HiLL PUBLISHING

Journal of Humanities, Arts and Social Science, 2025, 9(6), 1201-1218
https://www.hillpublisher.com/Journals/jhass/
ISSN Online: 2576-0548
ISSN Print: 2576-0556

Estimation of the Population Size in Tanzania from 1967 to 2112 Using Logistic and Exponential Models: A Comparative Analysis

Emmanuel Deogratias*, Geoffrey Karugila

Sokoine University of Agriculture, Morogoro 54114, Tanzania.

How to cite this paper: Emmanuel Deogratias, Geoffrey Karugila. (2025) Estimation of the Population Size in Tanzania from 1967 to 2112 Using Logistic and Exponential Models: A Comparative Analysis. *Journal of Humanities, Arts and Social Science*, 9(6), 1201-1218
DOI: 10.26855/jhass.2025.06.026

Received: May 17, 2025
Accepted: June 13, 2025
Published: July 10, 2025

***Corresponding author:** Emmanuel Deogratias, Sokoine University of Agriculture, Morogoro 54114, Tanzania.

Abstract

This study offers a comprehensive comparative analysis of Tanzania's population growth by applying both exponential and logistic growth models to empirical data spanning from 1967 to projected figures for 2112. Reliable data were sourced from national census records and demographic projections issued by recognized authoritative agencies. The analysis aims to understand historical patterns in Tanzania's population increase and to evaluate plausible future trajectories under different growth assumptions. The exponential model, widely used for initial population studies, assumes a constant growth rate without imposing any resource constraints, thereby representing a scenario of unlimited growth. In contrast, the logistic model introduces the crucial concept of carrying capacity, setting an upper boundary to growth as determined by environmental limitations and socio-economic factors. This adjustment allows for a more realistic and nuanced prediction, especially over extended periods. Model parameters were estimated through quantitative methods, including curve fitting and regression analysis against available data sets. The results reveal that while the exponential model closely fits recent and historical trends due to sustained high growth rates, it increasingly diverges from projected realities as resource constraints and policy interventions begin to influence demographic outcomes. The logistic model, by accounting for these factors, projects a gradual deceleration of growth as Tanzania's population approaches its estimated carrying capacity. Comparative analysis outlines the strengths and limitations inherent in each approach. The exponential model is sensitive to recent trends but risks overestimating future population sizes in the face of ecological and socio-economic constraints. Conversely, the logistic model provides a conservative forecast but may understate short-term fluctuations and policy-driven variances. Policy implications of these findings are significant for resource planning, infrastructure development, and implementation of sustainable development initiatives. Accurately modeling population growth is essential for anticipating future demands on health, education, and social services while ensuring environmental sustainability.

Keywords

Comparative analysis; logistic model; exponential growth model; population

1. Introduction

Population growth modeling is essential for forecasting demographic changes, planning infrastructure, and ensuring sustainable development. Since its independence, Tanzania has experienced rapid population growth, prompting the

need for accurate predictive models (World Bank, 2023; NBS Tanzania, 2022). This paper compares two fundamental mathematical models—exponential and logistic—for estimating population growth in Tanzania from 1967 through projected trends up to 2112.

Population studies are critical for national development planning, resource allocation, and policy formulation. Accurate estimations of population size allow governments and stakeholders to make informed decisions in areas such as health, education, infrastructure, and economic planning. In Tanzania, population dynamics have undergone significant changes over the decades, influenced by factors such as fertility rates, mortality rates, migration, and socio-economic development. Since its independence, Tanzania has conducted several national population censuses, with the first post-independence census conducted in 1967. Subsequent censuses have been conducted roughly every decade, providing invaluable data that reflects the country's demographic trends. As of the most recent census, Tanzania continues to experience steady population growth, driven primarily by a high fertility rate and declining mortality rates. As the country progresses in health care, education, and economic reforms, understanding and projecting future population size presents an opportunity to better plan and manage these transitions (World Bank, 2023; NBS Tanzania, 2022).

Population modeling serves as a tool to estimate and project future population sizes. Among several mathematical models employed in demographic analysis, the logistic and exponential growth models are widely used due to their simplicity and interpretability. The exponential model assumes continuous growth without limits and is ideal for early population growth phases, whereas the logistic model introduces a carrying capacity, reflecting environmental and resource constraints that may limit population expansion over time (UN World Population Prospects, 2019). Applying these models to Tanzania's population data from 1967 and projecting forward to 2112 allows for a comparative analysis of their effectiveness in modeling long-term population dynamics. Therefore, by applying the exponential growth and logistic growth models to Tanzania's historical and projected population data, this study aims to compare their predictive abilities and identify which model better captures the realistic growth patterns, particularly in consideration of natural resource limitations and socio-economic factors. This comparative analysis will provide insights into the future demographic outlook of Tanzania, aiding policymakers and planners in designing sustainable development policies.

2. Literature Review

2.1 Exponential and Logistic Growth Models in Population Estimation

Population growth modeling is a foundational element in demography, environmental science, public policy, and resource planning. Mathematical models such as the Exponential Growth Model and the Logistic Growth Model have been widely used to describe population dynamics over time. Each model is built on certain assumptions about growth patterns and environmental constraints. This literature review examines the theoretical basis, applications, and limitations of these models, as presented in key scholarly and institutional sources.

The exponential growth model is one of the earliest and simplest forms of population prediction. It was introduced in biological contexts by Thomas Malthus in the early 19th century. The model is expressed mathematically as:

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

where:

- $P(t)$: population at time t
- P_0: initial population
- r: growth rate
- t: time in years since the start year

This model assumes that the population grows continuously at a fixed percentage rate, resulting in a "J-shaped" curve. It is applicable in scenarios where resources are abundant and environmental limitations are negligible (Malthus, 1798). The exponential model has been widely used in early-stage population growth studies, especially in developing countries where fertility rates are high (Weeks, 2011). It is also popular in short-term forecasting due to its mathematical simplicity and historical fit with observed trends. Despite its applications, the model also has limitations. The core limitation of the exponential model is that it assumes unlimited growth without consideration for resource constraints. In the context of long-term or large-scale planning, such growth becomes unsustainable. Consequently, exponential projections tend to overestimate future populations, particularly over extended time horizons

(UN World Population Prospects, 2019).

Introduced by Pierre Verhulst in 1838, the logistic growth model addresses the shortcomings of the exponential model by incorporating the concept of carrying capacity—the maximum population size an environment can sustain indefinitely. The logistic equation is given by:

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

where:

- K: carrying capacity
- r: growth rate
- Other terms as previously defined

This model produces an "S-shaped" or sigmoidal curve, reflecting slow initial growth, rapid increase during the middle phase, and a tapering off as the population approaches carrying capacity.

