytechnic, Nekede, Nigeria
Corresponding author: oadeyemo@fpno.edu.ng

Abstract
Population growth modeling provides a quantitative basis for understanding demographic change and projecting future population sizes, especially in countries where census exercises face logistical and political constraints. This study applies and compares the exponential and logistic population growth models using Nigeria's population data from 1981 to 2023, with the objective of identifying the model that best describes and forecasts national population trends. Secondary data were obtained from the World Bank's World Development Indicators (WDI, 2023) and verified with the National Population Commission (NPC). The exponential model, expressed as $\ln[P(t)] = \ln[P_0] + rt$ was estimated by ordinary least squares (OLS) regression, while the logistic model, $P(t) = \frac{K}{1+\left(\frac{K-P_0}{P_0}\right)e^{-rt}}$. was fitted using nonlinear least squares (NLS). Model performance was evaluated using the Coefficient of Determination (R^2), Root Mean Square Error (RMSE), and Mean Absolute Percentage Error (MAPE), together with hold-out validation (1981–2015 for training, 2016–2023 for testing). Both models fit the data well ($R^2 > 0.999$), but the logistic model demonstrated higher predictive accuracy with RMSE = 3.11 million and MAPE = 1.08%, compared to the exponential model (RMSE = 4.48 million, MAPE = 1.61%). The unconstrained logistic fit implies 1.485×10^9 and projects a 2050 population near 428 million, while the exponential model projects 479 million. A policy-based sustainability scenario fixing $K = 350$ *million* yields a moderated 2050 population of *292 million*. The study concludes that the logistic model offers a more realistic long-term framework under resource constraints, whereas the exponential model remains useful for short-term upper-bound estimates.

Keywords: Population growth, Exponential model, Logistic model, Demographic modeling, Forecasting

Introduction
Population growth is a central concern in demographic research, with implications for economic planning, resource management, and social development. Accurate estimation of population dynamics allows policymakers to anticipate challenges in education, health care, housing, and food supply. Nigeria, Africa's most populous country, has experienced sustained growth over the past four decades, with population estimates rising from approximately 76 million in 1981 to over 227 million in 2023 (World Bank, 2023).

However, Nigeria's censuses have often been contested due to logistical, political, and methodological issues (Serra, 2021). As a result, demographic modeling offers an objective and reproducible means of producing reliable estimates. Two classical models dominate population growth theory: the exponential growth model, introduced by Thomas Malthus (1798), and the logistic growth model, proposed by Pierre Verhulst (1838).

The exponential model assumes constant proportional growth, suitable for populations not limited by resources, while the logistic model introduces a carrying capacity (K) to represent environmental or economic constraints. Comparing these two provides insights into whether Nigeria's growth remains unbounded or is gradually stabilizing.

This paper applies both models to Nigeria's population data from 1981–2023, evaluates their fit statistically, and identifies which offers the most reliable projection for future planning.

Materials and Methods

Data Sources

Population data were obtained from the World Bank's World Development Indicators (WDI, 2023) indicator SP.POP.TOTL (Population, total) and cross-checked against reports from the National Population Commission (NPC, 2023). The study period (1981–2023) provides 43 annual observations.

Model Formulations

(a) Exponential Growth Model

$$P(t) = P_0 e^{rt} \qquad (1)$$

Taking logarithms,

$$\ln[P(t)] = \ln[P_0] + rt$$

(b) Logistic Growth Model

$$P(t) = \frac{K}{1 + \left(\frac{K - P_0}{P_0}\right) e^{-rt}} \qquad (2)$$

where:
$P(t)$ = population at time *t*,
P_0 = 1981 population, and
r = intrinsic growth rate.
K denotes the carrying capacity, representing the theoretical upper limit of the population.

Estimation Techniques

For the exponential model, parameters were estimated using linear regression of $\ln P(t)$ on t. For the logistic model, parameters K and r were estimated via nonlinear least squares (NLS) using Excel Solver and Python optimization routines.

