JOURNAL OF MECHANICS OF CONTINUA AND MATHEMATICAL SCIENCES
www.journalimcms.org

ISSN (Online) : 2454 -7190 Vol.-20, No.-10, October (2025) pp 174-199 ISSN (Print) 0973-8975

SOUTH ASIAN DEMOGRAPHY: A NOVEL INSIGHT ON GROWTH RATE ACROSS THREE NATIONS

Anish Kumar Adhikary[1], Nasrin Nahar Rimu[2], Md. Antajul Islam[3] Shuvo Sarker[4], Rezaul Karim[5], Md. Monower Anjum Niloy[6] Pinakee Dey[7]

[1,2,3,4,5,6,7] Department of Mathematics, Mawlana Bhashani Science and Technology University, Tangail-1902, Bangladesh.

[1] Department of CIS, Daffodil International University, Dhaka-1216, Bangladesh.

[4]Department of Applied Mathematics, Gono Bishwabidyalay, Savar, Dhaka-1344, Bangladesh.

Email: [1]anishadhikary627@gmail.com, [2]nasrinnaharrimu@gmail.com
[3]antajul19026@gmail.com, [4]sarkershuvo.mbstu@gmail.com
[5]rezaul.math@mbstu.ac.bd, , [6]anjumniloy36@gmail.com, [7]pinakeedey68@gmail.com

Corresponding Author: **Pinakee Dey**

https://doi.org/10.26782/jmcms.2025.10.00011

(Received: July 07, 2025; Revised: September 22, 2025; October 04, 2025)

Abstract

This study showcases a novel insight into the growth rate of Bangladeshi, Indian, and Nepali people, focusing on historical population patterns, contemporary demographic trends, and future population projections. Asia, home to over 4.5 billion people, accounts for approximately 70% of the global population, with Bangladesh, India, and Nepal being the most populous countries in South Asia. To facilitate chances for more significant policymaking in these nations, this study will examine the growth rate and its effects in the years to come. The demographic shifts in Bangladesh are creating new economic opportunities, with insights that can guide policymakers in refining population strategies, which are also relevant to India and Nepal. This study thoroughly assesses the precision and relevance of five mathematical models, e.g., the least squares model, Malthusian (exponential growth) model, logistic growth model, hyperbolic growth model, and discrete logistic growth model, in forecasting demographic changes in Bangladesh, India, and Nepal from 1950 to 2100. Furthermore, the study offers a speculative analysis of how these countries have previously handled population growth and the strategies they may adopt in the future.

Keywords: Bangladesh, Growth Rate Comparison, India, Mean Absolute Percentage Error, Nepal, South Asian Countries.

I. Introduction

A population consists of individuals of the same species separated from other groups by distance or time. Even in close proximity, populations may exhibit genetic variations over time, known as clinal variation. Population models are mathematical frameworks that connect individual responses to changes in population density and structure, often referred to as life history features or vital rates. These models enhance ecological risk assessment by reducing uncertainty when extrapolating significant ecological impacts from sub-organism or individual-level data. Predictive algorithms increasingly rely on population models to forecast trends. Globally, population dynamics are critical, with an annual growth of approximately 80 million people, projected to continue without intervention. This growth influences economics, politics, culture, education, ecology, and natural resource prices. In high-density regions like Bangladesh, India, and Nepal, population growth outpaces resource development, posing significant challenges. Mathematical modeling, including exponential, logistic, hyperbolic, and linear regression models, is essential for predicting future population trends and addressing historical demographic questions.

Extensive research has explored population dynamics in Bangladesh, India, and Nepal, with figures on national and global scales. Organizations like the Population Reference Bureau, Census Bureau, United Nations Population Fund, and World Bank maintain global population databases, while the Bangladesh Bureau of Statistics tracks national demographic data. Studies such as Rifat Zahan (2020) [I] analyze socio-demographic shifts in Bangladesh, highlighting fertility declines and changing age structures. Mazharul (2016) [II] discusses Bangladesh's demographic transition, noting economic opportunities and policy challenges from a temporary "window of opportunity" peaking in the 2020s. Pinakee et al. (2023) [III] evaluate population growth models for Bangladesh and Sri Lanka, finding logistic and regression models most accurate for 2000–2022 projections. The aforementioned authors have similarly distinguished themselves in T-cell therapy through the implementation of the techniques presented in this literature.[IV], [V], [VI] Rezaul et al. (2024) [VII] examine Bangladesh's demographic transition, emphasizing policy implications and economic prospects. Furthermore, seminal studies in population dynamics have been incorporated to bolster the analytical framework. These authoritative references underpin parameter calibration and validate model outcomes, thereby enhancing the study's overall reliability and accuracy.[VIII], [IX], [X], [XI] Research also covers India and Nepal, where rapid population growth (0.88% and 0.86% annually, respectively) strains resources. Mathematical models, including exponential, logistic, and hyperbolic growth, are widely used to forecast population trends and assess environmental and societal impacts.

This study employs various mathematical population models, including exponential, logistic, hyperbolic, and linear regression, to analyze and forecast population growth in Bangladesh, India, and Nepal. Historical demographic data from national censuses, surveys, and global databases (e.g., United Nations Population Division) are analyzed to understand variable behaviors. These data inform model parameters, such as growth rates, carrying capacities, and dependency ratios. The exponential model assumes uncontrolled growth, while the logistic model accounts for carrying capacity constraints. Hyperbolic growth models historical demographic and economic trends, and linear regression establishes relationships between variables. Model outputs are compared to historical data (2000–2022) to assess accuracy and used to project future population metrics.

While many studies have independently assessed population dynamics and modeling in Bangladesh, India, and Nepal, few have provided a comparative analysis using multiple mathematical models across these three neighboring countries with shared socio-economic and geopolitical ties. This study uniquely integrates logistic, exponential, hyperbolic, and linear regression models to forecast and compare the demographic trajectories of these countries. By doing so, it highlights both the regional similarities and disparities in population growth patterns and resource constraints. The study also emphasizes the application of discrete and continuous forms of these models, showcasing their practical relevance in predicting population pressure on land and resources. Furthermore, it critically examines the implications of population growth on carrying capacity, adaptation, and sustainability.

Population growth in Bangladesh, India, and Nepal presents significant challenges and opportunities, necessitating precise mathematical modeling for effective planning. By utilizing exponential, logistic, hyperbolic, and linear regression models, this study seeks to provide accurate forecasting results, facilitating predictions of future population density. These insights can guide policymakers in leveraging the demographic dividend through strategic investments in infrastructure and human resources. The comparative analysis of multiple models enhances the robustness of projections, offering a valuable tool for addressing the complex dynamics of population growth in these densely populated regions.

II. Methods and materials

This research investigates the challenges, future hurdles, and opportunities associated with population growth and adaptation, influenced by chaotic demographic patterns across generational phases. Drawing on secondary data, projection analysis, and population models [XII], [XIII], [XIV], it integrates government reports, academic journals, and case studies [XV]. Major challenges include costly censuses, erratic population changes, and inconsistent data. Emerging obstacles encompass modeling non-linear dynamics and tackling global data inequities. Opportunities include applying interdisciplinary insights to urban planning and sustainability, and fostering global data cooperation. High costs render annual censuses unfeasible, underscoring the need for advanced modeling to refine demographic projections.

III. Implementation

This research applies mathematical models to population dynamics, using logistic growth, Malthusian, and least squares models to create population projections.