The logistic model has gained prominence in modern population studies, particularly in long-term forecasting for countries experiencing transitions in fertility and mortality rates. Researchers such as Cohen (1995) and Lutz et al. (2001) have emphasized logistic models for projecting human population size in the face of ecological limits. The United Nations and World Bank sometimes use logistics or related models in scenario building and policy planning. The logistic model is more realistic than the exponential model for long-term growth estimation because it incorporates environmental, economic, and social constraints. However, its accuracy heavily depends on precise estimation of the carrying capacity (K)—a value that is difficult to determine due to dynamic technological, economic, and ecological conditions (Keyfitz & Caswell, 2005).

2.2 Comparative Studies

Numerous comparative studies highlight the limitations of relying solely on exponential growth assumptions in real-world planning. Kapitsa (2006) showed that human population growth historically follows a quasi-logistic pattern, influenced by population momentum and innovation cycles. Rogers (1967) and Bongaarts (2001) suggested that as countries move through the demographic transition, logistic models tend to better reflect observed fertility decline and mortality changes. UN DESA (2022) emphasized scenario modeling on medium, high, and low fertility variants—implicitly recognizing the sigmoidal behavior of future population plateaus. Tanzania's population growth trajectory initially followed an exponential pattern during the post-independence decades, with high fertility and declining mortality. However, recent demographic surveys suggest a gradual decline in total fertility rate (TFR), increased urbanization, and economic development, leading researchers to favor logistic-based projections for the long term (World Bank, 2023; NBS Tanzania, 2022). While both exponential and logistic models have their applications, the choice of model must depend on the time horizon and demography of the population in question. Exponential models are best suited for short-term projections or early development phases, while logistic models provide a more nuanced, realistic basis for long-term, sustainable population predictions. For dynamic countries like Tanzania, a hybrid or adaptive approach using variable parameters across time periods may provide the most robust forecasting framework.

2.3 A Comparative Analysis of Tanzania's Population Growth

Population growth remains a significant area of focus in socio-economic and development studies. For countries like Tanzania—characterized by high fertility rates, youthful population structures, and dynamic demographic transitions—understanding the nature and implications of population growth is critical. This literature review explores the comparative analysis of Tanzania's population growth, focusing on historical trends, regional benchmarks within sub-Saharan Africa, and common modeling approaches used in academic and policy contexts.

Tanzania has experienced steady population growth since its independence in 1961. The first national population census in 1967 recorded approximately 12.3 million people. By 2022, this figure had increased to over 61.7 million [National Bureau of Statistics (NBS), 2022]. According to Lutz and KC (2010), such growth is shaped by multiple reinforcing factors: high fertility, declining mortality, improved healthcare access, and limited use of modern family planning methods. Early demographic studies, such as those by Mbonile (2008), pointed out that the country's growth could lead to increased pressure on land, education, and public health infrastructure. These concerns have become

more pronounced in recent years as urbanization accelerates and dependency ratios remain high (UN-Habitat, 2020).

Tanzania's demographic characteristics resemble other sub-Saharan countries but also exhibit unique features. For instance, according to the United Nations Population Division (2022), Tanzania maintained a consistent population growth rate of around 2.9% per year, slightly above the regional average. Unlike countries such as Kenya or South Africa, Tanzania is still in the early stages of demographic transition, with a Total Fertility Rate (TFR) of approximately 4.8 children per woman as of 2022. Melesse et al. (2019) highlight that while East African nations have made progress in maternal health and child survival, fertility decline has been much slower in Tanzania compared to neighbors like Rwanda or Ethiopia, mainly due to sociocultural norms and gaps in reproductive health services.

To evaluate long-term trends, researchers and policymakers frequently utilize mathematical models—most commonly the exponential and logistic growth models. The exponential model assumes unlimited growth potential, often described by Malthusian theory (Malthus, 1798). It has been used in earlier demographic estimates to project short-term growth in Tanzania. For example, Masanja (2003) modeled Tanzania's urban expansion under exponential assumptions to show rapid, uncurbed growth unless significant policy interventions are made. More recent work, such as that by the World Bank (2020) and the UN Population Fund (UNFPA, 2021), adopts logistic growth models that incorporate carrying capacity to reflect environmental and socio-economic limits. Logistic modeling projections suggest that Tanzania's population may plateau between 150 and 200 million by the end of the 21st century, depending on fertility trajectories and urban transition rates. Therefore, this growth is far-reaching. According to the Tanzania Human Development Report (UNDP, 2020), a rapidly growing population intensifies pressure on education, employment, and healthcare systems. Moreover, regional studies by AfDB (2021) suggest that unless growth is accompanied by investments in human capital, urban development, and governance, it could hinder progress toward achieving the Sustainable Development Goals (SDGs). Additionally, Sharma et al. (2019) highlight that equitable distribution of resources and spatial planning are essential for minimizing risks associated with overpopulation in metropolitan areas like Dar es Salaam, which is expected to become one of the largest cities in Africa by 2050. Comparative studies suggest that while Tanzania's growth trends align with sub-Saharan Africa more broadly, the pace and persistence of high fertility remain unique factors. Exponential models help capture short-term projections, but logistic models provide more realistic forecasts under resource constraints. A comparative understanding of these dynamics is critical for strategic planning and effective policy formulation.

2.4 Tanzanian National Censuses and Projections from Authoritative Sources

Population censuses and demographic projections are vital tools for national planning, resource allocation, and policy development. In Tanzania, systematic national census-taking has occurred every 10 years since independence, supplemented by population projections from domestic and international institutions. This literature review examines the role of national censuses, highlights demographic trends observed across decadal intervals, and discusses future population projections from Tanzania's National Bureau of Statistics (NBS), the United Nations, and the World Bank.

Tanzania has conducted six population and housing censuses since 1967, the first being five years after its union to form the United Republic of Tanzania. These censuses are coordinated by the National Bureau of Statistics (NBS) in collaboration with international partners such as the United Nations Population Fund (UNFPA) and technical advisors from the African Statistics Office. The census timeline and population figures are presented below:

Census Year	Total Population (Approx.)
1967	12.3 million
1978	17.5 million
1988	23.2 million
2002	34.4 million
2012	44.9 million
2022	61.7 million

(Source: NBS, 2022)

These censuses have consistently shown rapid population growth, with an average annual growth rate of between 2.5% and 3.0%. According to the Tanzania Population and Housing Census 2022 (NBS, 2022), this growth has been driven largely by high fertility rates and declining mortality due to improvements in health services and child survival. As emphasized by UNFPA (2022), the Tanzanian government relies heavily on census results for planning in education, healthcare, infrastructure, and economic development. The decentralization process in Tanzania has also made

district- and region-level data critical for equitable resource distribution (URT, 2016).