Model Evaluation Metrics

Accuracy was assessed using:

$$R^2 = 1 - \frac{\sum\left(P_t - \hat{P}_t\right)^2}{\sum(P_t - \bar{P})^2} \qquad (3)$$

$$RMSE = \sqrt{\frac{1}{n}\sum\left(P_t - \hat{P}_t\right)^2} \qquad (4)$$

$$MAPE = \frac{100}{n}\sum\left|\frac{P_t - \hat{P}_t}{P_t}\right| \qquad (5)$$

Training period 1981–2015 and testing period 2016–2023.

Results

Exponential Model Estimation

The fitted regression equation was:

$$\ln P_t = 18.1520 + 0.0266t$$

$$\hat{P}_t = e^{18.1520} e^{0.0266t} = 76{,}433{,}334 e^{0.0266t}$$

This corresponds to an annual growth rate of 2.66**%**. The model explained 99.9% of variation in the data $(R^2 = 0.9990)$.
However, residual analysis showed increasing deviation after 2010, indicating overestimation in later years.

Logistic Model Estimation

The logistic model was fitted as:

$$\hat{P}_t = \frac{1.485 \times 10^9}{1 + \left(\frac{1.485 \times 10^9 - P_0}{P_0}\right) e^{-0.02919t}}$$

Estimated parameters: $r = 0.0292$ (2.92% per annum), $K = 1.485 \times 10^9$ This model achieved $R^2 = 0.9995, RMSE = 1.05\ million$ and $MAPE = 0.53\%$. Residuals were smaller and symmetrically distributed, confirming superior fit.

Model Comparison

Statistic	Exponential Model	Logistic Model	Better Model
R^2	0.99901	0.99948	Logistic
RMSE (million)	1,443,632	1,046,376	Logistic
MAPE (%)	0.461	0.534	Exponential
Growth rate *r* (%)	2.66	2.92	-
Carrying capacity *K*	—	1.485×10^9	Logistic

Both models describe the observed trajectory closely explaining over 99.9 % of the variation; the logistic model slightly/marginally improves fit at the cost of an extra parameter.

Validation Results (2016–2023)

Year	Actual Population	Exponential Forecast	Logistic Forecast	Exp APE %	Log APE %
2016	195,443,700	195,477,048	194,844,169	0.017	0.307
2017	200,254,579	200,819,951	200,018,926	0.282	0.118
2018	204,938,755	206,308,889	205,321,057	0.669	0.187
2019	209,485,641	211,947,855	210,753,159	1.175	0.605
2020	213,996,181	217,740,948	216,317,852	1.75	1.085
2021	218,529,286	223,692,382	222,017,778	2.363	1.596
2022	223,150,896	229,806,484	227,855,603	2.983	2.108
2023	227,882,945	236,087,701	233,834,009	3.6	2.61

Mean Absolute Percentage Error (MAPE):

i. Exponential = 1.61%
ii. Logistic = 1.08%

Hence, the logistic model outperformed the exponential model in predictive accuracy.

2050 Projections

Under unconstrained fits:

i. Exponential**:** approximately 479 million
ii. Logistic**:** approximately 428 million

A scenario assumption of $K = 350million$ yields a moderated 2050 value of approximately *292 million* but increases in-sample error *(RMSE = 5.44 M*). Thus, unconstrained model projections represent statistical expectations, while fixed-*K* scenarios represent policy-based sustainability targets.

Discussion

Both models reproduce Nigeria's sustained population growth. The exponential model's assumption of unlimited growth causes overestimation beyond 2010, while the logistic model captures early deceleration. The estimated unconstrained *K* (= 1.5 billion) shows Nigeria remains in the accelerating

phase of demographic transition, yet a lower assumed K (= 350 M) illustrates possible stabilization consistent with *UN (2022)* medium-variant projections.
Previous studies (Acquah et al., 2018; Olanrewaju et al., 2020; Idemudia et al., 2023) similarly found logistic-type models outperform exponential ones for developing populations nearing transition.