Malthusian Model or Exponential Model:

Exponential growth describes a rapid, unchecked population increase, rare in nature[16]. Proposed by Thomas R. Malthus, this model, reviewed in [XVII], [XVIII]. Assuming the population N at time t_1 from an initial population P_0 at t_0 , use an inherent growth rate λ. The articulation of the Malthusian growth model is as follows:

$$P(t) = P_0 e^{\lambda(t-t_0)} \tag{1}$$

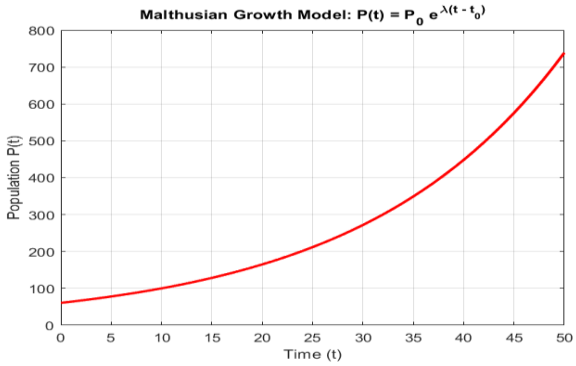

Fig. 1. Malthusian growth model.

Hyperbolic Growth Model

A compelling approach, often termed the hyperbolic growth model, posits that k is proportional to P. This reflects scenarios where larger populations signal favorable economic or social conditions, spurring higher birth rates and accelerating population growth. The resulting hyperbolic growth model is expressed as:

$$p(t) = \frac{p_0}{1-k(t-t_0)} \tag{2}$$

where P_0 is the initial population and t_0 is the reference time, capturing the dynamic interplay between population size and growth rate.

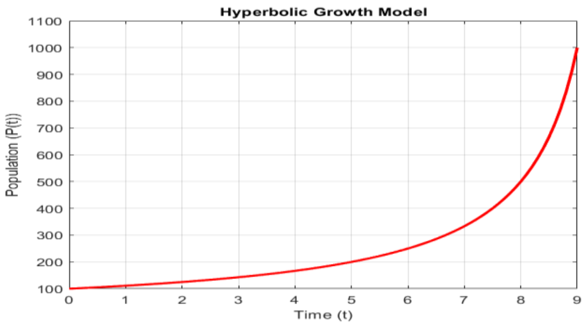

Fig. 2. Hyperbolic growth model.

Logistic Growth Model

In 1838, Belgian mathematician Pierre Verhulst pioneered the logistic model, revealing how population growth depends on its size and proximity to a fluid, uncertain carrying capacity [XIX]. The sigmoid logistic curve depicts growth as initially exponential, then tapering off as it approaches an environmentally imposed ceiling [XX], expressed as:

$$N(t) = \frac{KN_0}{N_0+(K-N_0)e^{\alpha(t_0-t)}} \tag{3}$$

Where the carrying capacity is

$$K = \frac{\alpha}{\beta} = \frac{N_1(N_0N_1-2N_0N_2+N_1N_2)}{{N_1}^2-N_0N_2} \tag{4}$$

and the population coefficient is

$$\alpha = \frac{1}{t_0 - t_1} ln \frac{N_0(N_2 - N_1)}{N_2(N_1 - N_0)} \quad (5)$$

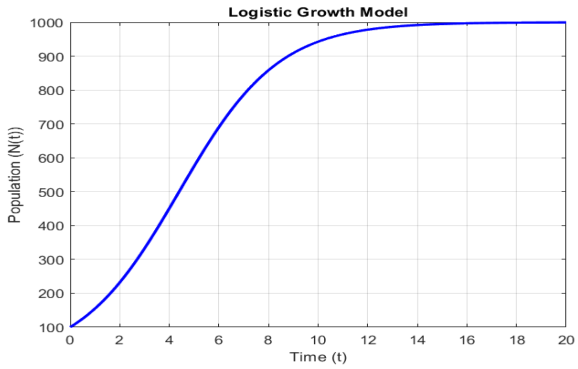

Fig. 3. Logistic growth model

Discrete Logistic Growth Model

Population dynamics often model growth using iterative equations. Let P_t and P_{t+1} represent populations at times t and $t+1$. One such model, sometimes referred to as the Verhulst process, has a general form:

$$P_{t+1} = r\, P_t(1 - \frac{P_t}{K}); \quad r > 0, K > 0, \quad (6)$$

which is a kind of discrete analog of the continuous logistic growth model.

For this model, if $P_t > K$ then $P_{t+1} < 0$. One such frequently used model is

$$P_{t+1} = P_t\, exp\left[r\left(1 - \frac{P_t}{k}\right)\right]; \quad r > 0, k > 0, \quad (7)$$

where $exp\left(\frac{-rP_t}{K}\right)$ is a mortality factor. In this case, if $P_0 > 0$, then $P_t > 0$ for all t.

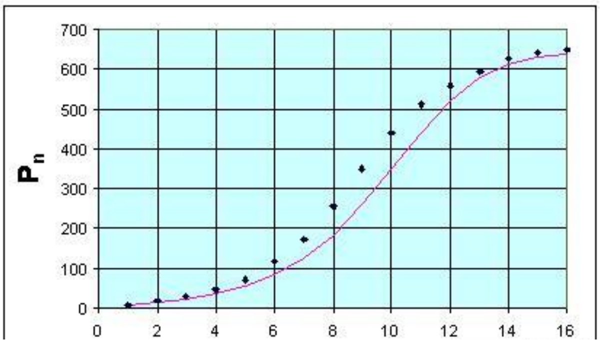

Fig. 4. Discrete Logistic Growth Models

Least Square Model

Linear regression predicts a linear connection between Y (dependent variable) and X (independent variable). The least squares model predicts time-series data values using prior trends [XXI], which matches historical data with a straight line. The regression equation is:

$$Y = a + bX, \tag{8}$$

Where a is the intercept and b is the slope(gradient). The parameters are calculated as:

$$a = \frac{\sum Y}{N} \quad \& \; b = \frac{\sum XY}{X^2}$$

With equations:

$$\sum Y = Na + b\sum X \tag{9}$$

$$\sum XY = a\sum X + b\sum X^2 \tag{10}$$

where,

$$\sum X = The\ total\ of\ all\ X\ observation$$

$$\sum Y = Total\ Y\ observations$$

$$\sum XY = The\ total\ of\ all\ X\ and\ Y\ products$$

$$N = The\ number\ of\ observations$$

By solving equations (9) and (10), the values for a and b may be inserted into equation (8) to create a regression line that predicts Y values for any X value.

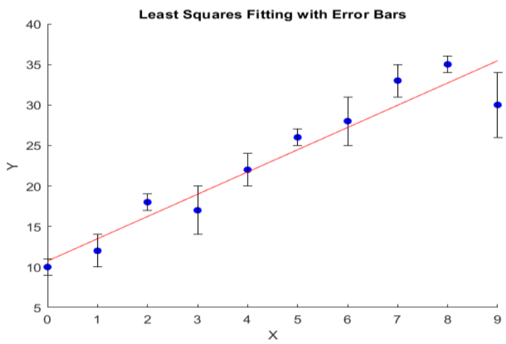

Fig. 5. Least Square Models

Calculation of different models and adaptation:

We analyzed the populations of Bangladesh, India, and Nepal using the Verhulst logistic, Hyperbolic, Discrete logistic, Malthusian, and Least Squares models, alongside a demographic adaptation. Our study focused on census data from 1950 to 2020 for these countries.