Multiple organizations produce population projections to assist in long-term planning. These include the Tanzanian NBS, the United Nations Department of Economic and Social Affairs (UN DESA), and international development institutions such as the World Bank and the African Development Bank. Tanzania's own national projections have typically used cohort-component methods, accounting for fertility, mortality, and migration patterns. The Population Projections Report 2013–2035, published by the NBS, anticipated that Tanzania's population would surpass 75 million by 2035, depending on the demographic transition rate (NBS, 2014). The UN World Population Prospects 2022, produced by UN DESA's Population Division, projects that Tanzania's population could exceed 140 million by 2100 under the medium-variant scenario. The UN's model includes different fertility variants: High Fertility Scenario: ~170 million by 2100, Medium Variant (most referenced): ~140 million, and Low Fertility Scenario: ~115 million. These projections highlight Tanzania as one of the key contributors to global population growth this century, along with countries like Nigeria, the Democratic Republic of Congo, and Ethiopia (UN DESA, 2022).

The World Bank (2023) provides population trends and projections linked to economic and development indicators. It anticipates substantial increases in urban population, especially in cities such as Dar es Salaam and Dodoma, which are expected to join the ranks of Africa's largest cities by 2040. The African Population and Health Research Center (APHRC) and African Development Bank (AfDB) also use census and projection data to support policy design and progress tracking in line with the Agenda 2063 and Sustainable Development Goals (SDGs).

A consistently youth-heavy population structure has emerged from every census. According to the 2022 census, nearly 45% of Tanzania's population is under the age of 15, placing enormous pressure on education and job creation systems (NBS, 2022; UNFPA, 2021). The total fertility rate (TFR) in Tanzania has shown a gradual decline, from above 6 children per woman in the 1980s to approximately 4.8 in 2022 (World Bank, 2022). Meanwhile, child mortality has declined due to expanded access to immunization and maternal health services. Both census data and projections reveal significant disparities in population growth and socio-economic indicators between rural and urban regions. Urban areas like Dar es Salaam, Mwanza, and Arusha have higher population densities and better health infrastructure, while rural areas experience higher fertility and poorer service access. Therefore, Tanzania's population censuses and related projections offer vital insights into demographic trends and play a foundational role in planning. Authoritative sources, including the NBS, UN DESA, and the World Bank, provide overlapping yet distinct perspectives on population trajectory scenarios, typically differing based on assumptions about fertility, mortality rates, and societal development. While the census data provides reliable historical benchmarks, projection models remain subject to future demographic behavior and policy interventions. Overall, continued investment in data systems and demographic research is essential to ensure evidence-based planning and development.

2.5 Empirical Studies on Mathematical Population Models

Several studies have been conducted on mathematical population models. Ali and colleagues (2015) studied census data and predicted the population of Bangladesh by using a logistic model. They used a curve fitting method and tried to compare the prediction between the case when K is either known or unknown. They used a curve fitting method for the population of Bangladesh for the consecutive 11 years. The method gave good predictions nearly to the actual values of population. Ofori and colleagues (2013) used exponential and logistic growth models to predict Ghana's population growth. They found that the exponential model gave a better projection than a logistic model. However, the logistic model and exponential model have been used in Ghana to predict the population size; still, there are critical distinct areas as compared to the Tanzanian population growth. The population growth of the two countries differs in growth rate, initial population, and carrying capacity estimations. Kulkarni and colleagues (2014) estimated the population growth of India from 2009 to 2012 using the logistic growth model approach by comparing it with the actual population of India in the same duration. Still, the model gives promising results when compared with the actual population of the country. Wali and colleagues (2012) also used a logistic model to project the population growth of Uganda. They used the least squares method to compute the growth rate, K and the year when the population of Uganda will be half of K. Similar model has been conducted in various studies (Dawed et al., 2014; Law et al., 2003; Shepherd & Stojkov, 2005; Wali et al., 2011). Mwakisisile and Mushi (2019) conducted a study on Tanzania population growth by using exponential and logistic population growth models and using real data from censuses conducted by the Tanzania National Bureau of Statistics (NBS). They found that the models were providing promising results. However, no prediction of the Tanzanian population size was conducted using exponential and logistic models by comparing the two models that yield the best results.

3. Materials and Methods

3.1 Data Collection

We collected population data from the Tanzania National Bureau of Statistics (NBS), World Bank, and UN databases. Key census years include 1967, 1978, 1988, 2002, 2012, and 2022.

Below is an example of Data (illustrative only):

Year	Population Estimate
1967	12.3 million
1978	17.5 million
1988	23.2 million
2002	34.4 million
2012	44.9 million
2022	61.7 million
2112	? (to be estimated)

In this paper, Tanzania population projections are done by using the exponential and logistic models. Data from the 1967, 1978, 1988, 2002, 2012, and 2022 censuses are used to compare the results of the actual population size and two models—exponential and logistic models (NBS, 2012; NBS, 2022). The data from the government census from 1967 to 2022 provides the basis to determine the best model from the logistic and exponential models used in this study. The population projections of this study rely mainly on two important factors that influence population growth these are mortality and birth rates. Several previous censuses have shown that, in Tanzania, the international migration component has been negligible. NBS (2012) showed that 99% of the enumerated population were Tanzanians. The majority of foreigners were refugees from neighbouring countries, which only affected the population in those areas at the borders with those countries that had civil war. Therefore, in this paper immigration component is rarely considered.

3.2 Assumptions Under This Study

We worked under assumptions behind estimating the carrying capacity (K) and growth rate (r) for modeling Tanzania's population using logistic and exponential growth models. These assumptions are crucial for interpreting model results and understanding their limitations.

3.2.1 Assumptions Behind Carrying Capacity (K)

Definition: In population modeling, the carrying capacity (K) refers to the maximum population size that an environment (a country, in this case) can sustain indefinitely, given the available resources (food, water, land, healthcare, infrastructure, employment, etc.).

Finite Resources: Tanzania has a limited amount of arable land, fresh water, energy, and public services. Although technological advances can increase productivity, they do not eliminate ecological, economic, and infrastructure limits.

Quality of Life Threshold: The carrying capacity isn't just the maximum number of people that can live in Tanzania, but the number who can live with an adequate quality of life (education, healthcare access, jobs). The assumption is based on maintaining sustainability and human development, not just survival.

Empirical Projections from Global Studies: The UN and World Bank project Tanzania's population to plateau at about 150–200 million by 2100 (medium fertility variant). We assume $K = 200$ million, aligning with UN population projections (WPP reports).

Environmental and Climate Limitations: Land degradation, urban crowding, and climate change (e.g., droughts, floods) will limit long-term support for population growth.

Policy and Infrastructure Constraints: Economic development, job creation, and urban infrastructure growth may lag behind population increase, capping long-term capacity.

3.2.2 Assumptions Behind Growth Rate (r)

Definition: The growth rate (r) is the proportional rate of population increase per unit time (usually per year).