Conclusion

The comparative analysis demonstrates that both exponential and logistic models fit Nigeria's historical population data with high accuracy, but the logistic model provides superior explanatory and predictive power. The exponential model remains useful for short-term analysis and as an upper-bound approximation, whereas the logistic model is recommended for medium- to long-term forecasting and policy planning.
Model-based forecasts project that Nigeria's population will reach approximately 270–280 million by 2050**,** gradually approaching the carrying capacity of approximately 350 million. Incorporating such model-based projections into national planning can improve allocation of resources in health, education, and infrastructure.

Acknowledgement

The author gratefully acknowledges the World Bank (WDI) **and** National Population Commission (Nigeria) for providing open-access population data. Appreciation is also extended to colleagues at the Department of Statistics, Federal Polytechnic, Nekede**,** for valuable input and computational support.

References

Acquah, I., Hayford, J., & Oduro, S. D. (2018). Comparative study of mathematical models for population growth in Ghana prisons.

Adele, B. J. (2007). *Falsification of population census data in a heterogeneous Nigerian society: The fourth republic example.* Journal of African Policy Studies, 13(2). University of Dayton eCommons.

Bacaër, N. (2011). *Verhulst and the logistic equation (1838).* In A Short History of Mathematical Population Dynamics (pp. 35–39). Springer.

Bongaarts, J. (2009). Human population growth and the demographic transition. Philosophical Transactions of the Royal Society B, 364(1532), 2985–2990.

Burnham, K. P., & Anderson, D. R. (2002). *Model selection and multimodel inference: A practical information-theoretic approach* (2nd ed.). Springer.

Creswell, J. W. (2014). *Research design: Qualitative, quantitative, and mixed methods approaches* (4th ed.). SAGE.

Idemudia, E. G., Solomon, R., & Musa, I. (2023). A comparative analysis of growth models on Nigeria's male, female and total population (1981–2021). FUDMA Journal of Sciences**, 7**(3), 262–269.

Malthus, T. R. (1798). *An essay on the principle of population* (1st ed.). (Open access editions).

Meyer, P. S. (1999). *A primer on logistic growth and substitution.* Program for the Human Environment, Rockefeller University.

Mwakisisile, A. J. (2019). Mathematical model for Tanzania population growth. Tanzanian Journal of Science, 45(2), 117–129.

National Population Commission (Nigeria). (2023–2025). Official website and census materials (including the 2023/24 NDHS release and the 2023 Digital Census brief).

Olanrewaju, S. O., Olafioye, S. O., & Oguntade, E. S. (2020). *Modelling Nigeria population growth: A trend analysis approach.* International Journal of Innovative Science and Research Technology, 5(4), 52–64.

Pearl, R., & Reed, L. J. (1920). On the rate of growth of the population of the United States since 1790 and its mathematical representation. Proceedings of the National Academy of Sciences, 6(6), 275–288.

Serra, G. (2021). *Contested numbers: Census controversies and the press in 1960s Nigeria.* Working paper, University of Manchester.

Tsoularis, A., & Wallace, J. (2002). Analysis of logistic growth models**.** Mathematical Biosciences, 179(1), 21–55.

United Nations, Department of Economic and Social Affairs, Population Division. (2022). *World Population Prospects 2022: Summary of Results.* Retrieved October 2025**.**

United Nations, Department of Economic and Social Affairs, Population Division. (2024/2025). *World Population Prospects (Data Portal).* Retrieved October 2025**.**

Weeks, J. R. (2015). *Population: An introduction to concepts and issues* (12th ed.). Cengage Learning.

World Bank. (2025). *World Development Indicators – Population, total (SP.POP.TOTL): Nigeria.* Retrieved October 2025**.**