Table 1: The Actual population of Bangladesh

Year	Actual Population(million)	Density	Growth rate
1950	39.72	268.48	2.05%
1955	44.31	299.48	2.39%
1960	50.39	340.57	2.84%
1965	58.5	395.33	3.04%

1970	67.54	456.43	2.54%
1975	74.7	504.81	2.40%
1980	83.92	567.18	2.47%
1985	95.95	648.47	2.59%
1990	107.14	724.08	2.15%
1995	117.79	796.02	1.88%
2000	129.19	873.06	1.92%
2005	140.91	952.26	1.53%
2010	148.39	1002.80	1.15%
2015	157.83	1066.58	1.20%
2020	167.42	1131.40	1.15%

Source: https://worldpopulationreview.com/countries/bangladesh-population

Table 1 shows Bangladesh's actual population, density, and growth rate from 1950 to 2020, with a population of 39.72 million in 1950.

Table 2: The Actual population of India

Year	Actual Population(million)	Density	Growth rate
1950	357.02	108.61	2.20%
1955	398.57	121.25	2.27%
1960	445.95	135.66	2.31%
1965	500.11	152.14	2.26%
1970	557.5	169.59	2.23%
1975	623.52	189.68	2.26%
1980	696.82	211.98	2.29%
1985	780.24	237.35	2.27%
1990	870.45	264.80	2.16%
1995	964.27	293.34	2.01%
2000	1059.63	322.35	1.84%
2005	1154.63	351.25	1.62%
2010	1240.61	377.40	1.39%
2015	1322.86	402.42	1.19%
2020	1396.38	424.79	0.96%

Source: https://worldpopulationreview.com/countries/india-population

Table 2 shows India's actual population, density, and growth rate from 1950 to 2020, with a population of 357.02 million in 1950.

Table 3: The Actual population of Nepal

Year	Actual Population(million)	Density	Growth rate
1950	8.39	57.07	2.20%
1955	9.28	63.09	1.91%
1960	10.16	69.09	1.88%
1965	11.23	76.32	2.09%
1970	12.5	84.94	2.20%
1975	13.92	94.62	2.20%
1980	15.6	106.00	2.37%
1985	17.54	119.18	2.33%
1990	19.61	133.28	2.46%
1995	22.3	151.55	2.34%
2000	24.55	166.87	1.72%
2005	26.28	178.59	1.08%
2010	27.16	184.55	0.50%
2015	27.61	187.60	0.54%
2020	29.34	199.41	1.79%

Source: https://worldpopulationreview.com/countries/nepal-population

Table 3 shows Nepal's actual population, density, and growth rate from 1950 to 2020, with a population of 8.39 million in 1950. Now, referencing data from Table 1, Table 2, and Table 3, we calculated the growth rates, carrying capacity for Bangladesh, India, and Nepal using diverse methods.

Malthusian model or exponential model:

For Bangladesh, $\lambda = 0.02055215409$
For India, $\lambda = 0.01948352357$
For Nepal, $\lambda = 0.01788444646$

Therefore, the required output for Bangladesh, India, and Nepal is, respectively,

$$P(t) = 39.72\, e^{0.02055215409(t-1950)}$$
$$P(t) = 357.02\, e^{0.01948352357(t-1950)}$$
$$P(t) = 8.39\, e^{0.01788444646(t-1950)}$$

Hyperbolic growth model:

For Bangladesh, $k = 0.01089646228$
For India, $k = 0.01063320873$
For Nepal, $k = 0.01020060376$

Therefore, the required output for Bangladesh, India, and Nepal is, respectively.

$$P(t) = \frac{39.72}{1-0.01089646228(t-1950)}$$

$$P(t) = \frac{357.02}{1-0.01063320873(t-1950)}$$

$$P(t) = \frac{8.39}{1-0.01020060376(t-1950)}$$

Logistic growth model:

The carrying capacity for Bangladesh is K=246.782, and the growth rate is α=0.03425209792.
The carrying capacity for India is K = 2625.846, and the expansion rate is α = 0.02883734735.
The carrying capacity for Nepal is K = 48.3389, and the expansion rate is α = 0.0285018742.

Therefore, the general answers for Bangladesh, India, and Nepal are as follows:

$$\mathrm{N(t)} = \frac{246.782*39.72}{39.72+(246.782-39.72)\ e^{0.03425209792(1950-t)}}$$

$$\mathrm{N(t)} = \frac{2625.846*357.02}{357.02+(2625.846-375.02)\ e^{0.02883734735(1950-t)}}$$

$$\mathrm{N(t)} = \frac{48.3389*8.39}{8.39+(48.3389-8.39)\ e^{0.02850187429(1950-t)}}$$

Discrete Logistic growth model:

The carrying capacity for Bangladesh is K = 246.782, and the growth rate is $r = 0.1377886683$

The carrying capacity for India is K = 2625.846, and the growth rate is $r = 0.0.1346934708$

The carrying capacity for Nepal is K = 48.3389, and the growth rate is $r = 0.1283571258$

Therefore, the general answers for Bangladesh, India, and Nepal are as follows:

$$p_{t+1} = p_t + 0.1377886683\, p_t \left(1 - \frac{p_t}{246.782}\right)$$
$$p_{t+1} = p_t + 0.0.1346934708\, p_t \left(1 - \frac{p_t}{2625.846}\right)$$
$$p_{t+1} = p_t + 0.1283571258\, p_t \left(1 - \frac{p_t}{48.3389}\right)$$

Least Square Model:

According to Tables 1, 2, and 3, the number of observations is N=15, and using equations (9) and (10), we get the values of a and b.

For Bangladesh $a = -3713.24681$ and $b = 1.920486$

For India $a = -30047.96419$ and $b = 15.552914$

For Nepal $a = -632.077298$ and $b = 0.327679$

Therefore, the general answers for Bangladesh, India, and Nepal are as follows:

$$Y = -3713.24.24681 + 1.920486X$$

$$Y = -30047.96419 + 15.552914X$$

$$Y = -632.077298 + 0.327679X$$

This is the general solution of the Least Squares Model for Bangladesh, India, and Nepal. Utilizing X values of 1, 2, 3, 4, etc., to get the Y population. Utilizing the general solution, we compute the populations of three nations from 1950 to 2100, as shown in Tables 4 through 9.

Table 4: The projected population of Bangladesh

Year	Exponential Model	Hyperbolic Model	Logistic Model	Discrete Logistic Model	Linear Regression Model
1950	39.72	39.72	39.72	39.72	32.29
1955	44.02	42.01	45.76	44.31	41.81
1960	48.78	44.58	52.49	49.32	51.32
1965	54.06	47.48	59.92	54.76	60.84
1970	59.91	50.79	68.03	60.63	70.36
1975	66.40	54.59	76.78	66.93	79.88
1980	73.58	59.01	86.12	73.65	89.40
1985	81.55	64.21	95.95	80.77	98.92
1990	90.37	70.41	106.16	88.26	108.44
1995	100.15	77.93	116.62	96.07	117.95
2000	110.99	87.26	127.18	104.16	127.47
2005	123.00	99.13	137.68	112.45	136.99
2010	136.32	114.73	147.98	120.88	146.51
2015	151.07	136.15	157.93	129.38	156.03
2020	167.42	167.42	167.42	137.86	165.55

The visualization of this table is given in the following figure.

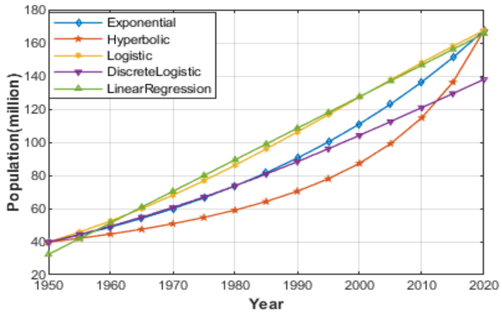

Fig. 6. Projected population of Bangladesh

Table 4 shows population projections for Bangladesh from 1950 to 2020 are presented using five models, e.g., Exponential, Hyperbolic, Logistic, Discrete Logistic, and Linear Regression. While the Logistic and Hyperbolic models align closely, the Linear Regression model predicts consistently higher values, reaching 165.55 million by 2020, slightly trailing the 167.42 million projected by the Logistic and Hyperbolic models.