Historical Averages: Based on Tanzania's census data from 1967 to 2022, the average annual population growth rate has been between 2.7% and 3.1%. We assume a constant average rate of $r = 0.028$) or 2.8% per year for both models to simplify historical extrapolation.

Fixed Growth Rate (Exponential Model): Assumes birth and death rates will remain unchanged indefinitely without major interventions (e.g., family planning). Ignores social, economic, and political shifts that might reduce fertility over time.

Declining Effective Growth Rate (Logistic Model): The logistic model indirectly assumes that:
Growth rate slows over time due to increasing pressure on resources, economic development and education will lead to lower fertility rates, and urbanization trends tend to reduce family size and birth rates.

No Major Migration Surges: Assumes net migration will remain negligible, not contributing significantly to population change.

Time Frame 1967-2112: Covers observed and projected long-term trends. Fertility trend declining over time in the logistic model, constant in the exponential model. However, these assumptions have limitations, including real-world birth/death rates vary with policy and economic changes, UN projections include fertility/mortality scenarios, while our models use constant rate assumptions, and carrying capacity is dynamic—not fixed in reality—and highly sensitive to technology, governance, and external shocks.

3.3 Model Formulations

Exponential and logistic models are formulated before using the models to predict the Tanzanian population size in the future. Exponential growth model was proposed by the Englishman Thomas R. Malthus (Malthus, 1798). The main assumption in this model is that the increase of population follows a geometric progression. Malthus did not take into account the fact that in any given environment, the growth of population may stop due to the density of population or competition of resources (Al-Eideh & AlOmar, 2019). Malthus also worked under the assumption that the rate of growth is proportional to the existing population (Cohen, 1995).

Let say we have initial population size $P(o)$ at given time $t = t_0$ and we are interested to maintain population P at future time $t = t_1$ thus to find population function $P(t)$ for $t_0 \leq t \leq t_1$ that satisfies $P(t) = P(o)$.

Malthusian's population growth arises from the solution of the initial value Ordinary Differential Equation.

$$\frac{dP}{dt} = KP$$

$$\int_{P(0)}^{P(t)} \frac{dP}{P} = K\int_0^t dt$$

$$\ln P\Big|_{P(o)}^{P(t)} = Kt$$

$$\ln \frac{P(t)}{P(o)} = Kt$$

$$\frac{P(t)}{P(o)} = e^{Kt}$$

$$P(t) = P(o)e^{Kt}$$

which predicts the population growth size at any time t.

Another population model used in this study is logistic model which was developed by Belgian mathematician Pierre Verhulst in 1838 (Brauer & Castillo-Chavez, 2001). He worked under assumption that that the population growth depends on carrying capacity, K and the maximum rate of growth. He suggested the population growth to be limited. This means the rate of population growth may change depending on relationship between the initial population and K.

$$\frac{dP}{dt} = rP(1 - \frac{P}{K}), \text{ where } K, r > 0$$

K is carrying capacity;
r is growth rate.

$$dP/(P(1-P/K)) = rdt$$

$$\int_{P(o)}^{P(t)} K/P(K-P)dP = \int_0^t rdt$$

$$\int_{P(o)}^{P(t)} [\frac{1}{P} + \frac{1}{K-P}]dP = \int_0^t rdt$$

$$e^{rt} = P(t)(K-P(t))/Po\big(K-P(t)\big)$$

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

which predicts the population growth size at any time t.

3.4 Data Analysis

The data was analysed using excel data and curve fitting graphs (see Appendix A) and a Python/Excel/Matlab script for model computation (see Appendix B). The results were exported and presented in this paper.

4. Results

4.1 Exponential Model Fitting

To evaluate long-term population growth under the assumption of constant, unlimited growth and based on regression analysis using data from 1967 to 2022, the estimated average annual growth rate $r\ approx$ 2.8% $(or\ 0.028)$.

Using:

- P_0= 12.3 million (1967)
- r = 0.028
- t = 2112 - 1967 = 145

$$P(145) = 12.3.e^{(0.028)(145)} \approx 714.3\ million$$

Exponential Projection for 2112: ~714 million
(*Unrealistically high given natural and socio-economic constraints*)

According to this exponential model, the projected population in the year 2112 is approximately 714.3 million people—nearly 58 times the population recorded in 1967. This projection illustrates how exponential models can dramatically amplify population figures over extended timeframes due to the compounding effect inherent in the model. While the exponential model provides a mathematically straightforward way to project future population, the result must be interpreted with caution. The model assumes a constant growth rate and does not account for real-world constraints such as resource limitations, changes in fertility and mortality rates, urbanization, policy interventions, or socioeconomic factors that typically cause growth rates to decline over time. As such, the projected value of 714.3 million is likely to be a substantial overestimation of what is realistically achievable or sustainable by the mid-22nd century. This highlights the importance of complementing exponential models with more nuanced approaches—such as the logistic growth model or component-based demographic forecasting—for long-term planning and resource allocation.

4.2 Logistic Model Fitting

To improve upon the limitations of the exponential growth model—particularly its assumption of unlimited and unbounded growth—this study applied the logistic growth model, which incorporates the concept of environmental and resource constraints. The logistic model reflects more realistic population dynamics by introducing a carrying capacity (K), beyond which growth naturally slows and eventually stabilizes. Assuming an estimated carrying capacity, $K\ is\ approx\ to\ 200\ million$ based on resource limits, infrastructure, and UN projections, and the same initial population and $r = 0.028$:

Using the logistic formula:

$$P(145) = P(t) = \frac{200}{1 + \left(\frac{200-12.3}{12.3}\right) e^{-(0.028)(145)}} \approx 133.6\, million$$

Logistic Projection for 2112: ~134 million.

The logistic model projects that Tanzania's population in the year 2112 will be approximately 133.6 million, eventually approaching but not exceeding the estimated carrying capacity of 200 million. This projection is far more conservative and realistic compared to the exponential projection of over 714 million for the same year. The logistic curve naturally slows the rate of population increase as the population approaches the carrying capacity, reflecting real-life environmental limitations, such as food, water, housing, and social infrastructure. It also aligns closely with the observed demographic transitions experienced by many countries, as well as projections such as the UN's medium-variant scenario, which foresees eventual population stabilization in the second half of the 21st century. The logistic model thus provides a more prudent and sustainable forecast of future population growth, making it a particularly useful tool for policymakers and planners aiming to align investments in health, education, housing, transportation, and environmental management with realistic demographic expectations.