Table 5: The projected population of India

Year	Exponential Model	Hyperbolic Model	Logistic Model	Discrete Logistic Model	Linear Regression Model
1950	357.02	357.02	357.02	357.02	280.22
1955	393.55	377.07	403.88	398.57	357.98
1960	433.82	399.50	455.65	444.11	435.75
1965	478.21	424.77	512.53	493.81	513.51
1970	527.14	453.45	574.62	547.81	591.28
1975	581.08	486.29	641.96	606.20	669.04
1980	640.53	524.26	714.43	669.01	746.81
1985	706.07	568.65	791.83	736.16	824.57
1990	778.32	621.26	873.77	807.52	902.33
1995	857.95	684.59	959.76	882.83	980.10
2000	945.74	762.31	1,049.15	961.77	1,057.86
2005	1,042.51	859.93	1,141.15	1,043.86	1,135.63
2010	1,149.18	986.22	1,234.91	1,128.57	1,213.39
2015	1,266.76	1156.00	1,329.47	1,215.25	1,291.16
2020	1,396.38	1396.38	1,423.85	1,303.18	1,368.92

The visualization of this table is given in the following figure.

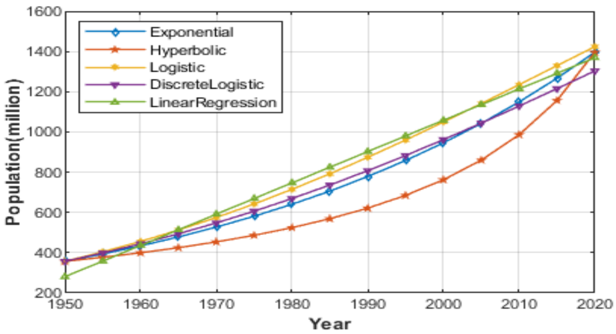

Fig. 7. Projected population of India

Table 5 population projections for the selected region (1950-2020) across five models reveal differing growth trends. The Exponential and Hyperbolic models align at 1,396.38 million, while the Logistic model forecasts 1,423.85 million. The Discrete Logistic model estimates 1,303.18 million, and the Linear Regression model predicts 1,368.92 million, showing consistent growth over time.

Table 6: The projected population of Nepal

Year	Exponential Model	Hyperbolic Model	Logistic Model	Discrete Logistic Model	Linear Regression Model
1950	8.39	8.39	8.39	8.39	6.89
1955	9.17	8.84	9.43	9.28	8.53
1960	10.03	9.34	10.55	10.24	10.17
1965	10.97	9.91	11.78	11.28	11.81
1970	12.00	10.54	13.09	12.39	13.44
1975	13.12	11.26	14.50	13.57	15.08
1980	14.35	12.09	15.98	14.82	16.72
1985	15.69	13.05	17.54	16.14	18.36
1990	17.16	14.17	19.16	17.52	20.00
1995	18.76	15.51	20.83	18.96	21.64
2000	20.52	17.12	22.54	20.44	23.27
2005	22.44	19.11	24.26	21.95	24.91
2010	24.54	21.63	25.97	23.49	26.55
2015	26.83	24.90	27.68	25.04	28.19
2020	29.34	29.34	29.34	26.59	29.83

The visualization of this table is given in the following figure.

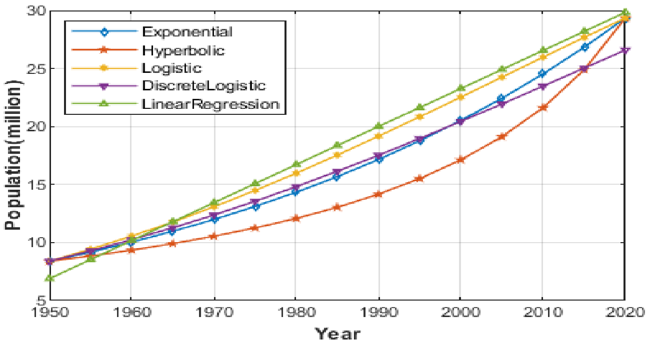

Fig. 8. Projected population of Nepal

Table 6 population projections for the region (1950-2020) across five models show varied growth trends. The Exponential, Hyperbolic, and Logistic models converge at 29.34 million by 2020, while the Discrete Logistic model estimates 26.59 million. The Linear Regression model forecasts the highest at 29.83 million, indicating steady growth.

Table 7: The projected future population of Bangladesh

Year	Exponential Model	Logistic Model	Discrete Logistic Model	Linear Regression Model
2025	185.54	176.35	146.25	175.07
2030	205.62	184.64	154.46	184.58
2035	227.87	192.26	162.42	194.10
2040	252.53	199.19	170.07	203.62
2045	279.87	205.42	177.35	213.14
2050	310.15	210.99	184.23	222.66
2055	343.72	215.92	190.66	232.18
2060	380.92	220.25	196.64	241.70
2065	422.15	224.04	202.14	251.21
2070	467.83	227.34	207.18	260.73
2075	518.47	230.20	211.76	270.25
2080	574.58	232.66	215.90	279.77
2085	636.76	234.77	219.62	289.29
2090	705.68	236.58	222.95	298.81
2095	782.05	238.13	225.92	308.32
2100	866.68	239.45	228.55	317.84

The visualization of this table is given in the following figure.

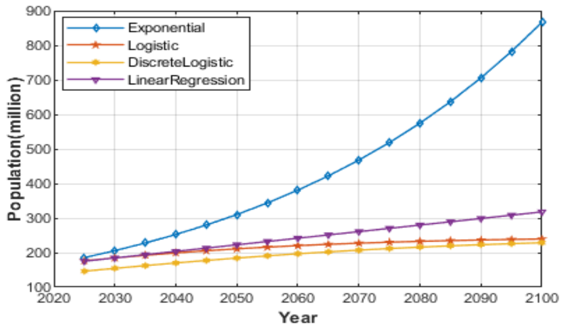

Fig. 9. Projected future population of Bangladesh

The population projections for the region from 2025 to 2100 across four models, Exponential, Logistic, Discrete Logistic, and Linear Regression, indicate steady growth. The Exponential model shows the highest population, reaching 866.68 million by 2100, while the Logistic model forecasts 239.45 million. The Discrete Logistic model predicts 228.55 million, and the Linear Regression model estimates 317.84 million by 2100. Each model reflects consistent upward trends over the decades.

In 1970, Bangladesh's growth rate was 2.54%. According to the population models, the growth rates for Malthus, hyperbolic growth, logistic, discrete logistic, and least squares models were 2.02%, 3.12%, 2.79%, 3.54%, and 3.92%, respectively, with the logistic model providing the closest estimate. From 1990 to 2020, Bangladesh's actual growth rates were 2.23%, 1.04%, and 1.15%, while the closest figures from the models were 2.12%, 1.40%, and 1.08%. Initially, the growth rate increased rapidly but gradually declined over time. When comparing actual population growth rates for 1970, 1990, 2010, and 2020 to the population model, the observed rates were 2.72%, 3.52%, 2.20%, and 1.75%, while the model's closest rates were 2.70%, 2.84%, 2.20%, and 1.85%. These comparisons reflect the initial rapid growth followed by a gradual slowdown over time.