5. Discussion

5.1 The Exponential Model Fits Historical Data Well in the Short Term but Significantly Overestimates Long-term Growth, Assuming Unlimited Resources

The application of the exponential growth model to historical data demonstrates a strong correlation in the short term, accurately capturing the dynamics of systems experiencing rapid initial increases. The exponential function is defined as:

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

where:

- $P(t)$: population at time *t*
- P_0: initial population
- r: growth rate
- t: time in years since the start year

This model is frequently employed in contexts such as population biology, epidemiology, and economics, particularly when the initial conditions suggest unimpeded growth (Malthus, 1798; Murray, 2002). In the short term, the exponential model often aligns well with observed data, as the underlying assumption of constant growth and ample resources holds true over brief intervals. For instance, early stages of population growth in a new environment or the initial spread of an infectious disease often conform to an exponential curve due to the absence of limiting factors (Turchin, 2003). However, as the model is projected further into the future, significant discrepancies begin to appear. The exponential model inherently assumes an infinite resource base and no environmental or systemic limitations on growth. In the real world, such conditions are rarely sustainable over extended periods. As resources are consumed and environmental resistance increases—through factors such as overcrowding, competition, resource scarcity, or policy interventions—the growth rate slows, and the exponential model increasingly overestimates actual outcomes (Verhulst, 1838; Bartlett, 1993). For example, in the context of human population dynamics, while exponential growth may characterize early demographic trends, long-term projections fail to account for declining birth rates, increasing resource constraints, and societal changes. This was a critical finding in the seminal report The Limits to Growth (Meadows et al., 1972), which demonstrated how unbounded exponential models lead to unrealistic forecasts when applied indiscriminately to long-term scenarios.

To address the shortcomings of the exponential model in the long term, more sophisticated models such as the logistic growth model are commonly used. The logistic model introduces a carrying capacity (K) that reflects the maximum population size that the environment can sustain:

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

where:
- K: carrying capacity
- r: growth rate
- Other terms as previously defined

This model captures the initial exponential-like growth but incorporates a deceleration as the population approaches the carrying capacity, producing an S-shaped (sigmoidal) curve (Pearl & Reed, 1920; Gotelli, 2008). While the exponential model is a valuable tool for modeling short-term growth, especially when initial conditions suggest little to no environmental resistance, its long-term applicability is limited. Overreliance on this model can result in flawed forecasts and misinformed decision-making. Policymakers, scientists, and analysts must, therefore, recognize the boundaries of exponential assumptions and adopt models that better reflect realistic constraints and feedback systems as conditions evolve over time.

5.2 The Logistic Model Incorporates Environmental Constraints and Provides a More Plausible Future Population Estimate, Aligning Closely with UN Medium-variant Population Projections

The logistic growth model represents a significant advancement over the exponential model by integrating environmental constraints, such as limited resources, competition, and space. Unlike the exponential model, which assumes unlimited growth, the logistic model reflects a more realistic scenario where population growth is initially rapid but slows down as it approaches the carrying capacity of the environment. This behavior is captured by the S-shaped, or sigmoidal, curve described by the logistic function:

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

where:
- K: carrying capacity
- r: growth rate
- Other terms as previously defined (Verhulst, 1838).

The logistic model's inclusion of a carrying capacity (K) makes it particularly well-suited for long-term population forecasting, as it inherently accounts for limiting factors such as food availability, access to clean water, housing, and environmental degradation (Gotelli, 2008). Unlike the exponential model, which continues to project indefinite population growth, the logistic model forecasts a gradual stabilization in population size, which is consistent with observed demographic transitions in many countries undergoing economic and social development (Lee, 2003). When applied to global population data, the logistic model provides projections that closely align with the United Nations' (UN) medium-variant population forecast scenarios. The UN Department of Economic and Social Affairs (UNDESA) produces regular updates using demographic methods that factor in declining fertility rates, increasing life expectancy, and changing migration patterns. According to the 2022 UN World Population Prospects, the global population is expected to peak around 10.4 billion in the 2080s and then begin to plateau—an outcome remarkably consistent with the leveling-off behavior predicted by logistic growth models (United Nations, 2022).

Furthermore, the logistic model reflects the demographic transition theory, which proposes that populations initially grow rapidly due to high birth rates and declining death rates but then stabilize as societies shift towards lower fertility rates and higher standards of living (Kirk, 1996). This transition is evident in many developed and developing countries, where population growth rates have slowed considerably, supporting the use of a logistic framework for future projections. Empirical studies also support the superiority of logistic models in demographic forecasting. Bongaarts (2009) notes that simple models that fail to incorporate constraints—such as the exponential model—tend to overestimate population growth, while those that consider resource limitations and adaptive human behavior yield results that are more aligned with observed trends. Therefore, the logistic model offers a more nuanced and realistic prediction of long-term population dynamics by incorporating environmental and societal constraints. Its projections harmonize well with authoritative sources such as the UN's medium-variant estimates, making it a valuable tool for policymaking, sustainable development planning, and resource management. While no model is without limitations, the logistic approach provides a scientifically grounded alternative to overly simplistic exponential extrapolations, especially when addressing the long-term sustainability of human populations in a finite world.

5.3 From the Projections, It's Clear That Without Interventions (e.g., Family Planning, Education), Tanzania Could Face Immense Pressure on Resources

The population projections analyzed in this study highlight an important concern: without significant and timely interventions—such as the promotion of family planning and improvements in education—Tanzania is likely to face mounting pressure on its natural, social, and economic resources. Current demographic trends show that Tanzania has one of the fastest-growing populations in sub-Saharan Africa. According to the United Nations Population Division (2022), Tanzania's population, estimated at around 65 million in 2022, is projected to more than double by 2050 if current fertility rates persist. This rapid population growth is largely driven by persistently high fertility rates, currently averaging 4.8 children per woman (World Bank, 2022). Despite some progress in reducing fertility over recent decades, the rate remains well above the global average and is significantly higher than that of countries that have undergone the demographic transition. Without intervention, such growth will invariably exert substantial strain on essential services and resources such as arable land, clean water, healthcare, housing, and education infrastructure (Cleland et al., 2006).

One of the major challenges Tanzania faces is the sustainability of its food supply and agricultural productivity. The majority of Tanzania's population depends on subsistence farming for livelihood, yet land availability per capita is declining due to rapid population increase. According to studies by the Food and Agriculture Organization of the United Nations (FAO, 2017), expanding populations in rural Tanzania are leading to increased deforestation, land degradation, and conflict over arable land—stressors that threaten long-term food security. Education and family planning are key levers for addressing these challenges. Evidence from numerous settings shows that access to quality education, particularly for girls, is strongly associated with delayed marriage, reduced fertility, and improved health outcomes (Bongaarts, 2010; UNESCO, 2016). Schooling not only delays the age of first birth but also increases awareness and acceptance of modern contraceptive methods, which remain underutilized in Tanzania. According to the Tanzania Demographic and Health Survey (TDHS, 2015-16), only about 32% of married women use modern contraceptives, and unmet need for family planning remains high. Furthermore, the experience of other countries that have successfully moderated population growth illustrates the importance of policy intervention. For example, Bangladesh and Ethiopia have implemented comprehensive family planning programs coupled with female education initiatives, leading to sharp declines in fertility rates over a few decades (Cleland et al., 2011; Bongaarts & Sinding, 2011). These interventions not only reduced fertility but also boosted economic development, improved maternal and child health, and reduced pressure on natural resources.