Table 8: The projected future population of India

Year	Exponential Model	Logistic Model	Discrete Logistic Model	Linear Regression Model
2025	1,539.26	1,517.10	1,391.60	1,446.69
2030	1,696.76	1,608.29	1,479.70	1,524.45
2035	1,870.37	1,696.56	1,566.69	1,602.22
2040	2,061.75	1,781.21	1,651.81	1,679.98
2045	2,272.71	1,861.61	1,734.34	1,757.74
2050	2,505.25	1,937.32	1,813.65	1,835.51
2055	2,761.59	2,008.02	1,889.21	1,913.27
2060	3,044.16	2,073.53	1,960.60	1,991.04

2065	3,355.64	2,133.79	2,027.50	2,068.80
2070	3,698.99	2,188.87	2,089.73	2,146.57
2075	4,077.47	2,238.90	2,147.20	2,224.33
2080	4,494.68	2,284.09	2,199.92	2,302.10
2085	4,954.58	2,324.72	2,247.98	2,379.86
2090	5,461.53	2,361.07	2,291.55	2,457.63
2095	6,020.36	2,393.48	2,330.85	2,535.39
2100	6636.36	2422.26	2366.11	2613.15

The visualization of this table is given in the following figure.

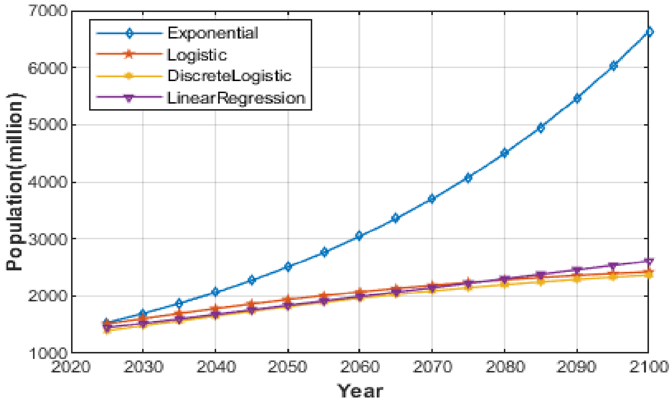

Fig. 10. Projected future population of India

The population projections for the region from 2025 to 2100 across four models, Exponential, Logistic, Discrete Logistic, and Linear Regression, indicate substantial growth. The Exponential model forecasts the highest population, reaching 6,636.36 million by 2100. The Logistic model predicts 2,422.26 million, while the Discrete Logistic model estimates 2,366.11 million. The Linear Regression model anticipates 2,613.15 million, with all models showing consistent growth throughout the decades.

Table 9: The projected future population of Nepal

Year	Exponential Model	Logistic Model	Discrete Logistic Model	Linear Regression Model
2025	32.08	30.96	28.12	31.47
2030	35.09	32.51	29.63	33.10
2035	38.37	33.99	31.10	34.74
2040	41.96	35.38	32.53	36.38
2045	45.88	36.69	33.89	38.02

2050	50.17	37.90	35.19	39.66
2055	54.87	39.02	36.42	41.30
2060	60.00	40.05	37.57	42.94
2065	65.61	40.98	38.65	44.57
2070	71.75	41.83	39.64	46.21
2075	78.46	42.59	40.56	47.85
2080	85.80	43.27	41.40	49.49
2085	93.83	43.88	42.16	51.13
2090	102.60	44.43	42.85	52.77
2095	112.20	44.91	43.48	54.40
2100	122.69	45.33	44.03	56.04

The visualization of this table is given in the following figure.

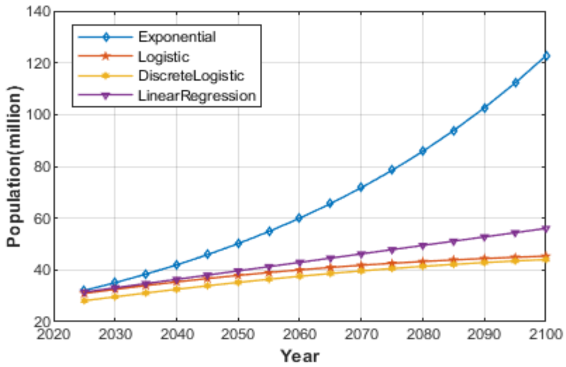

Fig. 11. Projected future population of Nepal

The population projections for the region from 2025 to 2100 across four models, Exponential, Logistic, Discrete Logistic, and Linear Regression, indicate steady growth. The Exponential model predicts the highest population, reaching 122.69 million by 2100. The Logistic model estimates 45.33 million, while the Discrete Logistic model forecasts 44.03 million. The Linear Regression model projects 56.04 million by 2100, with all models showing a consistent increase over the years. Figures 9, 10, and 11 also illustrate the projected population of the three nations.

Table 10: Mean Absolute Percentage Error (Population model) [MAPE]

	Exponential Model	Hyperbolic Model	Logistic Model	Discrete Logistic Model	Linear Regression Model
Bangladesh	8.73%	21.11%	1.47%	12.47%	3.99%
India	6.12%	17.85%	1.46%	4.94%	5.1%
Nepal	6.99%	16.89%	3.40%	7.24%	5.35%

The visualization of this table is given in the following figure.

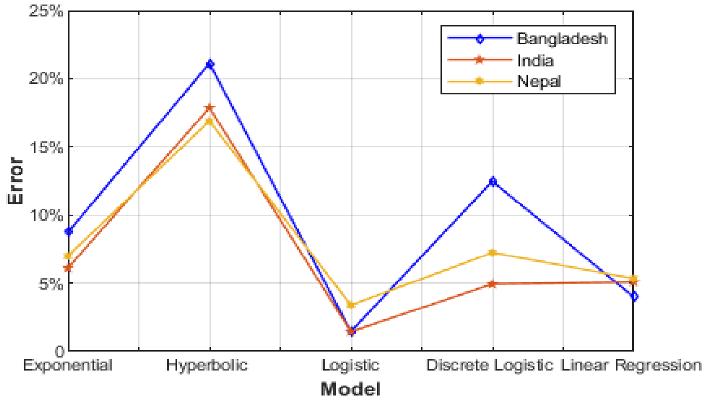

Fig. 12. Mean Absolute Percentage Error (Population model)

To check how accurate the mathematical models are, we look at the population numbers we calculated for both countries using the MAPE (Mean Absolute Percentage Error) from 1950 to 2020, as shown in Table 10 (Fig.12).

- **Bangladesh:** The MAPE for Bangladesh is 8.73% for the Malthusian model, 1.47% for the Logistic model, 21.11% for the Hyperbolic growth model, 12.47% for the Discrete Logistic growth model, and 3.99% for the Least Squares model. This suggests that the Logistic model has the lowest error, making it the most suitable for projecting Bangladesh's population.
- **India:** For India's population from 1950 to 2020, the MAPE values are 6.12% for the Malthusian model, 1.46% for the Logistic model, 17.85% for the Hyperbolic growth model, 4.94% for the Discrete Logistic growth model, and 5.10% for the Least Squares model.
- **Nepal:** For Nepal, the MAPE from 1950 to 2020 shows 6.99% for the Malthusian model, 3.40% for the Logistic model, 16.88% for the Hyperbolic growth model, 4.24% for the Discrete Logistic growth model, and 5.35% for the Least Squares model.

In conclusion, the Logistic model demonstrates greater accuracy compared to the other four models.

Table 11: Showing the Sum of Squared Error (SSE) in population growth in Bangladesh

Year	Actual Population	Exponential Model (SSE)	Hyperbolic Model (SSE)	Logistic Model (SSE)	Discrete Logistic Model (SSE)	Linear Regression Model (SSE)
1950	39.72	0.0000	0.0000	0.0000	0.0000	55.3249
1955	44.31	0.0841	5.2921	2.1025	0.0000	6.2500
1960	50.39	2.5921	33.6241	4.3684	1.1449	0.8836
1965	58.50	19.7136	121.0004	2.0164	14.0676	5.4756

Year	Actual Population	Exponential Model (SSE)	Hyperbolic Model (SSE)	Logistic Model (SSE)	Discrete Logistic Model (SSE)	Linear Regression Model (SSE)
1970	67.54	58.2169	282.2401	0.2401	47.9071	7.9524
1975	74.70	68.8900	404.4481	4.3569	60.0169	26.8944
1980	83.92	106.6276	620.0641	4.8400	105.7689	29.9524
1985	95.95	205.4400	1017.9076	0.0000	230.4964	7.9249
1990	107.14	282.0676	1341.7729	0.9604	355.5556	1.6900
1995	117.79	311.5969	1589.3764	1.3681	472.3924	0.0256
2000	129.19	330.2761	1765.8277	4.0369	628.5129	2.9584
2005	140.91	316.8481	1746.0096	10.3689	808.7044	15.4248
2010	148.39	146.8321	1135.4884	0.1681	760.8001	3.5328
2015	157.83	45.7969	469.4769	0.0100	808.5121	3.2400
2020	167.42	0.0000	0.0000	0.0000	870.5796	3.4969

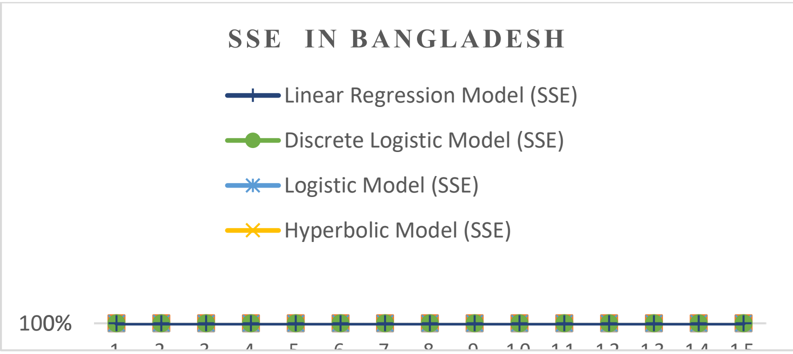

Fig. 13. Indicated a higher increase in population projection for Bangladesh SSE for the Exponential Model, Hyperbolic Model, Logistic Model, Discrete Logistic Model, and Linear Regression Model

Table 12: Showing the Root Mean Square Error (RMSE) population rate in Bangladesh

Model	Total SSE	MSE (SSE/15)	RMSE (√MSE)
Exponential Model	1894.99	126.33	11.24
Hyperbolic Model	11831.43	788.76	28.08
Logistic Model	35.89	2.39	1.55
Discrete Logistic Model	4463.46	297.56	17.25
Linear Regression Model	169.03	11.27	3.36

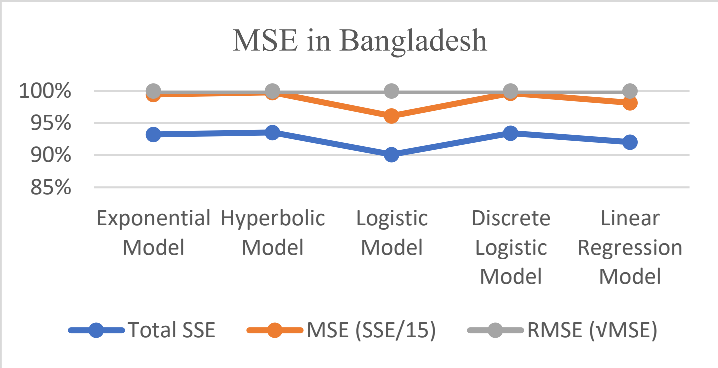

Fig. 14. Indicated a higher increase in population projection Bangladesh MSE for the Exponential Model, Hyperbolic Model, Logistic Model, Discrete Logistic Model, and Linear Regression Model

Table 14: Showing the Sum of Squared Error (SSE) in population growth in India

Year	Actual Population	Exponential Model (SSE)	Hyperbolic Model (SSE)	Logistic Model (SSE)	Discrete Logistic Model (SSE)	Linear Regression Model (SSE)
1950	357.02	0.00	0.00	0.00	0.00	5892.64
1955	398.57	25.20	466.24	28.96	0.00	1643.24
1960	445.95	147.74	2162.10	94.24	3.38	104.04
1965	500.11	478.36	5675.05	153.02	39.50	179.44
1970	557.50	918.30	10898.02	294.74	93.82	1142.59
1975	623.52	1790.86	18819.41	182.00	299.06	2917.60
1980	696.82	3130.20	29556.02	0.05	771.36	232.96
1985	780.24	5472.96	44974.22	0.16	1955.19	2080.56
1990	870.45	7921.66	70197.56	0.04	385.18	90.89
1995	964.27	4421.50	68447.90	0.16	19.67	0.06
2000	1059.63	1282.42	108249.40	0.01	615.60	4.53
2005	1154.63	124.34	123352.28	0.01	119.56	3.64
2010	1240.61	78.26	217057.14	2.38	125.31	524.53
2015	1322.86	189.74	63544.00	44.04	9.01	466.11
2020	1396.38	0.00	0.00	756.36	85.41	774.42

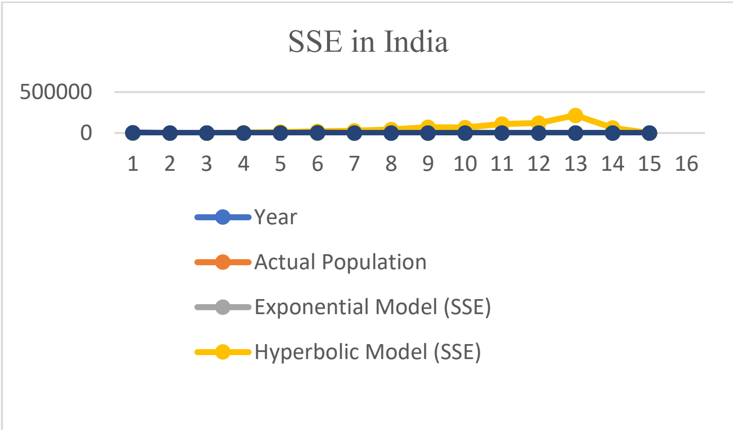

Fig. 15. Indicated a higher increase in population projection India SSE for the Exponential Model, Hyperbolic Model, Logistic Model, Discrete Logistic Model, and Linear Regression Model

Table 15: Showing the Root Mean Square Error (RMSE) population rate in India

Model	Total SSE	MSE (SSE/15)	RMSE (√MSE)
Exponential Model	27219.06	1814.60	42.61
Hyperbolic Model	869256.99	57950.47	240.80
Logistic Model	1584.60	105.64	10.28
Discrete Logistic Model	5122.74	341.52	18.48
Linear Regression Model	14753.33	983.56	31.38