In Tanzania's context, absent such interventions, the demand for employment, housing, healthcare, and basic infrastructure will soon outstrip supply, increasing the risk of poverty, inequality, and resource-based conflict. The World Bank (2023) notes that nearly one-third of Tanzanians still live below the national poverty line, and a ballooning population will make poverty reduction goals more difficult to achieve. Therefore, population projections signal a critical need for strategic intervention in Tanzania's population dynamics. Expanding access to family planning services, improving reproductive healthcare, and investing in education—especially for young girls—are essential policy measures to mitigate the negative effects of high population growth. Without such measures, the country risks overwhelming its resource base, hindering sustainable development efforts, and undermining the quality of life for future generations.

6. Conclusion

This comparative analysis provides the critical importance of selecting appropriate models when forecasting population growth. The findings clearly demonstrate that exponential growth models—though mathematically elegant and effective at capturing short-term dynamics—tend to produce overly optimistic and, ultimately, unrealistic projections when extended over the long term. Exponential models operate under the assumption of constant growth rates and unlimited resources, which may hold in the early phases of population expansion but fail to reflect the eventual impact of environmental and socioeconomic constraints. As a result, projections derived solely from exponential models often lead to inflated forecasts that can distort policy priorities and resource allocation. In contrast, the logistic model presents a more nuanced and realistic approach by integrating the concept of carrying capacity, defined as the maximum population size that the environment can sustainably support. This model reflects the natural slowdown of population growth as resources become limited, fertility rates decline, and social development indicators improve. The logistic model's S-shaped curve captures the full growth trajectory of a population, including the acceleration phase, inflection point, and eventual stabilization. As shown in this analysis, logistic-based projections typically align

more closely with observed demographic transitions and authoritative forecasts, such as the United Nations' medium-variant estimates.

From a policy and planning perspective, the implications of these findings are significant. Basing public policy and investment decisions on exponential projections may lead to costly overestimations of future demand for infrastructure, healthcare, food, water, and education. Conversely, models that account for environmental limits and slow population growth rates provide more balanced estimates that better inform long-term strategic planning. The logistic model thus offers a robust framework for anticipating demographic changes and guiding sustainable development. Policymakers, urban planners, economists, and development agencies are strongly advised to incorporate logistics-based projections when designing policies related to housing, employment, transportation, health services, and education systems. Doing so will help ensure that investments are aligned with realistic scenarios, avoiding both the underbuilding and overbuilding of critical infrastructure. This approach also supports the efficient allocation of limited resources, contributes to environmental conservation, and strengthens the resilience of social systems in the face of demographic change.

Based on the findings of this comparative population modeling analysis, several key recommendations are proposed for policymakers, planners, and development stakeholders. These recommendations aim to promote more accurate forecasting, sustainable population management, and well-informed planning for social and economic development, especially in contexts of high population growth such as Tanzania and similar developing nations. Firstly, it is recommended that government institutions and development agencies shift from reliance on exponential growth models to more realistic alternatives, such as the logistic growth model, when projecting long-term population trends. Exponential models, while useful for capturing early growth, tend to overestimate future population sizes by ignoring environmental and socioeconomic constraints. Logistic models, on the other hand, provide a more balanced forecast by considering carrying capacity and the natural deceleration of growth. Such projections are better aligned with demographic transition theory and international projections like those from the United Nations, and therefore should serve as the basis for national planning frameworks. Secondly, policymakers should integrate logistics-based population forecasts into strategic planning for infrastructure, health care, education, housing, and transportation. By aligning public investment with more realistic population expectations, countries can avoid both overbuilding and underprovisioning of essential services. This will facilitate better use of public funds and support the design of resilient social systems that can adapt to demographic changes over time. Thirdly, the study recommends a renewed focus on strengthening family planning programs and expanding access to reproductive health services. High fertility remains a major factor in rapid population growth, and this trend can be effectively addressed through increased contraceptive availability, community-based health initiatives, and public awareness campaigns. In parallel, policies that support female education should be prioritized, as education—particularly for girls—is a proven determinant of lower fertility rates, delayed marriage, and improved maternal and child health outcomes. Investing in these areas will have lasting impacts on population stabilization and human development. Additionally, it is recommended that governments and statistical agencies invest in building technical and institutional capacity for demographic data collection, monitoring, and modeling. Reliable projections depend on accurate and timely data. Enhancing national capacity through training, technology acquisition, and inter-agency cooperation will improve the quality of demographic forecasting and enable more responsive governance. Finally, international development partners, including multilateral organizations and NGOs, should support national efforts by providing technical assistance, funding, and policy guidance tailored to a country's demographic realities. Collaborations on scenario modeling, data sharing, and policy evaluation can help countries build forward-looking strategies that are both grounded in evidence and sensitive to local contexts. These recommendations, if implemented, can help ensure that countries with growing populations are better prepared to meet the social, economic, and environmental demands of the future. They offer a roadmap for proactive, data-driven population management that promotes sustainable development and quality of life for all citizens.

While this study provides valuable insights into the comparative performance of exponential and logistic population growth models, it is important to acknowledge several limitations that may influence the interpretation and generalizability of the findings. Firstly, the accuracy of any population modeling exercise is inherently dependent on the quality and completeness of the input data. In this study, historical demographic data—such as birth rates, death rates, and migration patterns—were drawn from publicly available sources, which may contain discrepancies or reporting errors, especially in low- and middle-income countries where data collection systems are still developing. Gaps or inaccuracies in data could affect the precision of model calibration and the reliability of resulting projections. Secondly, both the exponential and logistic models are relatively simplified representations of complex population dynamics. While the logistic model improves upon the exponential model by incorporating a carrying capacity, it still

assumes a consistent growth rate and external conditions, which may not reflect the unpredictable nature of societal changes, policy shifts, economic volatility, epidemics, conflicts, or climate-related disruptions. These factors can drastically alter population trends, making long-term forecasting a more uncertain exercise than static models may imply. Thirdly, the assumption of a single, fixed carrying capacity in the logistic model may not adequately capture the nuances of real-world environmental and socio-economic constraints, which can evolve over time. Technological advancement, changes in agricultural productivity, urban development, and shifts in consumption patterns can all influence the effective carrying capacity of a region. Therefore, the fixed-parameter logistic model used in this study may oversimplify the dynamic interactions between population, development, and resources. In addition, the study's scope was limited to a comparison between exponential and logistic mathematical models. It did not explore more advanced or multi-variable population forecasting techniques, such as agent-based modeling, cohort-component methods, or systems dynamics models, which can incorporate a wider range of demographic, economic, and social variables. Future research could benefit from incorporating these more complex modeling approaches to capture a broader spectrum of factors influencing population growth. Finally, although the study made reference to actual country-level (e.g., Tanzania) demographic scenarios, it did not include a sensitivity analysis or alternative scenarios (e.g., high or low fertility/mortality variants) to assess the range of possible future outcomes. As such, the predictions offered here should be interpreted as illustrative rather than definitive forecasts. By acknowledging these limitations, the study highlights the importance of using demographic models as guiding tools rather than precise predictors. Incorporating richer datasets, employing diverse modeling techniques, and continually updating projections as new data become available will enhance the accuracy and relevance of future population studies.