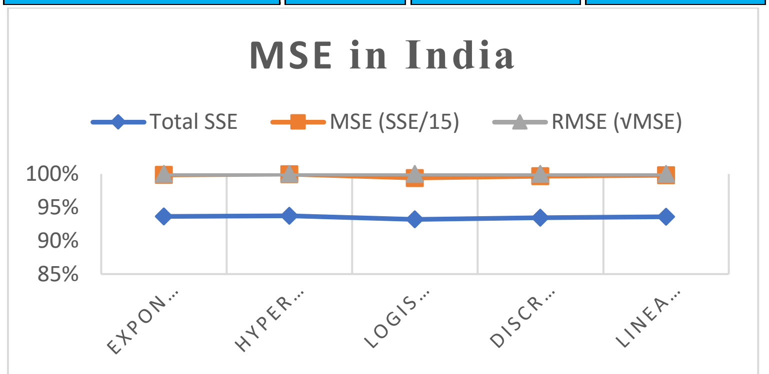

Fig. 16. Indicated a higher increase in population projection India SSE for the Exponential Model, Hyperbolic Model, Logistic Model, Discrete Logistic Model, and Linear Regression Model

Table 16: Showing the Sum of Square Error (SSE) in population growth in Nepal

Year	Actual Population	Exponential Model (SSE)	Hyperbolic Model (SSE)	Logistic Model (SSE)	Discrete Logistic Model (SSE)	Linear Regression Model (SSE)
1950	8.39	0.00	0.00	0.00	0.00	2.50
1955	9.28	0.0121	0.1936	0.0225	0.00	0.5625
1960	10.16	0.0169	0.6724	0.1521	0.0064	0.0001
1965	11.23	0.0676	1.7681	0.3025	0.0025	0.3364
1970	12.50	0.25	3.8416	2.5921	0.0121	0.8836
1975	13.92	0.064	6.9124	2.4964	0.0121	1.3456
1980	15.60	1.5625	12.3121	0.0016	0.0324	1.2544
1985	17.54	3.4225	20.0025	0.00	0.1600	0.6724
1990	19.61	6.0025	30.0256	0.2116	4.3564	0.1521
1995	22.30	12.5449	44.7601	2.2809	1.7956	0.1156
2000	24.55	16.3844	55.3924	3.9604	4.4544	0.0004
2005	26.28	15.0624	50.5441	4.7524	19.1025	0.0169
2010	27.16	7.0564	31.3921	1.5129	12.9601	0.1849
2015	27.61	0.6084	6.7600	0.0064	0.3240	0.3364
2020	29.34	0.00	0.00	0.00	7.5621	0.2401

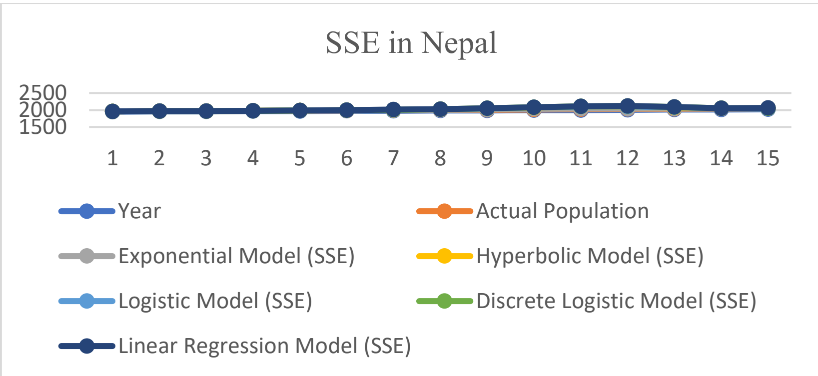

Fig. 17. Indicated a higher increase in population projection Nepal SSE for the Exponential Model, Hyperbolic Model, Logistic Model, Discrete Logistic Model, and Linear Regression Model

Table 17: Showing the Root Mean Square Error (RMSE) population rate in Nepal

Model	Total SSE	MSE (SSE/15)	RMSE (√MSE)
Exponential Model	66.79	4.45	2.11
Hyperbolic Model	209.39	13.96	3.74

Model	Total SSE	MSE (SSE/15)	RMSE (√MSE)
Logistic Model	15.99	1.07	1.03
Discrete Logistic Model	50.80	3.39	1.84
Linear Regression Model	7.92	0.53	0.73

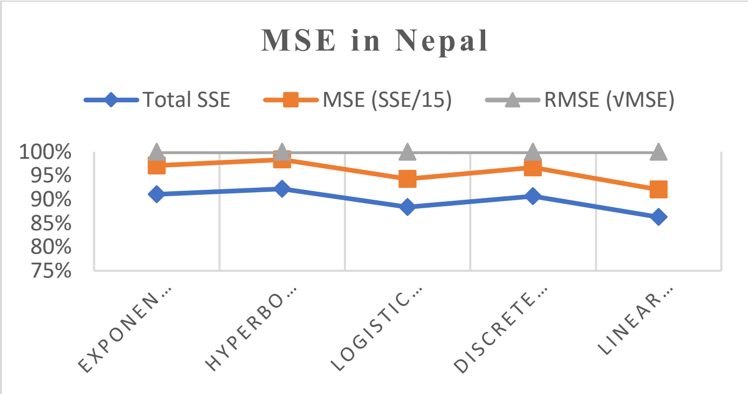

Fig. 18. Indicated a higher increase in population projection Nepal MSE for the Exponential Model, Hyperbolic Model, Logistic Model, Discrete Logistic Model, and Linear Regression Model.

In this study, Figs. 13-18 represents the higher increase in population projection for Bangladesh, India, SSE, MSE, Nepal, for the Exponential Model, Hyperbolic Model, Logistic Model, Discrete Logistic Model, and Linear Regression Model. In conclusion, the Logistic model demonstrates greater fit and accuracy compared to the other five models.

Limitations of our work: Census undercounts, migration reporting errors, and estimation uncertainties all reduce the reliability of secondary data. Undercounts miss certain groups, leading to incomplete population totals. Migration data often contains inaccuracies due to misreporting or unrecorded moves. Estimation methods rely on assumptions that may not always be accurate. These limitations can distort population figures and weaken the validity of research based on secondary data.

IV. Results and Discussion

The basic demographic perspective in population structure throughout time has been attempted to be seen in this paper. It seeks to anticipate future trends and changes in population structure based on past data that is now accessible. To accomplish the goals of this study, a variety of literature has been reviewed. Reliable data has been gathered using both domestic and foreign data sources. But until 2050, a basic arithmetic approach to population predictions was employed because there was insufficient data to provide a more accurate estimate.

The three sections of the study are Bangladesh's present demographic profile as of 2024, historical changes in population structure, and population projections until 2100.

The population of Bangladesh is growing annually, according to historical trends. 150 million people were counted in Bangladesh's 2011 population census, which is precisely twice as many as there were in 1971. However, there is hope because the growth rate is gradually falling and stands at 1.02%. Future forecasts of Bangladesh indicate that the population growth rate will continue to fall steadily until 2020, at which point it will sharply decline until 2100. Although the rate of decline is slowing, the overall population is expected to grow, reaching about 229 million by the end of the projected period.

To prevent a significant percentage of the population from becoming dependent, the government should focus on the long-term development of the elderly. To continuously monitor the population structure, Bangladesh already has a population policy. It is possible to improve the policies' sustainability and dependability for the upcoming years by revising them in accordance with current developments.

V. Conclusion

This study concludes by providing a method for analyzing the behavior of population projections. We specifically create forecasts of population growth for Bangladesh, India & Nepal. As a result, strategies should be created to achieve demographic advantage, keeping in mind that the Bangladeshi government's top priority is the population issue. Our study's findings indicate that population growth and adaptation are not controlled. The proliferation of specific demographic characteristics associated with population growth has the potential to diminish the land's carrying capacity and deplete commonly held resources, thereby undermining their ability to meet both current and future generational needs. Consequently, governmental authorities must implement strategic interventions aimed at mitigating the adverse implications of such growth. These may include the formulation of comprehensive national population policies that integrate sustainable resource management and environmental conservation measures. Furthermore, such efforts should be complemented by the recalibration of public social service frameworks, particularly those concerning housing, education, healthcare, food security, and employment opportunities, to ensure adaptive responsiveness to evolving demographic demands. They will be afflicted without being blessed if population growth and adaptation are not kept in check. The results of our analysis indicate that Bangladesh lags behind India and Nepal in a few areas. Additionally, we see that the logistic model's Mean Absolute Percentage Error (MAPE) is extremely low. From this vantage point, we can ultimately say that, when compared to the other models, the logistic model produces good forecasting results for long-term predictions. In contrast to the current state of the human population in Bangladesh, India, and Nepal, our study provides a good approximation for long-term predictions of the population growth trends.

Conflict of Interest

The authors declare that there is no conflict of interest regarding this paper.

References

I. A. N. M. Rezaul Karim, M. Nizam Uddin, M. Rana, M. U. Khandaker, M. R. I. Faruque, and S. M. Parvez, “Modeling on population growth and its adaptation: A comparative analysis between Bangladesh and India,” Journal of Applied and Natural Science, vol. 12, no. 4, pp. 688–701, Dec. 2020. 10.31018/jans.v12i4.2396.

II. C. S. Berkey and N. M. Laird, “Nonlinear growth curve analysis: estimating the population parameters,” Ann Hum Biol, vol. 13, no. 2, pp. 111–128, Jan. 1986. 10.1080/03014468600008261.

III. E. Cocks, “Malthus on population quality,” Soc Biol, vol. 18, no. 1, pp. 84–87, Mar. 1971. 10.1080/19485565.1971.9987904.

IV. G. F. Mulligan, “Logistic Population Growth in the World’s Largest Cities,” Geogr Anal, vol. 38, no. 4, pp. 344–370, Oct. 2006. 10.1111/j.1538-4632.2006.00690.x.

V. H. AL Mamun, E. Ali, K. Chandra Roy, R. Karim, N. Uddin, and P. Dey, “ANALYZING AND PROJECTION OF FORECASTING POPULATION OF BANGLADESH USING EXPONENTIAL MODEL, LOGISTIC MODEL, AND DISCRETE LOGISTIC MODEL”. 10.17605/OSF.IO/S5UCD.

VI. H. Mondol, U. Mallick, and Md. Biswas, “Mathematical modeling and predicting the current trends of human population growth in Bangladesh,” Modelling, Measurement and Control D, vol. 39, no. 1, pp. 1–7, Dec. 2018. 10.18280/mmc_d.390101.

VII. I. Ehrlich and F. Lui, “The problem of population and growth: A review of the literature from Malthus to contemporary models of endogenous population and endogenous growth,” J Econ Dyn Control, vol. 21, no. 1, pp. 205–242, Jan. 1997. 10.1016/0165-1889(95)00930-2.

VIII. M. A. Tabatabai, W. M. Eby, and K. P. Singh, “Hyperbolastic modeling of wound healing,” Math Comput Model, vol. 53, no. 5–6, pp. 755–768, Mar. 2011. 10.1016/j.mcm.2010.10.013.

IX. M. Aktar Mimi, M. Eaqub Ali, K. Chandra Roy, S. sarker, R. Karim, and P. Dey, “ANALYZE THE GROWTH RATE OF A PREY-PREDATOR SYSTEM WITH SIMULATION USING MATLAB,” 2023.

X. M. M. Islam, “Demographic transition and the emerging windows of opportunities and challenges in Bangladesh,” J Popul Res, vol. 33, no. 3, pp. 283–305, Sep. 2016. 10.1007/s12546-016-9174-z.

XI. P. Dey et al., “QUALITATIVE ANALYSIS OF DEMOGRAPHIC PERSPECTIVE AND HUMAN POPULATION MODEL WITHIN BANGLADESH AND SRI LANKA,” Journal of Mechanics of Continua and Mathematical Sciences, vol. 19, no. 12, pp. 139–158, Dec. 2024. 10.26782/jmcms.2024.12.00009.

XII. R. Islam et al., “PROLIFERATION OF STEM CELLS IN A POPULATION MODEL,” AfricanJournalofBiological Sciences Rashedul Islam / Afr.J.Bio.Sc, vol. 6, no. 5, pp. 2305–2328, 2024. 10.33472/AFJBS.6.5.2024.

XIII. R. Islam, K. Chandra Roy, N. Uddin, R. Karim, S. Sarker, and P. Dey, “DEMOGRAPHIC ANALYSIS AND COMPARISON WITH THE POPULATION OF BANGLADESH AND PAKISTAN”. 10.5281/zenodo.8241173.

XIV. R. Karim, M. A. Akbar, M. A. B. Pk, and P. Dey, “A study on fractional-order mathematical and parameter analysis for CAR T-cell therapy for leukemia using homotopy perturbation method,” Partial Differential Equations in Applied Mathematics, vol. 14, Jun. 2025. 10.1016/j.padiff.2025.101152.

XV. R. Karim, M. A. Akbar, M. A. B. Pk, P. Dey, and M. T. Tahmed, “Mathematical analysis of chimeric antigen receptor T-cell therapy for leukaemia using optimal control approach,” Journal of Umm Al-Qura University for Applied Sciences, 2025. 10.1007/s43994-025-00219-4.

XVI. R. Karim, M. A. Arefin, Md. M. Hossain, and Md. S. Islam, “Investigate future population projection of Bangladesh with the help of Malthusian model, Sharpe-lotka model and Gurtin Mac-Camy model,” International Journal of Statistics and Applied Mathematics, vol. 5, no. 5, pp. 77–83, Sep. 2020. 10.22271/maths.2020.v5.i5b.585.

XVII. R. Karim, M. A. B. Pk, P. Dey, M. A. Akbar, and M. S. Osman, “A study about the prediction of population growth and demographic transition in Bangladesh,” Journal of Umm Al-Qura University for Applied Sciences, vol. 11, no. 1, pp. 91–103, Mar. 2025. 10.1007/s43994-024-00150-0.

XVIII. R. Karim, M. A. Bkar Pk, M. Asaduzzaman, P. Dey, and M. A. Akbar, “INVESTIGATION ON PREDICTING FAMILY PLANNING AND WOMEN’S AND CHILDREN’S HEALTH EFFECTS ON BANGLADESH BY CONDUCTING AGE STRUCTURE POPULATION MODEL,” Journal of Mechanics of Continua and Mathematical Sciences, vol. 19, no. 3, pp. 65–86, Mar. 2024. 10.26782/jmcms.2024.03.00005..

XIX. R. Zahan and C. X. Feng, "Bayesian spatial analysis of socio-demographic factors influencing pregnancy termination and its residual geographic variation among ever-married women of reproductive age in Bangladesh," BMC Public Health, vol. 20, no. 1, p. 1348, Dec. 2020. 10.1186/s12889-020-09401-1.

XX. S. M. Henson, F. Brauer, and C. Castillo-Chavez, "Mathematical Models in Population Biology and Epidemiology," The American Mathematical Monthly, vol. 110, no. 3, p. 254, Mar. 2003. 10.2307/3647954.

XXI. T. J. Clark and A. D. Luis, "Nonlinear population dynamics are ubiquitous in animals," Nat Ecol Evol, vol. 4, no. 1, pp. 75–81, Dec. 2019. 10.1038/s41559-019-1052-6.