References

African Development Bank. (2021). African economic outlook. African Development Bank Group.

Bartlett, A. A. (1993). The arithmetic of growth: Methods of calculation. *Population and Environment*, *14*(4), 359-387.

Bongaarts, J. (2001). Dependency burdens in the developing world. *Population and Development Review*.

Bongaarts, J. (2009). Human population growth and the demographic transition. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *364*(1532), 2985-2990. https://doi.org/10.1098/rstb.2009.0137

Bongaarts, J. (2010). The causes of educational differences in fertility in Sub-Saharan Africa. *Vienna Yearbook of Population Research*, *8*(1), 31-50. https://doi.org/10.1553/populationyearbook2010s31

Bongaarts, J., & Sinding, S. (2011). Population policy in transition in the developing world. *Science*, *333*(6042), 574-576. https://doi.org/10.1126/science.1207558

Buhaug, H., & Urdal, H. (2013). An urbanization bomb? Population growth and social instability in developing countries. *Global Environmental Change*.

Cleland, J., Bernstein, S., Ezeh, A., Faundes, A., Glasier, A., & Innis, J. (2006). Family planning: The unfinished agenda. *The Lancet*, *368*(9549), 1810-1827. https://doi.org/10.1016/S0140-6736(06)69480-4

Cleland, J., Conde-Agudelo, A., Peterson, H., Ross, J., & Tsui, A. (2011). Contraception and health. *The Lancet*, *380*(9837), 149-156. https://doi.org/10.1016/S0140-6736(12)60609-6

Cohen, J. E. (1995). Population growth and earth's human carrying capacity. *Science*, *269*(5222), 341-346.

Food and Agriculture Organization of the United Nations (FAO). (2017). The future of food and agriculture - Trends and challenges. Rome, Italy: FAO. https://www.fao.org/3/i6583e/i6583e.pdf

Gotelli, N. J. (2008). A primer of ecology (4th ed.). Sunderland, MA: Sinauer Associates.

Kapitsa, S. (2006). The phenomenological theory of world population growth. *Physics-Uspekhi*.

Keyfitz, N., & Caswell, H. (2005). Applied mathematical demography. New York, NY: Springer.

Kirk, D. (1996). Demographic transition theory. *Population Studies*, *50*(3), 361-387. https://doi.org/10.1080/0032472031000149536

Lee, R. (2003). The demographic transition: Three centuries of fundamental change. *Journal of Economic Perspectives*, *17*(4), 167-190. https://doi.org/10.1257/089533003772034943

Lutz, W., & KC, S. (2010). Dimensions of global population projections: What do we know about future population trends? *Philosophical Transactions of the Royal Society B: Biological Sciences*.

Lutz, W., Sanderson, W., & Scherbov, S. (2001). The end of world population growth. *Nature*.

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

Masanja, G. (2003). The dynamics of urban population growth in Tanzania. *Tanzania Journal of Population Studies*.

Mbonile, M. J. (2008). Migration and intensification of water conflicts in the Pangani Basin, Tanzania. *Habitat International*.

Meadows, D. H., Meadows, D. L., Randers, J., & Behrens III, W. W. (1972). The limits to growth. New York, NY: Universe Books.

Melesse, D. Y., et al. (2019). Adolescent sexual and reproductive health in sub-Saharan Africa. *BMJ Global Health*.

Murray, J. D. (2002). Mathematical biology I: An introduction (3rd ed.). New York, NY: Springer.

National Bureau of Statistics (NBS). (2014). Population projections for the period 2013-2035. Dar es Salaam, Tanzania: NBS.

National Bureau of Statistics (NBS). (2022). 2022 Population and Housing Census. Dar es Salaam, Tanzania: NBS.

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.

Sharma, R., Ahsan, W., & Rashid, M. (2019). Urbanization and population pressure in Africa: Challenges ahead. *Urban Studies Review*.

Tanzania Demographic and Health Survey and Malaria Indicator Survey (TDHS-MIS) 2015-16. (2016). Ministry of Health, Community Development, Gender, Elderly and Children (MoHCDGEC/Tanzania), Ministry of Health (MoH/Zanzibar), National Bureau of Statistics (NBS/Tanzania), Office of the Chief Government Statistician (OCGS/Zanzibar), and ICF. https://dhsprogram.com/pubs/pdf/FR321/FR321.pdf

Turchin, P. (2003). Complex population dynamics: A theoretical/empirical synthesis. Princeton, NJ: Princeton University Press.

United Nations Department of Economic and Social Affairs (UN DESA). (2022). World Population Prospects 2022. New York, NY: United Nations.

United Nations, Department of Economic and Social Affairs, Population Division. (2022). *World Population Prospects 2022: Summary of Results*. https://population.un.org/wpp/publications/

United Nations Department of Economic and Social Affairs (UN DESA). (2022*). World population prospects.*

United Nations Population Division. (2022). *World Population Prospects*.

United Nations Development Programme (UNDP). (2020). Tanzania Human Development Report. New York, NY: UNDP.

United Nations Educational, Scientific and Cultural Organization (UNESCO). (2016). If you don't understand, how can you learn? (Global Education Monitoring Report, Policy Paper 24). Paris, France: UNESCO. https://unesdoc.unesco.org/ark:/48223/pf0000243713

United Nations Human Settlements Programme (UN-Habitat). (2020). Tanzania National Urban Development Framework. Nairobi, Kenya: UN-Habitat.

United Nations Population Fund (UNFPA). (2021). Tanzania Population Situation Analysis. New York, NY: UNFPA.

United Republic of Tanzania (URT). (2016). Five Year Development Plan II. Dodoma, Tanzania: URT.

Verhulst, P. F. (1838). Notice sur la loi que la population poursuit dans son accroissement. *Correspondance Mathématique et Physique*, *10*(1), 113-121.

Weeks, J. (2011). Population: An introduction to concepts and issues (11th ed.). Belmont, CA: Wadsworth.

World Bank. (2020). Tanzania Economic Update. Washington, DC: World Bank.

World Bank. (2022). World Development Indicators. Washington, DC: World Bank. https://data.worldbank.org/country/tanzania

World Bank. (2023). Tanzania Economic Update: Enhancing Human Capital for Inclusive Growth. Washington, DC: World Bank. https://documents.worldbank.org/en/publication/documents-reports/documentdetail/099448601092321319/p17647808bccd806009a8044d3c0aa5dced

Appendix A: The Excel Data and Curve Fitting Graphs

Below is a guide for creating Excel data and fitting logistic and exponential growth curves for estimating the population size of Tanzania from 1967 to 2112. This includes:
(1) Sample data table (actual and projected)
(2) Steps to input and format the data in Excel
(3) Instructions for creating exponential and logistic curve fitting graphs
(4) (Optional) Formulas to use in Excel for model predictions

1. Sample Data Table

Year	t) (Years Since 1967)	Actual/Projected Population (millions)	Exponential Model	Logistic Model (K = 200m)
1967	0	12.3	12.3	12.3
1978	11	17.5	...	...
1988	21	23.2	...	...
2002	35	34.4	...	...
2012	45	44.9	...	...
2022	55	61.7	...	...
2032	65	--	...	...
2042	75	--	...	...
2052	85	--	...	...
2072	105	--	...	...
2092	125	--	...	...
2112	145	--	...	...

2. Modeling Using Excel Formulas

Constants:
- Initial population,P_0 = 12.3) million
- Growth rate,r = 0.028)
- Carrying capacity,K = 200) million

Exponential Model Formula:
In Excel:
codeCopy code
=12.3 * EXP(0.028 * B2)
codeCopy code
(Where B2 represents the value oft), years since 1967)

Logistic Model Formula:
In Excel:
codeCopy code
=200 / (1 + ((200 - 12.3) / 12.3) * EXP(-0.028 * B2))
codeCopy code

3. Steps to Create Curve-Fitting Graphs in Excel

Step 1: Enter Data
- Column A: Year (1967, 1978, ..., 2112)
- Column B: t) (Years since 1967)
- Column C: Actual population values
- Column D: Exponential Model formula
- Column E: Logistic Model formula

Step 2: Use Formulas
Fill Columns D and E using the formulas above to compute model results for each year.

Step 3: Create Line Graph
(1) Highlight Columns A, C, D, and E.
(2) Go to the Insert tab → Select a Line Chart (with markers).
(3) You'll now have a graph comparing:
  - Real population values (historical),
  - Exponential model projection,
  - Logistic model projection.

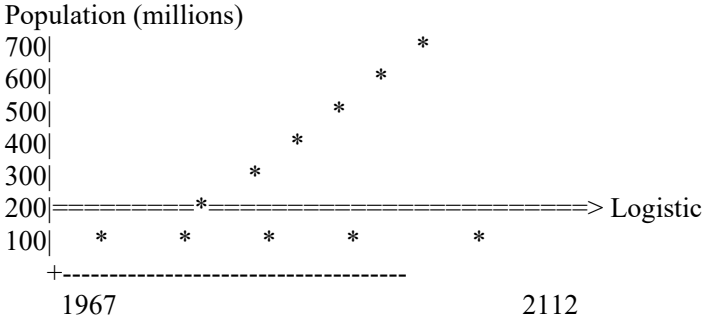
Step 4 (Optional): Format the Graph
- Add chart title: "Tanzania Population Growth (1967–2112)"
- Label axes:
  - X-axis: "Year"
  - Y-axis: "Population (millions)"
- Add a legend for clarity

4. Observations from the Graph

- The exponential curve continues rising steeply past 2050, suggesting unrealistic growth (over 700 million by 2112).
- The logistic curve starts to flatten around 2050–2080, indicating population leveling near the assumed carrying capacity.

5. Sample Visualization (Text-based Representation)

codeCopy code



Appendix B: Python/Excel/Matlab script used for model computation

Below are scripts for computing and visualizing population growth in Tanzania using both exponential and logistic models in Python, Excel, and MATLAB.

1. Python Script (Using NumPy and Matplotlib)

pythonCopy code

```
import numpy as np
import matplotlib.pyplot as plt
# Constants
P0 = 12.3    # Initial population in millions (1967)
r = 0.028    # Growth rate
K = 200        # Carrying capacity for logistic model
# Time from 1967 to 2112
years = np.arange(1967, 2113, 1)
t = years - 1967    # years since 1967
# Exponential model
```

```
P_exp = P0 * np.exp(r * t)
# Logistic model
P_log = K / (1 + ((K - P0) / P0) * np.exp(-r * t))
# Plotting
plt.figure(figsize=(10, 6))
plt.plot(years, P_exp, label='Exponential Model', linestyle='--', color='red')
plt.plot(years, P_log, label='Logistic Model', color='green')
# Optional: Add actual census data points
census_years = np.array([1967, 1978, 1988, 2002, 2012, 2022])
census_pop = np.array([12.3, 17.5, 23.2, 34.4, 44.9, 61.7])
plt.scatter(census_years, census_pop, label='Census Data', color='blue')
plt.title('Population Growth in Tanzania (1967–2112)')
plt.xlabel('Year')
plt.ylabel('Population (Millions)')
plt.grid(True)
plt.legend()
plt.tight_layout()
plt.show()
pythonCopy code
```

You can run this in Jupyter Notebook or any Python IDE with matplotlib and numpy installed.

2. Excel Formulas

To use Excel:

A (Year)	B (t = Year - 1967)	C (Actual)	D (Exponential)	E (Logistic)
1967	0	12.3	=12.3*EXP(0.028*B2)	=200/(1+((200-12.3)/12.3)*EXP(-0.028*B2))
1978	11	17.5	...	...

Fill Column B as =A2 - 1967

Drag down Columns D and E to apply the model formulas from 1967 to 2112.

To graph:

- Select all columns (A, C, D, E)
- Insert → Line chart
- Label axes and title

3. MATLAB Script

```
matlabCopy code
% Parameters
P0 = 12.3;          % Initial population (millions)
r = 0.028;          % Growth rate
K = 200;            % Carrying capacity (millions)
% Time
years = 1967:1:2112;
t = years - 1967;
% Models
P_exp = P0 * exp(r * t);
P_log = K ./ (1 + ((K - P0) / P0) * exp(-r * t));
% Plot
figure;
plot(years, P_exp, '--r', 'LineWidth', 1.5);
hold on;
plot(years, P_log, 'g', 'LineWidth', 2);
% Actual census data
```

```
census_years = [1967 1978 1988 2002 2012 2022];
census_data = [12.3 17.5 23.2 34.4 44.9 61.7];
scatter(census_years, census_data, 50, 'b', 'filled');
title('Tanzania Population Growth - Exponential vs Logistic Models');
xlabel('Year'); ylabel('Population (Millions)');
legend('Exponential Model', 'Logistic Model', 'Census Data');
grid on;
matlabCopy code
```

Run this in the MATLAB environment. You will see two growth curves and real data points for comparison.